UNITED NATIONS DEVELOPMENT PROGRAMME

WORLD HEALTH ORGANIZATION

GOVERNMENT OF SURINAM

PUBLIC WATER SUPPLIES AND SEWERAGE PROJECT

VOLUME III

WATER RESOURCES
(HYDROGEOLOGICAL AND HYDROLOGICAL STUDIES)

REPORT PREPARED BY THE
WORLD HEALTH ORGANIZATION
ACTING AS EXECUTING AGENCY
AND THE UNITED NATIONS ACTING
AS PARTICIPATING AGENCY FOR
UNITED NATIONS DEVELOPMENT PROGRAMME

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TABLE OF CONTENTS

Page

Chapter 1 - CONCLUSIONS AND RECOMMENDATIONS

Chapter 2 - PHYSIOGRAPHY AND GEOLOGY

Chapter 3 - CLIMATE

Chapter 4 - SURFACE WATER

Chapter 5 - GROUND WATER

Chapter 6 - WATER BALANCE STUDIES

Chapter 7 - WATER DEVELOPMENT

TABLES

ANNEXES

1. Sections (9 Sections, A to I inclusive)
2. Summary of Exploratory Drilling for Ground Water, Geological and Mining Service, 1950-1964
3. Well Data
4. Chemical Analyses
5. Rijsdijk Test (including 2 figures and 1 table)
6. Well Field at Rijsdijk (including 2 figures and 1 table)
7. Aspects of Well Design (including 1 table)
8. Well Construction with Nominal 12-inch Diameter Unplasticized Polyvinyl Chloride (PVC) Casing: A Case History (including 1 figure and 1 table)
9. Well Construction Costs (including 1 table)
10. Environmental Isotope Studies, Report of the International Atomic Energy Agency, September 1972 (including 3 figures and 4 tables)

ABBREVIATIONS

G.M.D.	Geologische Mijnbouwkundige Dienst (Geology and Mining Service of the Ministry of Development)
Min. of D. and D.	Ministerie van Districtsbestuur en Decentralisatie (Ministry of Rural Government and Decentralization)
B.W.K.W.	Bureau Water Kracht Worken (Hydro-Electric Division of the Ministry of Development)
S.W.M.	Surinaamse Waterleiding Maatschappij (Surinam Water Company)
Suralco	Surinam Aluminum Company
Sf	Surinam Guilder - US$1 = Sf1.87
TW	Test Well
OW	Observation Well

ENCLOSURES

FIGURES

PREFACE

Operations started on the project "Public Water Supplies and Sewerage (NET-4)" with the arrival of the Project Manager in September 1969. The Plan of Operations was signed by the Government of Surinam, the World Health Organization, and the United Nations Development Programme on 30 October 1970. The cooperating government agency was the Ministry of Rural Government and Decentralization. The World Health Organization was named Executing Agency and was assisted by the United Nations in the capacity of Participating Agency, by virtue of a Standard Letter of Agreement which was signed by the agencies in July 1970.

It is noted that no provision was made to contract for the consulting engineering services in the preparation of the engineering studies, reports, and designs. In this departure from the usual World Health Organization practice in UNDP(SF) preinvestment projects, the responsibility for the above tasks rested with the international professional staff assigned to the field activity of the project.

This final report represents a statement which descriptively, qualitatively, and comprehensively summarizes the findings and recommendations of the project team, incorporating the public water supplies, sewerage, and water resources investigation aspects of the project. It comprises the following four volumes:

Volume I - Summary Report
Volume II - Basic Data and Special Studies
Volume III - Water Resources (Hydrogeological and Hydrological Studies)
Volume IV - Water Supplies and Sewerage

The subject volume, Volume III, comprises the hydrogeological and hydrological studies conducted in the project and covers physiography, geology, climate, surface water, ground water, water balance, and water development.

Conferences and discussions were held with and direct assistance obtained from:

Ministry of General Affairs
Ministry of Health
Ministry of Public Works
Ministry of Agriculture
Ministry of Finance
Ministry of Development
Ministry of Rural Government and Decentralization

In March 1970, a mid-project review mission visited the project. The mission included the following:

Ross Milley	Assistant Regional Representative, UNDP, Trinidad and Tobago
G. D. Soerdjoesingh	Project Coordinator, Ministry of Rural Government and Decentralization
A. Jap Tjoen San	Surinam UNTAB Liaison Officer
Paul Bierstein	Chief, Preinvestment Planning, WHO, Geneva
Harry G. Hanson	Regional Advisor, Engineering and Environmental Sciences, PAHO/WHO, Washington
Whitman C. Dimock	Technical Advisor, Resources and Transport, Division of Economic and Social Affairs, United Nations, New York
John T. Robinson, Chairman	Zone Engineer, PAHO/WHO, Zone I Office, Caracas

The field operations were conducted by a team of United Nations specialized agency staff and Surinam Government staff. The team was structured as follows:

Permanent Field Staff

International Staff

World Health Organization:

S. G. Serdahely, Project Manager
J. G. Copley, Project Manager
J. L. Vincenz, Project Manager
C. L. Philipovsky, Sanitary Engineer (Waste Water)
R. J. Pitters, Sanitary Engineer (Water Supply)
Mrs. Christina Kambel, Secretary

United Nations:

V. R. Dixon, Hydrogeologist
C. K. Stapleton, Drilling Superintendent

Surinam Government Counterpart Staff

G. D. Soerdjoesingh, Project Coordinator

Engineers

R. Dihal
R. Randjietsingh
E. T. Tsai Meu Chong
R. Nanden
S. Autar

Surveyor

R. Biharie

Short-term Consultants

C. Clinton Davis, Management
D. Duba, Hydrology
C. N. Stutz, Industrial Waste
L. Huisman, Biological Filtration
Jean L. Vincenz, Management
Donald E. Crum, Water Waste

Visiting Specialists

M. Suleiman, PIP, WHO, Geneva
W. C. Dimock, UN, OTC
E. Elmore, ES, PAHO, Washington
O. Cordero, Fluoridation, PAHO, Washington
D. J. Williams, Fluoridation, Canada

Non-professionals

A. Ghafoerkhan
J. Orie
J. Ragoebar
H. C. Faerber
H. Rambalie
S. Ramdat
H. A. Khodabaks

Drilling Supervisors

A. Staphorst
P. Viereck
W. Bouman
S. Ramdas
M. Petricie
J. Doornkamp
E. Wilson

All of the agencies listed below, their representatives, and individuals readily contributed to the implementation of this project in an atmosphere of mutual assistance for the benefit of Surinam:

Army of the Kingdom of the Netherlands
Center of Agricultural Research in Surinam
Surinam Water Company
Surinam Aluminum Company
Billiton Company of Surinam
Mariënburg Sugar Enterprise
Bruynzeel Surinam Wood Company
Representatives of the Dutch Five-Year Plan
Representatives of several United Nations specialized agencies

It is with sincere appreciation that their efforts, as well as those of many others who also brought their ideas, comments, experience, and wisdom in generous and unsparing measure, are gratefully acknowledged.

During the long dry season of 1971, conditions developed in which the water supply system of the city of Paramaribo was unable to meet the demands, and this resulted in loss of production as well as the retrogression of service from continuous to intermittent. Aware of the possibly serious consequences of these developments, the Government requested the assistance of the incumbent staff of the UNDP(SF) project in effecting the necessary improvements to the water supply as well as to provide the investigation and planning required to meet present and future needs for the city system. As a result, the UNDP(SF) project was extended from the original three-year span to cover a 42-month period. The report incorporating the Paramaribo study is a separate and supplementary volume. A second six-month extension was requested by the Government for surface drainage studies. The report for these studies is also a separate and supplementary volume.

The metric system of weights and measures is used in Surinam for engineering purposes generally. However, standard practice in the design of water supply systems in the country has been to express pipe sizes in inches and to express pump capacities in U.S. gallons per minute. Accordingly, these units have been used in designs.

In estimating costs the currency used is the Surinam guilder (Sf.). The rate of exchange current when estimates were prepared during project operations was Sf.1.87 to US$1.00.

All elevations indicated in this report are referenced to the official NSP (Normal Surinam Level) datum. Established in 1958, NSP is based on the average sea level, measured at an automatic sight gage structure on the Suriname River at Purmerend Plantation, located near Paramaribo at Leonsberg. Elevations referred to an earlier datum, SP, are converted by Surinam authorities through the application of a negative 8.00 meter factor.

Acronyms used in this report are included in the glossary at the end of Volume I.

CHAPTER 1

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF CONCLUSIONS

General

1. Surinam contains two hydrologically distinct provinces, an interior Precambrian shield of crystalline rocks comprising 80% of the country where surface water is the most important, and a coastal basin comprising the remaining 20% where ground water resources are of major importance.

Surface Water

2. Seven first-order rivers drain the country towards the Atlantic. The Corantijn and Marowijne Rivers are the largest, forming the western and eastern boundaries. Together they drain about 58% of the country.

3. The main rivers are tidal, generally up to the first rapids, and they contain brackish water in the coastal area. Flows are seasonal with the highest flows between May and July and the lowest flows generally in November, coinciding with the seasonal rainfall.

4. Run-off is relatively high throughout most of the basement area with an average annual unit discharge of about 25 $l/s/km^2$. It is less along its northern fringe where the average annual unit discharge is about 15 $l/s/km^2$. The reason is attributed to remnants of the coastal basin sediments south of the Savannah area as mapped.

5. There are no stream flow measurements in the area of the coastal basin, although a well developed drainage sustained mainly by effluent ground water exists in the Savannah and Old Coastal Plain. The run-off is assumed to be low as in the northern fringe of the basement.

Aquifers

6. The coastal basin contains an abundance of ground water confined under artesian conditions with high water levels close to the ground surface.

7. The aquifers are composed mainly of graded coarse-grained angular quartz sand more or less kaolinitic. Hydraulic conductivities generally vary up to about 100 m/day and exceptionally may be more than 300 m/day.

8. The aquifers have been classified according to their geological age. The most important fresh water aquifers are the A Sand, probably of

Oligocene age; the Coesewijne aquifers of Miocene age; and the Zanderij aquifer of Plio-Pleistocene age. The division is into groups of aquifers, which are regionally interconnected. The distribution is complicated by unconformities or buried landscapes through which the main aquifers are interconnected in places.

9. The oldest aquifer to crop out extensively is the Zanderij aquifer in the Savannah area. The older aquifers terminate southward against the rising basement. Exceptions are the Upper Coesewijne aquifers, which are in contact with the overlying Zanderij aquifer to the south.

Ground Water Flow Systems

10. The Coastal Basin is divided into two parts based on ground water age and flow. To the south, coinciding with the Savannah and Old Coastal Plain, an active system is recharged directly from rainfall. Most activity appears to be in the upper sections where recharge is rapidly discharged. The regional flow is slow, at rates up to about 6 m/day, and the ground water age is up to 2,000 years BP. To the north, coinciding with the Young Coastal Plain, the ground water system is more or less static. There is virtually no hydraulic gradient, and ground water ages vary from about 13,000 to 20,000 years BP.

11. It is surmised from ground water age and other evidence that an active flow system extended throughout the basin during the Pleistocene and early Holocene times when the ocean level was lower. There is evidence of a reversed (inland) flow during the Holocene transgression as a result of ocean loading.

Ground Water Recharge

12. Based on one year of observation well records, annual recharge is estimated at 480 and 200 mm in the Savannah area west of Zanderij and in the Old Coastal Plain at Rijsdijk, respectively. For the present these can be regarded only as upper limits not universally applicable. Extensive areas of the Savannah have a clay surface, and recharge decreases towards the north in the Old Coastal Plain.

13. At Republiek, immediately north of the Savannah, the average annual recharge based on 26 years of records is estimated at 1,288 mm. This is in an area of ground water withdrawal and therefore indicates a potential for this kind of terrain, including an influent flow induced locally from Coropina Creek.

Water Balance Studies

14. Water balance studies indicate relatively high run-off and low evapotranspiration in the interior and the reverse for the northern basement fringe and probably the coastal basin. Evapotranspiration in the

north probably approximates the potential. Apparent values obtained as a difference between rainfall and run-off are higher than panevaporation measurements at Paramaribo and calculated values. It is assumed that evapotranspiration may be in the order of 1,800 mm/year and that deviations from this represent changes in storage. For an average year ground water discharge to the surface must equal the recharge, and in an overall water balance ground water is purely transitory within the system.

Ground Water Salinity

15. Salinity generally increases towards the coast. In the Zanderij aquifer the water is fresh throughout the Old Coastal Plain and brackish in the Young Coastal Plain, particularly adjacent to the rivers. The change is abrupt. Fresh water continues farthest north in the Coesewijne aquifers. In the A Sand higher salinity extends farthest inland along concealed fault lines.

16. Brackish ground water is widespread in the coastal area of Commewijne and apparently in the area of the Coppename River mouth.

Water Supplies

17. Surface water is the natural source of supply in the interior basement area, and ground water is the natural source in the coastal area where the quality is suitable.

18. The usefulness of the Suriname River as a source of fresh water begins upstream from Domburg. Withdrawals of up to 120 m^3/sec should maintain the chlorides at 100 to 200 ppm between Domburg and Paranam.

19. The available fresh water in the Saramacca River is conservatively estimated at 1 m^3/sec to maintain chlorides at 200 ppm between Santigron and Uitkijk.

20. Withdrawals of fresh ground water in the area of the Young Coastal Plain can be considered only as a mining operation with the fresh water replaced by brackish water. There are vast quantities of fresh water in storage (Figure 31), and withdrawals should not create serious problems, although an inland movement of water with higher chlorides now evident in the Paramaribo area must be considered in planning future sources of supply.

21. The ground water in the Old Coastal Plain is renewable, with the potential equivalent to the recharge rate.

22. The Savannah is a recharge area, but conditions are poor for the construction of high capacity wells.

23. Ground water supplies are available from the Coesewijne aquifers for the Kwatta-Leidingen and Pad van Wanica West projects. Both cases

involve the mining of fresh water, but no problems are envisaged in the foreseeable future.

24. Fresh water in the Paramaribo area is limited to the A Sand aquifer. With an input of water from Republiek maintained at 500 m^3/hr it is estimated that water withdrawn in the coastal area would have a chloride content of about 300 ppm by 1984 and 400 ppm by the end of the century. Under such conditions an additional input of fresh water will be required by 1980 to maintain the chlorides within the standards. This might be as an increase from Republiek or a supply from Rijsdijk (Zanderij aquifer) or Jarikaba (A Sand aquifer). The proposed well field at Livorno would provide fresh water to the local area with an excess pumped to Paramaribo, but the supply is from the same aquifer as at Zorg en Hoop and it cannot be regarded as an alternative to the other fresh water sources.

25. Meerzorg and western Commewijne is a problem area. The only local fresh water is in the A Sand, which terminates to the east and is under the influence of withdrawals at Zorg en Hoop. A supply for a minimum of 10 years should be available from this source before the quality is substandard, after which sources of supplies will be at a greater distance as at Morico, the area of Surnau Creek, or from across the river.

26. Fresh water in the Coesewijne aquifers has been established in the Nickerie area. The aquifers are deep and the wells relatively expensive. As needs increase this water might be mixed with water higher in chlorides from the upper Zanderij aquifer. Similarly, the quality of the Nickerie supply could be improved by adding a well constructed in the Coesewijne aquifer.

27. Problem areas in addition to Commewijne include La Vigilantia and Domburg. A well has been constructed to supply La Vigilantia. It is possible that the quality will deteriorate if water with high chlorides moves south under the influence of the Paranam wells and there is a danger of contamination from soda rich wastes. Alternative sources would be the Suriname River or a well located further south. To the north at Domburg there is no fresh ground water and the closest source is the Suriname River.

Protection of Ground Water Quality

28. Ground water is recharged directly by rain in the Old Coastal Plain and Savannah, and consequently the area is susceptible to soluble contaminants. Industrial wastes could be the main source of any contamination.

Well Construction

29. High capacity wells can be improved by adding more screen than has been customary. This would reduce entrance velocities, corrosion, and drawdown and would prolong the life of wells. The early failure of several wells may be caused by overpumping in relation to the amount of aquifer screened.

30. Wells constructed with unplasticized PVC casing and stainless steel screens should be most effective against corrosion. Large diameter casing of PVC has been used to a depth of 30 m, but handling problems are envisaged at depths of more than 100 m unless a temporary protective steel casing is used for construction.

31. It has been demonstrated that costs are less when wells are constructed by shift work.

RECOMMENDATIONS

Surface Water

1. Run-off volumes, flow rates, and unit discharges given in this volume may be used for planning surface water development.

2. A knowledge of salinity changes in the river estuaries is of prime importance. In this regard it is recommended that further studies should involve the assembly of all available salinity measurements and correlating them with upstream discharges.

3. Flow measurements should be made of selected streams representative of the Old Coastal Plain and Savannah areas. The information would permit a more accurate assessment of both surface water and ground water as sources of supply, and the possible effects of withdrawals.

Ground Water

4. The observation wells established in recharge areas should be maintained. Longer records of ground water level fluctuations when correlated with rainfall will provide a more accurate assessment of recharge. Water levels in cased test wells without recorders should be measured at least twice annually, in May-July when levels are high and in November when levels are low.

5. Water levels should be measured at least monthly in all available wells surrounding operating well fields. In addition, samples for chemical analysis should be taken quarterly, particularly in the direction of increasing salinity or towards water quality boundaries.

6. Accurate records of withdrawals must be kept, particularly from wells in the Young Coastal Plain. Cumulative withdrawal volumes compared with the estimated storage volumes and needs will be required for effective planning.

7. Filing of all basic data on drilling, pumping, water analyses and water levels must be continued. In this regard, it is to the credit of the SWM and GMD that such detailed records have been kept since 1930. To avoid loss, new information would best be summarized in the form of a published yearbook.

Water Supplies

8. The Kwatta-Leidingen and Pad van Wanica West supply systems should go ahead based on proven ground water sources, with the wells provided. Standby wells should be constructed. Future wells would best be constructed with PVC casing and stainless steel screen to guard against corrosion. The water levels and water quality should be monitored in surrounding wells as in Recommendation 5. In this regard, Well 1/69 is important for Kwatta-Leidingen and wells east of the Helena Christina Weg plant site are important for the Pad van Wanica system.

9. Wells to supply Meerzorg and western Commewijne should be constructed in the A Sand aquifer of western Meerzorg close to the river. The supply should last for at least 10 years. Exploration should continue in the Morico and Surnau Creek areas to ascertain the most favorable future source.

10. Supply systems should be constructed as required based on proven supplies from wells constructed at Tijgerkreek, Houttuin, Paradise, and Henar Polder, and also at Corantijn and van Drimmelen Polder after construction of the supply well. Well 33/72 should be used as a source of supply for La Vigilantia only if it can be shown that the wastes in the spoil area to the west are not toxic. In any event a regular check on the water quality must be maintained.

11. Exploration at Wonoredjo should continue to outline the extent of the shallow aquifer and to ascertain any leakage through the overlying sediments.

12. Plans should be prepared for additional supplies for Paramaribo from Republiek or Rijsdijk to be operative by 1980. The source should supply about 40% of the future requirements to be mixed with the water with higher chlorides from the Zorg en Hoop and Leysweg wells. Additional supplies from the Jarikaba area should also be considered. Costs and benefits of the proposed well field and treatment plant at Livorno should be reconsidered in the light of these suggestions.

Protection of Ground Water Quality

13. The Savannah and Old Coastal Plain should be designated a ground water conservation area. Planning and regulations should be such that there is no possibility of contaminating the aquifers with soluble pollutants.

Well Construction

14. Wells should be adequately screened to maintain low entrance velocities and to minimize drawdown.

15. PVC casing should be used where possible to protect against corrosion, and the diameter of the casing should be at least one nominal size

larger than the pump bowls in the upper section, depending upon the lowest anticipated depths of the pump.

16. In specifying pumps, sufficient allowance must be made for anticipated interference from other wells in a well field. Interference from the Zorg en Hoop wells extends as far as 10 km. Ideal well spacing would be between 100 and 200 m, beyond which only little is gained for larger costs.

17. Casing should continue above the ground surface with well pumps above ground, and with effective sanitary seals maintained to safeguard wells from contamination.

CHAPTER 2

PHYSIOGRAPHY AND GEOLOGY

MAIN PHYSIOGRAPHICAL AND GEOLOGICAL UNITS

The country consists of a more or less forest-covered, undulating Precambrian shield and a coastal plain.

The Precambrian shield, composed mainly of crystalline rocks, extends over an area of approximately 126,500 km^2 or about 80% of the country. It is at elevations mainly up to 250 m with a few peaks rising above 1,000 m. Juliana Top is the highest point at an elevation of 1,230 m. The Precambrian rocks continue northward beyond the shield, where they form the basement of a coastal basin (Enclosure 1).

The coastal plain is at elevations below 75 m, and in the coastal fringe elevations are seldom more than 5 m. It extends inland about 40 km in the east and 140 km in the west and is underlain by sedimentary formations from Cretaceous to Recent age, named the Corantijn Group (Doeve, 1957). Except for isolated Eocene inliers, formations older than Pliocene age are not known to be exposed. Onshore the thickest accumulation is about 2,000 m near the Corantijn River mouth. The sediments continue offshore for more than 140 km, where they are more than 4,000 m thick. Near the shelf edge a more or less complete succession is present (Gillman and Jardine, 1972), and sedimentation was in a marine environment, whereas to the south the succession is interrupted and sedimentation took place in terrestrial to shallow marine environments. The total volume of the basin sediments in both onshore and offshore areas of Surinam is estimated to be at least 150,000 km^3.

LAND FORMS

Land forms in the shield area reflect the underlying geology, having resulted from the weathering and erosion of the basement formations and from tectonic movements. They have been studied in detail by several investigators as an aid to photogeological mapping. O'Herne (1969) described 46 landscape types, which he grouped into eight units related to the main geological provinces.

The most prominent land forms of the interior are the Bakhuis, the Wilhelmina, and the Eilerts de Haan ranges, which extend across the southwest part of the country in a NW-SE direction. The Wilhelmina Mountains are the highest and most rugged. Verhofsted (1969) describes them as youthfully dissected along NE-SW structural directions. The van Asch van Wijck range forms a prominent ridge of dolerite extending northeast for more than 100 km from the southeast Wilhelmina Mountains. Immediately to the west of it is Tafelberg and the Emma range. The former is an isolated table-like remnant of subhorizontal sandstones. Isolated ranges rise to elevations generally between 500 and 600 m in the northeast, and a continuous highland area in the south forms the divide between the Guyana and Amazon drainage systems.

Although very little relief is displayed in the coastal plain, three land forms are distinguishable. Around the inland fringe is a Savannah Belt (Dek landscape) of Pliocene sediments. The relatively flat surface at elevations between 20 and 75 m is steeply dissected by streams. Krook and Mulders (1971) describe the surface as terraced. To the north an Old Coastal Plain at elevations between 5 and 12 m is underlain by Pleistocene sediments and is followed by a swampy Young Coastal Plain at elevations below 5 m.

From a study of 1:100,000 scale topographic maps, King (1964) recognized three erosion surfaces in the interior and surmised equivalent unconformities and sedimentation in the coastal area. The first or "Early Tertiary" surface, apparently late Eocene in age, was a smooth extensive surface now represented only by isolated remnants at elevations between 450 and 850 m and by bauxite caps in the coastal area. It was eroded, forming a "Late Tertiary I" surface now consisting of rolling plateaus and bevelled surfaces about 100 m below the "Early Tertiary" surface. The equivalent in the coastal area is the accumulation of Oligo-Miocene sediments on an irregular post-Eocene surface. The youngest "Late Tertiary II" surface comprises the lowland plains at elevations between 100 and 400 m, equivalent in the coastal area with the post-Miocene unconformity and the accumulation of Pliocene sediments. According to King, the surfaces are analogous with similar surfaces in other lands throughout the world.

DRAINAGE PATTERNS

The southern highlands form a divide between the coastal Guyana and Amazon drainage systems, and all the major rivers of Surinam flow directly to the ocean.

The NW-SE oriented highlands of the Bakhuis, Wilhelmina, and Eilerts de Haan ranges form a prominent drainage divide separating the Corantijn River from the remaining rivers. To the northeast of this divide the rivers flow generally to the NNE in the shield area, and, upon emerging onto the coastal plain, they turn towards the north. An exception is the large Marowijne River. It flows to the northwest and north in its middle reaches, but the tributaries and the downstream section flow generally to the NNE. Southwest of the highlands the Corantijn River and upstream tributaries flow generally northwest, but then turn to follow a more or less NNE course to the coast.

The large Corantijn and Marowijne Rivers flow directly to the ocean, entering perpendicular to the coastline, whereas the other rivers turn westward, their flows apparently insufficient to overcome the strong North Equatorial Current. According to Nota (1969), bottom velocities as high as 60 cm/sec have been measured at depths of 35 m in this current.

In detail, the drainage patterns tend to follow the structural lineations in the shield, and even lineations and anomalous turns in the coastal plain appear to relate to the underlying tectonic structure. In the Savannah Belt a well incised drainage pattern has developed, although this is not dense. The drainage is less dense in the Old Coastal Plain, and in the Young Coastal Plain it is incipient and swamps cover vast areas.

STRATIGRAPHICAL CLASSIFICATION OF THE BASIN SEDIMENTS

In 1927 Bracewell described a Coastal Plain and a White Sand Series in Guyana. Ijzerman (1931) described the basin sediments of Surinam following exploration drilling for water supplies between Paramaribo and Republiek. He divided them into younger Fluvio-Marine deposits of the coastal plain, and older Continental Alluvia equivalent to the Savannah Belt. Grantham and Noel-Paton (1937) classified the sediments as shown in Table 1. Although they were considered to be Quaternary and possibly Tertiary in age, the lithological divisions have generally remained until the present time but with names given to the different members, which were variously grouped. With the exception of the Demerara and Coropina formations, the nomenclature in Surinam and Guyana is different, although the same basic units are recognized.

A complete section near the deepest onshore part of the basin was obtained when the Rose Hall test for oil was drilled in 1941 near New Amsterdam in Guyana. Details of the test, which was drilled to 1,920 m, are given by Kugler et al. (1942). By comparing fossils with species found in Trinidad, Mio-Pliocene deposits were assumed to be present, but it was not until later studies of the pollen that Cretaceous and Lower Tertiary sediments were known. In Surinam the Nickerie test for oil was drilled in 1942-1943 intersecting the bedrock surface at 1,477 m. A similar sequence was found.

Van der Hammen and Wijmstra (1964) classified the sediments on the basis of pollen content. Seven pollen zones were outlined for the time interval from Upper Cretaceous to Quaternary. A post lower-Eocene to lower-Miocene hiatus was identified as the period when the coastal bauxite was formed. The nomenclature established by Grantham and Noel-Paton (1937) in the coastal areas was retained in the new stratigraphical table, with added names for the Bauxite Belt.

In 1959 the Alliance 28 test was drilled in the coastal area of eastern Surinam. A summary of the extensive research on the samples is given by van Voorthuysen (1969). The well intersected sediments from Holocene down to Upper Cretaceous age. Wijmstra (1969) compared the

Bracewell 1927 Guyana	'Jzerman 1931 Surinam	Grantham and Noel. - Paton 1937 Guyana	Kugler 1942 Guyana	Schols and Cohen 1956 Surinam	Bleakley 1956 Guyana		Doeve 1957 Surinam			
			Alluvium				Quaternary	Corantyn System	Youngest Formation	Recent Sediments
Coastal Plain	Fluvio - Marine Deposits	U. Clay Series	Demerara Clay	Demerara Series		Demerara Clay				Demerara Series
			Quaternary Terraces	Coropina Series		Coropina Formation				Coropina Series
										Bauxite
White Sand Series	Continental Alluvia	U. Sand Series	Berbice Formation	Zanderij Series	White Sand Series	Upper Sand			Bauxite Formation	Zanderij Series
		Int Clay Series				Intermediate Clay				
		A Sand				Lower ("A") Sand				
		L. Clay Series				Alternating Sand and Clay	Tertiary			
		L. Sand Series								
						Berbice Formation				Nickerie Series
										Bauxite

Table III - 1, Stratigraphic classifications of the coastal - basin sediments up to 1957 pollen with that reported in offshore Well SO-1, which contains marine microfossils. This permitted a comparison with zones established in Trinidad and led to more accurate dating, particularly of the Miocene sequence.

Montagne (1964) classified the sediments of the Onverdacht bauxite area in Surinam. The classification basically follows that of van der Hammen and Wijmstra (1964), and the names "Onverdacht Formation" for the Lower Tertiary sediments and "Coesewijne" for the Upper Tertiary sediments were proposed.

In a stratigraphical table presented by Noorthoorn v/d Kruyff (1970), based on data from oil tests, three main formations are identified based on differences in bulk density. The nomenclature is different from that already in use with the exception of the Nickerie formation for the Cretaceous deposits. Ages were established by pollen and other microfossils. According to Noorthoorn v/d Kruyff, the upper marker horizon is mid-lower Miocene in age, probably at the contact of Pollen Zones E and F of van der Hammen and Wijmstra (1964). When the given depths of the marker horizon are compared with other data in the coastal area, it appears that it is at the top of the A Sand or the Eocene sediments where the A Sand is missing (Enclosure 2). Furthermore, at offshore Tests SO-1 and MO-1 the depths given coincide with the top of the Miocene, which is limestone at these locations (Gillman and Jardine, 1972).

Wijmstra (1971) generally recognizes the same classification established with van der Hammen in 1964. He shows the A Sand of Guyana to be equivalent, at least in part, to the bauxite hiatus and, in his section, extends it into Surinam. He also revives the name "Zanderij Formation," originally named "Zanderij Series" by Schols and Cohen (1950), for Pliocene sediments in Pollen Zone G1, but retains the formation in the Upper Coesewijne.

Gillman and Jardine (1972) give the stratigraphical succession at Well GLO-1, about 140 km north of the eastern coast, and correlate the sequence with that of MO-1 (offshore) and CXI (onshore). The test ended at 4,663 m after intersecting a more or less complete succession of sediments down to Lower Cretaceous (Albian) age. Five sedimentary cycles are recognized. One of the most striking features indicated in the succession intersected by GLO-1 is the thick series of Pliocene to Recent terrigeneous sediments, indicating a major change after Miocene times.

A summary of the onshore classifications presented since 1927 is in Tables 1 and 2. General correlation between the offshore and onshore sequences is evident; however, the lithological units as known onshore do not continue far offshore. Wijmstra (1971) gives the most recent classification of the onshore sediments using established nomenclature. In the light of the correlation of Gillman and Jardine (1972), it is suggested that more distinction be given to the break at the end of the Miocene and that the Zanderij formation of Pollen Zone G be distinguished clearly from

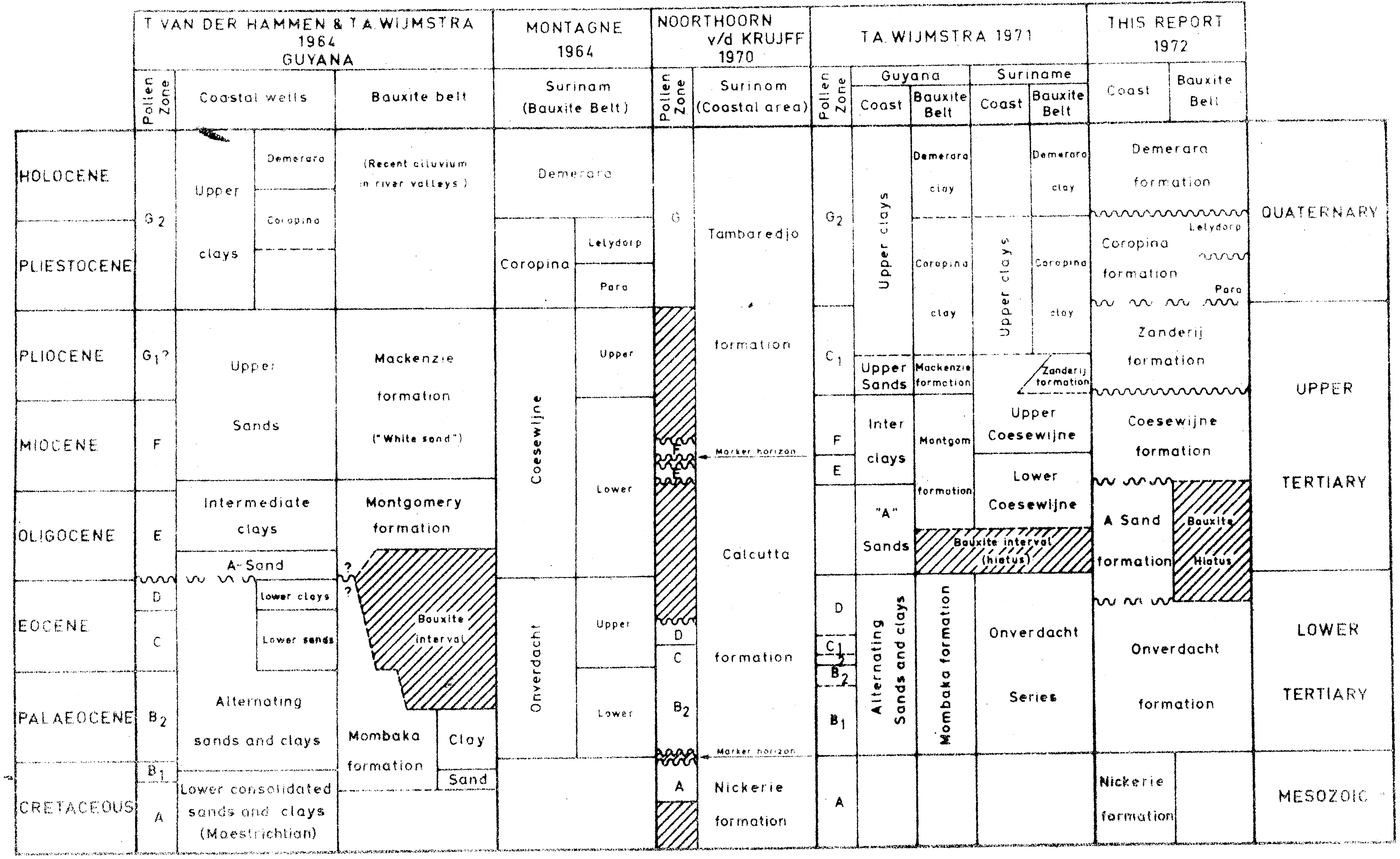

Table III-2, Stratigraphic classifications of the coastal-basin sediments from 1964 the Coesewijne formation of Pollen Zones E and F. It is suggested also that the A Sand be recognized in Surinam. Wijmstra includes it in his stratigraphical succession of 1969, but shows it only in his section of 1971 and not in his stratigraphical table for Surinam. Where present it is immediately below the upper marked horizon of Noorthoorn v/d Kruyff (1970) as shown onshore.

DESCRIPTION OF FORMATIONS

Precambrian

The ages of Precambrian rocks based on isotope studies are given by Priem et al. (1971). According to them the oldest rocks are highly metamorphosed gneisses, charnokites, and granulites that form the Bakhuis horst and adjacent areas in the northwest. An age of 2,600 million years (my) is suggested by them, based largely on comparisons with rocks in Guyana.

Most of the rocks, consisting of widespread granites with metasediments and metavolcanics, have an isotopic age of 1,810 ± 40 my. The metasediments and metavolcanics occur mainly in the east. They have been designated the Marowijne Group by Bosma and Groeneweg (1969).

In the center of the country, Tafelberg is the easternmost remnant of the Roraima formation which, according to McConnell et al. (1969), once covered at least 1.2 million km^2 of the Central Guyana shield. At Tafelberg the formation consists of about 700 m of relatively flat-lying reddish sandstones, with an isotopic age of 1,600 to 1,650 my.

Gabbroic and doleritic sills and dikes intrude the basement rocks. The rocks are designated the Avanavero Dolerite by Bosma and Groeneweg (1969), and according to Priem et al. (1968) the age is 1,500 to 1,800 my.

The basement rocks are deeply weathered. Weathering to depths of 70 m has been recorded in extreme cases. O'Herne (1966a) lists the depths of weathering for various rock types. It appears that it is deepest in basic rocks and metasediments (15-30 m) and least in granites (generally up to 16 m).

Triassic

The first known rocks to appear in Surinam after the Precambrian consist of dolerite in the form of long narrow dikes. They are particularly abundant in eastern Surinam and French Guiana, where they trend generally NNW-SSE. The name Apatoe Dolerite was proposed by Bosma and Groeneweg (1969) after the village of Apatoe on the Marowijne River. The age of samples from east and northwest Surinam is 227 ± 10 my (Priem et al., 1968).

Cretaceous (Nickerie Formation)

Sediments of Cretaceous age, named the Nickerie Formation by Schols and Cohen (1953), are known only from drilling in the northern coastal plain and offshore. They are the oldest sediments known in the coastal basin beginning with rocks of Albian age (Gillman and Jardine, 1972). Near Nickerie and offshore they comprise 55 to 60% of the basin sediments.

The Nickerie test intersected about 800 m of Cretaceous sediments beginning at a depth of about 600 m. A log of the test given by d'Autretsch (1950) lists mainly compact kaolinitic sand with gravel and multicolored shale. In eastern Surinam, Upper Cretaceous (Maestrichtian) sediments were intersected below 320 m by the Alliance 28 test (Wijmstra, 1969). The log given by van Voorthuysen (1969) lists mainly kaolinitic gravel and sand, calcareous at the top with shells and plant remains.

The depth to the top of the Cretaceous sediments along the coast is illustrated in Annex 1-H. It is based on the section of Wijmstra (1971), and data listed by Noorthoorn v/d Kruyff (1970).

Offshore 140 km at GLO-1 Gillman and Jardine (1972) recognize four sedimentary cycles. The first and second, in the middle and lower Albian, are transgressive, separated by a sharp regression. The third and fourth, in the upper Cretaceous, are regressive. The deposits are more than 1,825 m thick, topping at a depth of 2,738 m. They are mainly grey to greenish-grey carboneous and dolomitic clays with silt and sand. According to Gillman and Jardine, the microfauna and microflora compare with that in Senegal, West Africa.

Cretaceous sediments continue westward into Guyana. In southwest Guyana a deep east-west oriented graben between the Pakaraima Mountains to the north and the Kanuku Mountains to the south is filled with sediments of Jurassic and Cretaceous age known as the Takutu Formation (McConnell et al., 1969).

Palaeocene (Lower Onverdacht Formation)

Rocks of Palaeocene age are known from test wells in the coastal area and offshore. Occurrences as far south as Onverdacht have been described by Montagne (1964), who included them as the lower member of his Onverdacht series.

In the Onverdacht area the sediments occur at depths of about 40 to 50 m as coarse to fine-grained sand with a thin layer of kaolin or kaolinitic swamp clay at the top.

The most detailed description of the Palaeocene sequence in the coastal area is from the Alliance 28 test, where it was intersected from 200 to 320 m. According to van Voorthuysen (1969), it is for the most part shallow marine in origin with a rich marine fauna. It is composed mainly of sandy clays and clayey sands. Noncalcareous sediments with abundant brown coal and some gypsum occur in the depth interval 290 to 295 m. At this depth the boron content is relatively high (Porrenga, 1969), and van Voorthuysen (1969) suggests sedimentation in lagoonal conditions with very high salinity.

In Western Surinam, sediments of Palaeocene age are not clearly defined. At Nickerie interbedded sands and shales occur immediately above the Cretaceous.

Offshore at test GLO-1 Gillman and Jardine (1972) log 135 m of Palaeocene sediments topping at 2,600 m. They consist mainly of grey to brownish clay. An ocean transgression is indicated, followed by the beginning of a regressive sedimentary cycle, which continues to the end of the Miocene.

Eocene (Upper Onverdacht Formation)

Eocene sediments generally have been known as Alternating Sands and Clays below the bauxite hiatus. Montagne (1964) described the deposits from the Onverdacht bauxite area and included them as the upper member of his Onverdacht series.

The formation locally crops out in the Bauxite Belt. From open pit mines Montagne (1964) describes an old landscape with steep-sided hills capped by up to 10 m of bauxite. Under the bauxite a thick layer of kaolin is always present, below which the formation consists of kaolinitic sands, which become coarse towards the base. The sands are poorly sorted, with a 50% size generally between 300 and 500 microns. Fine sands are apparently better sorted.

To the west and east of the Onverdacht bauxite area yellow-mottled black clays intersected by test wells probably are Eocene in age.

In the coastal area Eocene sediments occur at greater depth, downfaulted from the Bauxite Belt. The top is at a depth of about 150 to 200 m in the east and 400 to 450 m in the west. They are more compact than the overlying sediments, which is reflected in bulk density logs (Noorthoorn v/d Kruyff, 1970). The sediments are variable in lithology. Extensive sands rich in kaolin are evident, but reddish-brown sands and grey, black, and reddish clays and kaolin also occur. At Paradise near Nickerie TW 5/72 intersected mainly lightly cemented, grey, white, and red mottled clay with interbedded grey sand from 410 to 446 m.

In the eastern coastal area the Alliance 28 test intersected Eocene sediments from 180 to 260 m. They consist of kaolinitic sands and sandy kaolin. In the middle from 215 to 220 m they are calcareous and contain a fauna of ostracods, mollusks, and fish, coinciding with a high boron content (van Voorthuysen, 1969).

Offshore at the GLO-1 test, Gillman and Jardine (1972) log 233 m of Eocene sediments from 2,367 to 2,600 m, consisting mainly of greenish-beige and bluish-green calcareous clays deposited throughout the first half of a regressive cycle of sedimentation.

Oligocene (A Sand Formation)

The name A Sand was first used by Grantham and Noel-Paton (1937). It has been used mainly in Guyana, but Wijmstra (1971) extended it into Surinam in his coastal section.

The formation is composed mainly of more or less kaolinitic coarse-grained angular quartz sand. In places, as at Meerzorg, the sand is fine- to medium-grained, and at other locations it contains fine rounded quartz gravel as at TW 10/70, Leiding 9A. Interbedded clay layers are present in places.

The upper contact normally is identifiable as a stiff grey clay, but locally, as in the Livorno area, and at T42 Calcutta (Wijmstra, 1971), A Sand in the overlying Coesewijne formation may be in contact with it. Gamma-ray and resistivity logs show the top of the formation contrasting with the overlying clays, and bulk density logs of onshore oil tests show a shift at the top of the A Sand, where present. The upper surface appears to be quite regular, dipping gently to the north (Enclosures 2 and 3).

The lower contact is not as readily identifiable. The formation may rest directly on Onverdacht sands, which generally are more kaolinitic and in places brown-colored. This contact is irregular, as indicated by the isopachs in Enclosure 3.

The formation does not crop out. It thins inland and ends against the rising basement or intervening Onverdacht sediments along the north side of the Bauxite Belt. It does not appear to continue inland south of the Saramacca River in the Calcutta-Tambaredjo area, which coincides with the coastal extension of the Bakhuis zone (Enclosure 2). In the coastal area it is about 80 m thick in the west beginning at a depth of about 350 m, and it is about 50 m thick to the north of Paramaribo beginning at a depth of about 180 m.

It is apparent that the A Sand formation was deposited north of the Bauxite Belt in valleys that were eroded in the Onverdacht formation following movements probably in Upper Eocene to Oligocene times. West of Paramaribo the formation is thick, apparently as an infilling of a NE-SW trending valley eroded along the line of the SE Bakhuis fault.

Miocene (Coesewijne Formation)

Montagne (1964) included all sediments above the Bauxite hiatus and below the Coropina formation in one formation, which he called the Coesewijne series. He divided this into a lower unit of Oligo-Miocene age and an upper unit, which he suggested was Pliocene in age.

In this report the name "Coesewijne Formation" is used to include only Miocene sediments above the A Sand.

Outcrops have not been reported, but sediments corresponding to Pollen Zone F are known to exist only 15 m below ground surface near Zanderij. The thickness in the coastal area varies up to 90 m in the east and 150 m in the west.

The formation onshore consists of clay and sandy clay with interbedded sands. The clays are generally dark grey or black with organic material. Locally a bluish-green clay is present in the lower sections, and in places kaolin is present. The amount of kaolinite is less than in the older clays, comprising only about 50%, with the remainder mainly montmorillanite (Porrenga, 1969).

The sand members vary up to 60% of the formation, but generally they comprise between 20 and 50% and are more abundant in the upper part. Individual sand layers are generally less than 10 m thick. Thicker sections appear to be complexes of more than one layer. The sand is medium- to coarse-grained and poorly sorted generally with a significant clay content.

A correlation of the sand layers shown in the sections (Annex 1) is based on lithology, stratigraphical position, and ground water quality. A NNW dip is apparent. The section from Groningen to Domburg gives the impression of deposition as deltas, possibly corresponding to early forms of the present Saramacca and Suriname Rivers with a divide near Koewarasan, where the sands make up only 19% of the formation, and Santo Boma, where it is almost entirely clay.

Van Voorthuysen (1969) describes the sediments intersected by the Alliance 28 test as terrestrial. Brown coal and pyrite are common, and not a trace of marine life was found. He indicates that peaks of high salinity as shown by the boron content coincide with the presence of gypsum, pointing to strong evaporation.

Offshore at Test MO-1 the section of Gillman and Jardine (1972) shows an 890 m Miocene section from 510 to 1,400 m, consisting mainly of limestone with three sandstone bands and with clay at the lower part of the Middle Miocene. Farther offshore at Test GLO-1 the Miocene is only 297 m thick, topping at 1,953 m and consisting of greenish-grey and brown calcareous clay.

Pliocene (Zanderij Formation)

Deposits of Pliocene age crop out around the perimeter of the basin forming the Savannah Belt and continue northward beneath the Coropina formation. They were first described as "Continental Alluvia" by Ijzerman (1931).

The name "Zanderij Series" was introduced by Schols and Cohen (1950) for the sediments originally described by Ijzerman (1931). Zanderij formation is used here for the onshore sediments in Pollen Zone G below the Coropina formation.

The formation consists mainly of coarse angular quartz sand, more or less kaolinitic with interbedded clay. Sections constructed from test well data suggest that the formation contains two main facies, a lower clayey and an upper sandy facies. The section across the Suriname River valley at Carolina (Annex 1-F) shows the relationships of the two facies and the Quaternary deposits. It appears that a facies rich in kaolin and grey clay with interbedded sands was first deposited and that a sandy facies followed, first filling in valleys eroded in the earlier facies and older formations.

Relatively high kaolinite is indicated in the Lower Pliocene section of the Alliance 28 test (Porrenga, 1969), which may be equivalent to the clayey facies observed inland.

In the coastal area near Paramaribo the thickest accumulations are mainly coarse sands in the depth interval of about 35 to 90 m infilling buried valleys (Enclosure 4 and Annex 1-A), which approximate the trends of the Suriname and Saramacca Rivers. In western Surinam the formation extends from a depth of about 50 m to as much as 200 m. Tests in the Nickerie area show mainly medium- to coarse-grained sand.

By far the thickest accumulation of Pliocene sediments is offshore. According to Gillman and Jardine (1972), about 1,730 m of Pliocene and Quaternary sediments were intersected by test GLO-1, consisting of about 300 m of greenish-grey clay at the base, followed by silty clay and silt.

Zonneveld (1951), van der Eyk (1957), and Montagne (1964) concluded that the sediments originated as "Continental Alluvia" as originally described by Ijzerman (1931), but Bakker (1957) suggested that they may in part have been deposited in a coastal environment. According to Krook and Mulders (1971), the sediments are estuarine-lagoonary clays and sands as well as fluvial sands, which display features suggesting deposition from rapid streams with variable discharge. He describes a definitely marine clay from drill holes in the Zanderij area. A terrestrial origin is suggested by van Voorthuysen (1969) for deposits as far north as Alliance, where they were intersected from 70 to 110 m by the Alliance 28 test well. He indicates that high salinity, as shown by the boron content of the upper sediments (Porrenga, 1969), coincides with the presence of gypsum, pointing to strong evaporation. He also states that there was not a trace of marine life.

The evidence points to a terrestrial to coastal environment in the present offshore area. Deltas of rivers draining the interior appear to have drifted westward as valleys eroded in the older sediments were filled, finally overlapping the eastern part of the next delta (Annex I A). This is in agreement with the studies of Krook and Mulders (1971). According to them, the heavy minerals strongly resemble the geology of the hinterland, but in the coastal area staurolite, which is most characteristic of the Armina Formation of eastern Surinam and French Guiana, is found far to the west because of beach drifting. This suggests that the fine grained sediments found offshore may have drifted far from the east.

Pleistocene (Coropina Formation)

The name Coropina series was first used by Schols and Cohen (1950) for sediments that crop out in the area of the Old Coastal Plain and continue northward beneath the Demerara clay.

The formation has been divided into a lower Para member (Montagne, 1964) and an upper Lelydorp member (Schols and Cohen, 1950). According to Montagne, the Para member in the bauxite area consists of heavy fine laminated stiff grey and brown clays with films of fine sand and with lenses of coarse unsorted sand, mainly near the base. He describes the Lelydorp member as containing a lagoonal facies with silts and sandy clays, and an offshore bar facies of fine sorted sand.

In the coastal area the formation consists mainly of grey and yellow clays with interbedded sand and sandy clay layers, and in places a lithological contact with the underlying Zanderij formation is not clear.

It is evident that the onshore area was subjected to fluctuations in sea level and that the coastline probably shifted considerable distances during Pleistocene times. Offshore bars point to a coastline at times as far south as the Bauxite Belt. From the samples of the Alliance 28 test, Porrenga (1969) indicates high salinity similar to the upper part of the Pliocene sediments but increasing towards the top. He suggests that the high salinity may represent hypersaline tidal flats or lagoons.

According to Brinkman and Pons (1968), the Para sediments were deposited during the Mindel-Riss interglacial period and the Lelydorp sediments were deposited during the Riss-Würm interglacial period. The latter has been confirmed by carbon-14 tests giving an age of 48,000 years BP (Bosma and Groeneweg, 1969). Erosion of the interglacial sediments must have taken place during the glacial periods when sea level was low. Nota (1969) suggests a sea level of about 90 m below present during the Würm glaciation, which eroded the surface of the continental shelf. Coral reefs

150 km offshore from western Surinam compare with similar reefs offshore from Guyana, the age of which has been established at 12,000 to 17,000 years BP.

According to Gillman and Jardine (1972), offshore at Test GLO-1 the regressive sedimentary cycle, which began in Pliocene times, continued, and silt and sand increased in the dominantly clayey sediments.

Holocene (Demerara Formation)

The name Demerara clay was given to the Recent sediments of Guyana by Kugler et al. (1942). The formation is at the surface throughout the Young Coastal Plain and in places extends south into the Bauxite Belt.

According to Brinkman and Pons (1968), the onwhore deposits begin with pyritic Mara clays deposited under rising sea level conditions ending at about 6,000 years BP, after which time Coronie deposits consisting of marine clay, peat, pagasse, and sand and shell ridges were deposited under more or less constant sea level conditions. The Coronie deposits are divided into three sedimentary phases: a Wanica phase (6,000-3,000 years BP), consisting mainly of shell and sand ridges; a Moleson phase (2,500-1,300 years BP), beginning with erosion, followed by pyritic clays during rising sea level conditions, and ending with brackish to fresh water clays and shell ridges; and, finally, a Comowine phase (post-1,055 years BP) in which marine clays were deposited after erosion. The shoreline has since receded, and, according to Brinkman and Pons, sections of accretion and erosion now alternate along the coast.

From a study of heavy minerals Krook (1969b) concludes that coarse sand of the sand ridges probably came from the Marowijne River and the fine sand probably was carried in suspension with clay minerals from the Amazon River. According to Nota (1969), recent deposition is confined to a belt up to 15 km offshore within the 25 m depth contour.

STRUCTURE

Geological structures relate either to ancient movements, which took place during Precambrian times, or to more recent post Permo-Triassic times associated with continental drift and the opening of the Atlantic Ocean, leading to the evolution of the coastal basin.

According to O'Herne (1966a), the structure of the Precambrian basement is characterized by block faulting and imbrication. Two major orogenic units have been identified: a Guyana orogeny to the northwest with predominantly north to northeast strikes, and a Surinam orogeny throughout most of Surinam with predominantly southeast strikes. Priem et al. (1971) suggest an age of about 2,600 my for the high-grade metamorphic assemblage in the northwest and an age of 1,810 ± 40 my for the structural unit of the east which they attribute to the Trans-Amazonian Orogenic Cycle.

Following the Precambrian the first structures to appear were generally NNW-SSE trending fissures into which the Apatoe dolerite was intruded (227 ± 10 my BP). May (1971) describes dikes of this general age surrounding the Atlantic and suggests that they relate to the onset of north Atlantic sea floor spreading in Permo-Triassic times.

Since Cretaceous times the northwest coast of South America has been the trailing edge of the continent as it drifted westward away from Africa. The area has suffered considerable faulting. Aleva (1970) describes faulting in the Adampada-Kabalebo (Bakhuis horst) area, and from different levels of laterization he postulates three periods of movement. Guicherit (1969) was able to distinguish faults affecting Eocene sediments with downthrows to the north, which he deduced from seismic surveys in the Onverdacht bauxite area. In adjacent coastal areas, Bleakley (1956) and Kugler et al. (1942) recognize faulting in the coastal area of Guyana and, according to Aguiar et al. (1969), block faulting affected Cretaceous and Tertiary sediments in the Amazon delta area.

In Surinam one of the most important structural features is the Bakhuis horst. It appears on the "Fotogeologische Kaart van Suriname" as a NE-SW trending area bounded by faults. There is evidence that the zone continues into the coastal area and even offshore. This is suggested by the basement surface and top Cretaceous contour maps of Noorthoorn v/d Kruyff (1970). It is suggested also in Enclosure 2, where contours on the Eocene-Oligocene surface bulge northward, probably representing Onverdacht sediments rising above the A Sand formation caused by a positive movement in late Eocene or early Oligocene times, followed by deposition of the A Sand in low areas. There is a thick accumulation of the A Sand in the buried trough-like valley, which coincides with the southeast Bakhuis fault west of Paramaribo. Additional evidence of the horst extending into the coastal area is the presence of oil within the zone at Calcutta and northwest of Paramaribo.

Southeast of the Bakhuis horst the Wilhelmina Mountain range is described by Verhofsted (1969) as being fractured in nearly all directions but with an ENE-WSW direction dominating. He gives evidence of right lateral displacements along NE-SW directions. This implies stress and strain in E-W and N-S directions.

A study of the drainage pattern was made as it relates to known faults in order to extend information on the structure of the basin. Investigators have described how the drainage patterns in the interior reflect structural features (Verhofsted, 1969; Maijer, 1969). The results of the drainage study are shown in Enclosures 1 and 2. A system of fractures is evident, radiating from an area south of Apoterie and east of the Takutu graben in Guyana. In the coastal area it is not clear whether lineations and lines joining anomalous turns of the rivers are caused by recent movements or by differential compaction of sediments, the deposition of which might have been controlled by such movements. Of particular interest is a lineation which coincides with the northern limit of the basement terrace and the southern limit of the Cretaceous and Mid-Lower Miocene on the maps of Noorthoorn v/d Kruyff (Enclosure 2).

The nature of the prime forces that caused the movements during Cretaceous and Tertiary times is uncertain. King (1964) and Aleva (1970) surmise uplift and erosion phases in the interior to coincide with transgressional and sedimentary phases in the coastal plain and offshore areas. The interior is part of an old shield, and therefore mobility likely originated in the oceanic area to the north. In this regard it is noted that the eastern margin of the Caribbean plate lies northwest of the basin.

Vine (1971) shows shallow focus earthquakes to the east of intermediate focus earthquakes along the plate boundary, suggesting a Benioff zone plunging beneath the margin of the Caribbean plate. This would result in a downwarping of the ocean floor around the plate edge, and the Guiana coastal basin may be the southern limit of such downwarping, with compensating uplift in the more rigid interior.

Dislocation of the basin sediments is apparent only up to Eocene times; however, later downwarping in the west is evident from the contours on top of the A Sand (Enclosure 2) and movements, which resulted in erosion of the Miocene surface, causing particularly thick accumulations of Plio-Quaternary sediments in the basin center and offshore.

It is possible that a high-level surface on the Zanderij formation beginning about 16 km west of the Coppename River (Krook and Mulders, 1971) reflects movement on the southeast Bakhuis fault. If this were so, it implies movement during Pliocene times.

Brinkman and Pons (1968) suggest movement as late as Holocene times. From a comparison of levels of sediments, the areas between Paramaribo and Coronie and between Nieuw Amsterdam and Georgetown are considered stable. Uplift is inferred between the Commewijne River and Cayenne. Rapid subsidence is inferred northwest of the Demerara River and slight subsidence near the mouth of the Corantijn River and southeast of Cayenne.

GEOLOGICAL HISTORY OF THE COASTAL BASIN

Apparently after a long period of stability an upwelling of the land occurred in Permo-Triassic times, resulting in mainly NNW trending fissures, which were intruded by the Apatoe dolerite marking the onset of sea floor spreading that resulted in the opening of the Atlantic Ocean.

A partial opening of the Atlantic occurred in Jurassic to Lower Cretaceous times, and opening of the South Atlantic was under way in Lower Cretaceous times (Vine, 1971). Infilling of the rift took place with a thick accumulation of Cretaceous sediments deposited first in transgressive and then in regressive sedimentary cycles (Gillman and Jardine, 1972). Sediments of this age also accumulated in the Takutu graben of southern Guyana.

Opening of the North Atlantic commenced in Upper Cretaceous times (Vine, 1971). The Americas drifted away from Africa, and the Guyana coastline was part of the trailing edge of the continent. Sediments continued to accumulate in a regressive cycle (Gillman and Jardine, 1972) originating from the interior shield.

Faulting of the Cretaceous and Lower Tertiary sediments occurred. Such movements were particularly evident at the close of Eocene times, probably breaking up the Early Tertiary surface. Subsequent erosion formed the Late Tertiary I surface (King, 1964). Apparently the coastal bauxite formed at this time on the caps of hills, and the A Sand was deposited in valleys and depressions in the coastal area.

Sedimentation diminished in Miocene times. Coastal swamps, lagoons, and small deltas with strong evaporation were characteristic of the present onshore area (van Voorthuysen, 1969), and a fringing reef evidently flourished offshore.

Post-Miocene movements caused erosion in the interior and coastal area, forming the Late Tertiary II erosion surface (King, 1964). Krook (1970) suggests an arid climate at this time. Abundant sediment was supplied from the interior, and a thick accumulation of Plio-Quaternary sediments infilled the downwarped basin center and offshore areas.

Ocean levels in Pleistocene times changed as a result of glaciation in the higher latitudes. Sedimentation took place during the interglacial periods and erosion took place during the glacial periods, when the ocean level was low. The Würm glaciation was at its peak about 18,000 years ago when the ocean level was 90 to 100 m below its present level (Nota, 1969, and Fauré, 1969). A rise of the ocean level during Holocene times followed the last glaciation, bringing the shore line inland beyond the present location to an optimum about 6,000 years ago, following which the Coastal Plain was formed.

CHAPTER 3

CLIMATE

GENERAL CLIMATIC CHARACTERISTICS

The climate is tropical, with two wet seasons and two dry seasons, of which the long rainy season from April to July and the long dry season from August to November are the most pronounced.

Mean monthly and annual climatic data are listed in Table 3 for Paramaribo and Table 4 for Zanderij. The data are fairly representative of the country.

The mean air temperature is about 27°C and slightly lower at higher elevations. The variation in monthly mean values is only about 2°C throughout the year, with January and February the coolest months and September and October the warmest. Diurnal temperature variations are in the order of 6 to 12°C, with the largest variations in the dry seasons.

The relative humidity averages about 80 to 82% and is only slightly lower in the interior. There is very little change throughout the year.

The prevailing northeast trade winds are gentle. The mean wind force is between 1.0 and 3.0 on the Beaufort scale in the coastal area and decreases inland. The strongest winds in excess of 2.0 generally prevail in the western coastal area.

The mean sunshine at Zanderij is 58%. It is higher in the dry season. Inland, less sunshine is received in the areas with heavier rainfall.

RAINFALL

The average rainfall at Paramaribo is generally representative of the country. Average monthly values are listed in Table 3 for the period 1931-1960, during which time the annual average was 2,208 mm.

Two wet seasons and two dry seasons are evident, with 50% of the annual rainfall occurring in the four-month long wet season and only about 20% occurring during the long dry season.

Elsewhere in the country data for the same 1931-1960 period are more or less restricted to the coastal area. Representative values in millimeters are as follows:

Nickerie	Totness	Cultuurtuin	Moengo	Albina
1,978	1,639	2,208	2,463	2,432

showing higher rainfall in the east and giving an average of 2,140 mm.

TABLE III-3

MEAN MONTHLY CLIMATOLOGICAL DATA FROM THE PARAMARIBO STATION FOR THE PERIOD 1931-1960

	Month												Year
	J	F	M	A	M	J	J	A	S	O	N	D	
Season	short wet	short dry		long wet				long dry				short wet	
Air temperature (^{o}C)	26.4	26.6	27.0	27.2	26.8	26.8	27.1	27.9	28.5	28.5	28.0	26.9	27.3
Relative humidity (%)	82	80	78	81	85	85	82	78	75	76	78	82	80
Sunshine (%)	47	50	52	48	44	51	62	71	77	76	64	49	58
Rainfall (mm)	193	150	162	232	321	303	226	167	86	87	109	174	2,208

TABLE III-4

MEAN MONTHLY CLIMATOLOGICAL DATA FROM THE ZANDERIJ STATION FOR THE PERIOD 1952-1970

	Month												Year
	J	F	M	A	M	J	J	A	S	O	N	D	
Season	short wet	short dry		long wet				long dry				short wet	
Air temperature (°C)	25.4	25.4	25.8	26.1	26.0	25.9	26.2	26.8	27.4	27.5	26.9	25.8	26.3
Relative humidity (%)	84.6	83.0	81.3	82.3	85.3	85.3	82.5	79.5	76.2	75.8	79.9	84.5	81.7
Sunshine (%)	46.4	45.7	40.2	43.7	38.7	48.8	60.7	67.8	72.9	71.7	64.7	51.4	54.4
Wind velocity (m/s)	1.67	1.71	1.70	1.73	1.59	1.48	1.42	1.36	1.41	1.35	1.44	1.46	1.53
Rainfall (mm)	193	161	150	221	319	273	209	162	79	73	113	172	2,125
Evaporation (mm) (composed)	98	95	107	108	100	100	113	118	131	131	112	97	1,310

Rainfall for various areas throughout the country is listed along with annual river discharges in Table 7 (page 33) and is shown on a daily basis for Zanderij and Oema (Rijsdijk) in Figures 26 and 29, respectively, and on a monthly basis for Republiek in Figure 27.

In the interior the seasonal distribution is the same as in the coastal area, but the depth is commonly between 2,500 and 3,000 mm in places and locally exceeds 3,000 mm.

In Figure 1 the frequency of rainfall in excess of 2,500 mm is plotted from annual isohyet maps for the years 1962-1968 inclusive (Meteorologische Dienst Suriname, Serie 1). This shows heavier rainfall across the center of the country. The pattern suggests the influence of highland areas; thus, in the west center the frequent high values correspond with the Wilhelmina Mountains. In the east, the area with most frequent high rainfall begins farther north, probably because of the influence of the Nassau and Lely Mountains, and the area with the most rain is the Tapanahony Valley between the Lely and the Oranje Mountains. Throughout most of the coastal plain the annual rainfall does not exceed 2,500 mm, and the frequency of such rains is low in an area extending south along the Saramacca and Suriname River valleys. Conditions in the southwest of the country appear to be similar to those in the coastal area. A large area corresponding with the Kayzer Mountains does not appear to receive rainfall in excess of 2,500 mm.

A similar pattern is evident for the frequency of annual rainfall less than 2,000 mm. In the period 1962-1968 such low rainfall does not appear in the Tapanahony valley southwest of the Lely Mountains, but frequently occurs in the coastal area, particularly the west, and in a small area of the Kayzer Mountains.

EVAPOTRANSPIRATION

Direct panevaporation has been measured since 1961 at Cultuurtuin in Paramaribo, and average daily values by months and years are listed in Meteorologische Dienst Suriname, Serie 1. Monthly and annual evaporation from these data are listed in Table 5. The average annual evaporation for the eight-year period is 1,655 mm, with a high of 1,825 mm and a low of 1,407 mm. The monthly evaporation is higher during the dry season and exceeds the average rainfall (Table 3) for the months of September, October, and November. Panevaporation at Paramaribo is compared with rainfall at Paramaribo, Republiek, and Zanderij in Table 6.

Potential evaporation was computed by means of a modified Penman equation (van Bavel, 1966, and Eagleson, 1970), using mean monthly climatological data from the Zanderij station for the period 1952-1970 inclusive (Table 4). Thus, the values are indicative of the Suriname River basin in the Savannah Belt.

TABLE III-5

MONTHLY AND ANNUAL EVAPORATION IN MILLIMETERS AT CULTUURTUIN, PARAMARIBO, FROM AVERAGE DAILY VALUES

	J	F	M	A	M	J	J	A	S	O	N	D	Year
1961	98	148	170	177	161	123	155	183	180	161	141	108	1,806[+]
1962	118	129	180	168	-	-	149	167	174	174	159	118	1,825[++]
1963	127	126	167	153	127	-	108	149	-	198	147	136	1,715[++]
1964	152	162	-	180	158	126	149	149	180	-	-	102	1,642[++]
1965	105	129	174	162	-	93	105	136	156	149	144	102	1,752[++]
1966	105	112	130	120	115	90	102	124	132	149	126	102	1,407[+]
1967	102	120	133	129	102	96	136	143	159	170	123	102	1,515[+]
1968	121	120	136	114	136	114	130	158	156	155	120	121	1,581[+]
Average	116	131	156	150	133	107	129	151	162	165	137	111	1,655

Source: Meteorologische Dienst Suriname, Serie 1

[+] Sum of monthly values

[++] From average daily value

TABLE III-6

PANEVAPORATION AT PARAMARIBO AND RAINFALL AT PARAMARIBO, REPUBLIEK, AND ZANDERIJ FOR THE YEARS 1962-1968 INCLUSIVE

Year	Panevaporation Paramaribo (Cultuurtuin) (mm)	Rainfall (mm)		
		Paramaribo (Cultuurtuin)	Republiek	Zanderij (Airport)
1962	1,825	1,698	1,599	1,856
1963	1,715	1,945	1,665	1,849
1964	1,642	1,555	1,437	1,387
1965	1,752	1,767	1,757	1,826
1966	1,407	1,907	1,935	2,149
1967	1,515	2,559	2,022	2,227
1968	1,581	2,188	2,233	2,340

The daily heat budget at the surface in millimeters of water per day (mm/day) is given by the equation:

$$H = R\ (1 - r)\ (0.27 + 0.47\ S) - GT_a^4\ (0.56 - 0.092\ e_d^{0.5})$$
$$(0.10 + 0.90\ S)$$

where:

R - Mean monthly extraterrestrial radiation in millimeters of water evaporated per day, recalculated using data from Intern Rapport No. 292 of Landbouwproefstation, Paramaribo, March 1971.

r - Estimated percentage of reflecting surface (Albedo), which was taken as 0.3.

S - Estimated ratio of bright sunshine to its maximum possible duration. The regression constants in the empirical relation between sunshine and radiation are taken as (0.27 = 0.47S), as advised by R. van der Weert and K. J. Lenselink after Broers et al. (1966).

Ta - Air temperature.

e_d - Saturated vapor pressure at mean dewpoint.

Wind velocities were taken at an elevation (Za) of 14.75 m above the surface.

The potential evaporation values calculated are 1,251, 1,262, and 1,310 mm annually, using roughness parameters (Zo) of 4, 5, and 10 cm, respectively. A slightly higher value of 1,422 mm was calculated by Bleakley (1956), using data from the Georgetown, Guyana, station in the Penman equation. The calculated values are lower than the measurements at Cultuurtuin, although they follow the same seasonal pattern (Figure 2).

Apparent evapotranspiration obtained indirectly as a difference between rainfall and run-off for the basement area (Table 12, page 80) averages 1,626 mm/yr, varying from 1,480 mm/yr in the Corantijn and Marowijne basins to 1,730 mm/yr in the Kleine Saramacca, Kabalebo, and Nickerie basins. The extreme low is 1,018 mm (Corantijn basin, 1969), and the extreme high is 2,076 mm (Nickerie basin, 1970). The apparent evapotranspiration equivalent to run-off exceeded by 50% (Table 14, page 83) varies from 1,480 to 1,795 mm/yr for basins of high and low run-off, respectively.

In summary, it is evident that indirect estimates of evapotranspiration agree well with direct measurements at Paramaribo. An average value of about 1,480 mm/yr is representative of the interior basement area, and a value of 1,655 mm/yr is representative of the coastal plain. Calculations based on the Penman equation are slightly lower. They are close to the indirect determinations for the interior basement, although data from the coastal plain is used.

CHAPTER 4

SURFACE WATER

RIVER BASINS

Seven first-order rivers drain the area of Surinam towards the Atlantic Ocean. Three main groups are distinguishable when comparing the extent and shape of the drainage areas.

A first group is represented by the larger Marowijne and Corantijn Rivers, with drainage areas of 68,700 and 67,600 km^2, respectively, which form the eastern and western boundaries of Surinam. Together they drain almost 58% of the country.

A second group is represented by the Coppename River (21,700 km^2) and the Suriname River (16,000 km^2), which drain approximately 24% of the country. The basins are elongated in a NE-SW direction located in the north-central area. They are separated by the Saramacca basin except in the extreme headwater area, where they have a common divide.

A third group is represented by the Nickerie River (10,100 km^2), the Saramacca River (9,000 km^2), and the Commewijne River (6,600 km^2). Together they drain about 16% of the country. The centrally located Saramacca basin is elongated in a NE-SW direction. The Nickerie basin in the west is less elongated, and the Commewijne basin in the east is subtriangular.

The drainage towards the coast is such that 38% of the area drains to the extreme west (Corantijn and Nickerie Rivers) and 27% to the extreme east (Marowijne River). The remaining 35% drains to the east central area discharging at the Coppename-Saramacca rivermouth and the Suriname-Commewijne rivermouth.

The rivers are tidal generally up to the most seaward rapids about 90 to 120 km inland.

RIVER FLOWS

The most important river-gauging stations are located in the basement area upstream from tidal influence. The locations and the corresponding drainage basin areas are shown in Figure 3. The flows are listed in Tables 7 and 8. Measurements are available for the Suriname and Marowijne Rivers from 1952 and for the rest beginning between 1961 and 1966, as shown in Table 8. They compare in magnitude with the three groups of drainage basins outlined.

TABLE III-7

RUN-OFF AND RAINFALL CHARACTERISTICS OF THE SURINAME AND MAROWIJNE RIVERS AND THEIR BASINS, 1952-1960

River, Station, and Drainage Area	Year								
	1952	1953	1954	1955	1956	1957	1958	1959	1960
Suriname River at Pokigron 7,750 km^2	+ 197 25.4 2,177	378 48.7 2,624	295 38.1 2,381	269 34.7 2,563	293 37.8 2,383	220 28.4 2,076	139 17.9 1,848	155 20.0 1,974	234 30.1 2,212
Marowijne River at Langetabbetje 63,700 km^2	1,529 24.0 -	2,088 32.8 -	1,717 26.9 2,569	1,955 30.7 2,510	1,943 30.5 2,249	1,776 27.9 2,194	1,745	2,095	1,503 23.6 2,513

+ 197 Mean annual discharge in m^3/s

25.4 Average annual unit discharge in l/s/km^2

2,177 Annual rainfall total in mm

L Estimated

TABLE III-8

RUN-OFF AND RAINFALL CHARACTERISTICS OF THE SURINAM RIVERS AND THEIR BASINS, 1961-1970

River, Station, and Drainage Area	Year									
	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Corantijn River at Mataway 51,600 km^2						+ E 811 15.7 2,138	E 1,388 26.9 2,354	E 1,647 31.9 2,534	1,434 27.8 1,893	1,464 28.4 2,436
Kabalebo River at Avanavero 9,020 km^2					E 53 5.9 1,463	E 71 7.9 2,025	E 166 18.4 2,171	E 252 27.9 2,705	154 17.1 2,134	155 17.2 2,464
Nickerie River at Blanche Marie 1,260 km^2							33 26.2 2,446			
Nickerie River at Stondansie 5,160 km^2			E 141 27.3 2,714	18 3.5 1,700	38 7.4 1,947	43 8.3 1,965	86 16.7 2,408	116 22.5 2,594	83 16.1 2,083	113 21.9 2,766

+ 811	Mean annual discharge in m^3/s
15.7	Average annual unit discharge in $l/s/km^2$
2,138	Annual rainfall total in mm
E	Estimated

TABLE III-8 (cont.)

RUN-OFF AND RAINFALL CHARACTERISTICS OF THE SURINAM RIVERS AND THEIR BASINS, 1961-1970

River, Station, and Drainage Area	Year									
	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Coppename River at Maksita Kreek 12,300 km^2					+ 189 15.4 2,115	211 17.2 2,175	267 21.7 2,511	E 382 31.1 2,866	334 27.1 2,307	
K. Saramacca River at Anoemafoetoe 1,340 km^2		14.4 10.8 1,913	26.4 19.7 2,287	6.7 5.0 1,966	12.6 9.4 2,016	9.7 7.2 2,150				
Saramacca River at Dramhosso 3,520 km^2	52 14.8 1,968	82 23.3 2,053	135 38.4 2,799	32 9.1 1,765	64 18.2 2,115	64 18.2 2,202	90 25.6 2,228	119 33.8 2,817	128 36.4 2,391	96 27.3 2,605
Suriname River at Pokigron 7,750 km^2	145 18.7 2,175	181 23.4 2,153	290 37.4 2,734	86 11.1 1,772	142 18.3 2,225	142 18.3 2,468	201 25.9 2,539	293 37.8 3,180	257 33.1 2,291	199 25.7 2,604
Marowijne River at Langetabbetje 63,700 km^2	1,049 16.5 1,907	1,891	E 2,261 35.5 2,843	E 992 15.6 1,842	E 960 15.1 2,059	2,434	1,715 26.9 2,481	2,979	1,784 28.1 1,955	1,642 25.8 2,637

\+ 189 Mean annual discharge in m^3/s

15.4 Average annual unit discharge in l/s/km^2

2,115 Annual rainfall total in mm

E Estimated

Flows vary seasonally, comparing with the seasonal rainfall distribution. This is illustrated by the hydrographs of the Marowijne and Corantijn Rivers (Figure 4). The highest flows are in May, June, and July, with a peak generally in May or early June, corresponding with the long wet season. The lowest flows are in November at the end of the long dry season. The short wet and short dry seasons are not as well defined, and at times they cannot be distinguished.

UNIT DISCHARGE

A wide variation of annual unit discharge is evident from the values listed in Tables 7 and 8. The parameter represents average conditions within a basin. It tends to decrease with increasing area, but in Surinam this is not necessarily the case. The values plotted against basin areas (Figure 5) show a slight decrease with increasing basin areas for most years, but this cannot be considered significant because of the variations in annual rainfall.

The frequency of average annual unit discharges for the years 1952-1970 inclusive is illustrated in Figure 6, with the basins divided into two groups. The first group represents high run-off basins for which the median unit discharge is 25 $l/s/km^2$, and the second group represents relatively low run-off basins for which the median unit discharge is 15 $l/s/km^2$.

A relationship is evident between the low and high run-off groups of basins in the form of a linear correlation between the two, which differ quantitatively (Figure 7). In the low run-off group the values of run-off are only 39 to 69% of those originating from the same rainfall depth in the high run-off group. The relationship of monthly rainfall and unit discharge is not well expressed; apparently the period is too short.

Although several factors such as the amount and intensity of rainfall, geology, topography, vegetation, and evaporation contribute to the amount of run-off and consequently the unit discharge, it is apparent that the geology in particular and the rainfall contribute most to the differences between basins. The geology is considered in more detail in the following section. It is evident from Figure 1 that the relatively low rainfall may partly explain the low unit discharge values of the Kabalebo, Nickerie, and Kleine Saramacca Rivers; however, from this figure one would not expect the close similarity of unit discharge for the Corantijn and Marowijne basins. Similarly, it is noted in Figure 7 that the data available for the low run-off basins generally is for lower rainfall, although a factor(s) other than rainfall plays an important role.

HYDROLOGICALLY DISTINCT AREAS

Differences in run-off as illustrated by unit discharge are evident within the drainage basins in the basement area as mapped (Fotogeologische Kaart van Suriname). Notably, the Kabalebo, Kleine Saramacca, and Nickerie (Stondansie) basins are characterized by low run-off. In addition to this, a common feature is their location along the northern fringe of the basement area on which at least a discontinuous veneer of basin sediments extends beyond the limit of the coastal basin (Krook and Mulders, 1971), as shown by the Savannah area. The Nickerie and Kabalebo basins actually include part of the Savannah upstream from the gauging stations.

The unit discharges represent average conditions throughout a basin, which may vary considerably. This is illustrated by differences in unit discharge for the Nickerie basin in 1967 (Table 8 and Figure 8) at Blanche Marie (26.2 $l/s/km^2$) and at Stondansie (16.72 $l/s/km^2$). Unfortunately, discharge measurements at Blanche Marie are available only for the one year, and, whereas it serves to illustrate the difference, its quantitative significance is questionable. The basin received above-average rainfall in 1967, which would give an above-average run-off in the upper basin, but it followed three years of below-average rainfall and therefore run-off in the lower basin might have been lower than expected because of depleted soil moisture. The part played by the Savannah, remnants of older basin sediments, and possibly deeper weathering with less erosion in areas of low relief would be to retain water that would normally run off a bare rock surface. Some of this may enter the zone of saturation, percolate locally to streams, and reappear as an effluent flow, while much of it would evapotranspire.

Differences in the amount of run-off probably occur in the Kabalebo basin as in the Nickerie basin with high run-off in the upstream areas; indeed, the difference likely exists in all the basins with a belt of low run-off extending along the entire northern fringe of the basement area. The possible southern limit of this low run-off belt is shown in Figure 3. The Surinam basin upstream from Pokigron falls south of it and hence high run-off is measured. The southward bulge coinciding with the Kleine Saramacca basin may represent the influence of low rainfall, in addition.

Unfortunately, there are no flow data available for the coastal area, and the run-off characteristics can be considered only indirectly. Infiltration and effluent ground water flow to streams is a feature of the Savannah area and most of the Old Coastal Plain, while natural discharge in the Young Coastal Plain is incipient and swamps abound. The hydrological features of these areas are considered in more detail in Chapter 6, Water Balance Studies.

HYDROLOGICALLY DISTINCT SEASONS

Long Wet Season

The influence of the long wet season on run-off is best illustrated by run-off data from the Suriname and Marowijne Rivers, for which the longest records are available (19 years).

The volume of discharge of the Suriname River at Pokigron in the four months of the long wet season, April-July inclusive, varies between 50 and 76% (average 62%) of the annual discharge volume.

The weight of the long wet season in contributing to the annual run-off of the Marowijne River basin is lower than for the Suriname River basin. It amounts to between 45 and 64%, for an average of 56%.

A correlation of average long wet season unit discharge with rainfall is given in Figure 9. The relationship appears to be closer when rainfall of the three antecedent months is added. A comparison of this relationship with the annual relationship (Figure 7) emphasizes that the long wet season is the major source of run-off (Figure 4).

Long Dry Season

The discharge of the Suriname River at Pokigron during the four-month long dry season (August-November inclusive) for the 19-year observation period varies between 10 and 28%, for an average of 17% of the total discharge. Thus, the average volume of the long wet season run-off is 3.65 times larger than that of the long dry season. The unit discharge of the recession period, which nearly coincides with the long dry season, compares with the relationship shown in Figure 7, whereby almost 60% of the unit discharges are between 10 and 16 $1/s/km^2$.

A parallel situation occurs in the Marowijne River basin, with the seasonal flows varying between 10 and 32 for an average of 17% of the arrival flow.

CHAPTER 5

GROUND WATER

HISTORICAL ACCOUNT OF GROUND WATER EXPLORATION AND DEVELOPMENT

The earliest recorded development of ground water involved the construction of a well at Sivaplein about 500 m from the Suriname River in Paramaribo. Drilling commenced in 1902 using a rig equipped with a steam pump for jetting. The well was completed at a depth of 164.45 m in 1903. It flowed above ground level at rates from 0.1 to 0.1 l/s, and variations in flow were related to tides. The chloride content of the water was 168 ppm, the dry residue was 540 ppm, and there was only a trace of sulphate, but the iron content was 9 to 10 ppm.

The Sivaplein well did not yield sufficient water, and in 1914 Prof. J. B. Harrison visited Surinam from Guyana to advise on the possibility of obtaining good drinking water from artesian wells in the coastal area as in Guyana, where numerous wells had been drilled since 1831. He thought the likelihood of obtaining such supplies was good. He believed that the fresh water was in sand above the basement and recommended a program of test drilling between Vierkinderen and Lelydorp where the rock was not deep.

Some of the drilling recommended by Harrison was accomplished, but it was not until 1928 and 1929 that serious exploration was carried out. This involved the drilling of tests along the railway between Paramaribo and Zanderij under the direction of Dr. Jenny van Weijerman (1929 and 1930). The drilling was mainly to depths between 10 and 30 m, with tests at Onverwacht and Lelydorp drilled to 62.8 and 74.2 m, respectively.

Following the exploration it was concluded that a supply of water for Paramaribo would best come from Republiek where the railway crosses Coropina Creek about 42 km south of the city. Wells were drilled to depths of 20 to 25 m and furnished with copper casing and up to 10 m of 6-inch-diameter saw-slotted copper screen. The water was first pumped to the city in 1933 through a 14-inch-diameter water main capable of supplying 300 m^3/hr, which could be increased to 360 m^2/hr. A vacuum system was used to pump the wells. Records of water levels and pumpages have been kept since the system went into operation.

Between 1930 and 1950 a total of 13 tests were drilled in the Nickerie area to depths up to 104 m, and three tests were drilled at Coronie up to a depth of 192 m. All gave poor quality water. An oil test about 21 km ESE of Nickerie was completed in 1943 at a depth of 1,453 m. This indicated fresh water to about 700 m and brackish water below.

In eastern Surinam a total of 13 tests were completed between 1940 and 1949 at Paranam, Joden Savanna, Landsboerderij, Albina, and Moengo.

An evaluation of all data relating to ground water was made by d'Autretsch (1950). He questioned whether the coastal aquifers were connected with the shallower aquifers inland. He suggested that fresh ground water might be flowing towards the ocean, pushing brackish water in front of it and extending above it because of differences in density. He recognized the existence of shallow brackish water and indicated that it might be a result of infiltration in the tidal river estuaries.

Between 1950 and 1965 a total of 42 test wells and production wells were drilled to extend information on ground water in the coastal area. A report by d'Autretsch on the first seven tests was published in 1953. The tests were between Chatillon and Nieuw Amsterdam. The formations were divided into three zones based on lithology and water levels. The lowest of the three zones corresponds to the A Sand formation and upper part of the Onverdacht formation, and the upper two zones correspond to the Coesewijne and Zanderij aquifers as outlined in this report, but with a poorly defined division between the two. D'Autretsch noted that the deeper aquifers had higher water levels and indicated that this was characteristic of a classical artesian basin.

A report on drilling between 1950 and 1957 by van Loon was published in 1958. The report includes a map showing a fresh-salt water boundary passing north from Paranam to Paramaribo, then to the west. According to van Loon the area east of Paranam and Paramaribo represents a fossil basin containing salt water.

As a result of the exploratory drilling program the Zorg en Hoop well field was established in 1958, and a number of small distribution systems supplied by deep wells followed.

In 1965 evidence of oil was found in the cuttings of a well being drilled at Calcutta and the Geology and Mining Service (GMD), which had been responsible for ground water exploration, shifted its attention towards oil.

The Surinam Water Company (SWM) constructed its own wells for the Paramaribo, Nickerie, and Albina water supply systems, which it operates, and constructed a number of wells for the Billiton Company supply at Onverdacht. The Surinam Aluminum Company (Suralco) constructed and operates its own wells to supply its plant at Paranam. Since 1966 the Ministry of Rural Government and Decentralization has concerned itself with drilling for water supplies for rural communities and operating small rural systems.

REVIEW OF EXISTING INFORMATION

Published literature relating to the subject is given in the list of references.

Logs of previously drilled exploratory wells and production wells were reviewed, paying attention to parameters such as water quality and water levels in addition to lithology in order to correlate the aquifers and avoid unnecessary drilling. In most cases the logs are quite detailed as might be expected when pilot drilling was by coring. This permitted the recovery of undisturbed clays for pollen studies, but sands were generally lost, appearing in the circulating fluid, and the exact contacts had to be estimated based on driller's logs.

In almost all cases chemical analyses included chlorides, total dissolved solids, pH, iron, and hardness.

Water levels and well elevations are given quite accurately for most wells.

The hydraulic properties of the aquifers are not given in any of the literature, and therefore basic data in both published and unpublished reports was used to obtain an approximate idea of these properties. Except for only a few tests, the pumping test data lists only discharges and the corresponding drawdown for the pumped well only without reference to time. Transmissivities were calculated from this data using a modified Dupuit-Theim equation:

$$T = \frac{2.3\,Q}{2\,\pi\,s_w} \; \frac{r_o}{r_w}$$

where T = transmissivity in m^2/day
Q = discharge in m^3/day
r_o = radius of the cone of interference
r_w = radius of the well
s_w = drawdown of the well

The lowest discharges were used where possible to avoid inaccuracies arising from large well losses. The radius of the cone of interference was assumed to be 200 m. This dimension enters the equation as a log function, and an error makes little difference. No correction was applied for partial penetration where it occurred. The values obtained in this manner tend to be low; however, they compare well with values obtained by more comprehensive tests. In a few instances there was sufficient information for a more thorough analysis. The results of these are given in Figures 11, 16, and 17.

Original water levels given in the reports were used to determine the regional shape of the piezometric surface and the likely flow systems that obtained before withdrawals (Figure 23). Water level data supplied by the Surinam Water Company (SWM) for wells at Republiek and near Paramaribo were used to evaluate the effect of withdrawals (Figures 27 and 43), and the data from Republiek were correlated with rainfall to estimate recharge in the area.

Logs of oil tests were made available by the GMD. These included resistivity, spontaneous potential, gamma ray, bulk density, and caliper logs. They were used to extend correlation throughout the coastal area and to provide information on salinity distribution. Estimates of salinity were made following the method outlined by Schlumberger Limited (Log Interpretation Charts, 1969 edition, p. 10).

FIELD AND LABORATORY PROCEDURES

Drilling

It was originally envisaged that drilling would start using two rotary rigs (FAILING 2500 and 1250) with single shifts, which would be increased as soon as possible to two eight-hour shifts on each rig followed by "round-the-clock" operations. Shift work was not accomplished except during the emergency drilling for Paramaribo and while drilling and inserting casing and screens in the deep wells near Nickerie.

Instead of shift work on two rigs, additional rigs with crews working a single shift per day were made available to maintain progress. A total of seven drilling rigs were used, although not all of them were operating throughout the project. The rigs, their estimated present-day capacity, and the amount of drilling performed by each are listed in Table 9.

The FAILING 2500 and 1250 rigs were used throughout the project, with the FAILING 2500 operating for some time in the Nickerie area, where deeper wells were required.

The FAILING 1500 rig was brought back into service in September 1970 after an overhaul. It is an old rig powered by a BUDA engine for which parts are not available.

The FAILING 1500 ss rig was used only for drilling in conjunction with Paramaribo studies.

The SOLITE rigs proved to be excellent for exploration up to depths of 100 m. They are easy to transport, do not require extensive site preparations, and the 5-inch diameter hole permits logging and the insertion of PVC pipe up to 3-inch diameter. On a few occasions pyritic nodules or layers were a problem.

TABLE III-9

RECORD OF DRILLING RIGS AND THEIR ESTIMATED CAPACITIES

Rig	Agency	Year purchased	Mount.	Max. open hole		Max. casing			Project drilling				
				Depth m	Dia in.	Depth m	Dia in.	Handling dia in.	Wells tests	Tot. meters	Largest bit in.	Shallowest m	Deepest m
Failing 2500	GMD	1967	trailer	1) 1,000	6	400	6	16	13	2,662	15	16	456
Failing 1500	GMD	1949	trailer	1) 250	6	180	6	12	8	1,485	17	70	240
Failing 1500 ss	SWM	1963	truck	2) 300	6	170	8	12	5	896	15	170	195
Failing 1250	D&D	1966	truck	3) 225	6	130	6	8	18	1,978	16	52	193
Solite (1)	GMD	1959	skid	100	5	50	4	6	34	1,857	5 7/8	6	102
Solite (2)	GMD	1959	skid	100	5	50	4	6	7	196	5 7/8	12	45
Acker (1) Auger	BWKW	1965	trailer	100	3				6	102	-	12	22
Acker (2) Hillbilly	BWKW	1965	skid	4) 300	4 1/4	70	4	6	2	484	4 1/4	218	216

1) Using 2 7/8 in. F.E. drill pipe
2) Using s 7/8 in. F.E. drill pipe (presently using 3 1/2 in.).
3) Using 2 7/8 in. I.F. drill pipe
4) Using BX rods

One of the major time-consuming activities was site preparation, and to expedite progress a site preparation crew was formed and sites were prepared in advance of drilling.

Drilling was by the normal mud-flush rotary method. With the larger rigs a string of surface casing was first inserted to depths up to 30 m to control the unstable Demerara clay and a slim hole (5 7/8-inch in to 7 7/8-inch dia) was drilled for logging. The well was then enlarged according to requirements.

Wing bits of various diameters up to 17 inches were used. Pilot bits were used for larger diameters, whereas smaller diameters were drilled with pilot, three-wing, and fish-tail bits. Rock roller bits were used rarely to cope with pyritic layers or to prove bedrock.

Penetration rates in excess of 80 and 60 m/day have been achieved with the FAILING 2500 rig and with the FAILING 1500 and 1250 rigs, respectively, when drilling slim holes. Average penetration rates of 8 and 5 m/hr are close approximations.

Bentonite based muds were used, imported under the trade names of BASCOGEL, MAGOGEL, and AQUAGEL, and for a number of tests a new fluid, REVERT, was tried.

Casing was normally clay sealed, except as specified for the construction of production wells. For many tests 2-inch and 3-inch diameter PVC pipe was installed, saw-slotted at the depths required. A well was constructed using 12-inch diameter PVC casing. An account of this is given in Annex 8.

Some aspects of well design and production well costs are given in Annexes 7 and 9, respectively, and data on the wells drilled during the project are given in Annex 3.

Well Logging

A log was prepared by the driller and samples representative of each meter drilled were collected for examination.

A NELTRONIC Model KL well logger owned by the GMD was made available to the project. The basic logger contains facilities for single-point resistivity and spontaneous potential logging. It is equipped with about 900 m of armored cable and is driven by a small portable 2 KVA generator. Additional tools operated from an auxiliary control panel include multisonde and fluid resistivity systems. A gamma-ray system was added to the unit by the project.

The multisonde system was not in working order. It was returned to the maker for repair, but in spite of this it has never been in working order during the project.

The combined gamma-ray, single-point resistivity and spontaneous potential logs were adequate for the needs of the project. They indicated far more detail than the drillers' logs and the samples. An estimate of the ground water salinity was possible, but this was frequently hampered by clay baseline shifts.

Hydraulic Properties of Well Samples

The hydraulic conductivity of a number of samples was determined using a JOHNSON permeameter. The values agreed closely with those determined from pumping tests for two wells, but for the most part they were too high. This may be because the samples were disturbed and not truly representative of the formation.

Specific yields of a number of samples were determined by measuring the volume of water required to saturate a known volume of wet but previously drained sand. Uncompacted, the values obtained varied between 10 and 25%. After compaction by tapping the container of sand on the bench, values ranging between 8 and 14% were obtained. The latter values probably represent most closely the specific yield of the aquifer material in its natural state.

Pollen Analysis

The pollen in selected clay samples from Wells 2/70 and 3/70 was examined by Mr. A. L. E. Amstelveen of the GMD, who identified the pollen zones in which the clays belong. The pollen zones established by van der Hammen and Wijmstra (1964) form the basic classification of the basin sediments. Unfortunately, it was not possible to continue this work and extend the control.

Mechanical Analyses of Sand Samples

Sand samples from some of the earlier test wells were analyzed mechanically under the supervision of Mr. L. Krook of the GMD. The practice was discontinued because, with the mud-flush rotary method of drilling, the samples were disturbed and contaminated. The slot size of screens was selected by comparing the aquifer sands visually with sands of known size ranges.

Well Development

After demudding, development methods included jetting with fresh water, surging, agitation with compressed air, and overpumping. A solution of polyphosphate was introduced into the screen area after demudding and initial jetting to disperse any remaining mud.

Test Pumping

A 6-inch and an 8-inch multistage turbine pump were available for testing. They were belt-driven from a tractor. The 8-inch pump was capable of pumping 28 l/s against a head of 30 m. Pumps powered by electricity were used for the Zorg en Hoop tests.

Discharges were measured by means of orifice weirs and water levels by electric or chalked tapes. Automatic water-level recorders were used on observation wells where possible.

In most instances a preliminary steptest was followed by a test at a constant discharge rate for up to 48 hours.

Tests on small diameter test wells were run using small horizontal centrifugal pumps.

Levelling

The elevations were determined of all wells and test wells drilled during the project and of selected wells that had been drilled previously. Exceptions were the wells drilled in the Nickerie area. Cellar level was taken as the top of the concrete cellar pipe or the top of the cement poured around the casing, where there was no cellar.

A profile was made along the road from the Afobaka Highway to the Suriname River at Carolina, along which 12 test wells were drilled.

The levelling was to second-order accuracy. All levels given are related to Normal Surinam Level (NSP), the zero of which is mean sea level measured at the mouth of the Suriname River during 1957.

Relevant information related to earlier references was converted to NSP levels using the differences given by the Higher Geodesy Division of the Ministry of Development where available. An exception was at Republiek where the reference point for the original studies of van Weijerman (1929 and 1930) was the railway line at the bridge over Coropina Creek. The elevation of the line is 4,104 m NSP, as determined by the project.

Chemical Analyses

Chemical analyses were performed at the Central Laboratory of the Ministry of Health. Standard volumetric methods were used for most determinations, but the cations sodium, potassium, calcium, and magnesium were determined by means of a flame photometer at the Cultuurtuin Laboratory of the Ministry of Agriculture, Husbandry, and Fisheries.

A total of 117 samples were analyzed up to the end of September 1972. The analyses are listed in Annex 4.

A small portable laboratory (HACH Model DREL-B) was used to obtain approximate results quickly. The specific electrical conductance was determined for a number of samples.

Environmental Isotopes

Studies of environmental isotopes in ground water were undertaken as an aid to understanding the ground water flow systems and recharge. This was accomplished through an agreement between the UN and IAEA.

The isotopes involved were oxygen-18, tritium, carbon-14, and carbon-13. These were determined at the IAEA laboratory in Vienna.

Close contact between the IAEA and project field staff was maintained. This included a visit to the field by one of the IAEA staff.

The IAEA report on its findings forms Annex 10 of this volume, and references to the findings are made throughout the volume.

Observation Wells

Most of the test wells drilled by the project were left with small diameter PVC casing, permitting the measurement of water levels or sampling for water quality.

Water levels of 11 wells were monitored regularly in the Zanderij-Rijsdijk area, where seasonal water-level variations occur. Four of these were equipped with STEVENS Type F automatic water level recorders. The water levels were compared with the corresponding rainfall as part of the recharge studies.

The water levels of five wells in the coastal area were measured in addition to the wells measured by the SWM. The only movement of significance was associated with the operation of the Zorg en Hoop wells. A recorder was placed over one of the older wells (GMD 19) to monitor this.

PRECAMBRIAN BASEMENT AS AN AQUIFER

The rocks of the basement are for the most part crystalline and impervious. They are deeply weathered, but the process involves the decomposition of felspars and ferromagnesian minerals into clay minerals and, although the weathered rocks may become more porous, the hydraulic conductivity would be too low to consider them as aquifer material. Clayey and micaceous sands were intersected locally above the hard basement by tests drilled in the Savannah area.

Widespread faulting of the basement has been described, but it is not known whether the fractures are open to permit a flow of water. Such open fractures could carry water into the coastal basin. An older flow system appears to have been relatively active along the coastal extension of the SE Bakhuis fault zone as indicated by the chloride distribution in the A Sand (Enclosure 3). Whereas this reflects conditions in the Tertiary sediments, it might be that the equivalent basement fracture zone is also pervious. The run-off in areas with widespread open fractures would tend to be less than in areas without fractures. In this regard the low run-off of the Kabalebo, Nickerie, and Kleine Saramacca Rivers might be significant; however, run-off is relatively high in the Nickerie River basin above Blanche Marie, which covers part of the Bakhuis horst, and therefore it seems unlikely that significant quantities of water flow through fractures in the basement at the present time. This is supported by the nature of the flow system in the coastal basin, which would receive such flows.

CRETACEOUS AQUIFERS

The Nickerie formation of Cretaceous age is confined deep in the coastal area (Annex 1-H). Logs of test wells drilled for oil indicate a dominance of sand and gravel in the sediments, but containing brackish water. Because of this and its depth the formation is only of academic interest as an aquifer and is not considered further.

ONVERDACHT AQUIFERS

General Description

The Onverdacht aquifers include the sand members of the Onverdacht formation. It has not been as widely explored for ground water as the overlying formations.

A more or less continuous downfaulted coastal unit is confined beneath younger Tertiary sediments and ends against the rising basement immediately north of the Bauxite Belt. In the Paramaribo area the top is at depths of 120 to 450 m. Individual sand aquifers appear to be up to 30 m thick, but zones of up to 50 m occur with only thin interbeeded clays. The aquifers constitute between 30 and 50% of the formation in most areas, about 60% in the Saramacca-Coppename rivermouth area (Annex 1-H).

A more or less discontinuous unit is present at higher levels in the Bauxite Belt. It locally crops out, but for the most part it is buried and surrounded by Coesewijne, Zanderij, and Coropina aquifers.

Aquifer Parameters

Where intersected by test wells the aquifers generally are richly kaolinitic, which limits the hydraulic conductivity.

The only aquifer test was run in 1962 on wells intersecting Onverdacht sands at Onverdacht in the Bauxite Belt (Figure 11). At this location the transmissivity averages 75 m^2/day. The thickness is about 10 m, giving an average hydraulic conductivity of 8 m/day. The aquifer is under leaky artesian conditions. The storativity is in the order of 10^{-3} to 10^{-4}. A value of 0.39 calculated for one of the observation wells is unrealistically high; however, it is significant that this well is farthest south and that the formation crops out close to the south, where there is open water in the old worked-out bauxite pit.

Short incomplete tests have been run on individual wells east and northeast of Paramaribo, where hydraulic conductivity values from 5 to 40 m/day have been estimated (Annex 2). At Meerzorg Well GMD 7, three tests run in the depth interval of 161 to 188 m indicate a hydraulic conductivity increasing with depth from 5 to 38 m/day, but at TW 6/70 to the east the zone from 225 to 231 m was bailed for 3 hours at an average of 0.1 1/s with a drawdown of 5.4 m.

There have been no tests on the aquifers in western Surinam.

It is assumed that non-leaky confined conditions prevail throughout the coastal area and that, with the high kaolin content, the effective porosity will be less than 0.1.

Chemical Quality

The wells at Onverdacht yield water low in dissolved solids. It is essentially a sodium chloride water with a dry residue of 75 ppm, chlorides of 19 ppm, and without sulphates. The pH is between 5.5 and 6.0 and the iron is only 0.1 ppm. Close to the north brackish water is reported from the mine workings. Water from the bauxite at one location had a chloride content of 4,065 ppm, and at a location from under the kaolin beneath the bauxite the chloride content was 3,672 ppm. To the east brackish water was pumped from the Groot Chatillon tests of GMD (Annex 2). Fresh water to the south and brackish water to the north compare with similar salinity changes in the overlying and surrounding Zanderij aquifer (Enclosure 4), with which hydraulic contact must exist.

In the coastal area east and northeast of Paramaribo the water is mainly brackish with chlorides generally in excess of 1,500 ppm. At Meerzorg Well GMD 7, the chlorides in the interval 161 to 188 m increase with depth from 323 to 590 ppm, and to the south at Well GMD 5, Livorno, water believed to be from the Onverdacht has a chloride content of only 111 ppm. At the latter locations the A Sand aquifer with fresh water rests directly on the Onverdacht formation. A similar condition appears to exist at Jarikaba (TW 25/72).

The salinity distribution estimated as NaCl is shown in Annex 1-H. The water appears mainly brackish in the west from Calcutta (CC-1) to Totness (TN-1) along the northwest flank of the Bakhuis zone, and fresh from Totness towards the basin center.

Water Levels

In the Bauxite Belt original water levels are indicated approximately only by the Groot Chatillon tests drilled in 1953. The wells flowed at an elevation estimated at about 2 m NSP.

At Onverdacht the original level at the site of the wells likely was higher than at Chatillon and higher than in the surrounding Zanderij aquifer, because of the nearby outcrop at an elevation of more than 20 m NSP. In 1962, when tests were run for a well water supply, the elevation of the piezometric surface was about -4.0 m NSP because of dewatering in the nearby mine. At the present time pumping levels in the supply wells are between -22 and -27 m NSP. In nearby observation wells the level is about -12 m NSP, and about 2 km to the north the open cast mines are being dewatered to depths of about -25 m NSP. Thus, in the Onverdacht area ground water flow is towards the mines and locally towards the wells.

In the coastal area the highest level recorded was at Nieuw Amsterdam where in GMD Test 6 the water rose to 3.9 m ACL or about 5 m NSP. The level is lower farther inland at Jagtlust (0.97 m ACL or about 3 m NSP), Meerzorg (0.75 m ACL or about 2.7 m NSP), and at Tamanredjo (0.2 m BCL or about 2.0 m NSP). This is evidence of an apparent inland flow of ground water as in aquifers above.

Recharge

There is no quantitative information on recharge in the Bauxite Belt. Local recharge at Onverdacht is suggested by the leaky artesian conditions established from pumping test data and the likelihood of water-table conditions immediately to the south of the wells where the aquifer crops out. The terrain is disturbed by mining operations, and the presence of water perched at the surface in worked-out areas suggests that infiltration must be slow.

In the coastal area these aquifers are everywhere confined to the inland slope of the piezometric surface, and water levels higher than in the overlying aquifers rules out the possibility of modern recharge.

A SAND AQUIFER

General Description

The unit corresponds with the A Sand formation, probably of Oligocene age, consisting of coarse- and fine-grained angular sand and in places of coarse angular sand and fine rounded gravel. The aquifer is present in the coastal plain north of the Bauxite Belt. It thins inland ending against the rising basement or intervening Eocene sediments. It is confined beneath Coesewijne clays and above the Onverdacht formation. Locally it is in contact with the lowest Coesewijne aquifer, which is also confined, and with sands of the Onverdacht formation below. The roof is relatively uniform, sloping gently with a gradient of about 0.003 m/m to the north, but the floor is irregular, conforming with the topography of the post-Eocene surface (Enclosure 3).

Along the coastal area an eastern and a western unit are evident, separated by an area coinciding with the Bakhuis zone, where the floor is higher and the aquifer is thinner or missing (Enclosure 2).

The eastern unit extends inland south of Paramaribo to the northern edge of the Bauxite Belt. It does not continue east beyond the Suriname River in areas south of Meerzorg. The aquifer is at a depth of 120 m in the south and 160 m near the coast, with corresponding thicknesses of a few meters to 60 m, respectively. A relatively thick section of aquifer extends inland following the SE Bakhuis fault, likely as an infilled buried valley.

The western unit is not exploited for water supplies, but is is known from oil tests. It begins west of the Bakhuis zone in the vicinity of the Coppename River and continues westward into Guyana, probably extending inland from 30 to 50 km, respectively. In the Nickerie area the top is at a depth of 350 m and the aquifer is up to 80 m thick.

The two units connect in the coastal strip by the Saramacca River near Calcutta and Tambaredjo. It is not known how far offshore the aquifer continues. Approximately 100 km offshore sediments of the same age consist of sand and limestone (Gillman and Jardine, 1972), at depths of 1,400 to 1,450 m; thus, the aquifer as it is known onshore is not in open contact with the ocean. Fine grained sediments of equivalent age would be in contact with the ocean more than 140 km offshore at a depth greater than 2,250 m.

Aquifer Parameters

The aquifer is everywhere confined. Flowing artesian conditions existed near Paramaribo before withdrawals and probably exist in the west at the present time.

Storage coefficients in the range of 10^{-4} to 10^{-5} have been determined from pumping tests in Paramaribo, and in the range of 10^{-3} to 10^{-4} from tests on the Leysweg wells to the west.

Hydraulic conductivities estimated from tests run in the Zorg en Hoop well field are from 80 to 190 m/day for an average of 116 m/day. At Leysweg the transmissivity has been estimated at between 2,300 and 4,100 m^2/day for a rounded average of 3,200 m^2/day (Figure 44). The aquifer thickness has not been determined, but it is believed to be about 10 m, in which case the hydraulic conductivity would be quite high at 320 m/day.

Hydraulic conductivity values, estimated from old incomplete data and listed in Annex 2, are mainly between 30 and 80 m/day, with an exceptionally high value of 374 m/day at Koewarasan. This well is in a similar position to the Leysweg wells with respect to the SE Bakhuis fault zone, which probably is very pervious. Test Well 10/70 drilled near this fault bubbled with gas, and when pumped there was an apparent rise in the water level. The estimated values are low for the area east and south of Paramaribo, where the aquifer approaches the boundary.

The sand is mainly graded, coarse grained, angular, and more or less kaolinitic. In a compact undisturbed state the effective porosity is likely in the range of 7 to 15%.

Water Levels

Water levels are known only in the eastern basin in the area surrounding Paramaribo where, before withdrawals, the piezometric surface was lower than in the underlying Onverdacht aquifers but higher than in the overlying aquifers.

The piezometric surface was generally above ground level and the wells flowed. The levels are listed in Annex 2, and they are shown relative to other aquifers in Figure 23.

There are no wells constructed in the A Sands in western Surinam. It is assumed that the piezometric surface will be above ground level as in Guyana.

Chemical Quality

The chemical quality is known only in the area of the lower Saramacca and Suriname Rivers. Elsewhere only a clue of the salinity is available as estimates from the logs of tests drilled for oil.

The water contains mainly sodium chloride in solution, with dissolved solid concentrations ranging from 340 to 2,100 ppm. The water is entirely within the field of primary salinity where noncarbonate alkali exceeds 50% (Figure 12). Sodium and potassium are the main cations.

Magnesium is no more than 30% and calcium is generally less than 10%. The anions are mainly chloride, with 10 to 30% bicarbonate and less than 10% sulphate.

The water usually contains gas. At Zorg en Hoop this is released in small bubbles as water is pumped from the wells, giving it a turbid appearance for a few seconds. The gas does not burn. Hydrogen sulphide is present in small quantities; however, for the most part the gas has no odor and probably is carbon dioxide. Dissolved carbon dioxide from 60 to 100 ppm has been reported but after most of the gas has escaped. The highest value reported is 127 ppm at GMD 20, Leiding 8. At TW 10/70 gas with a foul odor bubbled from the well. This takes place from GMD Well 42 near Calcutta but to a lesser extent.

The pH is generally in the 6.0 to 7.0 range. At Zorg en Hoop it varies between 6.5 and 7.0, and to the west at Uitkijk and Koewarasan it is 6.0. The highest value of 7.0 and 7.4 were reported from GMD, Nieuw Amsterdam, and GMD 16, Jagtlust, respectively, where the dissolved solids are higher.

The iron content is high, varying up to 17.5 ppm. The highest value reported was for a sample from GMD Well 20. Values generally are less than 5.0 ppm.

The total hardness is mostly in excess of the bicarbonate hardness, but the two are equal in places. The total hardness varies from 60 to 534 ppm, with high values where the dissolved solids are high. At Zorg en Hoop the range is from 60 to 175 ppm. The bicarbonate hardness varies from 50 to 5.5 ppm. Like the total hardness, the higher values are where the dissolved solids are high. At Zorg en Hoop the bicarbonate hardness ranges between 53 and 100 ppm, but an anomalously low value of 7 ppm was determined for a sample from Well 36/71.

The water has an aggressive character. Witness to this is the corrosion of steel casing in wells. An EVERDUR bronze screen when removed from one of the Zorg en Hoop wells after five years was pitted on the outer surface. EVERDUR bronze and stainless steel screens, when removed from wells, are shiny and have no trace of encrustation.

The dissolved solid content increases northward towards the coast. This is illustrated by the isochlors in Enclosure 3. The isochlors bulge inland to the southwest in the vicinity of Koewarasan, following the trend of the SE Bakhuis fault zone.

In western Surinam relatively fresh water is indicated, as deduced from the logs of tests drilled for oil. An exception may be at the mouth of the Saramacca River (SMS-1) where a sand formation, which may be the A Sand, has a relatively high salinity of 850 ppm as NaCl (Annex 1-H). The salinities indicated in this section are only relative. In this regard it should be noted that water with a dissolved solids content of 747 ppm and chlorides of 363 ppm was reported from the A Sand aquifer intersected by Well GMD C XI, which is close to TW PB-2, and fresh water is indicated at JKS-1, whereas the dissolved solids at TW GMD-6, Nieuw Amsterdam, only 2 km to the SE, were reported to be 3,100 ppm.

Recharge

There is no evidence of modern recharge to the aquifer, at least in the eastern basin; this is indicated by the corrected carbon-14 ages, which vary from 13,006 to 19,969 years BP. Palaeo-recharge is discussed further under Flow Systems.

COESEWIJNE AQUIFERS

General Description

The Coesewijne aquifer zone is equivalent stratigraphically to Pollen Zones E and F above the A Sand. It is composed largely of clay and sandy clay with interbedded sand aquifers, which appear to be hydraulically interconnected. The zone is up to 100 m thick in the Saramacca and Suriname Rivers area and up to 120 m thick in the Nickerie area, where the top is about 230 m below ground surface.

The zone is covered by the Zanderij aquifer. There are no known outcrops, but it is possible that there are outcrops locally in the Savannah area. In the Bauxite Belt it is absent at locations where the buried hills of the Onverdacht formation rise to elevations higher than the top of the zone.

The aquifers generally make up from 30 to 50% of the entire zone and in the east appear more frequently in the upper section, coinciding approximately with Pollen Zone F. Individual aquifers are normally up to 10 m thick, but locally they form complexes of two or more sandbodies separated by only thin clay partings.

The NNW dip of the zone is greater than that of the Zanderij aquifer, and thus there is contact between them in the Bauxite Belt and immediately to the north where water in the Zanderij aquifer contains brackish water and subsurface outcrops of the Coesewijne aquifers along the sides of the buried valley are in contact with it.

The lowest aquifer is in contact with the A Sand aquifer at places in the coastal area.

Aquifer Parameters

The zone is everywhere confined. Local exceptions may exist in the extreme south of the basin, where there is contact with the Zanderij aquifer at locations where it is unconfined. The confined condition of the aquifers is reflected by the storage coefficient, which is generally in the range of 10^{-4} to 10^{-5}.

Hydraulic conductivities estimated from pumping test data fall within a wide range of 10 to 130 m/day. The lower values are for aquifers with a substantial clay content. The highest value of 130 m/day was estimated for Well 4/70, which is the supply well for the Kwatta-Leidingen project. At this location the aquifer is relatively free of clay, and it is thick, probably representing a complex of more than one sand body. Pumping tests on some wells constructed in these aquifers are illustrated in Figures 13, 33, and 37. Estimates of hydraulic conductivities from incomplete pumping test data (Annex 2) give values generally ranging from 10 to 150 m/day in agreement with the values calculated from more complete information.

Averages of all hydraulic conductivities estimated are 43 m/day for the lower aquifers and 70 m/day for the upper aquifers. The distribution of the values is patchy, reflecting varied conditions in the several aquifer units within the zone. In general values are 40 to 70 m/day in the lower aquifers between the Suriname and Saramacca Rivers, decreasing west of the Saramacca River to 24 m/day at GMD Well D 2, Kampong Baroe, and 15 m/day at Well 2/70, Groningen. Values for the upper aquifers are more variable.

In western Surinam hydraulic conductivities of 10 and 42 m/day have been estimated for the aquifer at Paradise (Well 5/72) and Groot Henar Polder (Well 37/71). The two wells are approximately 6 km apart but appear to be within the same aquifer.

Effective porosities estimated from disturbed samples are similar to other aquifers with a variation from about 8 to 13%. An overall value of 10% is assumed.

Chemical Quality

Ground water in the Coesewijne aquifers is relatively low in dissolved solids throughout the coastal area except at locations near the coastline in the eastern part of the country. The dissolved solids are generally less than 800 ppm. The lowest value determined is 164 ppm for water from TW 3/71 at Rijsdijkweg, and the highest salinity recorded is for the aquifer at Nieuw Amsterdam (GMD 8), where the chlorides are 907 ppm.

Figure 14 is a trilinear diagram of the main cations and anions. The freshest water nearest any source of recharge is from TW 3/71. This water plots towards the sodium-potassium vertex with about equal amounts of sulphates and chlorides in the field of primary salinity. Farther north between the Saramacca and Suriname Rivers the magnesium increases at the expense of sodium and potassium with calcium remaining about the same. The anions maintain a similar proportion to the water at Rijsdijkweg, and the water tends to move into the field of secondary salinity. To the west and east the water remains within the field of primary salinity.

At Nickerie in the extreme west the cations are almost all sodium and potassium. Chlorides and bicarbonates are about the same, there are no sulphates, and the water falls within the field of primary alkalinity.

The salinity increases northward towards the coast in the area between the Saramacca and Suriname Rivers (Figure 14).

Measurements of pH indicate a wide range generally varying between 6.0 and 7.3 but with values as low as 5.7 and as high as 8.1.

Iron is high, ranging between 0.4 and 10 ppm. The high iron and relatively high sulphates reflect the pyrite and gypsum contained in the sediments (van Voorthuysen, 1969).

Water Levels

The piezometric surface in the coastal area near Paramaribo is 1.0 to 2.0 m NSP or close to ground level. This condition continues inland for about 24 km to the vicinity of Uitkijk and Koewarasan (Figure 23). Immediately to the south the level is lower. The lowest levels were measured at Well 31/71, Helena Christina Weg, where it is less than 0.5 m NSP. Farther to the south the aquifers are in contact with the overlying Zanderij aquifer, the water levels in which fluctuate seasonally.

In western Surinam only three wells are constructed in Coesewijne aquifers (Totness, Groot Henar, and Paradise). The static water levels are approximately 2 m NSP, comparing with the northern coastal area in eastern Surinam.

Recharge

There are no known outcrops of the zone, and therefore recharge by the direct infiltration of rainfall may be discounted. The rivers and streams are effluent under natural conditions, and it is doubtful whether any of them are in contact with the zone; therefore, recharge as an influent flow from surface water may also be discounted.

The aquifers are in contact with the Zanderij aquifer in places and may be considered as extensions of the same system with the possibility of recharge in the form of a subsurface flow from the Zanderij aquifer; however, the piezometric surface and differences in water quality between the two aquifer zones, under natural conditions, suggest that a flow of water from one aquifer to the other must be negligible.

ZANDERIJ AQUIFER

General Description

The Zanderij aquifer is equivalent to the sandy facies of the Zanderij formation. It crops out, forming the Savannah Belt, and continues northward, dipping gently in that direction confined beneath the Coropina clays and above the Coesewijne formation. It is not known how far the coarse sand aquifer extends offshore. At about 100 km offshore (SO-1 and MO-1) its equivalent is silty and sandy clay and clay.

In the Savannah Belt the distribution of aquifers is very irregular. In places there are no clean sands. Where present the sands are usually highly kaolinitic. Conditions improve northward, and in the Bauxite Belt the aquifer appears to be present everywhere except locally, where buried bauxite hills rise to higher elevations.

The base is irregular, corresponding to the post-middle Miocene erosion surface (Enclosure 4). The thickest aquifer sections with the coarsest sand infill the valleys of this surface.

The upper limit of the aquifer is taken as the top of the main sandbody, but in places this is difficult to define because of overlying Quaternary sands.

Thicknesses vary up to 20 m in the Savannah Belt and are generally between 10 and 20 m in the Bauxite Belt. In the coastal area of eastern Surinam the aquifer begins at a depth of about 30 to 40 m and the thickness attains 40 to 50 m in buried valleys, which approximate the locations of the present rivers. At Nickerie in western Surinam it begins at about 50 m and the thickness is approximately 165 m, but this may include some overlying Coropina sands.

Aquifer Parameters

In the coastal area the aquifer is confined beneath Coropina and Demerara clays, whereas southward the overlying Coropina sediments locally become more arenaceous and leaky artesian and unconfined conditions exist.

Between the Saramacca and Suriname Rivers confined artesian conditions prevail at least as far south as Sidodadie Weg, west of Lelydorp. Witness to this is the aquifer test run on Well 44/71, which clearly indicates non-leaky artesian conditions with a storativity in the order of 10^{-4} (Figure 15). This condition prevails also at OW 25/71, de Crane Weg, which was measured during the test. The water level in this well fluctuates, suggesting possible leaky artesian conditions (Figure 29). The fluctuations relate to those at OW 3/71, Rijsdijk, about 8 km to the south.

Leaky artesian conditions are indicated locally in the Rijsdijkweg area by the seasonal water level fluctuations at OW 3/71 and by the aquifer test (Annex 5).

In the Savannah Belt and areas bordering to the north, conditions vary from artesian to water table. At Republiek various conditions are illustrated by data from past pumping tests. These data have been replotted in Figures 16 and 17. The data in Figure 16 fit leaky artesian to water table type curves; on the other hand, the data in Figure 17 for wells 1 km to the south indicate artesian conditions with a boundary.

The hydraulic conductivity is low in the Savannah Belt and adjacent areas to the north, limited mainly by the presence of kaolin. At Republiek transmissivities between 24 and 126 m^2/day have been calculated (Figure 16) for an average of 83 m^2/day. The equivalent hydraulic conductivity probably is in the order of 15 to 20 m/day. To the south a higher transmissivity of 352 m^2/day is evident (Figure 17), but it is not known whether the water levels from which the value was calculated are already influenced by a boundary.

At Rijsdijk an average transmissivity of 880 m^2/day was calculated, which, with an aquifer thickness of 20 m, gives an average hydraulic conductivity of 44 m/day (Annex 5). Similarly, the test at Sidodadie Weg (Figure 15) gave transmissivity values of 894 to 1,120 m^2/day for an average of 1,007 m^2/day and a hydraulic conductivity of 75 m/day.

In the coastal area, hydraulic conductivities of up to 140 m/day have been estimated from old incomplete data (Annex 2). The average of those estimated is 72 m/day for both the east and the west coastal areas. It is likely that much higher values prevail locally as indicated by lithology; however, in these areas the water is brackish and very little data are available.

A specific yield of 13% was estimated for the aquifer at Republiek. This is equivalent to the regression coefficient of rainfall on aquifer recharged in a correlation of rainfall and recharge (Figure 28). It compares with values of 10 to 14% determined for samples from wells north of the Savannah Belt. Samples from test wells in the Savannah Belt west of Zanderij gave values of 8 to 12%.

Chemical Quality

The ground water is fresh in the Savannah and Bauxite Belts, but the salinity increases northward towards the coast.

A trilinear plot of the main cations and anions (Figure 18) shows a scattering of points. The cations are grouped to a certain extent with alkaline earths only just exceeding alkalis and with magnesium slightly higher than calcium. The waters with higher dissolved solids maintain more or less the same proportion, but the anions plot at the chloride vertex and in the field of primary and secondary salinity.

In the Savannah area the water is very low in dissolved material. Dissolved solids of 46 and 86 ppm have been determined for samples taken in the Zanderij-Matta area and to the east near Powakka. The pH is low, likely because of humic acids from the vegetation. It appears to be lowest at shallow depth. A sample from a depth of 3 to 6 m taken from TW 7/71 had a pH of 3.7 and the water was brown colored from decayed vegetation. At TW 6/71 nearby in a sample taken from a depth of 12 to 15 m the pH was 5.5 and the water had no color. Near Powakka a sample from TW 48/71 had a pH of 5.1. A low pH of less than 6.8 generally prevails in the Savannah area.

At Republiek, immediately to the north of the Savannah area, the dissolved solids of up to 66 ppm and the pH of 5.0 to 5.6 are still low, and an iron content of 0.3 to 1.3 ppm has become significant. Fresh water continues north from Republiek but with anomalously high chloride values of up to 448 ppm reported in the Onverwacht area (Annex 1-B).

The northern limit of fresh ground water varies considerably (Enclosure 4), and the change to brackish water may be quite sharp. Between the Suriname and Saramacca Rivers water with low dissolved solids continues north of Sidodadie Weg, where water from TW 44/71 contains 222 ppm of dissolved solids. One kilometer west of Lelydorp TW 35/71 yields water with dissolved solids of 311 ppm (Cl = 73 ppm), whereas chlorides of 1,170 ppm were reported in water from a well drilled on the northern side of Lelydorp. Suralco wells yield water with up to 150 ppm of dissolved solids, whereas only 4 km to the north the dissolved solids in water from TW 6/72 at La Vigilantia is 1,564 ppm.

Fresh ground water near the northern limit for fresh water contains dissolved solids between 50 and 250 ppm. The higher values are from the area west of the bauxite mines, where the fresh water extends farther to the north. In this area the sulphates are relatively high. At up to 70 ppm they are higher than the chlorides, which are between 15 and 30 ppm. The pH is variable, with measured values between 5.5 and 8.0, and the iron is high, between 0.2 ppm and 4.1 ppm.

Brackish water is found farthest inland immediately north of the bauxite area of Onverdacht. The salinity of the brackish water is caused mainly by sodium chloride, but there is relatively more magnesium and sulphate than in sea water. The salinity is highest in the thickest parts of the aquifer, where the dissolved solids are between 2,000 and 5,000 ppm. It has been indicated that in the southern coastal area the thickest parts of the aquifer approximate the locations of the present Suriname and Saramacca Rivers, suggesting deposition in the form of deltas. In the Groningen-Domburg section (Annex 1-A) it can be seen that the salinity decreases westward to a dissolved solids content of 1,174 ppm at Uitkijk (GMD 21), in what would be the Pliocene Suriname River delta, and that the eastern part of the equivalent Saramacca delta, which it apparently overlaps, contains water with more than 5,000 ppm dissolved solids.

Water Levels

Water levels are highest in the Savannah area, where levels of almost 10 m NSP have been observed (Figure 26).

At Republiek immediately north of the Savannah area the water level at SWM, OW-7 (Figure 27), which is only slightly influenced by pumping, fluctuates generally between 0 and 2.5 m NSP for an average of 1.25 m NSP.

The level declines northward to the area of Helena Christina Weg where it is at about sea level, then it increases again (Figure 23). Water level fluctuations also diminish towards the north.

In the Nickerie area the levels were originally 2 to 4 m NSP. At Nanni Polder approximately 2 km to the south the water level in TW 47/71 is 0.05 m BCL, which would be approximately 2.5 m NSP.

Recharge

The Zanderij aquifer is probably the only extensive aquifer in the basin that receives recharge directly by the infiltration of rainfall. This takes place mainly in the Savannah area and immediately to the north. Seasonal ground water level fluctuations have been measured as far north as de Crane Weg (Figure 29). It likely is close to the northern limit of recharge, which must pass through overlying Coropina sands.

COROPINA AND DEMERARA AQUIFERS

General Description

The Demerara and Coropina are essentially clay formations confining the Zanderij aquifer below. Interbedded sand aquifers occur locally mainly in the form of lenses (Annex 1-B and -C). In the coastal area the Coropina aquifers are difficult to distinguish from the Zanderij aquifer below. They probably are all interconnected.

In the Bauxite Belt the Coropina sands are connected hydraulically with the underlying Zanderij aquifer at least locally (Annex 1-B and -C). In this area the sand formations are exploited for small individual water supplies by means of dug wells. On a regional scale the formation may be regarded as an aquitard above the Zanderij aquifer.

At Wageningen in the west a relatively thin sand layer extends throughout an area of several kilometers in the depth interval from 23 to 40 m.

Small aquifers are present in the terraced alluvium along the banks of the main rivers in areas extending into and beyond the Savannah Belt (Annex 1-F). Long sand ridges at the surface in the Young Coastal Plain are of minor importance for individual supplies.

Aquifer Parameters

The only test run on a Coropina aquifer was at Wageningen where a 4 m thick sand aquifer from 23 to 27 m BCL is used as a source of water supply. A hydraulic conductivity of 75 to 50 m/day and a storativity of 0.00014 were calculated for the aquifer.

Hydraulic conductivities of up to 2 m/day have been calculated for the Coropina as an aquitard in the Rijsdijk area (Annex 5), but it is likely that values are higher for individual sand members. Conditions vary from non-leaky artesian to water table.

Chemical Quality

The salinity distribution appears to follow the same pattern as in the Zanderij aquifer below, with mainly brackish water in the coastal area and fresh water in the Bauxite Belt and river valley areas to the south.

In the west relatively fresh water with a chloride content of 260 to 300 ppm occurs as far north as the village of Wageningen; however, the salinity increases towards the coast and the chlorides are 860 ppm and more than 1,000 ppm at 2.5 and 10 km, respectively, in the polder area to the north.

Detailed analyses of water samples from the Coropina aquifers are given in Annex 4.

Water Levels

Water levels are known only locally and therefore it is not possible to construct a regional flow pattern. It appears that the levels are similar throughout the coastal basin and that very little flow can be expected. At Wageningen the level is 1.45 m BCL, which is about 0 m NSP, and in the Lelydorp area, where the aquifer is in contact with the Zanderij aquifer, levels must fluctuate between 0.1 and 0.7 m NSP.

At Carolina a thin shallow aquifer in the left bank area of the Suriname River is in contact with the river, and there is a hydraulic gradient in the order of 0.002 to the river (Annex 1-F).

Recharge

The seasonal fluctuations in the Zanderij aquifer at Rijsdijk (Figure 29) must be a result of recharge entering the Lelydorp aquifer above.

At Carolina the aquifer is shallow and recharge likely enters through the thin cover of fine grained sediments or from the Zanderij aquifer in the west.

Very little is known about recharge to the aquifer elsewhere. The presence of brackish water in the coastal area suggests that the aquifers are full and recharge does not occur.

SALINITY DISTRIBUTION

The chemical characteristics of ground water have been described for each of the main aquifers. These characteristics are compared in Figure 19.

All of the waters trend towards the field of primary salinity, the sodium-potassium vertex, and the chloride vertex. Water from the A Sand aquifer has the least variation and falls entirely within this field, whereas water from the Zanderij aquifer displays the most variation, trending towards the field of primary salinity with increasing dissolved solids. The Coesewijne aquifers have characteristics generally between the two, with a notable sulphate content in the east, which diminishes towards the west. In the coastal fringe area the Coesewijne aquifers contain an anomalously high proportion of bicarbonate in the form of sodium bicarbonate. This occurs in the Nickerie area and at Calcutta and Alliance. It is associated with a relatively high pH, between 7 and 8, contrasting with the values generally below 7 elsewhere.

On the whole, fresh water is present in all the aquifers of the Savannah and Old Coastal Plain areas and the salinity increases northward towards the coast. In the coastal fringe area the Coesewijne aquifers contain the freshest water, followed by the A Sand aquifer. The salinity in the Zanderij aquifer increases abruptly, generally coinciding with the southern limit of the Young Coastal Plain. It is highest in the vicinity of the major rivers where the aquifer is thicker (Enclosure 4); however, in western Surinam, where it is thickest, the salinity is relatively low in the coastal area even though the distance to the basin fringe (recharge) area is greater than in the east.

From west to east in the coastal area the salinity varies both laterally and vertically (Annex 1-H). The deepest part of the basin appears to contain brackish water throughout, as indicated by the logs of deep tests drilled for oil. In the log of the Nickerie test (NIC-1) it is stated that water is fresh down to 700 m, below which it is brackish.

The brackish water appears to coincide generally with the Cretaceous sediments.

High salinity is particularly extensive in the vicinity of the Coppename-Saramacca rivermouth. It occurs in all aquifers but is lowest in the A Sand or at the top of the Onverdacht formation. The location coincides with the northwestern flank of the Bakhuis horst. It is matched by anomalously high salinity extending inland along the SE Bakhuis fault zone (Enclosure 3) in the A Sand but not the higher aquifers.

Brackish water is widespread throughout the Young Coastal Plain east of the Suriname River (Annex 1-E). In this area the A Sand is present only in the coastal fringe (Enclosure 2), where together with the Coesewijne aquifers it contains fresh water at least locally (Alliance). Brackish water in the Coesewijne aquifers further south probably arises from contact with the Zanderij aquifer above and the Onverdacht aquifers below. An exception is at Morico and near Commetewane Creek.

TEMPERATURE

The temperature of ground water increases with depth, generally following the geothermal gradient of 1°C rise for each 30.5 m of depth (Figure 20). The increase continues to depths greater than illustrated. Worts (1958) reports a temperature of 37.8°C at 366 m for the Whim well in the Corantijn coast area of Guyana, and temperatures of 38° to 44°C at depths from 426 to 486 m have been reported (Montgomery, 1969).

At up to 40 m in recharge areas the temperature approximates 26°C, which is about the mean monthly air temperature at Zanderij during the long wet season when most recharge takes place.

Two temperature zones are evident, at least in the uppermost 100 to 180 m. Throughout most of the coastal area as far north as the vicinity of Paramaribo (GMD 20, Leiding 8, and GMD 17, Tamanredjo) the temperatures are generally within 1°C for a given depth, and there is a perceivable increase of up to 1°C towards the north for depths up to about 120 m. In the coastal fringe there is the same general geothermal gradient, but the temperature is 1.5 to 2.0°C higher than in the south. The condition is evident throughout the coastal area, as indicated by the almost identical trend of increase at GMD 28, Alliance, and GMD 13, Nickerie. The difference is evident mainly in the upper 120 m. This is particularly shown by the Bonded Warehouse Well at Georgetown (Worts, 1958), which follows the higher temperatures of the coastal fringe above 100 m and the gradient and temperature range of the inland wells below 100 m. Thus, the higher temperature range in the upper aquifers of the coastal fringe is anomalous. A further and probably related anomaly is the relatively high temperature of brackish water in the Zanderij aquifer at Domburg and at TW 17/71 about

10 and 8 km south of Paramaribo, respectively. The temperature of water from these wells is like that at a similar depth in the coastal fringe.

The differences in temperature may be the result of palaeo-recharge at different times under different climatic conditions, in which case the warmer water in the coastal fringe would represent the earlier recharge under conditions with average temperatures possibly 2 to 3°C higher than at present.

A more probable explanation involves the coastal fringe water farther north and deeper in the offshore section of the basin when the ocean level was lower (Figure 25) and subsequently being "squeezed" south again to the present position during the Holocene transgression, as a result of ocean loading. This suggests that to gain up to 2°C the water must have been at least 60 m deeper, and with regional dips of the basin sediments in the order of 0.002 to 0.004 the water might once have been as much as 16 to 22 km farther north. The ocean loading no doubt continued farther inland up the main river valleys, resulting in the anomalously high temperatures of the brackish water in the Zanderij aquifer south of Paramaribo.

A further anomaly is the relatively low temperature of water pumped from the Coesewijne aquifers at depths of 230 to 250 m in the Nickerie area. At about 31°C this is 2°C lower than expected from the regional gradient. An explanation is not possible with the information at hand. It is unlikely to represent modern recharge at this location and depth, unless it enters the area as rapid fissure flow originating at a relatively high elevation in the basement to the south, and if it represents older recharge it is surprising that it has not yet adjusted to the prevailing geothermal conditions.

TIDAL LOADING OF AQUIFERS

Tides pass far inland up the rivers generally as far as the most seaward rapids. In the Suriname River the tidal range increases upstream from Paramaribo to a maximum in the vicinity of Paranam, then decreases again. A maximum range of 1.3 m is recorded as far inland as Phedra.

Tidal loading of aquifers was first recognized in 1903 when variations in the flow of the Sivaplein well at Paramaribo were related to tides. The well was about 500 m from the Suriname River, and the flow varied between 0.1 and 0.3 l/s.

Static water level variations in wells near the rivers have been recorded as far inland as Carolina, and there is no doubt that the condition exists near rivers throughout the coastal plain.

Static water level variations of four aquifers intersected by Well GMD 16 at Jagtlust, near Paramaribo, are shown in Figure 21. Data on tidal ranges are not available for 1954, when measurements were made in the well, and to calculate the approximate tidal efficiencies of the aquifers a range of 1.85 m between Paramaribo and Nieuw Amsterdam for the years 1966-1968 was used. The high levels for the upper two layers compare with the previous high tide. The delay is up to two hours and increases for the lower aquifers, until delays of approximately six hours for Layer 3 and 10.5 hours for Layer 4 are evident.

GROUND WATER LEVELS AND ATMOSPHERIC PRESSURE

Water level variations in wells have been related to changes in atmospheric pressure. This is illustrated in Figure 22 by the water level of OW 9/71, which characteristically has two high levels and two low levels daily at about the same time. The highest level, corresponding with low pressure, occurs at about 16.00 hrs and a lesser peak occurs at about 04.00 hrs, whereas low levels corresponding with high pressure occur at about midday and midnight. The variation in water level is generally up to 3 cm, corresponding with atmospheric pressure variations of up to 7 cms equivalent of water. The barometric efficiency of the well from average values is 55%. This is for an aquifer apparently under watertable conditions.

Water level variations caused by atmospheric pressure occur throughout the basin. They appear on the drawdown versus time curves of pumping tests (Figure 45 and Annex 5) and on the hydrograph of OW3/71, Rijsdijk (Figure 29). Here the sharp rises of the water level up to 5 cm occur at the time of heavy rainstorms when the atmospheric pressure would be low.

FLOW SYSTEMS

Ground Water-Surface Water Relationship

Under the present flow systems, all the evidence points to effluent streams and rivers.

In the Savannah area the many streams flow permanently, although the flow decreases in the dry season. The sections Powakka-Carolina and along the Saramacca Road west of Zanderij (Annexes 1-F and 1-G, respectively) show the streams and the Suriname River to be effluent without doubt.

The hydraulic gradient is small along the river flats west of Carolina. In places it is flat, but it steepens to a maximum about 1.5×10^{-3} near the river. The gradients are steeper towards the streams in the Savannah terrain, where values up to 6.7×10^{-3} occur.

Similar conditions are evident in the Savannah area of western Surinam. More than 100 tests were drilled to depths of up to 20 m at Stondansie near the Nickerie River as part of a dam site investigation (Girec, 1967). Elevations and water levels are given with the logs of most wells. Some of the water levels given are lower than the river, suggesting influent conditions; however, when the data is examined carefully most of the quoted water levels are the same as lithological contacts, and therefore it appears that the "water levels" probably are neither phreatic nor piezometric levels. When only the tests that log sand or silty sand throughout are taken, the quoted water levels are higher than the river level with only two questionable exceptions. Thus the Nickerie River may be regarded as effluent in the Savannah area.

North of the Savannah effluent conditions are again evident in the Old Coastal Plain at Republiek. This is illustrated in Figure 47 by the equipotential lines before withdrawals, which show a flow of ground water towards Coropina Creek. At the present time an influent flow apparently is induced locally by operating the wells.

In the Young Coastal Plain there is no evidence of hydraulic contact between the rivers and the main aquifers. The piezometric surface of the aquifers before withdrawals was generally near or above ocean level, which would mean effluent conditions. At the present time water levels are below sea level in the A Sand aquifer near Paramaribo, but any induced flow from the river must be insignificant because of the intervening plastic clays.

It is likely that flows induced from the rivers by wells could only occur in the Old Coastal Plain and Savannah areas. Even at Paranam, along the northern fringe of the Old Coastal Plain where withdrawals are heavy from the Zanderij aquifer, there is no evidence of induced recharge from the Suriname River. Of two Paranam wells sampled for tritium, one nearest the river (3,000 m) had an insignificant tritium content of only 1.1 ± 0.04 TU, whereas a well to the west farther from the river (5,000 m) had a tritium content of 3.5 ± 0.6 TU, indicating younger water away from the river.

Based on more depleted oxygen-18 values near the rivers, it is suggested in Annex 10 that a different recharge mechanism might exist or have existed near the rivers. This implies an influent flow from the rivers. There is no evidence of such a condition at the present time as discussed above. Additional evidence is the presence of brackish water in the Zanderij aquifer near the river north of Paranam. This would have been replaced by fresh river water if the river was influent. This does not rule out the possibility of such a condition existing in the period 13,000 to 20,000 years BP, when recharge evidently took place in the coastal area under colder climatological and possibly more arid conditions. The relatively depleted oxygen-18 values near the rivers could also occur under an effluent flow system with older water recharged under colder conditions now in riverine discharge areas and with less depleted younger water between the rivers. It is noted, however, that the $\delta^{18}O$ values of modern recharge vary between -2.3 and -3.3%, and the distribution therefore may not be significant.

Identification of Ground Water Flow Systems

At first appearance a simple ground water flow system might be envisaged in the coastal basin with recharge entering around the perimeter, then flowing generally northward into the offshore area, finally to discharge into the ocean. There seems to be no doubt that such a system has existed in the past, but at the present time the basin is full of water with a relatively high base level and there is virtually no flow in the coastal area.

Two main ground water flow systems are evident, from the water levels (Figure 23), corrected carbon-14 ages, and tritium contents of the water. To the south an active system coinciding approximately with the Savannah Belt and Old Coastal Plain is characterized by a regional hydraulic gradient towards the north, seasonal water level fluctuations, and relatively young water. To the north, in the area of the Young Coastal Plain, a more or less static system is characterized by relatively high water levels, a slight hydraulic gradient inland, and older ground water.

The two systems are separated by a zone with low water levels generally between sea level and 1.0 m NSP. This is shown between de Crane Weg and Helena Christina Weg in Figure 23, coinciding approximately with the northern limit of the Old Coastal Plain and the basement shelf north of the bauxite. It may extend further inland elsewhere, following the edge of the Young Coastal Plain (Figure 24).

Ground Water System of the Savannah and Old Coastal Plain

The system includes all aquifers down to the Upper Coesewijne and locally the Onverdacht. The aquifers may be regarded as separate entities, but on a regional scale they form one interconnected system. The Lower Coesewijne and A Sand aquifers may locally extend southward into the area, but they appear to have poor connection with the upper aquifers and more properly belong to the system of the Young Coastal Plain.

The regional hydraulic gradient decreases towards the north from high levels in the order of 10 m NSP (OW 9/71) and probably more in the Savannah area to between sea level and 1.0 m NSP near the northern limit of the Old Coastal Plain. Locally the pattern is complicated by effluent streams.

Seasonal water level fluctuations in the Savannah area generally vary up to about 1 m (Figure 26), with higher values in the upland areas away from effluent streams, and with particularly large fluctuations in areas with steep slopes (OW 7/71). The overall head distribution and seasonal variation is indicative of a general flow towards the north but with local flows towards the many streams particularly in and close to the Savannah area (Figure 24 and Annex 1-G).

The hydraulic gradient generally diminishes north of Rijsdijk, where water levels are more variable (Fig. 23). The slight differences in water levels in this area probably are caused by differences in recharge, discharge to streams, and evapotranspiration. Recharge is unlikely to be uniform throughout the area because of the complex lithology of the Coropina formation. Recharge through "windows" in this formation is suggested in Annex 5. The number of streams diminishes north of Rijsdijk; however, drainage generally persists on the Old Coastal Plain and streams likely receive effluent ground water when levels are high. Similarly, evapotranspiration will be higher where the watertable is closer to the ground surface. The water level differences generally are paralleled by variations in dissolved solids, suggesting variable recharge and the presence of local flow systems. Thus at van Hattem Weg and Sidodadie Weg water levels are higher than expected from a regional gradient between Rijsdijk and de Crane Weg-Helena Christina Weg, and the dissolved solids are slightly lower in both cases (Figure 18). The analysis of water from TW 38/71 is given in preference to that of Well 44/71 for Sidodadie Weg because there is a better balance between the cations and the anions.

The largest seasonal water level fluctuations in the order of 2.5 m are observed at Republiek, immediately north of the Savannah Belt (Figure 27). The fluctuations decrease in magnitude towards the north, where they are about 0.5 and 0.2 m at Rijsdijk (OW 3/71), respectively (Figure 29). The gradient is greatest when water levels are at a maximum in the long wet season. The maximum is about 1.0×10^{-3} during this season along the northern edge of the Savannah area. The average gradient is 7.1×10^{-5} from Republiek to Rijsdijk and 2.5×10^{-5} from Rijsdijk to de Crane Weg, excluding local variations.

Flow velocities calculated using average hydraulic conductivities and assuming an effective porosity of 10% would be 1.9 cm/day (6.9 m/yr) for a total of 2,030 years from Republiek to Rijsdijk, decreasing to 1.5 cm/day (5.4 m/yr) for a total of 1,480 years between Rijsdijk and de Crane Weg. The calculated flow rates are slow; however, they are in general agreement with the isotope data (corrected carbon-14 age of 1,921 years at Rijsdijk - Annex 10).

In terms of volumes, the northward flow would amount to about 22.6 m^3/m/year between Republiek and Rijsdijk and 9.1 m^3/m/yr between Rijsdijk and de Crane Weg. This would be equivalent to a flow of 0.36 million m^3/yr between Republiek and Rijsdijk, for a 16 km-wide flow path between the Saramacca River to the west and Republiek and the bauxite mines to the east, and an overall 0.72 million m^3/yr for approximately 32 km between the Saramacca and Suriname Rivers.

The values given above are regional estimates and do not take into account local recharge, which is discussed in detail in the section "Assessment of Recharge." It will be found that the flow volumes are almost insignificant when compared to the local recharge.

The ground water flow system extends only throughout the fringe area of the coastal basin, which is the only part of the basin that is hydrologically active at present. There is no evidence of significant subsurface flow from the system into the Young Coastal Plain area, and therefore all recharge must be discharged within the system. Under natural conditions the current year's recharge will be discharged, leaving the older water in storage flowing slowly northward and eventually discharging likely as evapotranspiration at the northern limit of the Old Coastal Plain. Thus the water is apparently old (up to about 2,000 years) within the system even in deeper layers in the Savannah area (OW's 6/71, Annex 10, Table A). The more significant tritium values of more than 2 TU probably reflect better than average recharge conditions locally with vertical flows induced by pumping.

In summary, the flow system of the Savannah and Old Coastal Plain area is full of water and is active hydrologically, but with most movement occurring at shallow depths where recharge appears to be balanced by discharge.

Ground Water System of the Young Coastal Plain

The ground water system in the area of the Young Coastal Plain includes all aquifers from the surface to the basement with the Zanderij and Upper Coesewijne aquifers extending into it from the active system to the south. The system extends throughout the deeper coastal section of the basin and continues offshore for an unknown distance. The various aquifers may be interconnected locally, and differences in head and water quality exist regionally.

The system is virtually static. Corrected carbon-14 ages onshore are in the order of 13,000-20,000 years BP for water in the A Sand aquifer and 11,600 to 13,700 years BP for water in the Coesewijne and Zanderij aquifers, indicating insignificant flow at the present time but better recharge connection to the Coesewijne and Zanderij aquifers than to the A Sand aquifer. There are no seasonal water level fluctuations and therefore local direct recharge is not significant.

Palaeo-Ground Water Flow Systems

The corrected carbon-14 ages of ground water in the Young Coastal Plain area relate to the time of the Würm glaciation, which was at an optimum about 18,000 years BP when the eustatic level of the Atlantic Ocean was 90 to 100 m below its present level, and to the Holocene transgression when the ocean level rose, attaining its present level about 6,000 years BP (Figure 25).

Under the conditions described, the approximate hydraulic gradient would have been in the order of 7.3×10^{-4} to 5.5×10^{-4} with discharge 100 to 150 km, respectively, beyond the present shoreline. This assumes a uniform gradient from the perimeter of the basin to the discharge location, and adequate recharge to maintain water levels as at present around the perimeter. The area of discharge is not known. The aquifers as known onshore do not continue as such to the shelf edge, where sediments of equivalent age are clays and silty clays. A possibility is that discharge took place vertically through the limestones logged in oil tests about 100 km offshore (Gillman and Jardine, 1972).

Flow velocities might have reached 73 cm/day with the hydraulic gradients suggested above and with hydraulic conductivities up to 100 m/day and an effective porosity of 10%. This would give a residence time of 560 to 1,000 years for ground water in the basin, including the present offshore area. These are maximum values, which give an approximate order of magnitude under uniform conditions; however, uniform conditions are not evident in all aquifers. Water with an age of 19,969 years in the A Sand at Houttuin (Well 2/69) is farther inland than water with an age of 16,090 at Uitvlugt (GMD 19) in the same aquifer. This suggests variations in the recharge potential to the A Sand aquifer with poor conditions near Houttuin. A rock boundary is known south of this area (Enclosure 3). More active flow conditions might have existed to the north. It is later suggested that an inland flow must have been most active along the SE Bakhuis fault zone, which is close to the Uitvlugt well. This should also apply in reverse with a gradient to the north. Relatively younger water (13,006 years) from Well 36/71 at Zorg en Hoop probably reflects an induced flow from the lowest Coesewijne aquifer, which is in contact with the A Sand throughout this area.

Considering only the ground water in the Young Coastal Plain and excepting water from TW 17/41, a cessation of recharge is apparent, beginning about 13,000 years BP when the ocean level was 60 to 70 m below the present level. It is suggested that from this time discharge to the ocean, probably through reef limestones, decreased and then more or less ceased, and that ocean loading during the Holocene transgression compressed the aquifers, squeezing or displacing ground water, which would flow through the aquifers in front of the shoreline. The shoreline must have advanced at an average rate of 7 to 8 m per year, rising at an average rate of about 5 mm per year. Unfortunately, it is not possible to be quantitative without a knowledge of the extent, configuration, and hydraulic properties of the aquifers offshore, and the water levels before and during the early stages of the transgression. Even the present levels are probably lower than they were about 6,000 years BP.

Evidence in support of ocean loading and an inland movement of ground water is as follows:

- The anomalously high ground water temperatures in the coastal fringe areas suggest that water now in the coastal fringe might have been at least 60 m deeper and 16 to 20 km further north.

- The slight inland gradient of the piezometric surfaces.

- The high head in the A Sand and lower Coesewijne aquifers in relation to the upper Coesewijne and Zanderij aquifers. The former are more confined, whereas the latter extend further inland where they are in contact with the surface. Thus, water in the upper aquifers would more readily dissipate farther inland and even discharge at the surface.

- An insignificant sulphate content in water from the A Sand aquifer compared with the Coesewijne aquifers. It is suggested that when the base level was low a relatively rapid flow took place northward through the system and solution was at a minimum, and that as the ocean advanced the flow diminished and was finally reversed, with water reentering the lower Coesewijne aquifers from the A Sand. Since approximately 6,000 years BP this water has been virtually static, taking into solution the available soluble materials, which include sulphates in the Coesewijne aquifers of the east.

- The salinity distribution is indicative of an inland flow. Brackish water is present in the Zanderij aquifer largely in the main river valleys, where the aquifer is thicker and the ocean loading would extend farthest inland. The inland extension of water with high chlorides in the A Sand aquifer along the SE Bakhuis fault also suggests an inland flow, particularly along the fault zone.

- Significantly higher bicarbonates in water from the Coesewijne aquifer nearest the coast may be caused by sediments richer in calcium bicarbonate deposited in a marine environment farther to the north (Calcutta, Alliance).

In summary, palaeo-flow systems appear to have involved a northward flow of water when the base level was lower during the Würm glaciation and a reversed inland flow during the Holocene transgression.

ASSESSMENT OF MODERN RECHARGE

Savannah Area near Zanderij

Water levels have been observed since March-April 1971 in a number of wells and creeks along the road west of Zanderij. Of these, OW's 7/71 and 9/71 are equipped with automatic recorders. Unfortunately, although more than 12 months of observations are now available, they cover part of two water years (1971 and 1972).

Apparent recharge estimates at well locations are given in Table 10, for an equivalent water year from December 1971 to April 1972 followed by May to November 1971. They are based on monthly water level changes (Figure 26), making an allowance for recession at equivalent elevations, as indicated in the dry season. An effective porosity of 0.13 (Figure 2 is assumed to obtain the water equivalent.

TABLE III-10

APPARENT RECHARGE ESTIMATES IN THE ZANDERIJ AREA FROM WATER LEVEL FLUCTUATIONS IN OBSERVATION WELLS

	9/71	7/71	6/71	5/71	2/71	1/71
Apparent aquifer recharged, mm	4,100	9,100	5,700	5,300	3,900	4,800
Water equivalent (eff. porosity 0.13 mm)	530	1,180	740	430	505	625
Percent of rainfall Zanderij-2,533 mm	21	42	29	17	20	24

Referring to Annex 1-G, it can be seen that OW 9/71 on high ground and OW 2/71 on relatively low ground are the only wells located away from streams or steep slopes. The recharge estimates are similar for each of the two wells, averaging 507 mm. The equivalent rainfall of 2,428 mm is 8% higher than the 29-year average of 2,252 mm. Reducing the recharge estimate proportionately gives a value of 480 mm, which probably is the most accurate estimate for this kind of terrain.

Water levels in the other wells are influenced by lateral flows in addition to recharge at the site. The largest fluctuation and apparent recharge are at OW 7/71. This well is located on a relatively steep slope, and consequently the water level is influenced by a flow of recent recharge from the west to Cola Creek. Discharge is rapid at this location. When levels are high, water seeps to the surface and runs off down the slope to Cola Creek, and Well 5/71 flows.

The Zanderij formation is particularly sandy where the observation wells are located. At other locations in the Savannah Belt (Powakka, Hanover, and Stondansie), it is more clayey and water remains perched at or near the surface. With the present limited information there is no way of estimating the relative amounts of clay and sand on a regional basis and hence regional recharge volumes. To obtain very approximate figures it is assumed that recharge is effective over only 50% of the

Savannah area. On this basis the annual recharge to the Savannah between the Suriname and Saramacca Rivers (570 km^2) would be about 137 million m^3/year, and for the Savannah area throughout the entire country (area 8,500 km^2) it would be 2,040 million m^3/year.

Republiek Area

Water levels have been observed in a number of production and observation wells and in Coropina Creek since the initial exploration in 1928-1930. The hydrographs for Well A, OW-7, and Coropina Creek, together with rainfall and annual withdrawals, are contained in Fig. 27, and the locations of the points are shown in Figure 47.

There are 26 complete years of records available for OW-7, which is located north of Coropina Creek about 500 m from the center of the well field. Gross recharge estimates were made from the hydrograph on a monthly basis by correcting the observed water level changes for recession, estimated at 1 m/month for levels above 0 m NSP and 0.4 m/month for levels below 0 m NSP, and comparing the values obtained with the corresponding rainfall. The annual values correlate better than the monthly values, with the best correlation of 84% obtained by using the December to November gross aquifer recharged and the November to October rainfall, and rejecting the high and the low points. The direct correlation is illustrated in Figure 28. A mean annual recharge of 1,288 mm, amounting to 65% of the mean annual rainfall, is obtained from the aquifer recharged and an effective porosity of 0.13 equivalent to the regression coefficient of rainfall on aquifer recharged.

The amount of recharge estimated is credible. The high water level in OW-7, virtually unchanged since withdrawals began in 1933, indicates that the withdrawals are sustained by local recharge. The 3,434 million m^3 of water withdrawn in 1970 would be sustained largely by the direct recharge to about 2.7 km^2 of aquifer. The tritium content of ground water from the well field also supports local recharge directly from the current year's rainfall. The values of about 10 TU compare with the values of tritium in rain sampled in 1970 at Cayenne and San Juan.

The similarity of the hydrographs for Coropina Creek and OW-7 indicates a direct connection between the creek and ground water. The original ground water levels at Republiek and their relationship to Coropina Creek levels were presented by van Weijerman (1930). The water level elevations varied about the same as the level of the creek for wells near the creek, where the center of the well field is now located, and the levels in wells up to 600 m from the creek were generally higher by 0.5 to 1.5 m, indicating effluent conditions. Since 1935 the level in the creek has varied between 0.5 and 2.5 m NSP, whereas the low levels of OW-7 have declined generally between -0.5 and -1.0 m NSP. The decline is a result of withdrawals from the wells to the south, and variations from year to year reflect differences in the annual precipitation. The creek passes between

OW-7 to the north and the well field to the south, and therefore flows over the northern and likely the western sections of the cone of interference. Influent seepage must take place here at least during the dry seasons. Thus, the operation of the well field induces recharge from the creek, the flow in which is largely sustained by effluent ground water from the Savannah area.

Rijsdijk Area

Seasonal water level fluctuations of about 0.5 and 0.2 m have been measured at OW 3/71 (Rijsdijk) and OW 28/71 (de Crane Weg), respectively. Both of the wells are within the area mapped as the Lelydorp (sandy) member of the Coropina formation. Below the surface this appears to consist of clay and sandy clay with irregular interconnected sand lenses through which water may percolate. It is suggested in Annex 5 that these act as recharging "windows."

The Rijsdijk pumping test (Annex 5) indicated non-leaky artesian conditions in the Zanderij aquifer to the north and east and leaky artesian conditions in the Zanderij and Coropina aquifers to the south. The Sidodadie Weg test (Figure 15) indicated non-leaky artesian conditions at Sidodadie Weg and de Crane Weg, whereas the relatively higher water level and low dissolved solids in water at Sidodadie Weg (Figures 18 and 23) suggest leakage and local recharge.

A recharge of 196 mm, rounded to 200 mm, is estimated from the hydrograph of OW 3/71 for the equivalent water year December to June 1972 and July to November 1971. This assumes a recession of 0.1 m/month and an effective porosity of 0.13. The equivalent rainfall of 2,901 mm was above average; however, the peaks on the hydrograph are similar for 1971 and 1972, and therefore it is assumed that the estimate of 200 mm will be close to the average.

The low tritium values and corrected carbon-14 ages indicate that the recharge does not percolate deeply, and under natural conditions it is likely that most of the new recharge remains near the surface in the Coropina sediments. The tritium value of 2.7 ± 0.4 TU in water from OW 3/71 indicates that part of the recharge percolates deeply, but it is not clear whether this is induced by prolonged pumping at a location where leakage through the overlying Coropina is particularly significant.

Recharge Volume in the Old Coastal Plain

The amount of recharge in the Old Coastal Plain has been estimated only at Republiek and Rijsdijk, and to apply these values over wide areas may be misleading; furthermore, Republiek is a withdrawal area and the calculated recharge probably represents a potential rather than the natural recharge. To obtain an approximate recharge volume, the average of 340 mm for Rijsdijk (200 mm) and Zanderij (480 mm) in the Savannah area is used, giving a volume of 0.34 million m^3/km^2.

Between the Suriname and Saramacca Rivers the area is taken from the Savannah to an E-W line through Rijsdijk 16 km to the north. It amounts to 530 km^2, giving an annual recharge volume of 180 million m^3. For the 200 mm of recharge estimated at Rijsdijk, the volume would be 106 million m^3 annually.

Recharge conditions in western Surinam are not known from observation. The area west of the Bakhuis zone evidently has subsided, and more of the Old Coastal Plain is covered by Demerara deposits with the Coropina exposed irregularly (Enclosure 2). To obtain an approximate order of magnitude for recharge, it is assumed that conditions are similar east-west throughout the basin and that a recharge of 0.2 to 0.34 million m^3/km^2/year takes place throughout a strip 16 km wide for the approximate basin width of 350 km. This amounts to between 3.2 and 5.4 million m^3/year per kilometer width for a total of between 1,120 and 1,890 million m^3 annually.

Young Coastal Plain System

From corrected carbon-14 ages of ground water in the A Sand, Coesewijne, and Zanderij aquifers, it is evident that there is no modern recharge in the system.

DISCHARGE

An active flow system, corresponding with the Savannah area and Old Coastal Plain, and a more or less inactive flow system in the coastal area to the north have been described. Under these circumstances there can be no natural discharge offshore and any subsurface discharge into the area of the Young Coastal Plain from the active system to the south must be negligible. Thus, the only natural ground water discharge can take place within the active flow system of the Old Coastal Plain and Savannah area. An exception is evapotranspiration directly from the water table in the coastal area.

In that discharge must be equivalent to recharge for an average year, it probably is in the order of 500 mm/yr (15 $l/s/km^2$) in the Savannah area and 200 mm/yr (6 $l/s/km^2$) in the Old Coastal Plain (Rijsdijk).

Recharge evidently decreases towards the north and natural discharge must decrease likewise. This is reflected by the decrease in the number of streams towards the north (Figure 24). Unfortunately, there are no stream flow measurements from which it is possible to ascertain the amount of effluent ground water flow, thus differentiating it from evapotranspiration.

Withdrawals of ground water are limited to water supply systems and the dewatering of open pit bauxite mines.

Approximate withdrawals for water supply systems are listed in Table 11.

There are no records available of the water pumped from the bauxite mines. It includes dewatering, mainly of the Coropina sediments and the upper part of the Zanderij aquifer, and the rain which falls into the pits. There is no evidence of widespread interference. Water levels in test wells at Onverdacht were about -4 m NSP in 1962, indicating interference from the nearby mining operations, but at TW 22/72 immediately west of Suralco's Lelydorp mine the water level was approximately 2 m NSP in August 1972. It is understood that the Billiton Company operates five pumps rated at 1,000 m^3/hour for 20 hours/day in each of two mines. Assuming that the pumps operated at about 60% efficiency, the pumpage would then be about 60,000 m^3/day (21.9 million m^3/year) from each mine. Each mine pit is about 0.5 km^2 and should receive about 1.1 million m^3 of rain annually; therefore, the ground water pumped from each mine should be about 19.8 million m^3/year. These withdrawals are only temporary.

TABLE III-11

GROUND WATER WITHDRAWALS FOR WATER SUPPLY SYSTEMS

		Withdrawals	
Supply System	Aquifer	m^3/day	1971 million m^3
OLD COASTAL PLAIN - SAVANNAH			
Albina	Zanderij	120	
Onverdacht	Onverdacht	1,500	
Paranam	Zanderij	20,000	
Republiek (for Paramaribo)	Zanderij	9,300	
YOUNG COASTAL PLAIN			
Alliance	Coesewijne	30	
Groningen	Coesewijne	65	0.024
Kampong Baroe	Coesewijne	40	0.015
Koewarasan	Coesewijne	200	0.073
Meerzorg	A Sand	45	0.016
Nickerie	Zanderij	1,000	0.307
Paramaribo (Zorg en Hoop)	A Sand	17,174	6.269
Totness	Coesewijne	280	0.102
Wageningen	Coropina	1,000	

CHAPTER 6

WATER BALANCE STUDIES

MAIN COMPONENTS OF THE HYDROLOGIC CYCLE

The main hydrologic cycle components in regional and basin water balance studies are rainfall, river and stream flow (run-off), subsurface (ground water) outflow and discharge, evapotranspiration, and changes in storage. For an average year under natural conditions it is assumed that there is no change in storage and that the outflow components balance the inflow. This may not be the case for annual or seasonal balances when changes in storage will feature largely as ground water and soil moisture, and locally as surface water in swampy areas.

The different components are known with varying degrees of accuracy, with the measured rainfall and river flows the most accurate, probably within 10%.

Rainfall is the only input component of the country at large and of the drainage basins in the basement area, and it probably is the most precisely measured. The values listed for the individual drainage basins were published by the Hydraulics Research Division. They are based on rainfall distribution studies.

The river flows listed in the tables are from data published by the Hydraulics Research Division. Unfortunately, all the gauging stations are within the basement area or along the contact with the coastal basin. There are no measured run-off data for the coastal plain and run-off can be estimated only approximately from data of the basement fringe areas (low run-off basins), and by adjustment in water balance equations.

Under the conditions described in Chapter 5, it may be assumed that rivers and streams are effluent, and that there is no subsurface discharge from the Old Coastal Plain to the Young Coastal Plain and thence offshore. Thus, for an average year ground water recharge in the Savannah and Old Coastal Plain must discharge also within that area, and in an overall balance discharge will feature as surface water and evapotranspiration, with ground water only transitory within the system.

Of the outflow components, evapotranspiration is the largest and also the least accurately known. The only evaporation measurements are for Paramaribo. Panevaporation tends to be on the high side, but it is generally most accurate in humid areas and therefore the measurements are probably fairly well representative of the coastal area. In the interior the most accurate estimates are obtained indirectly as the difference between rainfall and run-off in the simplest water balance equation assuming no other outflow.

DRAINAGE BASINS IN THE PRECAMBRIAN BASEMENT AREA

Simple hydrologic balances for the main river basins above the indicated gauging stations during the period 1961 to 1970 are listed in Table 12. It is assumed that rainfall, run-off, and evapotranspiration as the difference between rainfall and run-off, are the only components involved for the average year.

Of particular interest is the higher apparent evapotranspiration in basins with low run-off and the wide variation of the low run-off (Table 13). The basins with highest apparent evapotranspiration are those which drain only the northern part of the basement and particularly the northern fringe. Tertiary sediments have been mapped in the northern part of the Nickerie and Kabalebo basins, and it is well known that remnants of these sediments continue further inland. Rainfall must infiltrate the sediments, which will retain the water for evapotranspiration, thus reducing run-off. The average values are 100 to 200 mm higher than in the high run-off basins, which is comparable with the amount of evaporation during the dry season, when it exceeds rainfall by about 40%.

The average apparent evapotranspiration for the Kleine Saramacca and Nickerie (Stondansie) basins is higher than expected from the average panevaporation (1,655 mm) at Paramaribo by 87 and 130 mm, respectively, and it might be assumed that the difference is part of another outflow component such as run-off or subsurface outflow. The difference is between 5 and 8% of the average panevaporation, which is within the pretended accuracy of 10%. Furthermore, it is not known whether the evaporation measurements at Paramaribo are representative of other areas of the country. The river flow is measured locally, and therefore it would not be correct to adjust its value. The evidence is against a subsurface outflow of any significance, because of the slow ground water flow and the age of ground water in the coastal basin. The Nickerie River basin above Stondansie is particularly interesting because it has a long northern divide of about 100 km, mainly in the Savannah, along the contact with the basement; therefore, of all the river basins, it is the most likely to lose water as a subsurface outflow into the coastal basin. This implies a ground water divide south of the surface water divide taken as the basin limits, which is unlikely. Using values from the Zanderij-Republiek area ($k = 10$ m/day, $I = 0.001$, and $m = 20$ m) in the simplified Darcy equation $Q = kIA$, the subsurface flow would be about 0.22 m^3/sec for the 100 km northern divide. This is insignificant, amounting to less than 0.3% of the 80 m^3/s average river flow. There is even less likelihood of a subsurface outflow from the Kleine Saramacca basin. Because any subsurface outflow is insignificant, it is assumed that the difference between rainfall and run-off is evapotranspiration for an average year, and that changes in storage will take place from year to year mainly in the form of soil moisture and ground water in the low run-off basins. It is concluded that the evaporation potential in the northern basement area is higher than the evaporation measured at Paramaribo. In this case the values

TABLE III-12

RAINFALL, RUN-OFF, AND APPARENT EVAPOTRANSPIRATION IN MILLIMETERS FOR RIVER BASINS ABOVE INDICATED GAUGING STATIONS

River Basin	Year									
	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Marowijne (Langetabbetje)	1,907 520 1,387 - 124	1,891	2,843 1,118 1,725 + 214	1,842 492 1,350 - 161	2,059 475 1,584 + 73	2,434	2,481 855 1,626 + 115	2,979	1,955 875 1,080 - 431	2,637 810 1,827 + 316
Corantijn (Mataway)						2,138 495 1,643 + 197	2,354 856 1,498 + 52	2,534 1,005 1,529 + 83	1,893 875 1,018 - 328	2,436 895 1,541 + 95
Suriname (Pokigron)	2,175 590 1,585 - 42	2,153 736 1,417 - 210	2,734 1,178 1,556 - 71	1,772 350 1,422 - 205	2,225 580 1,645 + 18	2,468 580 1,888 + 261	2,539 815 1,724 + 97	3,180 1,190 1,990 + 263	2,291 1,045 1,246 - 381	2,604 810 1,794 + 167
Saramacca (Dramhosso)	1,968 466 1,502 - 53	2,053 740 1,313 - 242	2,799 880 1,919 + 364	1,765 287 1,478 - 77	2,115 574 1,541 - 14	2,202 574 1,628 + 73	2,228 806 1,422 - 133	2,817 1,064 1,753 + 198	2,391 1,145 1,246 - 309	2,605 860 1,745 + 190
Coppename (Maksita Cr.)					2,115 485 1,630 - 55	2,175 542 1,633 - 52	2,511 684 1,827 + 142	2,866 980 1,886 + 201	2,307 855 1,452 - 233	
Kl. Saramacca (Anoemafoetoe)		1,913 340 1,573 - 165	2,287 620 1,667 - 71	1,966 158 1,808 + 70	2,016 296 1,720 - 18	2,150 227 1,923 + 185				
Kabalebo (Avanavero)					1,463 186 1,277 - 387	2,025 248 1,777 + 113	2,171 580 1,591 - 73	2,705 880 1,825 + 161	2,134 540 1,594 - 70	2,464 542 1,922 + 258
Upper Nickerie (Bl. Marie)							2,446 825 1,621			
Nickerie (Stondansie)			2,714 860 1,854 + 69	1,700 110 1,590 - 195	1,947 233 1,714 - 71	1,965 261 1,704 - 81	2,408 525 1,883 + 98	2,594 710 1,884 + 99	2,083 506 1,577 - 208	2,766 690 2,076 + 291

For each basin the upper figure is rainfall, the second is run-off, the third is the difference between rainfall and run-off or apparent evapotranspiration, and the fourth is the deviation of the apparent evapotranspiration from average.

TABLE III-13

AVERAGE AND APPROXIMATE VARIATION OF RAINFALL, RUN-OFF, AND APPARENT EVAPOTRANSPIRATION IN MILLIMETERS FOR RIVER BASIN ABOVE INDICATED GAUGING STATIONS

River Basin	Years	Rainfall, P mm	Run-off, Q mm	Apparent Evapotranspiration (P-Q) mm
Marowijne (Langetabbetje)	7	2,246 ± 12%	735 ± 20%	1,511 ± 24%
Corantijn (Mataway)	5	2,271 ± 14%	825 ± 26%	1,446 ± 22%
Suriname (Pokigron)	10	2,414 ± 29%	785 ± 52%	1,627 ± 22%
Saramacca (Dramhosso)	10	2,294 ± 23%	739 ± 58%	1,555 ± 21%
Coppename (Maksita Cr.)	5	2,394 ± 25%	709 ± 34%	1,685 ± 13%
Kl. Saramacca (Anoemafoetoe)	5	2,066 ± 8%	328 ± 70%	1,738 ± 10%
Kabalebo (Avanavero)	6	2,160 ± 28%	496 ± 69%	1,664 ± 19%
Nickerie (Stondansie)	8	2,272 ± 23%	487 ± 78%	1,785 ± 8%

given in Table 12 will represent annual balances with deviations from the average basin apparent evapotranspiration, probably indicating changes in storage.

RUN-OFF PROVINCES IN THE BASEMENT AREA

Estimated rainfall, run-off, and apparent evapotranspiration for provinces of high, moderate, and low run-off exceeded by 5, 50, and 95% are listed in Table 14. The exposed basement not included in the drainage basins listed in Tables 8 and 12 occurs along the northern fringe of the basement area, and therefore it is assumed that it will have low run-off (Figure 3). The area of moderate run-off includes the Coppename basin above Maksita Creek only. It is listed for convenience, for the basin no doubt includes upstream areas of high run-off, downstream areas of low run-off, and transition areas between.

The rainfall was computed using the mean values from the correlation of annual rainfall and average annual unit discharge (Figure 7) and the areas of the provinces.

The run-off exceeded by 5, 50, and 95% are the values given in the frequency analyses of average annual unit discharge (Figure 6) and the areas of the provinces, excepting the moderate run-off province for which it was computed from average annual unit discharge of 32, 21, and 10 $l/s/km^2$.

It is assumed, as for the basins, that rainfall, run-off, and evapotranspiration are the only components. In high run-off areas the run-off appears to increase and the apparent evapotranspiration to decrease as rainfall increases. In the moderate and low run-off areas more of the rainfall infiltrates and is available for evapotranspiration. Differences from the 50% run-off value are shown as changes in storage. Decreases in storage during a dry year would not only reflect the lower precipitation but the higher evapotranspiration (Table 6) of increased storage from previous wet year(s).

COASTAL BASIN AREA

It has been established that subsurface discharge from the basin to offshore areas is insignificant if it exists at all (Chapter 5 - Flow Systems, pages 69-71). Under thsse circumstances a water balance for the area is reduced to the three components—rainfall, surface water outflow, and evapotranspiration—with changes in storage from year to year reducing to zero for an average of several years.

Unfortunately, there are no direct stream flow measurements for the area and evapotranspiration is the most accurately known output component as pan measurements at Paramaribo, computed evapotranspiration, or by an analogy with the low run-off basins of the northern basement fringe.

TABLE III-14

VALUES OF THE MAIN HYDROLOGIC CYCLE CONSTITUENTS IN THE LOW, MODERATE, AND HIGH RUN-OFF PROVINCES FOR RUN-OFF EXCEEDED BY 5, 50, and 95%

Run-off Province	Annual Hydrologic Cycle Constituents	Run-off Exceeded								
		by 5%			by 50%			by 95%		
		mm	mill m^3	%	mm	mill m^3	%	mm	mill m^3	%
High Run-off	Rainfall, P	2,700	243,621	100	2,270	204,822	100	1,880	169,632	100
90,230 km^2	Run-off, Q	1,230	110,983	46	790	71,282	35	380	34,287	20
	Apparent Evapotranspiration ET = P-Q	1,470	132,638	54	1,480	133,540	65	1,500	135,340	80
Moderate	Rainfall, P	2,700	33,210	100	2,270	27,306	100	1,880	23,124	100
Run-off	Run-off, Q	1,065	13,099	40	695	8,549	31	335	4,121	18
12,300 km^2	Apparent Evapotranspiration ET = P-Q	1,575	19,373	58	1,575	19,372	69	1,575	19,373	80
	Possible Storage S	+ 60	+ 0.238	2	0	0	0	- 30	- 0.369	2
Low	Rainfall, P	2,700	70.20	100	2,270	59.02	100	1,880	48.88	100
Run-off	Run-off, Q	850	22.10	32	475	12.25	21	160	4.16	8
26,000 km^2	Apparent Evapotranspiration ET = P-Q	1,795	46.67	66	1,795	46.67	79	1,795	46.67	88
	Possible Storage S	+ 55	+ 1.430	2	0	0	0	- 75	- 1.95	4

The simple balance for an average year is as follows, excluding surface water inflow from the basement:

Rainfall	=	Evapotranspiration	+	Run-off	±	Storage
2,135		1,655		480		0 mm
62,982		48,822		14,160		0 million m^3 (29,500 km^2)
100%		77.5%		22.5%		

The rainfall given is the average for the coastal area stations including Zanderij, and the evapotranspiration is the average panevaporation measured at Paramaribo (Chapter 3). The run-off, obtained as the difference, is equivalent to a unit discharge of 15.2 $l/s/km^2$, which is virtually the same as the median for the low run-off basins (Figure 6).

It is known that rainfall percolates to recharge ground water directly in the Savannah area and the Old Coastal Plain, but without a subsurface discharge this is only transitory and does not feature in the output from the basin. The recharge estimates given in Chapter 5 are 480 mm for the Savannah and 340 mm for the Old Coastal Plain, giving a total of 3,930 million m^3/yr or about 6% of the annual water movement in the coastal basin, excluding the surface water flow from the basement area.

THE LOWER SURINAME RIVER BASIN

Brokopondo below the Afobaka Dam is taken as the upstream limit of the basin (Figure 30). The total area of the basin is approximately 16,000 km^2, of which 3,350 km^2 are below Brokopondo. Upstream the area is 7,750 km^2 to Pokigron and 4,730 km^2 between Pokigron and Brokopondo, including the reservoir. Details of the basin area are in Table 15.

The mean discharge at Pokigron is 217 m^3/s (28 $l/s/km^2$), computed from the 19-year period 1952 to 1970 inclusive.

In October 1965 operation of the dam at Afobaka commenced, and thereafter the regime of the Lower Suriname River has been controlled mainly by release of water after hydroelectric power generation and of surplus water from impounded storage. The mean annual discharge at Brokopondo is 260 m^3/s for the five-year period 1966 to 1970. Thus, the input components of a water balance for an average year will include this flow and the precipitation on the lower basin.

The output components will include only surface water outflow and evapotranspiration, since it has been established that there is no subsurface outflow of significance in the coastal area (Chapter 5).

TABLE III-15

AREAS OF THE SURINAME AND SARAMACCA RIVER BASINS IN SQUARE KILOMETERS

	Basement	Savannah	Coastal Plains		Total
			Old	Young	
Suriname River Basin					
To Pokigron	7,750				7,750
To Afobaka	2,830				10,580
Reservoir	1,900				12,480
To Brokopondo	150			20	12,650
To Phedra	810			120	13,580
To Mouth					16,000
Right bank		260	200	470	
Left bank		460	580	450	
Total km^2	13,440	720	780	1,060	16,000
%	84	4.5	4.9	6.6	
Saramacca River Basin					
To Dramhosso	3,480			40	3,520
To Anoemafoetoe	1,330			10	4,860
To Kwakoegron					6,670
Right bank	1,360			100	
Left bank	280			70	
To Mouth					9,000
Right bank		120	280	1,540	
Left bank		160	230		
Total km^2	6,450	280	510	1,760	9,000
%	71.6	3.1	5.7	19.6	

The water balance for an average year will then read as follows:

$$\begin{array}{l} Q_{ri} \;+\; P \;=\; ET \;+\; Q_{ro} \quad Q_w \pm S \\ 8{,}199 + 7{,}254 = 5{,}544 + 9{,}898 + 11 \pm 0 \text{ million } m^3 \end{array}$$

where:

Q_{ri} = Surface water inflow equivalent to the 5-year mean discharge of 260 m^3/s at Brokopondo

P = Precipitation taken as 2,166 mm, the long-term average of Paramaribo and Zanderij (Tables 3 and 4)

ET = Evapotranspiration taken as 1,655 mm, the 8-year period average at Paramaribo (Table 5)

Q_{ro} = Surface water outflow at the rivermouth calculated from the other components to balance the equation

Q_w = Discharge of wells (Republiek and Paranam)

The outflow Q_{ro} is the sum of 8,199 million m^3 inflow at Brokopondo and a contribution of 1,699 million m^3 downstream. The 1,699 million m^3 is equivalent to a unit discharge of 16 $l/s/km^2$, which compares with the average of 15 $l/s/km^2$ for low run-off areas. It is in keeping with the conditions expected in the basement and coastal area downstream from Brokopondo.

The well discharge is a little higher than the withdrawals at Republiek and Paranam. No account is taken of the withdrawals in the Young Coastal Plain because withdrawals from the A Sand are regarded as a mining of fresh water mainly replaced by brackish water from the north.

Water is pumped from the bauxite mines in the Old Coastal Plain area. In Chapter 5 - Discharge (page 76), it was estimated that about 19.8 million m^3 of ground water is pumped annually from each of the two Billiton Company mines. There are three mines worked in the area, and the total dewatering might therefore be in the order of 60 million m^3/yr. The water is pumped to waste and discharges as a surface water outflow. Ground water levels remain high in the surrounding area, and therefore it is unlikely that the dewatering causes a decrease in storage. Because of this it is not included in the balance equation as a separate item.

The approximate area of the active ground water flow system is 1,500 km^2, incorporating the Savannah and Old Coastal Plain. With an annual recharge of about 340 mm (average of 480 mm at Zanderij and 200 mm at Rijsdijk - Chapter 5) to the system, approximately 510 million m^3 of the water in the equation pass through the ground water phase.

THE LOWER SARAMACCA RIVER BASIN

The lower basin is taken as the section downstream from Dramhoso on the main stem of the river and downstream from Anoemafoetoe on the tributary Kleine Saramacca River (Figure 30).

The total area of the basin is about 9,000 km^2, of which 4,140 km^2 is the lower basin as described. Areas of the basin are listed in Table 13.

The mean discharge at Dramhosso is 86 m^3/s (24.5 l/s/km^2) for the 10-year period 1961-1970, and at Anoemafoetoe it is 12 m^3/s (9.0 l/s/km^2) for the six-year period 1962-1966 and 1970. There are no storage reservoirs and there are no well discharges of significance.

A balance for the lower basin in an average year is as follows:

$$\begin{array}{ccccccccc} Q_{ri} & + & P & = & ET & + & Q_{ro} & \pm & S \\ 3{,}090 & + & 8{,}967 & = & 6{,}852 & + & 5{,}205 & \pm & 0 \text{ million m}^3 \end{array}$$

where:

Q_{ri} = Surface water inflow equivalent to the average flows at Dramhosso and Anoemafoetoe

P and
ET = are as previously described for the lower Suriname basin

Q_{ro} = Surface water outflow equivalent to Q_{ri} plus an adjustment of 2,115 million m^3 to balance the equation

The 2,115 million m^3 contribution to surface water outflow is equivalent to a unit discharge of 16.2 l/s/km^2, which compares with the average 15 l/s for low run-off areas in keeping with expected conditions.

The active ground water flow system within the basin has an area of about 1,010 km^2, assumed to be equivalent to the area of the Savannah and Old Coastal Plain. With a recharge averaging 340 mm, as in the Lower Suriname River basin, approximately 343 million m^3 of the water would pass through the ground water phase.

CHAPTER 7

WATER DEVELOPMENT

AVAILABILITY OF WATER FOR USE

Suriname River

The Suriname River flows through the most densely populated part of the coastal area, where it is tidal and contains brackish water.

Increases in flow downstream from Pokigron for a fictitious case are given in Table 16. The listed flows are based on unit discharges for high and low run-off terrain given in Figure 6. The Savannah and Coastal Plains are assumed to have low run-off.

Since 1966 the flow has been controlled by the operation of the dam at Afobaka and mean annual discharges for the years 1966 to 1970 were 198, 243, 300, 246, and 314 m^3/s, for an average of 260 m^3/s. The daily minimum discharges for the same period were 138, 131, 203, 223, and 241 m^3/s.

A useful approximation of the flow available for use in the coastal area may be obtained by using the average flow of 260 m^3/s and the minimum flow of 130 m^3/s (131 m^3/s in 1967 rounded) released from the dam and adding the flows downstream from Brokopondo (Table 16) for run-off exceeded by 50 and 95%, respectively. The flows at Paranam would be 278 and 136 m^3/s (Figure 30).

According to Ringma (1961) a discharge of 150 m^3/s at Paranam keeps the chlorides at a level of 200 ppm or less upstream from the river's cross-section 2-3 km beyond Domburg. At the same discharge a level of 100 ppm of chlorides is maintained approximately in the vicinity of Surnau Creek.

It is concluded that, with a five-year average annual flow of 260 m^3/s and a minimum flow of 130 m^3/s at Brokopondo, the chloride content of the river water in the vicinity of Surnau Creek should be maintained at 100 to 200 ppm with upstream withdrawals of up to 120 m^3/s.

Saramacca River

The average discharge is 86 m^3/s at Dramhosso for the 10-year period 1961 to 1970, and for the Kleine Saramacca River at Anoemafoetoe it is 12 m^3/s for the six-year period 1962 to 1966 and 1970.

From a frequency analysis of daily flows during the dry season at Dramhosso, flows of 1 m^3/s are exceeded by 99.99%, 1.5 m^3/s are exceeded by 95%, and 2 m^3/s are exceeded by 90% of the daily discharges. These are regarded as critical flows for the purpose of estimating the water

TABLE III-16

HYPOTHETICAL FLOWS OF THE SURINAME RIVER AT VARIOUS LOCATIONS

Location	Area in km		Run-off m^3/s exceeded by		
	High Run-off	Low Run-off	5%	50%	95%
To Pokigron	7,750		300	194	95
To Brokopondo					
Basement	2,980		116	74	36
Reservoir		1,900	52	29	10
Alluvium		20			
			468	297	141
To Phedra		930	25	14	5
			493	311	146
To Paranam		298	8	4	1
			501	315	147
To Mouth		2,122	57	32	11
	10,730	5,270	558	347	158

available for use. A contribution from the Kleine Saramacca River is discarded because 68% of the daily discharges at Anoemafoetoe are zero.

The 1.5 to 2.0 m^3/s critical flow is a portion of the 95% exceeded flow of 40 m^3/s at Dramhosso, and the same proportion may be used to obtain the critically low flow at Uitkijk downstream, from which the salinity becomes too high for use. Assuming the basin between Dramhosso and Uitkijk (approximately 3,026 km^2) has low run-off characteristics, the estimated flow contribution exceeded by 95% would be 15 m^3/s, which would reduce by proportion (0.05) to 0.75 m^3/s, rounded to 1 m^3/s. This gives a critical flow of up to 3 m^3/s at Uitkijk. The flow should maintain the level of chlorides at 200 ppm between Santigron and Uitkijk (Ringma, 1961).

The conditions of analysis are conservative. It is concluded that up to 1 m^3/s could be taken from the river upstream from Uitkijk, realizing that, in a critical period of low flow, a temporary increase in chlorides might occur.

Renewable Ground Water of the Savannah and Old Coastal Plain

The maximum amount of water theoretically available is equivalent to the recharge throughout the area. Under natural conditions this is estimated at between 0.2 and 0.48 million m^3/km^2/year, for an average of 0.34 million m^3/km^2/year (Chapter 5 - Assessment of Modern Recharge, page 75). The total volume for the area between the Saramacca and Suriname Rivers is estimated at about 200 million m^3/yr and for the total area of the system about 3,900 million m^3/yr.

Withdrawals would change the present equilibrium and flow pattern, resulting in a decrease of natural discharge mainly as a reduced effluent flow to streams. An increase in the amount of recharge may also be induced both directly from the infiltration of rainfall and from streams. This situation is apparent at Republiek, where the estimated recharge of 1.28 million m^3/km^2/yr is much more than the estimates at other locations. It may be regarded as a potential available in the area immediately north of the Savannah.

The Savannah Belt is an important recharge area, but the hydraulic conductivity of the aquifer material is limited by an abundance of admixed kaolin and therefore it is not suitable for the construction of high capacity wells. Conditions for well construction improve generally towards the north; however, the amount of recharge decreases in this direction to zero at the northern limit of the system (Figure 24.) In places this limit is also marked by a sharp change from fresh to brackish water, and large withdrawals in excess of local recharge would induce this water to flow south into the system. This may be the case at Paranam, where 20,000 m^3/day are withdrawn by the Suralco wells, which are only 3 km south of the brackish waterfront (Enclosure 4).

Whereas water supplies might be obtained at locations throughout the system, Republiek and Rijsdijk are considered particularly suitable areas for the development of large-scale withdrawals—Republiek because of the large potential and Rijsdijk because it is located near the northern part of the system, closer to the population centers but removed from the brackish waterfront (Figure 31).

An estimate of the potential in the Republiek area is obtained by considering the 80 km^2 area outlined in Figure 31 and the recharge estimate for Republiek. This is rounded off to 1 million m^3/km^2/yr because the conditions may not be as favorable throughout the entire area. It gives a total of 80 million m^3/year (210,000 m^3/day), which should be considered a maximum for present planning purposes to be reviewed as development takes place. It is based on direct local recharge only, but withdrawals lowering the head would also induce a flow from the Savannah area. Well fields should be planned to pump about 30 l/s from each square kilometer. With the low hydraulic conductivity and with water table to leaky artesian conditions, three wells each pumping 10 l/s are envisaged spread over each square kilometer.

A 32,200 m^3/day supply of water from 17 wells in the Rijsdijk area is considered feasible. Details of this are given in Annex 6.

There is insufficient information to assess the potential east of the Suriname River and west of the Saramacca River. For the present one can only assume that conditions will be similar to those between the two rivers.

Because the aquifers are under leaky artesian and locally water table conditions and because they receive recharge, they are also susceptible to contamination. This applies particularly to soluble materials that might be contained in any future industrial wastes. The area should be protected against such eventualities by appropriate legislation and planning.

Nonrenewable Ground Water of the Young Coastal Plain

The area corresponds with the more or less inactive ground water system of the Young Coastal Plain in which fresh water is stored in the Coesewijne and A Sand aquifers, and locally in the Onverdacht and Zanderij aquifers. Exceptions are in most of Commewijne and apparently in the Coppename River mouth area, where the water is brackish, and in the Boxel-Domburg area, where the lower aquifers are not present and the Zanderij aquifer contains brackish water.

The resource is considered nonrenewable because there is no evidence of modern recharge, and withdrawals will eventually result in replacement by brackish water from the north. A flow of fresh water might be induced from the south by withdrawing water from the upper aquifers near the southern limit of the system, but this would not offset flows from the north also. The effect of withdrawals from the A Sand aquifer in this system is illustrated in Figure 42, which shows the interference from the Zorg en Hoop well field extending to the boundary in the south. A flow pattern has developed whereby most water comes from the north, and even the flow from the south in the direction of the boundary, which comprises only about 11% of the total, will ultimately be replaced by water from the northwest and northeast.

The conditions are such that withdrawals of fresh ground water from the system can be considered only as a mining operation. It is not mining in the strict sense that the aquifers would be dewatered, but it is mining fresh water, which will be replaced by brackish water.

The system is complicated further by hydraulic contact between aquifers containing water with different chemical qualities. Thus, in places the Upper Coesewijne aquifers with fresh water are laterally in contact with the Zanderij aquifer containing brackish water, and withdrawals from the Coesewijne aquifer would induce an invasion of brackish water from the Zanderij aquifer.

The system contains large volumes of water on storage, and, although withdrawals would amount to mining, there is no cause for immediate alarm. Estimated volumes of fresh water available in the area of the Saramacca and Suriname Rivers are given in Figure 31. They are based on 10% effective porosity of the estimated aquifer volumes. From the limited information available, it is obvious that there are vast quantities of water in storage in the west, although the fresh water generally is deeper than in the east. To obtain an approximate order of magnitude, the volume of the A Sand aquifer between Totness and the Corantijn River is estimated at about 80 km^3. This is based on a thickness of 50 m near the coast, decreasing to zero at the basement shelf about 40 km inland. With an effective porosity of 10% the equivalent water volume would be 8 km^3. In addition there is fresh water in the overlying Coesewijne aquifers, and water of inferior quality in the Zanderij aquifer.

It is possible that, with increased withdrawals and lower water levels in areas of heavy withdrawals, there might be a small amount of subsidence. Such a condition has not been observed at Paramaribo where the largest withdrawals take place. On the other hand no measurements have been made as a check. This would be worthwhile when it is realized that the land surface is generally not more than 2 m above mean sea level.

WATER SUPPLY PROJECTS - GROUP 1 IN THE DISTRICTS OF SURINAM AND WEST COMMEWIJNE

Kwatta-Leidingen

Requirements

The proposed water supply system extends about 10 km west of Paramaribo, mainly south of Middenpad van Kwatta (East-West Highway) to the

Saramacca Canal, a distance of about 5 km. The treatment plant and storage facilities are being constructed on the east side of Leiding 9A in the approximate center of the distribution system. An extension will include Uitkijk and Jarikaba.

The population is estimated at 12,500 persons and is expected to increase to 27,500 in 1987. Estimated water requirements are shown graphically in Figure 34. These are based on estimates given in Volume IV. An annual increase of 4% was used to estimate the cumulative withdrawals after 1987.

Available Sources of Water

The aquifer system is illustrated schematically in Figure 32 and in more detail in the map and sections of Enclosure 4 and Annex 1. The Zanderij, Coesewijne, and A Sand aquifers are all present at the site of the treatment plant, but the Coesewijne aquifers are the only ones which contain potable water. The Saramacca and Suriname Rivers are too distant to consider as sources with ground water available in the area.

The Coesewijne formation extends into the area from the south as a spur buried beneath the Zanderij formation. At the plant site the main Coesewijne aquifer is about 30 m thick, topping at 70-75 m BCL and apparently consisting of a complex of sand layers with clay partings. A similar thickness appears to prevail to the south, southwest, and north. It thins to the east and probably to a less extent to the west (Figure 32).

Assuming that the aquifer extends throughout the area, it should be in contact with the Zanderij aquifer around the perimeter of the buried Coesewijne spur (Enclosure 4). These contacts are water quality boundaries to the system, because of the brackish water in the Zanderij aquifer. Their estimated distances from the plant site are 12 km west, 8 km east, and 3.5 km north.

To the south water is fresh throughout the system. The formation is almost all clay in the Santo Boma area, but aquifers persist to the SSE (Pad van Wanica) and SSW (Koewarasan). A recharge boundary occurs in the Lelydorp area in the form of a contact with the overlying Zanderij aquifer, which contains fresh water at this location; however, this is about 14 km south of the plant site.

The piezometric surface is virtually flat (Figure 23) and thus there is no significant natural flow in the system. At the plant site the static water level elevation is about 0.8 m NSP (1.94 m to 2.12 m BCL), and the aquifer is under nonleaky artesian conditions. The transmissivity is between 2,300 and 2,500 m^2/day, with an equivalent hydraulic conductivity of 170 to 180 m/day.

The A Sand aquifer is at a depth below 160 m at the plant site, where it is about 40 m thick. It is not a suitable source of potable water because of the chemical quality (TW 10/70, Annex 4). The chlorides are 333 ppm and the water gives off a gas with a foul odor. Farther west in the Jarikaba area the aquifer contains fresh water (Enclosure 3), and it might be considered as an alternative source of supply.

Effect of Ground Water Withdrawals

Withdrawals from the Coesewijne aquifer at the plant site would result in a movement of water towards it from all directions. Because the aquifer thins to the east, the flow from this direction likely will be less than from other directions.

From a test run on Well 4/70 (Figure 33), it is apparent that interference extended to 3.5 km (to the north) in 72 hours and by extrapolation to about 10 km in one year and about 17 km in ten years. From this it is clear that withdrawals will cause brackish water to invade the aquifer from the Zanderij aquifer in the north, west, and east. Whereas a flow of fresh water would be induced from the south, this would be offset by interference with the Koewarasan and Pad van Wanica projects.

Under the circumstances described, withdrawals of fresh water from the Coesewijne formation at the plant site must be considered as a "mining" operation, with the extractable volume of fresh water limited by the volume of the aquifer and its effective porosity up to the nearest water quality boundary. A water volume of 53.5 million m^3 is estimated, based on an effective porosity of 0.1 and an aquifer volume estimated for a circular area with a radius of 3.5 km (Figure 32). From the estimated cumulative withdrawal curve in Figure 34, the 53.5 million m^3 of water should be sufficient to meet the needs of the supply system well beyond the year 2000.

Water Quality

The salinity of the water is relatively low. It increases in the aquifer towards the north as illustrated in Figure 14. At Well 4/70 the dry residue is 610 to 640 ppm with chlorides about 110 ppm and sulphates 180 ppm. Magnesium is the dominant cation and sulphate the dominant anion.

The pH is a little low, between 6.5 and 7.0, and, as in most of the coastal area, the iron is high, in this case between 4.3 and 9.3 ppm.

Detailed analyses are given in Annex 4. The analysis for Well 1/69, Stolkslust, indicates the highest values likely to occur during the operation of the system before the aquifer is contaminated with brackish water from the Zanderij aquifer.

Operation of Wells

Well 4/70 was constructed as a supply well at the plant site. It is 89.95 m deep with nominal 8-inch diameter casing to 72.13 m BGL, and with 13.8 m of 8-inch telescope size, No. 40 slot, JOHNSON stainless steel screen, adjacent to the aquifer from 73.4 to 87.2 m BCL.

The yield characteristics of the well are illustrated in Figures 33 and 34. Although it has been pumped at rates up to 30 l/s, the yield is rated at 25 l/s for an entrance velocity not exceeding 3 cm/sec.

A yield of 25 l/s should be sufficient up to the year 1983 based on a 16 hr/day operation. A pump yielding this quantity of water should have the suction at least 8 m BCL, allowing for a pumping level of 7 m BCL.

A standby well will be necessary. It could be constructed as close as 20 m from the existing well because the two would not be pumped simultaneously, interfering with each other.

A second well will be required in 1983, and it is likely that the original well will have to be replaced by that time because of corroded casing. A second well would best be located in an east or west direction. The expected interference for various well spacings is given by the interference curve in Figure 33. A spacing of between 100 and 200 m likely will be the best, after which large increases in the length of a feeder main would give only small savings on interference and consequent pumping costs. The optimum spacing may be determined at that time from the prevailing costs.

It is suggested that the water level and water quality be monitored at Well 1/69, Stolkslust, at all times, particularly since this well is in the direction of the nearest water quality boundary.

Pad van Wanica West

Requirements

The proposed water supply system covers an area of approximately 60 km^2 located south of Paramaribo on the west side of Pad van Wanica. The site of the treatment plant and storage is expected to be by Helena Christina Weg near the Magenta Canal in the west central area of the distribution system.

The population is estimated at 12,500 persons and expected to increase to 22,500 in 1987. Estimated water requirements are shown graphically in Figure 39. These are based on estimates given in Volume IV. An annual increase of 4% was used to estimate the cumulative withdrawals after 1987.

Available Sources of Ground Water

The aquifer system is illustrated schematically in Figure 35. The Zanderij, Coesewijne, and A Sand aquifers are all present.

The Zanderij aquifer extends throughout the area. It is generally 10 to 15 m thick, increasing to more than 40 m in the east and southeast where it contains brackish water. The chlorides are 500 to 800 ppm in the area immediately west of Pad van Wanica and increase to more than 2,000 ppm eastward. As a source of water supplies the aquifer is best to the south where the water is everywhere fresh, and where it receives recharge. The northern limit of recharge appears to be in the de Crane Weg area.

With the exception of the lowest member, the Coesewijne aquifers comprise a complex of saturated sands interbedded with clay, which are all hydraulically interconnected with each other and with the overlying Zanderij aquifer. A boundary to the northwest is evident from the log of the Santo Boma well, and the buried Onverdacht hills now being mined for bauxite also form a boundary to the southeast. A water quality boundary exists to the east, where the aquifers are in hydraulic contact with the brackish water zone of the Zanderij aquifer. The lowest Coesewijne aquifer appears to be in contact with the A Sand aquifer.

The A Sand aquifer extends southward into the area, and wedges out. The availability of fresh water from this aquifer is limited, and Paramaribo presently relies on this source for 65% of its water supplies. Because of this, an alternative source for the Pad van Wanica system would be advisable and in the best interest of regional water resources planning.

Ground Water Withdrawals

Helena Christina Weg Plant Site

Well 31/71 was drilled at the proposed plant site. The log is contained in Figure 36; the aquifers intersected are listed in Table 17; and a pumping test on the well is illustrated in Figure 37. The limits of the aquifer system are as illustrated in Figure 35 and as listed below.

1) An aquifer boundary close to the west (Santo Boma) and also approximately 7 km to the southeast (bauxite area).

2) A water quality boundary to the east, approximately 1.5 and 2.5 km from the plant sites in the Zanderij and Coesewijne aquifers, respectively.

3) No direct recharge within the area.

4) Negligible natural flow within the system.

Under the conditions described, withdrawals of water at the plant site would result in a flow of water towards the site from all directions except the west, and the available fresh water would be withdrawn when the brackish water front reaches the plant site.

TABLE III-17

AQUIFERS AND AVAILABLE FRESH WATER AT THE HELENA CHRISTINA WEG PLANT SITE

Aquifer	Depth m	Thickness m	Estimate of Available Water million m^3
Zanderij	47-55	8	
U Coesewijne	62-64	2	10.8
	66-70	4	
	73-78	5	
	86-96	10	9.8
L Coesewijne	117-124	7	
A Sand or Onverdacht	126-135	9	
	139-143	4	

Estimates of the available fresh water listed in Table 17 are based on aquifer thicknesses, an assumed effective porosity of 0.1, and an area represented by a semicircle the radius of which is the distance from the plant site to the brackish waterfront as depicted in Figure 35.

Comparing the estimates of available fresh water with the estimated cumulative withdrawals given in Figure 39, it is evident that there is sufficient fresh water available in the Upper Coesewijne aquifers to meet the needs at least until the year 2000.

Well 31/71 was constructed in the lowest of the Upper Coesewijne aquifers. The rated yield is up to 14 l/s with a drawdown of 15 m. The rated yield of the well should be sufficient to satisfy the demand until 1978 based on a 16 hour/day operation or until 1981 based on a 24 hour/day operation, after which a second well will be required. There will be mutual interference from the operation of additional wells, the amount of which will depend upon the well spacing. Spacings of between 100 and 200 m should be suitable.

Ground Water Withdrawals

Sidodadie Weg (Well 44/71)

Well 44/71 was constructed by Sidodadie Weg as an alternative source of supply, approximately 3 km south of the plant site. The well was constructed in the Zanderij aquifer (Figure 35).

The location is close to the northern limit of recharge. The water quality boundary described in the Helena Christina Weg area continues southward and is approximately 3 km east of the well.

The results of a 43-hour pumping test on the well are contained in Figure 38. The cone of interference is evidently asymmetrical, with a steeper gradient to the south in the direction of the recharge area. Interference extending 2 km to the south and 4 km to the north suggests about twice as much water flowing to the well from the south as from the north, assuming the aquifer thickness and transmissivity to be about the same in each direction.

The rated yield of the well is 21 l/s with a drawdown of 3.5 to 4 m (pumping level 8 to 8.5 m BCL). With a yield of 21 l/s the well should meet the needs of the system until 1982, based on a 16-hour/day operation.

Water Quality

Detailed chemical analyses of water samples taken from wells drilled throughout the area are listed in Annex 4. A summary of the analyses is contained in Table 18, which includes the analyses of water from Helena Christina Weg Well 31/71 and Sidodadie Weg Well 44/71. The high and the low values from wells in the area surrounding each of these wells indicates the general range of dissolved constituents.

TABLE III-18

CHEMICAL QUALITY OF GROUND WATER AT THE HELENA CHRISTINA WEG AND SIDODADIE WEG SITES AND SURROUNDING AREAS

	Na	K	Mg	Ca	Cl	SO_4	CO_3	Res	pH	Fe	Mn	F
High	56	7	27	31	90	100	30	425	7.3	4.0	0.4	0.1
H. Chr. 31/71	56	7	3	25	70	75	30	425	7.3	1.8	0.4	0.1
Low	39	5	3	14	54	70	24	337	6.3	0.4	0.4	0.4
High	35	5	15	18	73	67	48	311	6.9	3.3	0.4	0.3
Sidodad 44/71	30	5	3	15	17	57	42	222	6.5	3.0	0.2	0.2
Low	30	4	3	3	17	26	27	215	5.7	0.8	0.2	0.0

All analyses except pH are in ppm.

The analyses show that the water at both locations falls within the standards for public water supplies with the exception of iron, for which treatment will be necessary. The pH is generally low.

Details of the brackish water to the east are listed in Annex 4 for TW's 17/71 and 33/71. The salinity of this water increases to the east.

Operation of Wells

A standby well will be required for the system. It is suggested that this be constructed in the upper aquifers. It may be that it will be better than Well 31/71, in which case it would be the permanent producer.

Additional wells when required should be towards the south in the direction of recharge.

Water levels and chemical quality should be monitored in the surrounding wells, particularly to the east in the direction of brackish water.

West Commewijne and Meerzorg

Present Supplies

A small distribution system in the Meerzorg area is supplied by wells. There are two wells at the plant site but only one is used. They each are constructed with screens in the A Sand aquifer below 141 m. One well is equipped to pump at a rate of 4 l/s.

Supplies of water at Nieuw Amsterdam are obtained by barge from Paramaribo. Storage up to 400 m^3 is provided; the water is distributed by pipes to a few local buildings and elsewhere it is delivered by tank truck.

At Mariënburg swamp water is impounded. It is treated by coagulation with alum and is then piped to the streets. This water is not suitable for drinking.

Individual rainwater catchments are widely used throughout the area.

Requirements

The water requirements of the communities from Meerzorg to Mariënburg are estimated at 1,250 m^3/day in 1987 and 5,860 m^3/day in 2001; for the whole area, including Alkmaar, Spieringshoek, and Tamanredjo, the requirements are estimated at 3,900 m^3/day in 1987 and 9,280 m^3/day in 2001. Details of the individual communities are given in Volume IV.

Available Sources of Water

The only local fresh water is in the A Sand aquifer at Meerzorg (Figure 40). The aquifer is at a depth between 141 and 150 m and thins out against the Onverdacht sediments to the east. Where it has been drilled it consists of medium- to fine-grained kaolinitic sand with a relatively low hydraulic conductivity in the order of 30 m/day.

A volume of about 210 million m^3 is estimated for the aquifer bounded by the river to the north and west and by the 300-ppm isochlor to the east. With an effective porosity of 0.1, the available fresh water would be about 21 million m^3. Interference from the Zorg en Hoop wells extends into the area (Figure 42).

More permanent supplies of ground water may be found to the south where the Zanderij aquifer receives recharge as at Paranam and Rijsdijk; however, it is not expected that such conditions will be less than 10 to 15 km south of the East-West Highway across intervening swampy terrain with no communications.

The Suriname River is a potential source of supply, but the quality is not suitable downstream from Domburg.

Surnau Creek might be regarded as a potential source of water. It is a right bank tributary of the Suriname River, entering upstream from Domburg, and its closest point to the supply area is about 10 km south of Tamanredjo across swampy terrain without communications. Should a supply be considered from this area, ground water from the Zanderij aquifer would be more suitable.

Fresh ground water has been discovered at Morico (Wells 9/70 and 10/71), but the water is brackish within 3 km to the west in the same aquifer. The distance involved from Morico to Tamanredjo is about 30 km.

Water with a marginal chloride content of 276 ppm was discovered at a depth of 90 to 100 m at Commetewane Creek (TW 4/71, Annex I-E) about 14 km west of Tamanredjo; however, the water is brackish close to the east and west. The area may be close to the northern limit for fresh water. It would not be suitable for the development of large supplies as it would soon be contaminated by an inflow of brackish water.

Proposed Source of Water

For immediate use the water in the A Sand aquifer at Meerzorg is the obvious source. It is estimated that the aquifer contains 21 million m^3 of water with a chloride content less than 300 ppm.

For planning purposes it is assumed that the maximum volume of fresh water could not be withdrawn. Assuming that only 10 million m^3 is available, at the estimated 1987 needs this would be sufficient for Meerzorg for 20 years (0.456 million m^3/year) or to supply Meerzorg, Jagtlust, Nieuw Amsterdam, Voorburg, and Mariënburg for 10 years (0.97 million m^3/year).

At the present time water is moving westward through the aquifer to the Zorg en Hoop well field (Figure 42, flow paths 19, 20, and 21). This flow could be arrested and the maximum amount of water secured for local use by locating supply wells as far west as possible up to the river.

It is proposed that supply wells be constructed west of the present Meerzorg plant. At this location the aquifer probably is about 15 m thick (Enclosure 3) and may be more coarse-grained than found at TW 16/71. It is about 8 km from the 300 ppm isochlor. Three supply wells each pumping 15 l/s would be sufficient to meet the needs of the system from Meerzorg to Mariënburg. The capital cost would be about Sf.16,000 per well excluding pumps.

In the event that such a project was realized, TW 6/71 should be maintained as an observation well to monitor the water level and chloride content.

After the withdrawals of fresh water in the Meerzorg area, future sources might be from west of the river, the Morico area, or from the Surnau Creek area to the south as ground water or surface water. At the present time there is no indication of development to the south.

Koewarasan

A water distribution is supplied by two 4-inch diameter wells, 80 m deep, with screens in one of the Coesewijne aquifers. They are equipped to supply 25 and 15 m^3/day. The system was recently extended to include the Santo Boma prison to the east.

The present requirement is for 200 m^3/day. This is expected to increase to 600 m^3/day by 1987 and 1,400 m^3/day by 2001. The requirements are negligible compared with the fresh water stored in the Coesewijne and A Sand aquifers (Fig. 31), and additional supplies may be obtained by adding more wells.

Houttuin

There is no organized water supply system for this rural area. Requirements are in the order of 350 m^3/day and are expected to increase to 710 m^3/day by 1987 and 1,600 m^3/day by the year 2001.

The only local source of ground water is in the A Sand aquifer which is under the influence of pumping at Paramaribo and terminates about 2 km to the south (Enclosure 3 and Figure 42).

Well 2/69, constructed by the project, is capable of yielding 6 l/s with a drawdown of 9 m, which is sufficient to meet the present needs of the area. The entire aquifer was not screened; therefore, it should be possible to construct a well with a higher yield and use Well 2/69 for standby purposes.

The quality of the water is given in Annex 4. It is uncertain in the future because of interference from Paramaribo. In the event that the quality becomes unacceptable, a supply from another location would be necessary. An extension of the Paramaribo or Pad van Wanica West systems may be the solution at that time.

Domburg

There is no water supply system at present. Requirements are in the order of 600 m^3/day and are expected to be 1,250 m^3/day by 1987 and 2,900 m^3/day by 2001.

The nearest sources of fresh ground water are the A Sand aquifer in the vicinity of Houttuin about 10 km to the NW and the Zanderij aquifer in the vicinity of La Vigilantia about 10 km to the south.

The Suriname River is the closest source of supply; however, the location coincides approximately with the downstream limit for fresh water under the present flow conditions, and therefore withdrawals would best be 4 or 5 km upstream.

PARAMARIBO

Present Supply

The present water supply comes from three well fields at Republiek, Zorg en Hoop, and Leysweg.

The Republiek well field was established in 1933. It is about 36 km south of the city immediately north of the Savannah area. It contains a total of 25 wells, all of which are constructed in the Zanderij aquifer at depths up to 30 m. Nineteen of the wells are pumped by a vacuum system, and the remaining six are equipped with turbine pumps. Withdrawals since 1933 are given in Figure 27. The present rate is 9,400 m^3/day. The water is pumped to Paramaribo through a 14-inch ID water main, which follows the railway, then the highway. Lelydorp and other communities along Pad van Wanica up to the outskirts of the city receive water from this line, and the remaining water is mixed with water from the Zorg en Hoop wells near the water tower.

The Republiek water that reaches Zorg en Hoop is not metered. It is estimated that 3,400 m^3/day reach Zorg en Hoop based on the chloride content of the two waters, the mixed water, and the pumpage from the Zorg en Hoop wells. A booster station under construction near Lelydorp is expected to increase the flow to 500 m^3/day. Assuming that the usage before the city remains constant, the supply at Zorg en Hoop should amount to about 6,000 m^3/day. The water has a chloride content of 15 ppm.

The Zorg en Hoop well field at Paramaribo was established in 1958. It consists of 17 wells in an area of about 1 km^2, which are constructed in the A Sand aquifer at depths of 150 to 170 m. A number of earlier wells were constructed in the Coesewijne aquifer zone at depths of about 120 m, but these were abandoned because of a rapid increase in the chloride content of the water (Wells N1 and N2). This probably was caused by an invasion of the aquifer by water from the Zanderij aquifer. The project assisted in the construction of the three new wells to augment the supply during the water shortage in 1971. The well field supplied 17,200 m^3/day in 1971. The chloride content is not the same for each well. It is increasing slowly and presently varies between 200 and 220 ppm.

In 1971 the project assisted in drilling three wells at Zorg en Hoop and exploration wells at Makkaholoweg near Livorno. The drawdown-discharge relationships of these wells are given in Figure 46.

In 1972 withdrawals commenced at the new Leysweg well field to the west of the city. The field consists of four wells, two of which are presently equipped with pumps. The present yield is about 4,500 m^3/day. The chloride content of the water was 250 ppm and has increased to 270 ppm since withdrawals began.

Future Plans

It is planned to equip the remaining two wells at the Leysweg well field and increase the supply to 300 m^3/hr or 7,200 m^3/day.

Plans are being prepared to construct a new well field and treatment plant at Livorno, about 5 km south of Zorg en Hoop. The wells would be constructed in the A Sand aquifer. It is expected that the plant will be in operation in 1975, supplying water initially to the surrounding area. A total supply of 600 m^3/hour or 14,400 m^3/day is envisaged, with water in excess of local requirements being pumped into the city system. The chloride content of this water is presently 114 ppm.

Water Requirements

Estimates of future requirements are illustrated in Figure 41. The total daily pumpage from 1954 to 1969 increased at a rate slightly more than 10% per annum.

A range of possibilities is given after 1971 based on yearly increases of 2, 4, 6, and 8. Growth rates evidently vary throughout the city, with the highest rates of increase to the north and the south in the order of about 8%. This is discussed in detail in Volume IV. It is assumed here that an increase in the demand for water will be up to 4%

within the present city limits, but will be up to a maximum of 8%, at least initially, as areas of extension to the north and south are included, with an overall average of about 6%.

Available Sources of Water

Ground water is available from the A Sand aquifer in the coastal area and from the Zanderij aquifer to the south as at Republiek and Rijsdijk.

There is fresh water in the Coesewijne aquifers to the west and southwest of the city, but in the interest of regional planning this water is appropriated to the Kwatta-Leidingen, Pad van Wanica West, and Koewarasan projects.

The availability of ground water from the A Sand and Zanderij aquifers is illustrated in Figure 31. In summary it is estimated as follows:

A Sand Aquifer (not recharged)		million m^3
Zone AI,	Paramaribo and south (Zorg en Hoop and Leysweg), chlorides <300 ppm 230 - 48 (used)	182
Zone AII,	Koewarasan, 18 km SW of Paramaribo, chlorides <300 ppm	190
Zone AIII,	Jarikaba, 20 km W of Paramaribo, chlorides <300 ppm	748
Zone AIV,	SE Bakhuis fault zone N of Paramaribo to the coast, chlorides 300-400 ppm	424
Zanderij Aquifer (recharged)		m^3/day
Rijsdijk,	26 km SSW of Paramaribo, chlorides about 30 ppm, water not appropriated - compared with Santigron project Volume IV	32,000
Republiek	and area to the west, 36 km south of Paramaribo, chlorides 15 ppm, 80 km^2 at 1 million m^3/year = 2,740 m^3/day/km^2	220,000

It is estimated that 230 million m^3 of water were originally available in Zone AI. The 48 million m^3 withdrawn by the Zorg en Hoop wells since 1958 is subtracted from this amount. The estimate probably is a minimum, as no account has been taken of water in the lowest Coesewijne aquifer and local aquifers in the Onverdacht, which are in hydraulic contact with A Sand aquifer.

Water from all zones in the A Sand aquifer may be withdrawn by wells constructed as at Zorg en Hoop and Leysweg. Estimated depths to the top of the aquifer and the thickness are shown in Enclosure 3. To construct the most efficient wells adequate screen should be installed (Annex 7). Forty-slot stainless steel screens have been found the most suitable. For the 6- and 8-inch diameter screens used, an allowance of 1.4 to 1.8 l/s per meter of screen, respectively, would be suitable to maintain low entrance velocities and minimize entrance losses, thus reducing operating costs and probably prolonging the life of the wells. Wells should not be spaced less than 100 m apart to avoid excessive interference and to save on operating costs. An optimum spacing generally is 150 to 200 m, beyond which the decrease in interference is only small for large distance.

In the Republiek area wells must be spaced to take full advantage of the available recharge, which is estimated as sufficient to sustain a withdrawal rate of about 30 $l/s/km^2$. The hydraulic conductivity of the aquifer is relatively low, and therefore the capacity of individual wells to yield water will be limited. As a guide, a minimum of three $wells/km^2$ pumping a total of 30 l/s is envisaged. The use of stainless steel screens and PVC casing should provide wells with a long life.

A possible well field at Rijsdijk is considered in Annex 6.

Effect of Withdrawals

Present Withdrawals

Interference in the A Sand aquifer due to withdrawals of Zorg en Hoop is illustrated in Figures 42 and 43.

The shape of the cone of interference clearly reflects aquifer boundaries to the south, particularly effective in the direction of Houttuin, and an inflow of water mainly from the north.

The shape of the cone is complicated by other factors such as variations in aquifer thickness and leakage from the overlying lower Coesewijne aquifer. Thus, equipotential lines are closely spaced to the north where the aquifer is relatively thin and are more widely spaced towards the SE Bakhuis fault and the buried valley to the east (Enclosure 3), in which directions the aquifer thickens and the transmissivity increases. Contact with and leakage from the lowest Coesewijne aquifer occurs in a zone extending northwest from Houttuin. This appears to have modified the effect of the boundary to the southwest, resulting in less drawdown.

Estimated flows for each of the 22 flow paths (Figure 42) are listed in Table 19. Rather than adjust the hydraulic conductivity for each flow path, one value was assumed. This was adjusted by trial and error to obtain the total discharge of 17,807 m^3/day, which is close to the measured

TABLE III-19

APPROXIMATE FLOW DISTRIBUTION TOWARDS ZORG EN HOOP IN THE A SAND AQUIFER

Flow Path	Flow Path Width (W) (meters)	Flow Distance (L) -3m to -4 m NSP (meters)	Aquifer Thickness m (meters)	Flow Q $\frac{W\ km}{L}$ m^3/day
1	1,100	1,300	7	326
2	1,400	1,300	6	355
3	1,100	1,100	6	330
4	800	700	6	374
5	700	600	7	449
6	500	500	10	550
7	400	400	10	550
8	400	300	11	806
9	400	300	12	880
10	350	250	12	924
11	300	200	12	990
12	300	200	12	990
13	300	200	13	1,072
14	300	200	14	1,155
15	400	250	14	1,232
16	400	200	15	1,100
17	400	300	15	1,100
18	500	400	16	1,100
19	800	700	19	1,193
20	1,000	900	19	1,160
21	1,100	1,000	12	715
22	1,000	1,200	10	456
			Total Q	17,807

Refer to Figure 42 and assume k = 55 m/day.

1971 discharge of 17,174 m^3/day. The hydraulic conductivity of 55 m/day compares with values estimated from pumping data.

It is evident from the flow study that only 1,852 m^3/day or 12.3% of the total 17,807 m^3/day enters from the south (flow paths 1, 2, 3, 21, and 22), and from the flow lines that water entering from the east and west is eventually replaced by water from the north.

The chloride content of the water from the Zorg en Hoop wells has increased since withdrawals commenced and now stands at between 205 and 220 ppm. The value varies depending upon the relative pumpage from individual wells. Chlorides are lowest in wells to the south (Corantijn Street) and highest in the wells to the northwest (Overeem Canal wells). The increase in chlorides is to be expected with most water entering the area from the north where the chloride content is higher. This is illustrated by the migration southward of the 300 ppm isochlor (Figure 42).

Interference from the new Leysweg well field is not shown in Figure 42. Tests on the wells (Figure 44) indicate a high hydraulic conductivity and relatively little interference extending to a distance of about 1.5 km. It is expected that water previously flowing towards Zorg en Hoop in paths 3, 4, and 5 will now flow towards Leysweg and that the -2 m NSP equipotential line will pass west of the new well field.

Future Withdrawals

It has been established that water withdrawn from the A Sand aquifer in the coastal area is replaced by an inflow of water with higher salinity from the north and not by fresh water recharge. This process will continue.

Cumulative withdrawals from the A Sand aquifer are shown in Figure 41 for 2, 4, 6, and 8% increases in the requirements, less 6,000 m^3/day supplied from the Republiek well field. Assuming that the overall requirements will increase at 6%, then 230 million m^3 of water, equivalent to the estimated usable water stored in Zone AI (Figure 31), will have been withdrawn by 1984. Similarly, 650 million m^3, equivalent to the estimated usable water stored in Zones AI and AIV, will have been removed by 1998. Thus, after 1984 it can be expected that all water pumped from the Leysweg, Zorg en Hoop, and proposed Livorno wells will have a chloride content of 300 ppm, increasing to about 400 ppm by the end of the century.

The quality will vary at the different well fields, particularly up to 1984. This will be reflected in the system, depending upon how the distribution is managed. From calculated flow velocities and the present salinity distribution in the aquifer, it is estimated that water from the Leysweg wells will have a chloride content of 300 ppm in two years or shortly thereafter, and water pumped from the Zorg en Hoop wells will have a chloride content of about 275 ppm in five years. Most of the water pumped from the Zorg en Hoop wells is expected to enter 75% via flow paths

6 to 16 (Figure 42) and 25% via flow paths 17 to 19, with the Leysweg well field to the west and the proposed Meerzorg well field to the east. Mixed with Republiek water, the chloride content pumped from the Zorg en Hoop plant is expected to be between 220 and 240 ppm in 1980.

The planned Livorno well field is located between the Leysweg, Zorg en Hoop, and Meerzorg well fields to the north and the aquifer boundary to the south, and consequently the piezometric surface will be lowered more than at other locations. The approximate volume of fresh water (Cl = 110-200 ppm) obtainable from storage in the A Sand aquifer south of Paramaribo is estimated at about 40 million m^3. This volume of water would be withdrawn in eight years by the Livorno wells pumped at 14,400 m^3/day. As water is withdrawn, a flow system will develop whereby water flows into the area from the west (south of Leysweg) and from the east (southeast of Meerzorg), and with an increase in gradient more (brackish) water should enter from the Onverdacht formation in the east.

The conditions described envisage all water, less 6,000 m^3/day from Republiek, withdrawn from the Leysweg, Zorg en Hoop, and Livorno well fields. With an additional source outside the area the rate of increasing chlorides would be slowed down.

At Republiek the interference of the wells is not extensive. The water level in OW7, at a distance of about 750 m from the center of the well field, has remained almost unchanged since withdrawals began (Figure 27). This indicates a state of equilibrium whereby withdrawals are sustained by local recharge. In this case the 3.42 million m^3 withdrawn annually is sustained by recharge to about 3.4 km^2 on the basis of 1 million m^3/km^2/year. There was an apparent water shortage each year during the dry season, but this reflected the limitation of the vacuum system. The problem was overcome by adding wells independent of the vacuum system. It is evident that wells must be widely spaced for maximum benefit. Should withdrawals exceed the local recharge rate, water levels would decline and the yield would diminish.

Extensive ground water development in the Republiek area would affect the flow in some of the creeks, which would become influent locally. This would be particularly noticeable in the dry season.

Future supplies might be considered from the A Sand aquifer in the Jarikaba area to the west. The effect of such withdrawals would be similar to those at Paramaribo (Zorg en Hoop, etc.), but the estimated volume of stored water is larger than in the Paramaribo area.

Interference with Other Interests

Other communities with an interest in water from the A Sand aquifer are Meerzorg, West Commewijne, and the Houttuin-Domburg area.

The only fresh water readily available to the Meerzorg area is contained in the A Sand aquifer, which is already under the influence of pumping from Zorg en Hoop. The interference will particularly increase after the Livorno well field is put into operation. A well field is proposed near the river in the western part of Meerzorg to secure as much fresh water as possible for local use. This is expected to be sufficient for 10 years.

Similarly, the A Sand in the Houttuin area is the only source of fresh ground water for local use and for the Boxel-Domburg area to the southeast. Interference, particularly from the proposed Livorno well field, likely will cause an advance of poor quality water into the aquifer from the Onverdacht formation in the south and east.

Selection of Future Water Sources

The selection of future water sources and the location of well fields will depend largely on the chemical quality to be accepted. It is assumed that the International Standards for Drinking Water (WHO, 1963) will be used as a guide.

The chloride content of the present Zorg en Hoop supply is a little higher than the Maximum Acceptable Concentration of 200 ppm, but it is brought to about 180 ppm by dilution with water from Republiek. The supply from the Leysweg wells has a chloride content of about 270 ppm. It is pumped directly into the system without mixing with other water.

After the construction of the booster station at Lelydorp any additional supplies are expected to come from the A Sand aquifer in the coastal area. In the previous section it was anticipated that, under such conditions, the chloride content will increase to about 300 ppm by 1984 and 400 ppm by the end of the century. To maintain a supply with a quality within the Maximum Acceptable Concentration, additional water must come from a source other than the A Sand in the Paramaribo area.

Other available sources have been outlined. Of these a supply from Jarikaba would be the closest. The quality is acceptable (chlorides 80 ppm), but the dissolved solid content is too high to consider the water as an effective dilutant for the local water. In this regard a supply from Rijsdijk or preferably an increase from the Republiek area would be better. To maintain a supply with a chloride concentration of 200 ppm, a mixing ratio of 1 part Republiek water to 1.6 or 1.2 parts of local water from the A Sand aquifer, when the latter has a chloride content of 300 and 400 ppm, respectively, is required.

Future plans should consider water from another source to be made available about the year 1980. Although the Jarikaba area is closest, the growth of the Paramaribo system is more likely to be in a north-south direction, limited to the west by the Kwatta-Leidingen system. Furthermore, although the water is fresh it is not ideal for diluting the local supply. An increase in the supply from Republiek or a supply from Rijsdijk is the alternative. This would involve the placing of a new feeder main by 1980, sized to provide the future requirements. If the local A Sand water is to be diluted, the additional water up to 1990 should be about 30,000 m^3/day, which could be supplied either from Republiek or Rijsdijk.

SURINAME RIVER INDUSTRIAL AREA

Onverdacht

The village of Onverdacht is supplied with ground water from the Billiton Company plant. The supply comes from five wells constructed in the Onverdacht formation. The average yield of each well is 15 m^3/hr. Only three are normally used, but all five are used in the dry season.

The daily withdrawal is about 1,000 m^3, only a portion of which supplies the village. The estimated requirement of the village is 150 and 160 m^3 in 1987 and 2001.

Additional supplies may be obtained by adding wells, which should be spaced at least 150 to 200 m apart. The prevailing regional ground water flow direction appears to be from the southwest, and for this additional wells would best be constructed towards the west, although the aquifer is evidently recharged locally.

Smalkalden

Treated Suriname River water is the source of supply. The plant has capacity of 45 m^3/hr. No problems are anticipated.

Paranam

The refinery is supplied by water pumped from eight wells, and an extension of the system supplies water for local domestic requirements.

The wells are about 38 m deep. They are constructed with 14-inch inner casing and 18-inch outer casing grouted in position to a depth of about 23 m, below which there is 15 to 20 m of 12-inch diameter, 40 to 80 slot, stainless steel screen, surrounded by a gravel pack.

The wells are equiped to pump 50 to 60 l/s each for a total supply of about 20,000 m^3/day. The water has a low mineral content, but it is corrosive to the extent that pumps must be replaced frequently.

Present requirements are for about 20,000 m^3/day. There is no indication of expansion that will require more water.

The wells are constructed in the Zanderij aquifer. At this location it occupies a buried valley, the walls of which are composed of Onverdacht sediments.

The hydrogeological setting appears to be similar to that at Rijsdijk, with recharge entering locally through a leaky aquifer roof. Recharge appears to be mainly to the west as indicated by isotope studies.

It is understood that slight fluctuations in the chloride content of the water are seasonal. This suggests that local recharge is not sufficient to sustain the withdrawals and that native ground water moves laterally into the area.

Ground water is brackish in the aquifer about 4 km to the north. In light of this, a line of observation wells is maintained between the wells and the brackish water area.

The present relatively large withdrawals are close to the northern limit for fresh water in the Zanderij aquifer. The rate of withdrawals is probably higher than the inflow of local recharge, which will cause a lateral flow into the area, mainly from the north and the south. Thus far, the inflow from the brackish water area has not created a problem, and it appears that the withdrawals are largely sustained by local recharge and an inflow of fresh water from the south. Should brackish water encroach upon the well field to the extent that the water is no longer usable, the only recourse will be to move the well field further south or to treat Suriname River water.

<u>La Vigilantia</u>

Water is presently obtained from rainwater catchments, excepting one or two establishments in the northern area which receive water from Paranam.

Estimated requirements are for 183 m^3/day increasing to 366 m^3/day by 1987.

The Zanderij aquifer is the main aquifer in the area. It occupies a buried valley in Onverdacht sediments, which are also aquiferous (Enclosure 4).

The ground water in the immediate vicinity of La Vigilantia is brackish, but to the south it is fresh. Through a program of test drilling the approximate location of the fresh-brackish water front has been identified. The change occurs close to the south of Meursweg. It is possible that the front might be moving slowly southward as a result of withdrawals at Paranam although there is no evidence of such a movement as yet. An additional complication is imposed by the existence of a lagoon which receives spoils from the Suralco plant. This is immediately south of Meursweg and about 1 km west of the Afobaka Highway. The spoils are rich in soda.

The Suriname River is another possible source of supply. The location is upstream from the brackish water section.

Well 32/72 was constructed as a supply well south of La Vigilantia and north of the Suralco plant at Paranam. The location is about 1 km south of the fresh-brackish waterfront. Testing indicates a good well with a specific capacity of 10 l/s/m. The data indicate that the aquifer is under non-leaky artesian conditions and under tidal influence from the river, in which case there would be no direct local recharge and water would approach the well entirely as a lateral flow within the aquifer.

It is possible that continued withdrawals, particularly with the Paranam wells to the south, will cause the brackish water to advance south towards the well.

Assuming overall aquifer thickness of 10 m and an effective porosity of 10%, the volume of water contained in a circular area with a radius of 1 km (the approximate distance to the brackish water) would be about 3 million m^3. The estimated requirement for 1987 is 0.133 million m^3, and therefore there should be no problem in developing the supply. Some leakage may take place as interference extends further, and because of this possibility the existence of any toxic materials in the Suralco wastes must be ascertained before a decision is made to use the source. In the event that there are no toxic substances, samples must be taken monthly for full chemical analysis, which should be plotted on triangular graphs to detect any changes in the nature of the water. A rising pH should indicate soda contamination.

Should brackish water encroach on the well or the aquifer become contaminated in the long-range future, the alternative sources would be the Zanderij aquifer south of the Paranam wells, or the Suriname River.

DISTRICT WATER SUPPLIES

Saramacca

Groningen

Groningen has a water distribution system supplied by two wells, one of which (Well 2/70) was drilled during the project. Both wells screen one of the Coesewijne aquifers.

The well was tested at rates up to 3.7 l/s, with a drawdown of 5.1 m, which is the approximate rated yield. It is pumped at 2.5 l/s.

The older well taps the same aquifer and is also equipped to pump 2.5 l/s.

The water has a dissolved solids content of 400 ppm. The pH is between 6.4 and 6.8, and analyses for iron indicate a concentration between 0.9 and 5.9 ppm.

The present pumpage is about 65 m^3/day. The requirements are estimated at 600 m^3/day in 1987.

Fresh ground water nearest to the land surface is present in two Coesewijne aquifers at depths between 110 and 140 m. Water in the Zanderij aquifer above is brackish.

The A Sand aquifer appears to be missing. An early test drilled to a depth of 189.72 m intersected mainly hard sandstone below 140 m, which probably is the Onverdacht formation. Apparently fresh water flowed from the test well, but there are no written records of this.

Wells in 1987 will be required to yield up to 16 l/s based on a 10 hr/day pumping operation. The thickness of the Coesewijne sands varies in the area, but the total is in the order of about 10 m. A well with 10 m of 8-inch diameter screen should yield this quantity of water. For future supplies a well constructed with screens in the sandstone below 140 m might be considered. It is possible that it will have better drawdown and yield characteristics than the Coesewijne sands.

Tambaredjo

The small community with a population of about 200 is expected to require about 60 m^3/day by 1987.

Ground water from one of the Coesewijne aquifers below a depth of 80 m should be the best source of supply. Any gas should be removed during the aeration process to remove iron. Alternatively the area might be considered as an extension of the Groningen system.

Tijgerkreek

Only individual supplies are available as rainwater catchments. Future requirements are expected to be 350 m^3/day in 1987 and 820 m^3/day in 2001.

From the log of Well 7/72 it is evident that fresh water is available in the Coesewijne aquifers, particularly between depths of 100 and 165 m, where a total of 30 m of sand aquifer could be screened in three layers. The thickest is 20 m between 131 and 151 m.

A 10 m-thick sand from 178 to 188 m may be the A Sand. Below this fresh water appears to be present in Onverdacht aquifers at least to a depth of 240 m.

Well 7/72 was constructed as a supply well for a proposed water distribution system. The 8-inch well has a screen adjacent to a Coesewijne aquifer from 130.5 to 139.5 m BCL.

The well has been tested at rates up to 18 l/s. It is rated to yield 10 l/s with a drawdown of 5.5 m. This is sufficient water for the 1987 requirements based on a 10 hr/day pumping operation.

The water contains gas, but this will be removed by aeration during treatment to remove iron. The gas is mainly hydrogen sulphide. It does not burn.

Calcutta

There is no organized water distribution, and water is obtained mainly from individual rainwater catchments. Requirements are expected to be 350 m^3/day in 1987 and 820 m^3/day in 2001.

Following the discovery of oil shows in the Calcutta area a number of test wells were drilled. The logs indicate the presence of fresh water in the Coesewijne aquifers between depths of 80 and 200 m and in Onverdacht aquifers down to about 250 m.

Oil spots occur at random throughout the Coesewijne sands, at least in the tests drilled along the river road.

A screen was placed in what may be the A Sand aquifer from a depth of 193 to 202 m in Test Well C-6 drilled to the south near the intersection of the Calcutta Road and the East-West Highway. The well still flows and discharges small amounts of gas.

Ground water at Calcutta probably will have an objectionable oily taste and odor; therefore, it is suggested that a supply well be drilled to the south near the old test C-6 or that the area be supplied as an extension of the Tijgerkreek system. Any gas would be removed by aeration during treatment for iron.

Kampong Baroe

A small water distribution system is supplied by 129 m deep well, which taps one of the Lower Coesewijne aquifers. The well contains 3-inch diameter PVC casing and 15 feet (4.57 m) of 3-inch EVERDUR screen. It is equipped to pump 4 l/s. The present requirement is 40 m^3/day. It is estimated that the needs in 1987 will be 430 m^3/day and in 2001 will be 1,015 m^3/day.

The extensive Coesewijne aquifers between depths of 100 and 130 m are the first fresh water aquifers below ground surface (Figure 31). Water is brackish in the overlying Zanderij aquifer.

The present supply well was drilled to 120 m only. It is possible that the A Sand aquifer extends into the area, topping at about 140 m; however, it would be close to the southern boundary of the aquifer.

The pumping rate of the present well is in excess of the theoretical rated yield for the screen.

An additional well constructed in the same aquifer will provide more water when required. The present well intersected approximately 18 m of Coesewijne aquifer. An 8-inch diameter well with screens adjacent to the entire thickness should produce water at the rate of about 32 l/s.

Coronie and Nickerie

Totness

A water distribution system is supplied from a single 8-inch diameter well. The well is 167 m deep, constructed with 4.57 m of screen adjacent to a Coesewijne aquifer.

The static level was 0.4 m BCL and on test the well was pumped at rates up to 10 l/s with a drawdown up to 3.3 m. It is presently equipped to pump at the rate of 8 l/s, which is the approximate rated yield of the screen in place. The dissolved solids content is 311 ppm, the pH is 6.8, and the iron is reported to be very high at 18 ppm.

The present use is 280 m^3/day, and the needs are estimated at 486 m^3/day in 1987 and 1,135 m^3/day in 2001.

The Coesewijne aquifers below 160 m are known to contain fresh water, and from Annex 1-H it is apparent that the A Sand aquifer is present, probably topping at a depth of about 230 m. The quality of the water in the Zanderij aquifer is questionable. It may be fresh in the upper section from about 80 to 100 m, with the salinity increasing to the base.

The present well is capable of yielding water at the rates required up to 1987; however, the well was drilled in 1961 and it is possible that the casing is corroded, especially at the base near the EVERDUR screen. Because of this it is suggested that a new well be constructed soon in the same aquifer to insure against an interruption of the supply.

Wageningen

A distribution system supplies water to the village and has recently been extended northward into the polder area. The system is supplied by two 8-inch diameter wells. The wells are 27 m deep and contain 6-inch diameter, 60 slot, Everdur bronze screens adjacent to a thin Coropina sand aquifer.

A short pumping test was run on one of the wells in August 1970, from which an average hydraulic conductivity of 75 to 80 m/day was calculated.

The wells are pumped at a rate of about 9 l/s each with a drawdown of about 8.5 m. The static water level is 1.4 m BCL.

In 1970 the pumpage was 658 m^3/day. An increase to 1,000 m^3/day was estimated to supply the polder area to the north and for expansion in the village.

The aquifer from which water is presently obtained extends northward into the polder area. At the village the chloride content is 280 to 300 ppm, but it increases to 800 ppm within 2 km to the north. The extent of the aquifer and the quality of the water to the south are not known.

The quality of water in the Zanderij aquifer below is probably similar to the existing supply, at least in the upper sections down to about 120 m (WA-1, Annex 1-I).

The Coesewijne formation appears to be thin at this location, and the next major aquifer is the A Sand, which begins at a depth of about 220 m and continues to about 275 m. For the most part the aquifer contains fresh water, but the SP log of WA-1 suggests the presence of brackish water in the upper section from 224 to 234 m.

The Nickerie River water is brackish as far as about 5 km upstream from the village.

For additional supplies a well constructed with screens in the A Sand aquifer would provide water with a quality better than the present source of supply.

If such a well is constructed, an SP log should indicate whether there is brackish water in the upper section as suspected and, if this is so, care must be taken to seal it off with the casing.

The aquifer likely is compact with low hydraulic conductivity and therefore adequate screen must be installed. Based on tests in the Nickerie area, 1.0 to 1.5 m of screen per 1 l/s should be suitable.

The cheapest source of water is from the shallow Coropina aquifer as at present; however, as withdrawals continue, there is the danger of contamination with higher chlorides from the north.

Groot en Klein Henar Polders

There is no organized water distribution system, and individual supplies are obtained mainly from rainwater catchments. Future requirements are expected to be 60 m^3/day in 1987 and 1,470 m^3/day in 2001.

Fresh water is present in the Coesewijne aquifers at depths from 225 m probably to more than 300 m and from the A Sand aquifer, which should be present beginning at a depth of about 330 m. Well 37/71 intersected a total of 42 m of sand, forming four distinct aquifers between 225 and 300 m.

Water with a higher dissolved solids content is present in the Zanderij aquifer at depths between 60 and 200 m. At Nickerie the chloride content of water from this aquifer is generally between 200 and 400 ppm.

Well 37-71 was constructed as the initial supply well for the proposed distribution system at a cost of Sf.29,504. The log is given in Figure 48.

The well is rated to yield up to 12 l/s with a drawdown of 20 m. The amount of drawdown per unit of discharge increases above 7 l/s.

Theoretically, the well should be capable of meeting the needs of the system up to 1987, but it likely will be necessary to replace it before that time. A well with a higher capacity might be constructed with longer screens adjacent to the lower aquifers.

The water is low in dissolved solids and slightly acidic, with a pH of 6.5 to 6.7. The iron is up to 2.0 ppm (Annex 4).

When a second well is required, consideration should be given to using water from the Zanderij aquifer and mixing it with water from the Coesewijne aquifer. A well approximately 80 m deep would cost less than the deeper wells. Assuming a chloride content of up to 400 ppm in the Zanderij aquifer, a mixture of about two parts Coesewijne water and one part Zanderij water would be required to obtain the recommended chloride maximum of 200 ppm.

Paradise

Individual water supplies are presently obtained from rainwater catchments. Future requirements are expected to be 1,519 m^3/day by 1987 and 3,550 m^3/day by 2001.

Fresh water is present in the Coesewijne aquifers from 230 to 300 m. Below this depth down to at least 440 m the dissolved solid content is higher but the water is fresh. This section includes the A Sand aquifer, probably beginning at 315 or 445 m and continuing to 406 m. Well 5/72 intersected a total of about 65 m of sand, which could be screened in the section from 235 to 406 m BCL.

Water with a higher dissolved solids content is present in the Zanderij aquifer from 40 to 205 m.

Well 5/72 was constructed at a cost of Sf.31,379 as the initial supply well for a proposed water distribution system. The log is given in Figure 48.

The well is rated to yield up to 15 l/s with a drawdown of 5.5 m. The amount of drawdown per unit of discharge increases at discharge rates in excess of 12 l/s.

The water is very low in dissolved solids. Chlorides are up to 53 ppm and the dry residue is 220 ppm. It is a sodium bicarbonate water with a pH of 7.1 to 7.8. The highest iron content determined is 2.2 ppm (Annex 4).

The one well will produce sufficient water for initial requirements, but for a 16-hr/day pumping operation it falls short of the requirement in 1987. A second well constructed in the Zanderij aquifer to a depth of about 60 m might be considered. It would be a cheaper source of supply. Assuming the chloride content is up to 400 ppm, 1.5 parts might be mixed with 2 parts of water from the Coesewijne aquifer to obtain a supply with a chloride content of 200 ppm. Should the water in the Zanderij aquifer be unacceptable, a second well in the Coesewijne aquifers and or the A Sand would be the only alternative. As a guide for well design, up to 1.3 l/s per meter of screen should be considered.

Corantijn and Van Drimmelen Polders

A water supply system is proposed for this area west and south of Nickerie. The requirements are expected to be about 1,500 m^3/day by 1987.

Well 29/72, initially drilled to 450 m, is planned as a production well for the system with screens adjacent to a Coesewijne aquifer between 266 and 284 m. The well should yield sufficient water initially, but it may not be adequate for 1987, by which time it will be necessary to replace it. The construction of a well in the Upper Zanderij aquifer might be considered. It would yield water with an inferior quality, but the well would be cheaper and the water when mixed with water from the deeper aquifer should have an acceptable quality.

Nickerie

The Surinam Water Company operates the water system which is supplied by two wells constructed in the Zanderij aquifer at depths of about 40 m. Water requirements are presently 900 to 1,100 m^3/day. The chloride content is 263 ppm.

Water with a lower salinity may be obtained from deeper aquifers below about 230 m. This could be mixed with the present supply to improve the quality.

Commewijne

General

In the coastal area fresh water is known only in the A Sand aquifer at Meerzorg, in the Coesewijne and possibly the A Sand aquifers at Alliance, and in the Coesewijne and possibly the Zanderij aquifers at Morico. Water with an inferior chemical quality but still usable is known at Spieringshoek (Cl = 355 ppm), which probably is related to the fresh water at Alliance, and near Commetewane Creek (TW 4/71, Cl = 276 ppm).

The population is concentrated mainly along the right bank of the Suriname River and the left bank of the Commewijne River. This area has been considered separately as the West Commewijne and Meerzorg project. Communities as far as Spieringshoek and Tamanredjo might be regarded as extensions of it because there is no closer alternative.

Alliance Area

A small distribution system at Alliance is supplied by a well which was constructed in 1964. It contains 4-inch diameter casing to a depth of 101.9 m, below which 4.75 m (15 feet) of 4-inch diameter, 40-slot, EVERDUR screen with the bottom at 105 m is adjacent to a Coesewijne aquifer. The well is equipped to pump at a rate of about 2.5 l/s.

There are no water distribution systems at other communities in the area, and water supplies are obtained mainly from rainwater catchments.

The present requirements are for 30 m^3/day at Alliance. It is estimated that the area will require 170 m^3/day in 1987 and 400 m^3/day in 2001.

There is fresh water in the Coesewijne aquifers and likely in the A Sand aquifer. The fresh water probably is confined to an area of about 25 km^2 around Alliance. Though the area is restricted, the volume of water in storage is enormous in relation to the requirements of the small isolated communities.

The water may be obtained as at Alliance by means of small diameter drilled wells constructed with a small SOLITE drill.

Communities along the East-West Highway

The population is scattered along the sides of the Highway, and water is obtained by individual rainwater catchments. Small quantities may be obtained by means of shallow wells dug into the sand bars which the road follows, but such supplies are not usually available in the dry season.

The only known sources of fresh water are at Commetewane Creek and Morico. Well 10/71 at Morico might be equipped to supply water for collection by trucks, and similarly, a well might be considered at Commetewane. Well 4/71 drilled at this location was abandoned.

Marowijne

Wonoredjo (Moengo)

A water distribution system is presently supplied by treated surface water purchased from Suralco. It is intended to supply the system from an independent source. Test drilling has proved fresh water in a sand aquifer from 13 to 17 m at the site of the storage reservoir. Drilling is continuing to determine the extent of the fresh water before a supply well is designed. The requirements are expected to be about 1,000 m^3/day by 1987.

Albina

A water distribution system operated by the Surinam Water Company is supplied by two wells, 25 to 30 m deep. They supply about 120 m^3/day. The requirements are expected to be up to 500 m^3/day by 1987.

The shallow aquifer should receive direct recharge from the infiltration of rainfall with conditions similar to the Savannah near Zanderij. An observation well is suggested to determine the recharge more accurately.

There is a large leakage of diesel oil on the ground near the wells. This may contaminate the aquifer locally, and consequently it may be necessary to relocate the wells.

Inland Communities

Most inland communities are located along the main rivers, and therefore water supply problems are not anticipated.

Brokopondo and Klaaskreek along the Suriname River obtain supplies from wells drilled in the old river alluvium. Similarly drilled wells will be used to supply the system at New Lombé and Mui Creek. It is likely that these shallow aquifers are recharged directly by rainfall, but the operation of wells near the river probably will induce infiltration from the river. These conditions may extend inland for as much as 40 km beyond the Savannah area.

A small supply well (28/72) was drilled for the agricultural experimental station at Cobitie, west of the Saramacca River in the Savannah area. Development was prolonged because of the kaolin mixed with the sand. The well is 12 m deep and will yield water at a rate of 1 l/s with 1 m of drawdown.

Attempts to drill a well for Powakka were unsuccessful. The Zanderij formation at this location is almost entirely kaolin and sandy kaolin. Dug wells will be the best source of supply under these conditions.

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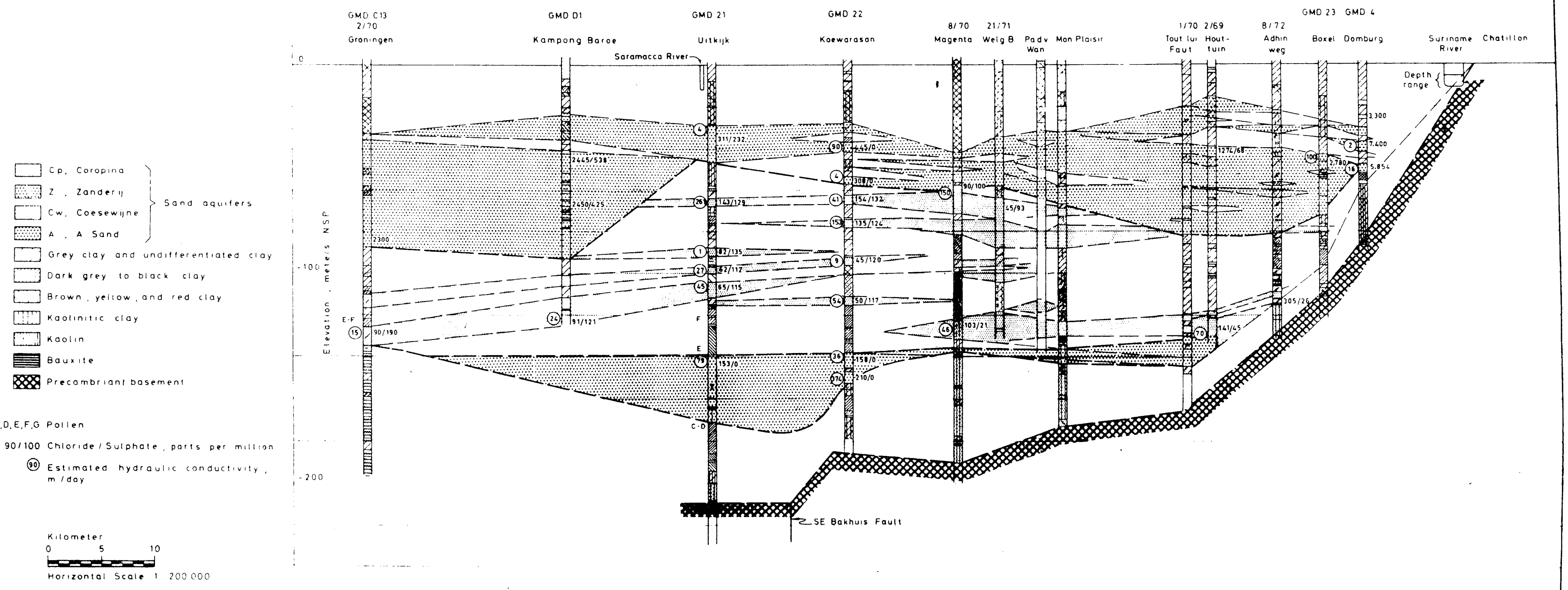
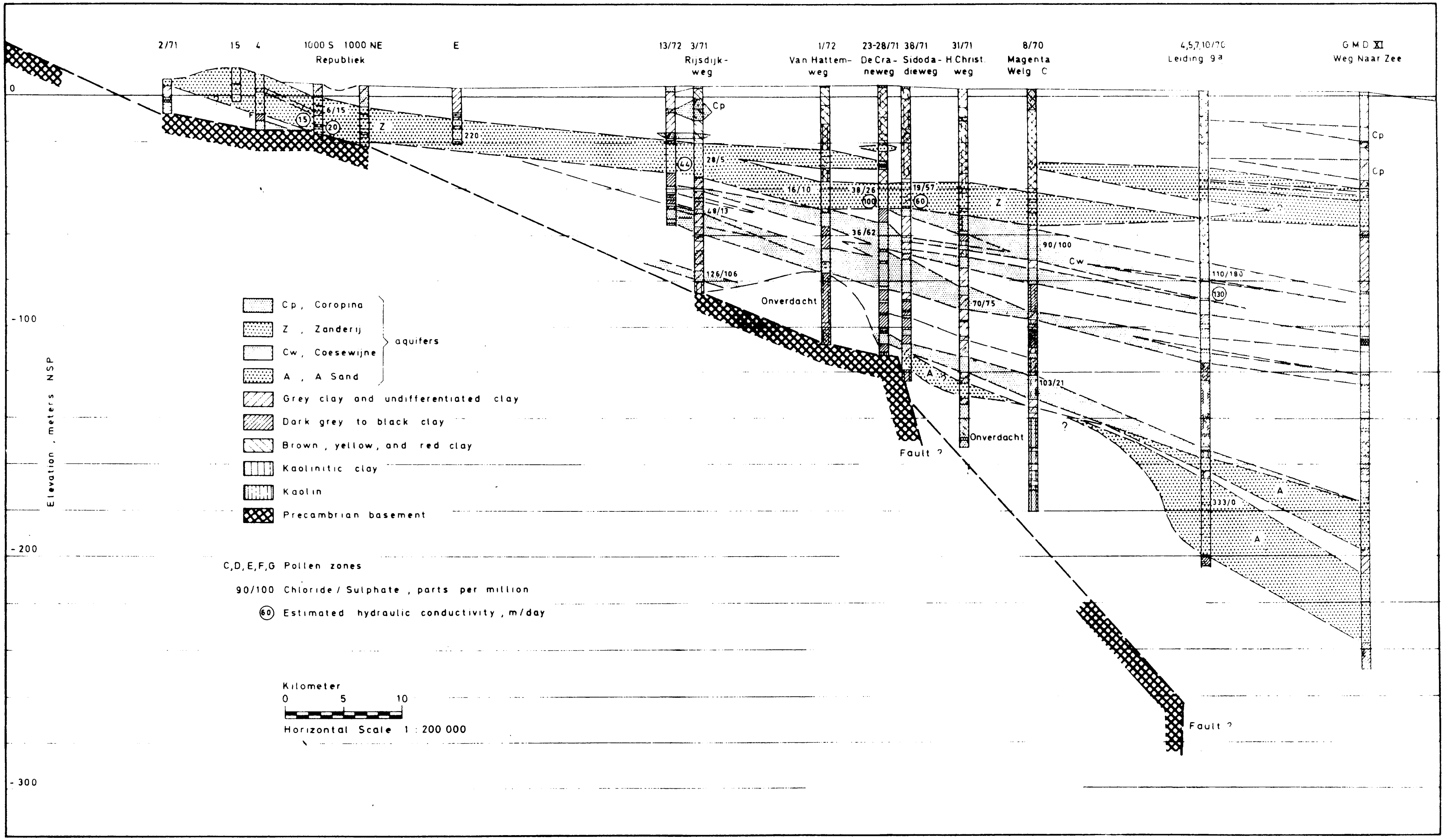
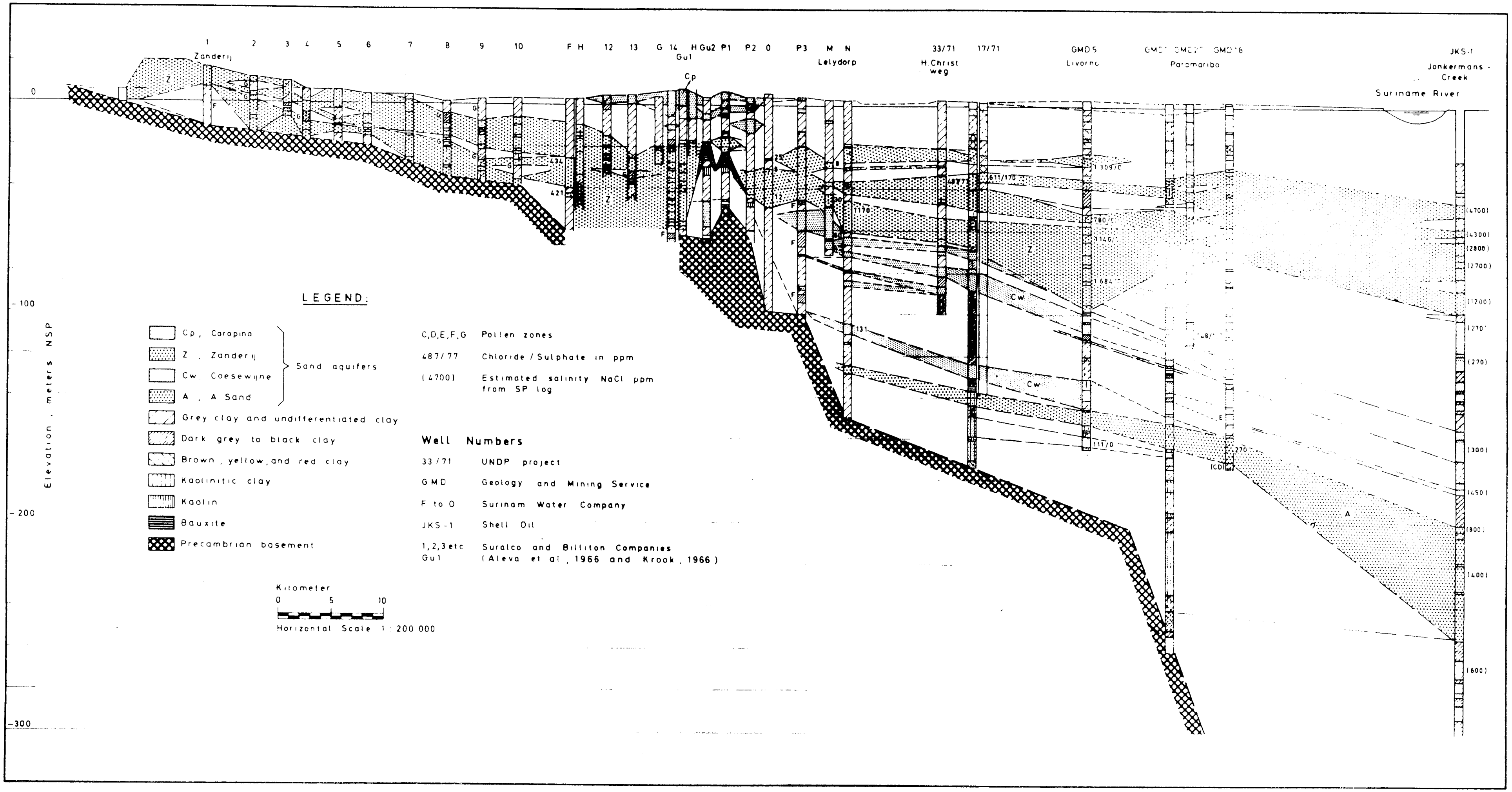


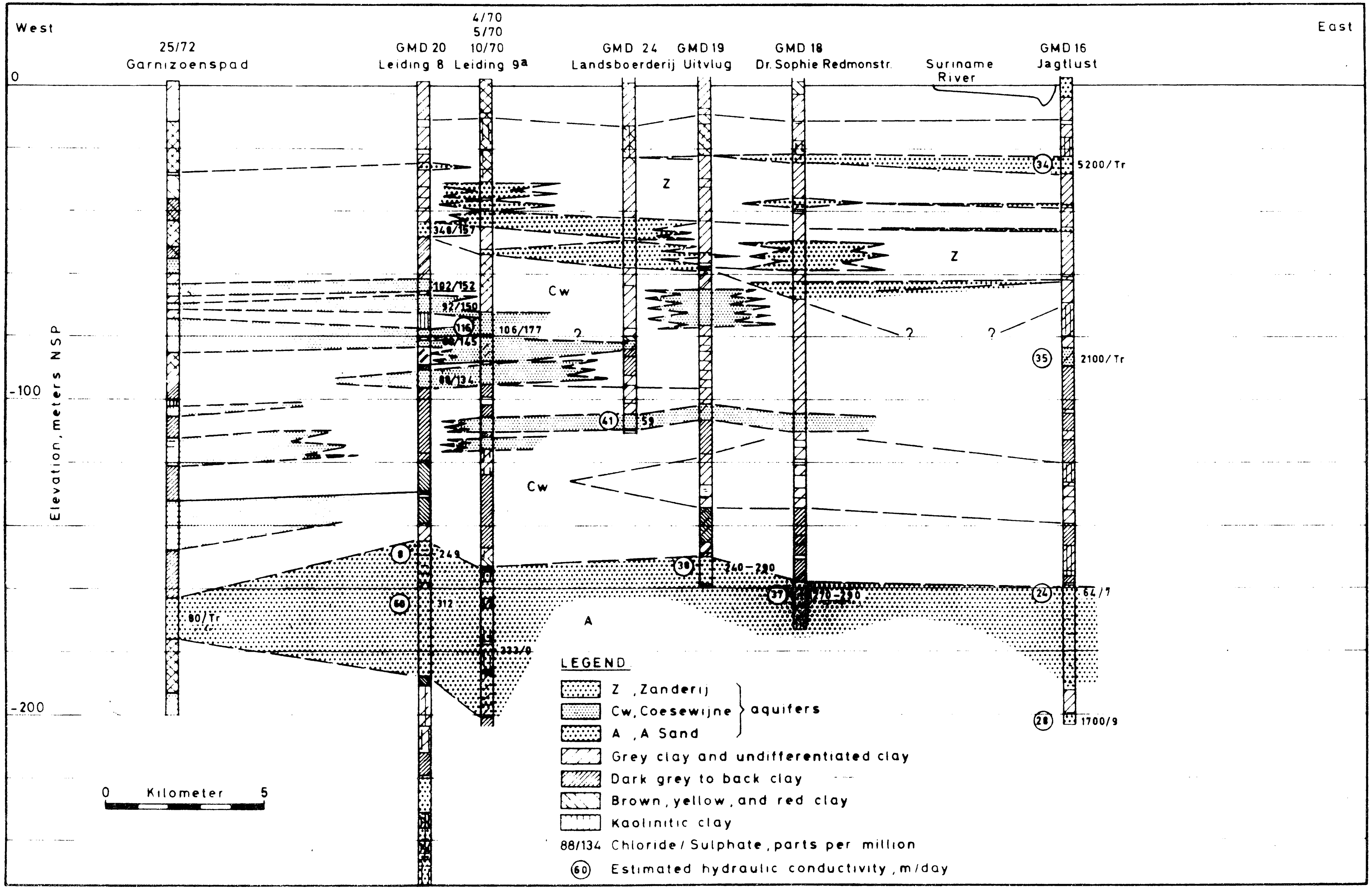
Annex 1-A, Section Groningen to Domburg



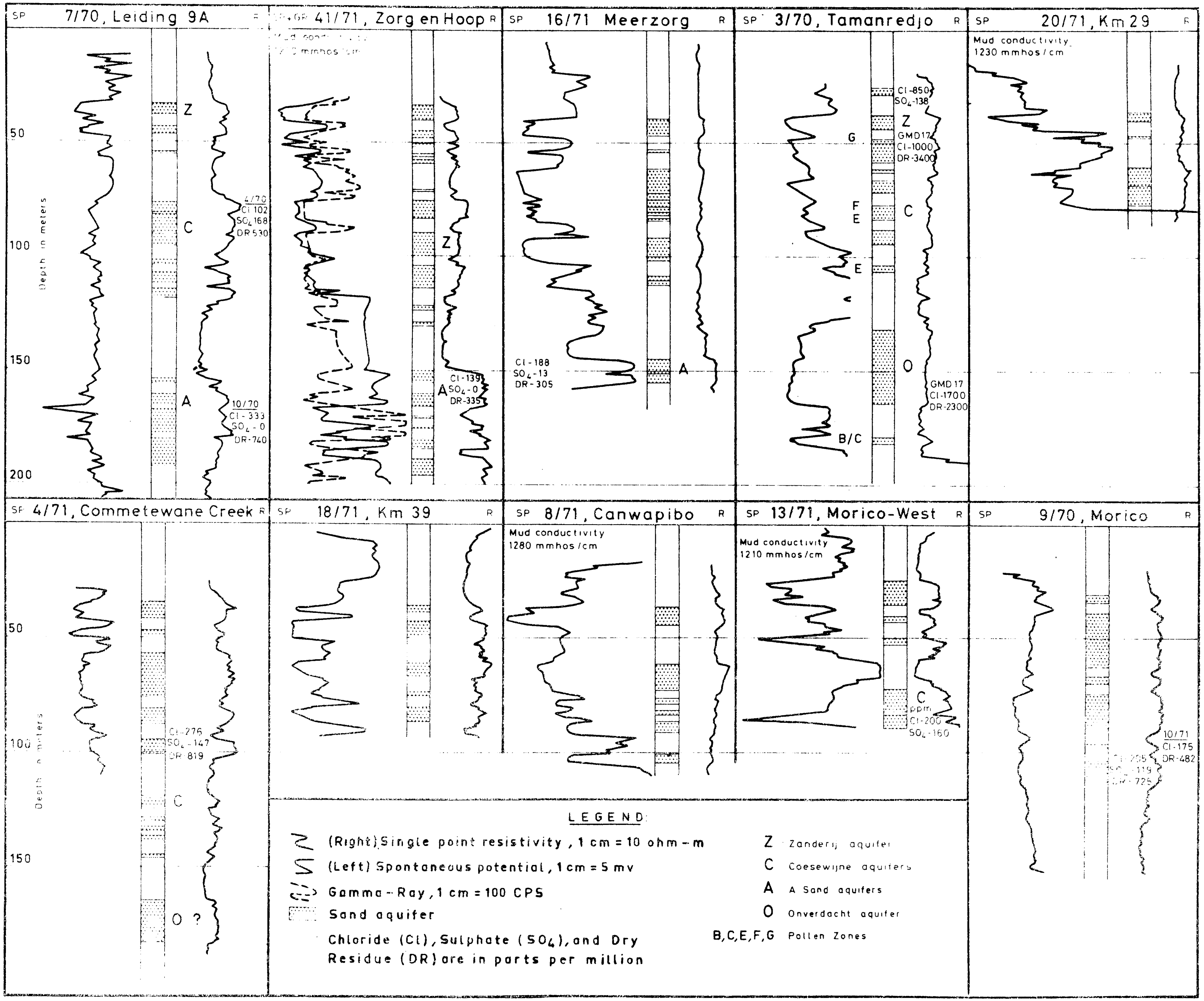
Annex 1-B, Section Republiek to Weg Naar Zee



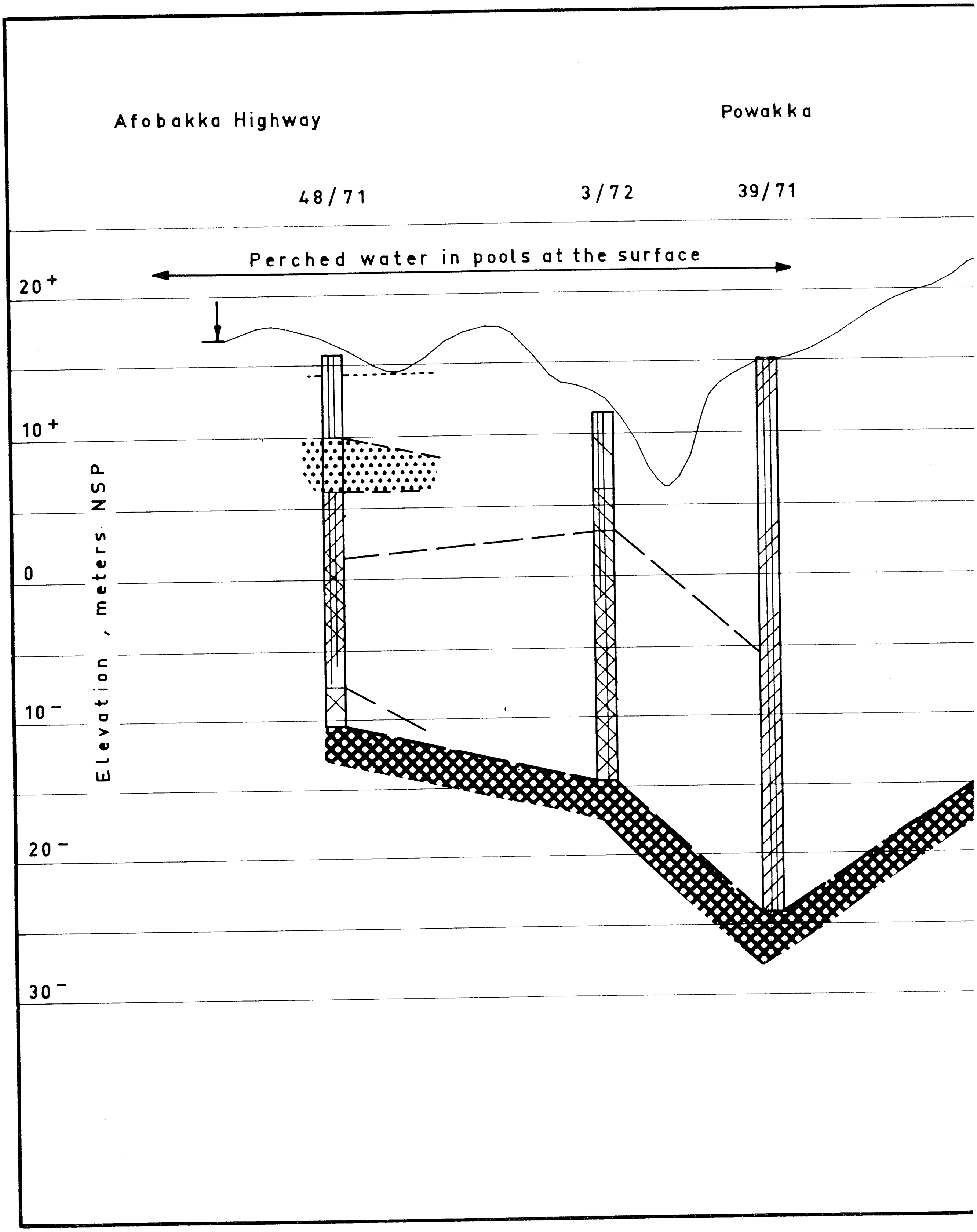
Annex 1-C, Section from Zanderij to Jonkermans Creek

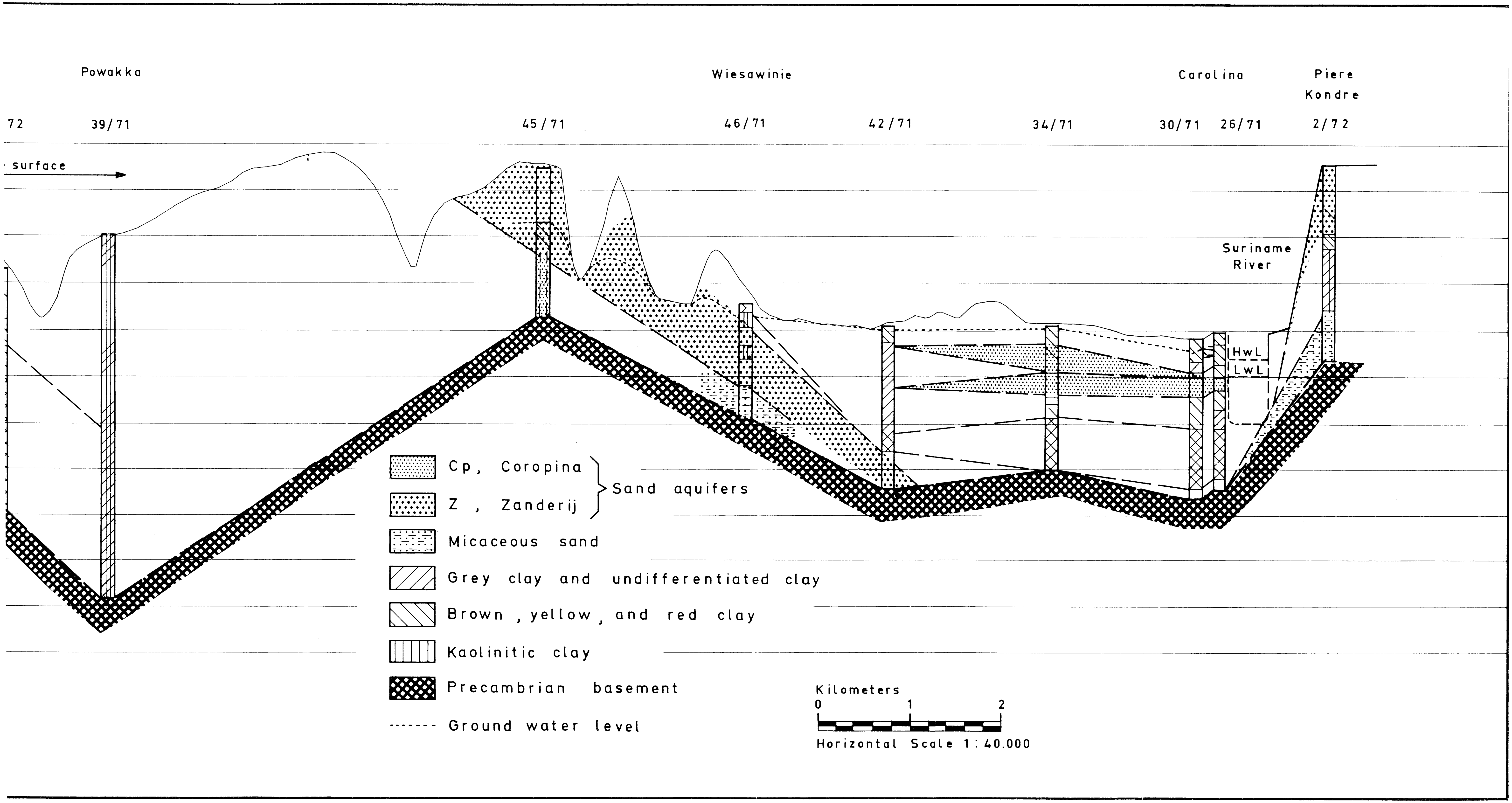


Annex 1-D , Section from Garnizoenspad (TW 25/72) to Jagtlust (GMD 16)

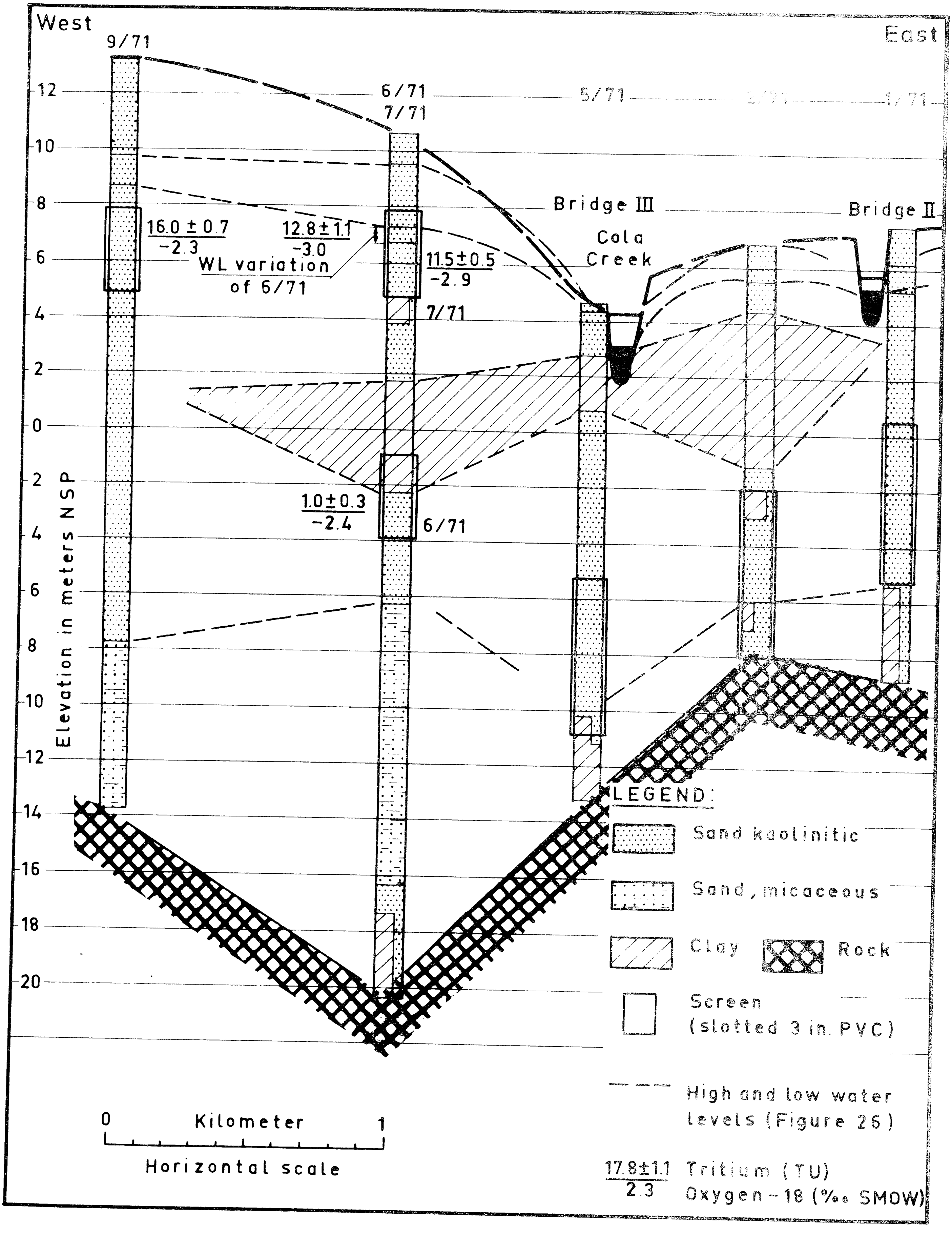


Annex 1-E, Logs of selected wells along an East-West section from Leiding 9A, District of Surinam, to Morico, District of Commewijne.

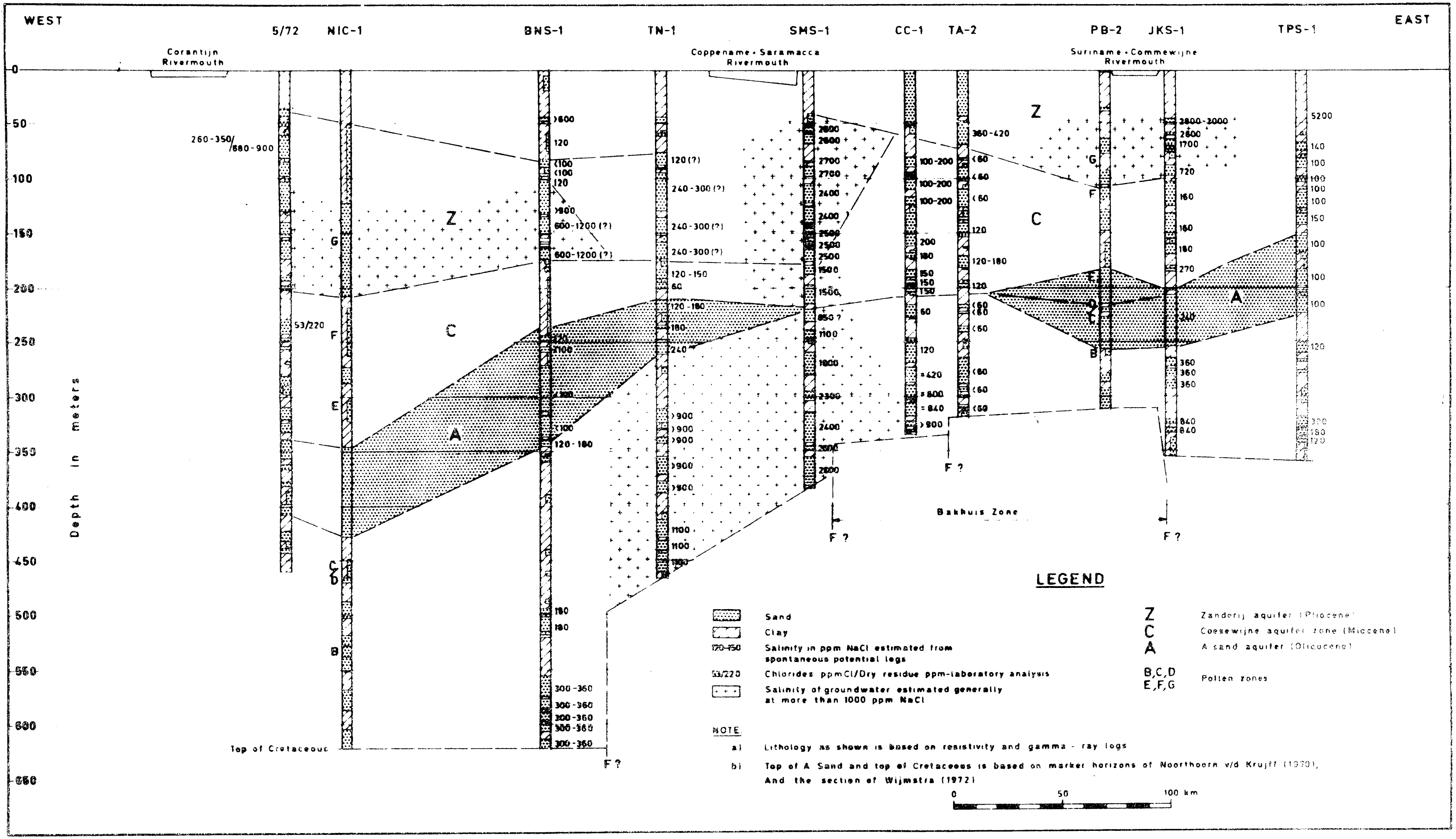

Afobakka Highway
Powakka
48/71
3/72
39/71
Perched water in pools at the surface
20 +
10 +
0
10 −
20 −
30 −
Elevation , meters NSP



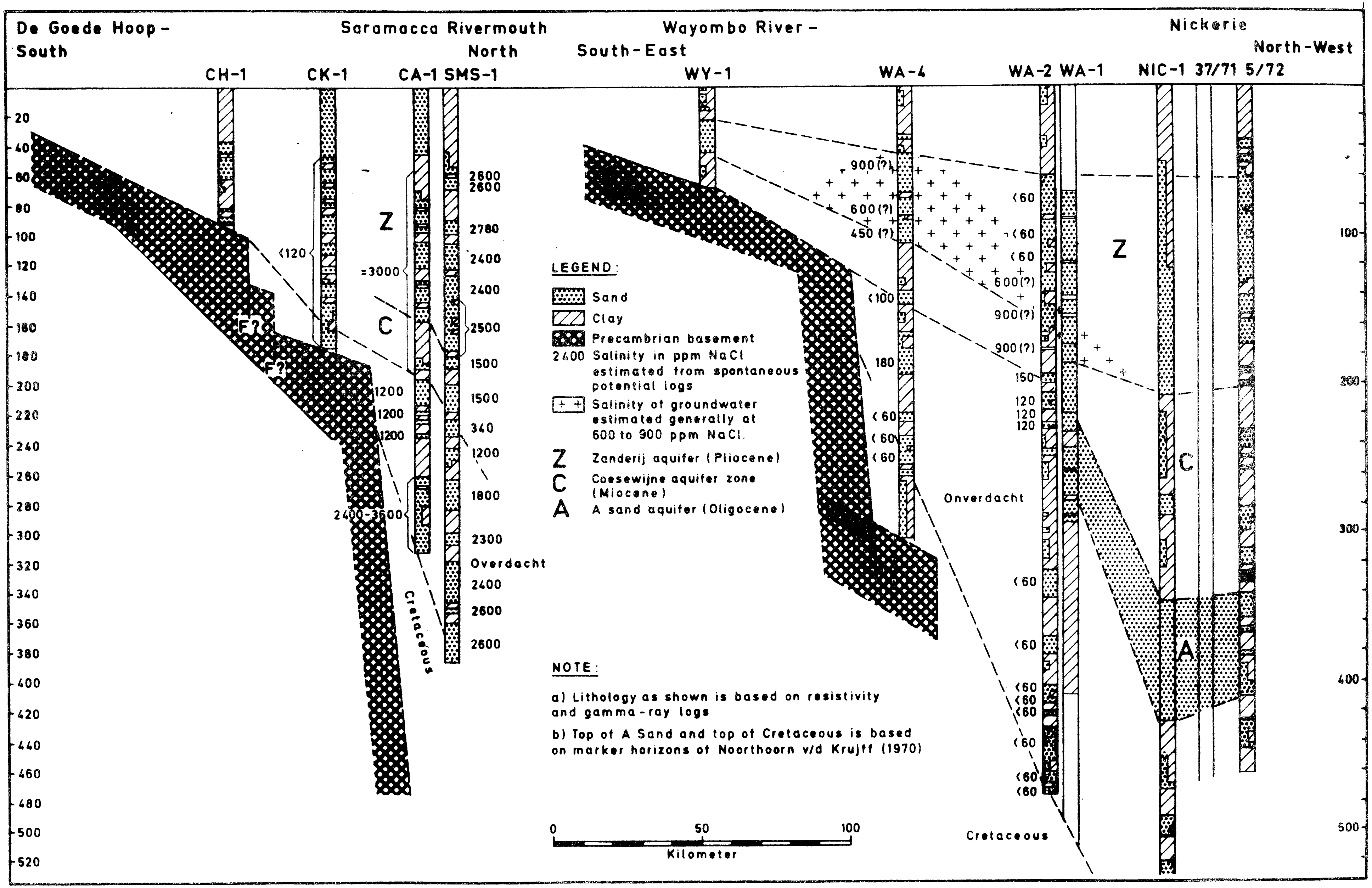
Annex 1-F, Section through Powakka and Carolina in the Suriname River valley



Annex 1-G , Section west of Zanderij along the Zanderij-Saramacca road



Annex 1-H , - Section Nickerie to Alliance showing lithology and groundwater salinity of Tertiary and Quaternary sediments as deduced from well logs



Annex 1-I- , Sections: De Goede Hoop (Coppename River) to Saramacca Rivermouth, and the Wayombo River to Nickerie showing lithology and groundwater salinity as deduced from well logs

ANNEX 2

SUMMARY OF EXPLORATORY DRILLING FOR GROUND WATER, GEOLOGICAL AND MINING SERVICE, 1950-1964

Well No.	Date	Location	Elev. N S P	Depth m	Test Depth m	Aquifer	Static Water Level m CL	T m^2/day	Av. k. m/day	Q/s l/s/m	Quality		
											Cl ppm	TDS ppm	pH
1	Dec. 50	Zorg en Hoop		263	158.0-164	A					136	339	6.5
2	Feb. 51	Zorg en Hoop		84	41.1- 45.6	Z					217		
3	May 51	Zorg en Hoop		167.5	157.6-162.5	A	+0.65 ?	394	82	3.8	180	446	6.5
4		Domburg		90.7	26.2- 27.9	Z	0				3,300	7,987	8.1
					38.4- 43.5	Z	0	11	2	0.1	7,400	16,800	6.3
					49.2- 52.8	Z	0	58	16	0.5	5,854		6.5
5		Livorno	3.143	167.2	25.7- 32.1	Z	-1.2	228	45	2.2	1,309	2,477	6.2
					51.2- 58	Z	-1.6	551	110	5.3	781	2,034	3.0
					61 - 66	Z	-1.6	580	116	5.7	1,140	2,792	3.5
					82 - 86.5	Z	-1.6	171	34	1.6	1,684	4,130	6.5
					161.3-166.3	A or O	-0.2	322	64	3.1	111	460	6.5
6		Nieuw Amsterdam		375	179.5-186	A	+2.37	34	7	0.3	890	2,100	7.7
					262 -269	O	+3.90	155	31	1.5	2,500	4,445	7.0
7	Sep. 52	Meerzorg		188.5	141 -148	A	+0.5	155	31	1.5	177		
					161 -166	O	+0.7	26	5	0.2	323		
					170.5-179.5	O	+0.75	41	8	0.4	520		
					180.5-188.5	O	+0.75	169	34	1.6	500		
8	Jan. 53	Nieuw Amsterdam		171.2	41.5- 47	Z	+0.35	63	13	0.6	1,080		
					84 - 92	Z	+0.45	415	83	4.0	1,374		
					127.4-132	C	+0.50	58	12	0.5	907		
					133.5-138.5	C	+0.50	48	10	0.5	1,400		
9	1953	Nw. Nickerie	2.36		42 - 47	Z	+1.65	398	80	3.8	213		
10	1953	Nw. Nickerie			40.9- 48.5	Z		322	64	3.1	203		
11	1953	Nw. Nickerie			42.8- 50.5	Z					202		
12	June 53	Nw. Nickerie	1.07	47.5	42 - 45.5	Z	+1.5	580	116	5.6	235		
13	Sep. 53	Nw. Nickerie	0.59	112	46 - 49.6	Z	+1.6	514	128	4.9	420		6.0
					66.5- 71.1		+1.5	402	80	3.9	421		6.0
					82.4- 86.1		+1.95	145	29	1.4	450		6.0
					102.0-106.5	Z	+1.9	178	34	1.7	570		6.5
14	Oct. 53	Nw. Nickerie	1.69	49	43.5- 47.7	Z	+0.75	269	54	2.6	155	586	5.0
15		Nw. Nickerie			38.2- 44	Z					232		
16	Apr. 55	Jagtlust		205.6	24.5- 30	Cor.	-1.97	169	34	1.6	5,200		6.5
					85.5- 91	Z	-1.11	174	35	1.6	2,100	6,100	6.5
					161.1-164.8	A	+0.45	97	24	0.9	614	1,300	7.4
					201.8-205.6	O	+0.97	110	28	1.0	1,700	3,200	7.2
17	Jun. 55	Tamanredjo	(+ 1.75 MP)	194.8	30.9- 35.5	Z	-1.20	223	45	2.1	1,000	5,300	6.2
					159.6-164.2	O	-0.20	194	39	1.8	1,700	2,300	6.9
					58.4- 63	Z or C	-1.20	143	29	1.4	1,000	3,400	5.9
18	Aug. 55	Zorg en Hoop	2.458	176	166.2-170.8	A	+0.90	185	37	1.8	270	611	6.3
19	Sep. 55	Uitvlugt	2.811	163	156.4-161.8	A	+0.40	192	38	1.8	240		
20	Sep. 56	Leiding 8	0.865	303.5	45.2- 49.5	Z	+0.40	151	30	1.4	348	1,179	6.7
					61.9- 66.5	C	+0.58	177	35	1.7	102		6.4
					67.7- 72.3	C	+0.65	228	46	2.2	92	637	7.0
					76.8- 81.4	C	+0.67	196	39	1.9	86	518	6.7
					91.4- 96.0	C	+0.55	343	69	3.3	82	511	7.0
					146.8-151.4	A	+1.95	38	8	0.3	249	548	6.0
					162.5-165.8	A	+2.00	302	60	2.9	312	669	6.0

Well No.	Date	Location	Elev N S P	Depth m	Test Depth m	Aquifer	Static Water Level m CL	T m^2/day	Av. k. m/day	Q/s l/s/m	Quality		
											Cl ppm	TDS ppm	pH
21	May 57	Uitkijk	1.138	255.5	30.2- 34.8	Z	+0.52	22	4	0.2	309	1,174	6.1
					65 - 66.1	C	+0.53	261	261	2.5	143	596	6.3
					89 - 92.7	C	+0.5	6	1	0.06	83	413	5.8
					97.7-101.5	C	+0.59	107	27	1.0	63	400	6.2
					105.5-110.1	C	+0.47	290	45	2.8	65	366	5.8
					140.4-145	A	+1.38	397	79	3.8	153	482	6.0
22	Aug. 57	Koewarasan	2.674	189.3	40.2- 44.5	Z	-0.9	463	90	4.4	445	1,842	6.4
					56.5- 60.0	Z	-0.92	19	4	0.2	308	1,265	6.0
					65.5- 70.0	C	-0.92	206	41	2.0	154	749	6.0
					76.2- 80.3	C	-0.94	615	153	5.9	135	675	6.7
					96.0- 99.1	C	-2.00	28	9	0.2	45	435	6.8
					114.0-117.9	C	-1.07	218	54	2.1	50	475	6.0
					138.3-142.9	A	+0.30	179	36	1.7	158	468	5.8
					150.8-155.4	A	+0.30	1,870	374	17.8	215	504	6.3
23		Boxel		122.5	45.2- 52.8	Z	-0.48	688	138	6.6	2,770	5,410	6.3
							-0.78	498	100	4.8	2,780	5,820	6.1
24	Mar. 58	Landsboerderij	2.27	112	106.3-111.4	C	-0.5	207	41	2.0	59	370	6.3
25	May 58	Zorg en Hoop	2.75	163.2	158.7-163.3	A	+0.5	660	132	6.3	182	408	6.3
26	July 58	Zorg en Hoop	1.74	163.2	156.4-161	A	+0.46	421	84	4.0	195	382	6.5
27	Sep. 58	Paramaribo	2.48	117.2	111.1-115.7	C	-0.86	320	64	3.1	148	522	6.2
28	Aug. 59	Alliance	0.838 ?	337.5	42.0- 45.9	Z		150	50	1.4	1,736	5,200	6.6
					62.0- 66.6	Z	+0.93	105	21	1.0	323	1,300	6.8
					78.2- 82.8			142	28	1.4	263	1,110	
					94.4- 99		+1.44	44	9	0.4	212	1,020	
					101.4-106	C	+1.27	155	31	1.5	196	940	
29	Sep. 59	Alliance	1.335 ?	224									
30	Oct. 59	Alliance	0.875 ?	214	104.2-108	C		120	30	1.1	198	939	6.8
31	Apr. 60	Meerzorg	2.298	146.3	141.7-146.3	A		167	33	1.6	190	450	6.0
32	July 60	Zorg en Hoop	2.043	161	156.4-161	A	-0.75	543	109	5.2	150	353	6.2
33		Zorg en Hoop			154.2-160.4	A					157	353	6.2
34		Zorg en Hoop			154.8-158.7	A		537	134	5.1			
36	Oct. 61	Totness	2.27	168	162.4-167	C	-0.40	308	62	2.9	77	311	6.8
37	Feb. 63	Santo Boma	3.30	139.9	131.4-136	C	-1.15	198	40	1.9	69	292	6.0
C3	June 53	Groot Chatillon		42.2	12.3- 18	O					369-1,838		6.8-7.2
					24.8- 27						224-1,066		
					27 - 32						1,050		
					33.5- 36						5,236		
					36.5- 42						5,753		
C4		Groot Chatillon		12	11 - 12	O					159-626		
C5		Groot Chatillon		27.5	7.6- 8.3	O					400-524		
					25.1- 27.5						4,566-5,104		7.0
C6		Groot Chatillon		47.1	10.7- 11.4	O					735	3,656	7.6
					12.6- 13.6						1.020	3,744	7.6
					20.6- 21.8						4,188	3,149	7.3
					22.3- 33.8						1,900		
1 and 2	Sep. 64	Kampong Baroe	4.00	129	44 - 50	Z					2,446	5,012	6.0
					60.5- 72	Z					2,450	5,200	5.9
					123.5-129	C	-1.9	120	24	1.1	91	442	6.1

ANNEX 3 - WELL DATA

(Explanation on page A3-7)

Well No.	Location	Drill	Elev. CL m NSP	Type	Depth		Casing		Screen		Aquifer	SW L m CL
					Drill m BCL	Finish m BCL	Dia in.	Depth m	Dia in.	Length m		
1/69	Stolkslust	F-1250	1.763	TP	110.3	91.4	4	77.2	4	4.6	Cw	-1.48
2/69	Houttuin	F-2500	2.436	P	135.0	131 (80	6 8	126.5 75.0	5 4	4.6 4.6	A Z	-3.97 -3.03)
1/70	Tout-lui-Faut	F-2500	2.42	TP	168.1	148.7	6	144.1	5	4.6	A	-3.14
2/70	Groningen	F-1250	3.211	P	140.6	137.6	6	132.8	4	4.6	Cw	-1.46
3/70	Tamanredjo	F-2500	2.731	TA	191.3	28.8	8	21	4	4.6	(Cp)	-1.80
4/70	Leiding 9A	F-1250	2.374	P	104.0	87.1	8	72.1	6	9.2	Cw	-1.54
5/70	Leiding 9A	F-1500	2.093	T	219.0	75.6	6	74	4P	4.4	Cw	-2.07
6/70	Meerzorg	F-2500	1.207	TA	236	230.5	4	225.6	4	5.7	O	-3.9
7/70	Leiding 9A	F-1500		E	207.8							
8/70	Magenta-Welg. C.	F-1250	3.124	TA	193.5	130.1	6	123.7	4	4.6	(Cw)	-3.24
9/70	Morico	F-2500		TA	153.2	118.8	6	104.5	5	9.2	Cw	-2.35
10/70	Leiding 9A	F-1500		TA	190	175.4	6	168.4	4	9.6	A	-2.01
1/71	Zanderij-Matta	SOL. 1	7.529	T	16.2	13	3P	7	3P	6	Z	-2.0
2/71	Zanderij-Matta	SOL. 1	6.891	T	14.9	14.9	3P	8.9	3P	6	Z	-0.84

Well No.	Location	Drill	Elev. CL m NSP	Type	Depth		Casing		Screen		Aquifer	SW L m CL
					Drill m BCL	Finish m BCL	Dia in.	Depth m	Dia in.	Length m		
3/71	Rijsdijk	F-1250	4.710	O	92.4	40.2	4 (4 (4	30.9 52.2 82.3	4P 4 4	9.3 9.2 4.6	Z Z-Cw Cw	-5.08 -4.96) -5.05)
4/71	Commetewane	F-2500		TA	188.4	100.4	6	95.2	4	4.6	Cw	-2.47
5/71	Zanderij-Matta	SOL. 1	4.742	T	18	16	3P	10	3P	6	Z	-0.42
6/71	Zanderij-Matta	SOL. 1	10.714	T	31.4	18	3P	15	3P	3	Z	-3.9
7/71	Zanderij-Matta	SOL. 1	10.409	O	6	6	3P	3	3P	3	Z	-1.35
8/71	Canwapibo	F-2500		E	112.7							
9/71	Zanderij-Matta	SOL. 1	13.367	T	27.7	9	3P	3.5	3P	5.5	Z	-4.42
10/71	Morico	F-2500	2.528	TP	92	90.7	8	79	6	9.2	Cw	-2.64
11/71	Morico-W.	SOL. 1		TA	73							
12/71	Morico-W.	SOL. 1		TA	93							
13/71	Morico-W.	SOL. 1	3.595	T	95	86	3P	80	3P	6	Cw	-2.3
14/71	Canwapibo	SOL. 1	4.306	E	87							
15/71	Rijsdijkweg	F-1250	7.134	T	91.8	30	3P	24	3P	6	Z	-5.47
16/71	Meerzorg	F-2500	1.370	T	159	157.3	6	144.1	5	9.2A	A	-2.63
17/71	Pad v. Wanica	F-1250	2.687	T	140.9	47.5	3P	41.5	3P	6	Z	-2.98

Well No.	Location	Drill	Elev. CL m NSP	Type	Depth		Casing		Screen		Aquifer	SW L m CL
					Drill m BCL	Finish m BCL	Dia in.	Depth m	Dia in.	Length m		
18/71	Commewijne KM 39	SOL. 1		E	90							
19/71	Commewijne KM 36	SOL. 1		E	86							
20/71	Commewijne KM 29	SOL. 1		E	83							
21/71	Welgedacht B	F-1250	2.506	T	134.7	74.2	3P	68.2	3P	6	Cw	-2.75
22/71	Commewijne KM 24	SOL. 1		T	86	69.3	2P	63.3	2P	6	Cw	-3.62
23/71	de Crane Weg	F-1250	4.911	T	118.6	72	3P	66	3P	6	Cw	-4.1
24/71	Helena Chr. Weg	SOL. 1		TA	54							
25/71	Magenta-Welg. C	F-1500	3.196	T	70	66	3P	60	3P	6	Cw	-3.3
26/71	Carolina	Ack. 1	5.321	T	16.3	6.2	2P	4.2	2P	2	Cp	-3.22
27/71	Corantijn Polder	Ack. 2		E	266.1							
28/71	de Crane Weg	F-1250	4.847	O	130	56	3P	50	3P	6	Z	-4.9
29/71	Helena Chr. Weg	SOL. 1	2.504	T	102	68	3P	62	3P	6	Cw	-2.0
30/71	Carolina Rd	Ack. 1	4.323	T	17.5	6.2	2P	4.2	2P	2	Cp	-2.2
31/71	Helena Chr. Weg	F-1500	2.907	P	156.8	94.8	8	83.6	7	9.2	Cw	-2.9
32/71	de Crane Weg W.	F-1250	4.034	T	129	56	3P	50	3P	6	Z	-4.36
33/71	Helena Chr. Weg	SOL. 1	3.282	T	102	44	3P	38	3P	6	Z	-3.95

Well No.	Location	Drill	Elev. CL m NSP	Type	Depth		Casing		Screen		Aquifer	SW L m CL
					Drill m BCL	Finish m BCL	Dia in.	Depth m	Dia in.	Length m		
34/71	Carolina Rd	Ack. 1	5.879	T	16.1	7.5	2P	4.5	2P	3	Cp	-1.82
35/71	Tawajari Weg	SOL. 1	5.983	T	78	52	3P	46	3P	6	Cw	-6.6
36/71	Zorg en Hoop (C7)	F-1500ss	1.327	P	171	161.3	8	150.3	7	6.1	A	-6.8
37/71	Gr. Henar Polder	F-2500		P	301	234.3	8	226.4	6	9.2	Cw	+1.12
38/71	Sidodadie Weg	F-1250	4.517	T	128.6	57	3P	45	3P	12	Z	-4.63
39/71	Powakka	SOL. 1	15.992	TA	39	16	4	10	4	6	Z	-4.63
40/71	Zorg en Hoop (PO)	F-1500ss	1.984	P	171.5	169.9	8	150.8	7	9.2	A	-8.09
41/71	Zorg en Hoop (C9)	F-1500	1.846	P	201.5	163	8	151.5	5	9.2	A	-8.0
42/71	Carolina Rd	Ack. 1	6.193	T	18.3	18.3	2P	17.3	2P	1	Z	
43/71	Powakka	SOL. 1	9.036	E	30							
44/71	Sidodadie Weg	F-1250	4.593	TP	62	59.5	8	43	7	13.7	Z	-4.19
45/71	Powakka-Carolina	SOL. 1	22.835	T	16.4	10					Z	-5.21
46/71	Carolina Rd	Ack. 1	8.137	T	12.6	8	2P	4	2P	4	Cp	
47/71	Nami Polder	Ack. 2		T	218	64	3P	58	3P	6	Z	-0.63
48/71	Powakka W.	SOL. 1	16.561	E	27	9	3P	6	3P	3	Z	-1.67
1/72	van Hattem Weg	F-1250	5.766	T	114	49	3P	43	3P	6	Z-Cw	-5.5

Well No.	Location	Drill	Elev. CL m NSP	Type	Depth		Casing		Screen		Aquifer	SW L m CL
					Drill m BCL	Finish m BCL	Dia in.	Depth m	Dia in.	Length m		
2/72	Pierre Kondré	Ack. 1	23.596	T	21.6	9	2	3	2P	6	Z	-7.40
3/72	Powakka	SOL. 1	12.361	E	27							
4/72	Sabakoe	SOL. 1	5.416	E	6							-1.71
5/72	Paradise	F-2500		P	455.8	253.6	8	232.7	6	13.7	Cw	+0.93
6/72	La Vigilantia	F-1250	1.612	TA	79.3	28	3P	22	3P	6	Z	-1.68
7/72	Tijgerkreek	F-1500	1.922	P	240	139.8	8	125.7	6	9.2	Cw	-0.47
8/72	Adhin Weg	F-1250		T	130.9	117	3P	111	3P	6	Cw	-4.0
9/72	Republiek E	SOL. 1	5.696	T	15.7	14	3P	10	3P	4	Z	-0.62
10/72	Hanover	SOL. 1	8.726	T	21	15	3P	12	3P	3	Z	-5.30
11/72	Coropina Cr-Hwy.	SOL. 1	5.008	T	36	23	3P	20	3P	3	Z	Flows
12/72	Mon Plaisir Weg	F-1500ss	3.001	T	175.4	131	3P	125	3P	6	Cw-A	-4.6
13/72	Rijsdijk S	SOL. 1	6.507	T	66	38	3P	35	3P	3	Z	-4.04
14/72	Rijsdijk	F-1250	6.048	TPA	52	49.8	12P	32	6	13.7	Z-Cw	-4.2
15/72	Rijsdijk N	SOL-2	4.276	T	45	32	3P	29	3P	3	Z	-2.44
16/72	Rijsdijk S	SOL-1	6.357	T	36	23	3P	21	3P	2	Cp	-3.94
17/72	Makkabolo Weg	F-1500ss	3.211	T	195	165	3P	153	3P	12	A-O	-5.37

Well No.	Location	Drill	Elev. CL m NSP	Type	Depth		Casing		Screen		Aquifer	SW L m CL
					Drill m BCL	Finish m BCL	Dia in.	Depth m	Dia in.	Length m		
18/72	Rijsdijk E	SOL. 1		TA	50.2							
19/72	Rijsdijk E	SOL. 2	8.109	T	41	41	3P	37	3P	3	Z	-5.77
20/72	Rijsdijk E	SOL. 1	8.021	T	35	34	3P	31	3P	3	Z	-5.59
21/72	Rijsdijk E	SOL. 2	7.90	T	21	20	3P	17	3P	3	Cp	-4.97
22/72	Rijsdijk-Hwy	SOL. 1	8.899	T	69.9	27.5	3P	24	3P	3.5	Z	-7.04
23/72	van Drimmelen P.	F-2500		PA	16							
24/72	Cobitie	SOL. 2		TA	23	11	4P	9	3Ev	2	Z	-4.6
25/72	Garnizoenspad	F-1500	2.267	T	200	178	3P	172	3P	6	A	-1.12
26/72	Makkaholo Weg	F-1500ss		P	183	179	8	145.3	6	18.3	A	-5.27
27/72	La Vigilantia	SOL. 1		E	38							
28/72	Cobitie	SOL. 2	19.945	P	12	11	4P	9	3Ev	2	Z	-4.58
29/72	Corantijn Polder	F-2500		P	453							
30/72	La Vigilantia	SOL. 1	2.873	T	50	25.5	3P	15.5	3P	10	Z	-4.30
31/72	Wonoredjo	SOL. 2	3.323	T	27	18.5	4P	13	4P	5.5	(Z)	-1.90
32/72	La Vigilantia	SOL. 1		T	50	28	3P	22	3P	6	Z	-4.30
33/72	La Vigilantia	F-1250		P	25	24.7	12P	14.6	4	9.2	Z	-4.93
34/72	Wonoredjo	SOL. 2		T	27	18	3P	15	3P	3	(Z)	-0.75

ANNEX 3

Explanation

NSP Normaal Surinaams Peil (Normal Surinam Level) is average ocean level at the mouth of the Suriname River in 1957

CL Collar level

Type

P	Production well	14
TP	Temporary production well	4
T	Test well cased	46
E	Exploratory test uncased	12
O	Observation well with automatic recorder	3
A	Abandoned	15

Casing diameters in inches are nominal

P denotes PVC

Screen diameters in inches are nominal

i.e., 6-in nominal is 6 5/8-in OD (6 pipe size)

7-in nominal is 7 1/2-in OD (8-in telescope size)

P denotes saw slotted PVC

Aquifer Cp = Coropina, Z = Zanderij, Cw - Coesewijne, A = A Sand,

O = Onverdacht, ( ) = uncertain.

Well No	Location	Aquifer	Depth	Date	Lab No	Na	K	Ca	Mg	Cl	SO_4	Alkalinity			Cations	Anions	Cat/An	pH	TDS Com	Dry Res	Hardn's as $CaCO_3$		Fe	Mn	Cu	Al	F	NO_3	NO_2	NH_3 -	H_2S	SiO_2	SAR	Spec Cond
												Total as CO_3	p	m							Bic	Tot												
			Meters			Parts per million							Equivalents per mill						Parts per million															mmhos/cm
1/69	Stolkslust	Z	43 - 48							634	192																							
		Cw	62.9 - 65.7							184	198																							
			86.6 - 91.4	11 Jun '71	37	86	111	34	87	150	194	3	0	0.1	12.87	8.37	1.49	8.1	565	734	55	361	1	1.1				neg	pos	pos			1.82	
				3 July'72	103	22.5	8.3			148	172	99	0	3.3		11.04		7.4	560		165	165	18	1.1			0.2	neg	pos	pos				
2/69	Houttuin	Z	14 - 45							1274	68																							
		A	126.4 - 13.1	2 Jun '71	36	101	6	7	19	141	45	48	0.7	0.9	6.45	6.07	1.06	8.3	367	328	45	53	7.3	0.1	neg	?	0.1	neg	neg	pos	pos		14.20	
1/70	Tout Lui Fout	A	144.1 - 148.7							137																								
2/70	Groningen	Z	86.2 - 91							2300																								
			132.8 - 139.6	19 July'71	15					88	108							8.3		461			5.9	0.11				neg	neg	neg				
				20 July'71	41	117	9	4	17	79		51	0.1	1.6	6.92	9.22	0.75	6.4	531	417	82	100	0.9	0.3				pos	pos	neg			17.99	
				20 July'71						90	190	96						6.8																
3/70	Tamanredjo	Co	24.2 - 28.7	3 Aug '70	11					851	138							8.0		3380				neg										
4/70	Leiding 9ᵃ	Cw	72.8 - 87.1	10 Nov '70	18					120	183							6.5		614			4.3	0.5				neg	neg	neg				
				18 Jan '71	21					113	186	81	0.4	2.3				7.0	498	617			7.5	0.2										
				6 Jan '72						130	270	87						6.7		637			7	3	3	0.05	0.2					11.5		
				6 Jan '72	76	44	12	30	48	106	177	81	0	2.7	7.67	9.38	0.82	6.8	129	637	129	311	9.3	0.7			0.2	neg	neg	pos			1.16	
				1 June'72	101	56	7.5	44	60	102	168	93	0	3.1	9.74	9.64	1.01	7.9	625	530	155	155	16.0	1.1			0.1	pos	pos	pos			1.29	
5/70	Leiding 9ᵃ	Cw	70.9 - 75.6	20 Oct '70	17					139	184							8.5		664														
			91.5 - 96.3							140																								
6/70	Meerzorg		225.8 - 2305	9 Oct '70	16c					400	32							7.0		994														
8/70	Magenta-Welged. C	Cw	125.4 - 131.1		20					103	21	48	0.4	1.2				6.5		273			8.3	1.1										
9/70	Morico	Cw	103.6 - 112.9							205	119	129	0.4	3.9		12.60		6.9	725				9.6	0.8										
10/70	Leiding 9ᵉ	A	178 - 188	29 Jan '71	22	222	8.3	15	22	333	neg	60	0.1	1.9				6.7	740		96	135	10.1	neg			<0.1						6.54	
				4 Feb '71	24																										pos			
3/71	Rijsdijkweg	Z	30.9 - 40.2	19 Apr '71	32	13	4	35	12	28	5	51	0.2	1.5	3.39	2.59	1.31	8.0	148	120	74	74	4.1	1.7		?	0.2	neg	neg	pos			0.55	
		Cw	54.2 - 63.5	8 Apr '71	31	40	2.5	6.4	6	48	13	33	0.3	0.8	2.61	2.72	0.97	7.2	148.9	164	41	44	2.5	0.1	neg	?	0.1	neg	neg	2			9.89	
		Cw	82.3 - 86.9	9 Mar '71	29	133	6.2	2.5	11.3	121	104	45	0.4	1.0	7.01	6.97	1.03	6.3	433	470	67	69	5.0	0.16			0.5						25.39	
4/71	Commetewane	Z	95.2 - 100	8 Mar '71	27	221	14	21	36	276	147	105	0.7	2.8	13.89	14.34	0.96	6.7	819	819	142	214	8.0	0.5									6.85	
6/71	Zanderij-Metta	Z	11.6 - 14.6	2 Aug '71	47	4	<4	<3.5	<3	3.4		6	0	0.2	0.69	0.30	2.31	5.5	23.9	46	8	3.6	0.8	neg			2	neg	pos	neg			1.22	
				2 Aug '71						7.5	3	12				11.1		5.4					0.95		0.35		0.2							
7/71	Zanderij-Matta	Z	3 - 6	2 Aug '71	46	3	<4	<3.5	<3	33	0	9	0	0.3	0.65	1.23	0.53	3.7	56	86	12	32	1	pos			neg	neg	neg	neg			0.93	
				2 Aug '71						5	0	0						4.8					1.3											
10/71	Morico II	Z	80.2 - 88.4	21 May '71	96	137	4	12	33	175	53	69	0.10	2.20	4.37	8.34	1.11	8.3	483	462	109	109	15.0	0.2			neg	neg	pos	pos			3.31	
13/71	Morico West	Z	80 - 86	28 Jul '71						200	160	33											6.5											
15/71	Rijsdijkweg	Z	24 - 30	9 Jul '71						28	8	24																						
16/71	Meerzorg II	A	160 - 165	7 Jul '71	40	119	7	6	14	192	14	30	0	1.0	6.81	6.69	1.02	6.0	382	399	50	88	14.3	0.4				neg	pos	neg			19.92	
				24 Jul '71				40		195	0	60				7.50		6.6					2.9											
				21 Jul '71				46		185	0	69				8.66		6.6					3.25											
				18 Jul '71	49	104	8	9	13	188	13	30	0	1.0	6.24	6.67	0.95	6.0	365	401	50	82	0.8	0.07			0.2	pos	pos	neg			16.40	
17/71	Pad van Wanica	Z	35.5 - 47.5	4 Aug '71						850	175	51				29.09		6.5					2.8											
				4 Aug '71	48	181	11.5	59	103	611	117	15	0	0.5	19.57	20.17	0.9	6.0	1097.5	1625	23	484	5	2.2			3	pos	pos	neg			3.28	
21/71	Welgedacht B	Cw	68.2 - 74.2	26 Jul '71	44	47	4	16	22	45	93	33	0.2	0.9	4.75	4.31	1.10	6.3	260	351	45	132	2.8	0.4				neg	pos	pos			1.27	
				22 Feb '72						45	195	45						6.5					4.25	0.9	1.1	0.15	0.3					8.5		
				22 Feb '72	85	43	4.1	22	23	27	116	45	0	1.5	4.96	4.68	1.06	6.4	280	375	72	139	2.2	0.02			0.1	pos	pos	pos			1.53	

Annex III - 4, Chemical analyses

Well No	Location	Aquifer	Depth	Date	Lab No	Na	K	Ca	Mg	Cl	SO_4	Alkalinity			Cations	Anions	Cat/An	pH	TDS Com	Dry Res	Hardn's as $CaCo_3$		Fe	Mn	Cu	Al	F	NO_3	NO_2	NH_3	H_2S	SiO_2	SAR	Spec Cond
												Total as CO_3	p	m							Bic	Tot												
			Meters			Parts per million							Equivalents per mill.						Parts per million															mmhos/cm
22/71	Commewijne Km 24	Cw	64. - 70	26 Jul '71						760	40	12				22.66		5.8					3											
				27 Jul '71	45	823	16	114	148	1830	0	21	0.6	0.1	54.07	52.31	1.04	5.4	2952	6330	228	1064	30.0	3.2				neg	pos	pos			12.01	
23/71	De Craneweg	Cw	64 - 72	2 Sept'71						37.5	65	48				4.01		6.6																
				2 Sept'71	55	44	2	12	11	36	62	30	0	1.0	3.46	3.31	1.05	5.7	207	283	50	75	6.7	0.1			neg	pos	neg	neg			2.20	
25/71	Magenta-Welged. C	Cw	60 - 66	27 Aug '71						105	148	57				7.90		6.3					1.75	1.7		0.07								
				27 Aug '71	51	35	1.6	7	7	40	15	27	0	0.9	2.49	2.34	1.07	6.9	132.6	180	44	45	3	trace			0.1	neg	pos	pos			2.24	
				15 Feb '71	82	46	5	23	31	90	100	39	0	0.3	6.83	5.92	1.17	6.3	334	406	65	80	4	0.4			0.1	pos	neg	neg			1.47	
				15 Feb '71						112.5	140	45				7.58		6.3					5.5	2.0	0.6	0	0.4					25		
26/71	Carolina	Cp	4.3- 6.3	31 Aug '71						45	28	15						5.2					5.6			0.17						3		
				31 Aug '71	54	24	2	4	4	40	31	2.4	0	0.08	1.62	1.86	0.87	4.7	107.4	128	4	29	9	0.3			neg	neg	neg	pos			2.04	
28/71	De Craneweg	Z	45 - 51	26 Aug '71						42.5	45	42				3.54		6.3					1.2			0.2								
				26 Aug '71	50	35	4	10	12	38	26	27	0	0.9	3.11	2.51	1.23	5.7	152	215	46	83	2.2	0.2			neg	neg	pos	pos			1.75	
29/71	Helena Christinaweg		62 - 68	14 Sept'71						60	120	36				5.39		6.3					1.2									25		
				15 Sept'71	56	39	6	27	14	54	70	24	0	0.8	4.71	3.78	1.24	7.3	234	335	40	141	0.4	0.4			0.4	neg	pos	neg			1.53	
30/71	Carolina		4.2- 6.2	27 Sept'71						23	25	12						5.5					5											
				27 Sept'71	57	130	11	165	79	22	26	9	0	0.3	20.67	1.46	14.2	6	448	197	17	179	5.5	0.2			0.2	pos	neg	neg			2.09	
31/71	Helena Christinaweg		85 - 95.2	29 Jan '72						67.5	250	36				8.30		5.4					4	2.2	0	0	0	36	neg			23		
				31 Jan '72	81	56	7.5	3.5	25	70	75	30	0	10	4.86	4.53	1.07	7.3	267	425	52	121	1.8	0.4			0.1	neg	neg	pos			2.44	
32/71	De Craneweg	Z		7 Oct '71						30		54						6.1					0.1	0	0	0						40		390
				8 Oct '71	61	34	<4	11	<3	27	67	48	0	1.6	2.38	3.75	0.64	6.9	194	247	79	100	3.3	0.3			0.3	pos	pos	neg			2.35	
33/71	Helena Christinaweg	Z	38 - 44	29 Sept'71						500	60	42				16.75		6.3					6			0								
				30 Sept'71						510		48						6.2					6		6.5	0	0					16		
				30 Sept'71	58	129	9	45	89	487	77	9	0	0.3	15.41	15.63	0.99	6.1	845	1170	14	530	2.7	0.3			0.2	neg	neg	pos			2.57	
34/71	Carolina	Cp	4.5- 7.5	21 Oct '71						5	2	6				0.38		5.6					0.1	0	0	0	0.1					6.5		
				22 Oct '71	66	<3	<4	<3	<3	4	10	3	0	0.1	0.63	0.42	1.5	5.4	30	46	7	7	0.2				0	neg	neg	neg			0.93	
35/71	Tawajariweg	Z		14 Oct '71						90		42						6.3					3	1.4	0	0.1	0					8.1		
				18 Oct '71						80	5	42				3.76		6.4			74	129	3.2	1.2	2	0	0.15					37		
				18 Oct '71	65	35	4	15	18	73	50	33	0	1.1	3.85	4.20	0.92	6.4	228	311			0.8	0.4			0.1	neg	neg	trace			0.69	
36/71	Zorg en Hoop	A	154.9-161.3	15 Oct '71						220		98						6.5					2.5	1.3		0	0					13		
	(Corantijnstraat				64	111	7	8	13	190	trace	42	0	1.4	6.48	6.76	0.96	6.8	371	433	15	80	5.3	0.2			0.1	neg	neg	pos			5.62	
37/71	Groot Henarpolder	Cw	229.36-234.12	10 Dec '71						100	3	60						6.9		300			1.6		0.2									
				10 Dec '71	7[illegible]	87	<4	<3	<3	79	neg	60	0	2.0	4.28	4.23	1.05	6.7	236	290	17	17	2.0	0.1			0.2	neg	trace	neg			27.0	
				21 Jan '72	80	58	5	3.5	3	68	neg	51	0	1.7	3.07	3.62	0.85	6.5	188.5	292	86	86	0.7	trace			0.1	pos	neg	neg			18.0	
38/71	Sidodadieweg	Z	45 - 57	9 Nov '69	69	33	4.1	9.3	11.5	19	57	39	0	1.3	2.27	2.18	1.04	7.0	172.9	249	73	84	0.3				0.3	pos	neg	pos			5.39	
39/71	Powakka	Z		5 Nov '71						232	10	51				8.45		6.4					0.85	1.2	0.5	0.1								
40/71	Zorg en Hoop(Postoff.)	A	148.9-169.8	5 Nov '71	67	103	6.6	8.6	12	167	0	45	0	1.5	4.47	6.21	0.72	6.9	342.2	422	74	74	2.3	0.1			0.4	pos	pos	pos			17.10	
41/71	Zorg en Hoop (SWC C9)	A	150.2-162.9	11 Nov '71						180	0	45				6.58		5.6			74	74	4.5	0	1.1	0.07					0			
					68	89	5.8	7	10.8	139	trace	42	0	1.4	3.33	5.31	0.63	6.8	293.6	335			4	0.1			neg	pos	pos	trace			15.80	
42/71	Carolina	Z	- 18.3	23 Nov '70	70	4.5	<4	<3	<3	9	trace	12	0	0.4	0.70	0.65	1.08	6.4	35.5	112	11	11	3.0	trace			0.1	neg	neg	neg			1.43	
										5	4	18				0.81							0.1	0	0	0						2		
44/71	Sidodadieweg	Z	43 - 47.6	30 Dec '71						30	70	42				6.53		6.7							0	0	0.1					28		
					75	30	5	3.5	15	17	57	42	0	1.40	4.42	3.07	1.35	6.5	169.5	222	64	84	3.0	0.2			0.2	neg	neg	trace			4.96	
47/71	Nannipolder	Z		22 Feb '71						417	50	18				13.40		5.1					2	2.3	0.6	0.05	0					19		1275
					86	121	6.6	19	47	343	37	3	0	0.1	11.77	10.47	1.12	5.1	576.6	881	52	266	12.5	0.1			neg	pos	pos	pos			3.42	

Annex III - 4, Chemical analyses (continued)

Well No	Location	Aquifer	Depth	Date	Lab No	Na	K	Ca	Mg	Cl	SO$_4$	Alkalinity			Cations	Anions	Cat/An	pH	TDS Com	Dry Res	Hardn's as CaCo$_3$		Fe	Mn	Cu	Al	F	NO$_3$	NO$_2$	NH$_3$	H$_2$S	SiO$_2$	SAR	Spec Cond
												Total as CO$_3$	p	m							Bic	Tot												
			Meters			Parts per million							Equivalents per mill						Parts per million															mmhos/cm
48/71	Powakka West	Z		29 Dec '71						10	4	1						5.1					0.1	0	0	0.1	0.1					1.8		
					74	66	<4.1	<3.5	<3	6	neg	3	0	0.1	0.72	0.27	2.66	5.1	26.2	33	5	5	0.04	neg			neg	pos	neg	neg			0.46	
1/72	van Hattenweg	Z	43 - 49.	11 Sept '72	112	28	4	6	8	16	10	51	0	1.70	2.28	2.36	0.97	7.4	123	192	86	86	4.0	0.2			0.1	neg	pos	pos			1.77	
2/72	Pieré Kondre		6.3- 9.1	18 Feb '72	84	3.7	4.1	4.3	3	trace	trace	6	0	0.20	0.72	0.20	3.60	4.3	21	79	10	60	0.6	0.3			neg	pos	pos	neg			0.33	
5/72	Paradise		229.2 -253.5	10 May '72						30	5	75	0	2.50		3.45		7.5					0	0								10		
				11 May '72	94	84	4	3	3	53	trace	66	0	2.20	4.15	3.69	1.12	7.1	213	220	112	112	2.2	0.06			neg	pos	neg	neg			8.11	
				29 May '72	98	47.5	4.1	3.5	3	14	0	72	0	2.40	2.59	2.79	0.93	7.8	144	219	117	117	1.6	neg			neg	pos	pos	neg			4.58	
6/72	La Vigilantia			1 Mar '72						700	20	129	0	4.30	24.26			6.6					0.5	0	0	0	0					12.8		2100
				1 Mar '72	87	367	9	10	31	560	19	66	0	2.20	19.24	18.39	1.05	6.5	1062	1564	109	109	2.0	0.07			0.2	pos	pos	pos			12.98	
7/72	Saramacca Peperhol		125 -139	15 Jul '72	156	266	6.3	14.2	24.7	102	280	144	0	4.80	14.46	13.50	1.07	7.0	837	698	241	241	1.1	0.2			0.1	pos	pos	trace			9.97	
8/72	Adhinweg		111 -117	11 Apr '72	81	144	5.8	5	18	305	26	24	0	0.80	7.14	9.94	0.71	6.7	528	679	41	109	4.0	0.22			0.1	neg	pos	pos			4.53	
11/72	Mainroad/Coropina Cr		20 23	25 Apr '72	93	37	4.1	3.6	3	neg	neg	6	0	0.2	0.69	0.20	3.45	6.0	20	63	10	10	0.4	0			neg	trace	trace	trace			0.28	
12/72	Mon Plaisirweg		125 -131	10 May '72						82	170	78	0	2.60	11.27			6.1					0.5	0								16		630
					95	126	4	6	10	49	170	36	0	1.20	6.70	6.12	1.09	6.9	401	341	62	62	2.2	0.44			neg	pos	pos	neg			9.61	
14/72	Rijsdijkweg		32 - 49	2 Aug '72	108	15	4	4	4.8	16	trace	46	0.05	1.50	1.34	2.00	0.75	8.1	90	129	73	73	0.7	0.08			0.2	neg	neg	pos			1.20	
22/72	Rijsdijkweg			1 Aug '72	107	18	4	12	9	13	neg	51	0.10	1.60	2.22	2.07	1.06	8.5	107	172	81	81	2.2	0			neg	pos	pos	pos			0.88	
24/72	Coebitie			22 Aug '72	110	8	4	3.5	1	trace	neg	neg	3	0	0.1	0.58	0.10	6.0	20	20	50	54	0.1	0			neg	pos	trace	pos			1.40	
25/72	Garnizoenspad			20 Sept '72	115	51	4	6	9	80	trace	51	0	1.70	3.36	3.96	0.95	8.1	191	242	86	86	0.70	0.1			neg	pos	neg	pos			3.08	

Annex III - 4, Chemical analyses (continued)

Well No	Location	Aquifer	Depth	Date	Lab No	Na	K	Ca	Mg	Cl	SO_4	Alkalinity			Cations	Anions	Cat/An	pH	TDS Com	Dry Res	Hardn's as $CaCo_3$		Fe	Mn	Cu	Al	F	NO_3	NO_2	NH_3	H_2S	SiO_2	SAR	Spec Cond
												Total as CO_3	p	m							Bic	Tot												
			Meters			Parts per million							Equivalents per mill						Parts per million															mmhos/cm
	Coronie	C		20 Sept'72	113	59	4	16	19	85	70	39	0	1.30	4.98	5.36	0.93	7.8	291	342	65	100	1.2	0.2			ne	trace	neg	pos		2.28		
GMD 28	Alliance			11 May '71	33	237	17	27	43	197	179	210	0.4	6.6	15.63	16.29	0.96	7.7	910	928			0.4	0.15	neg	?	0.1	pos	pos	pos			6.57	
	Billiton	O		8 Oct '71	62	12	<4	<3	<3	19	trace	6	0	0.2	1.04	0.74	1.41	6	47	75			0.1	0			0.1	pos	neg	neg			3.62	
										25		9						5.4					0 2	0.7	0.1	0								
	Brownsweg			5 Aug '71	60	6	<5	61	<5	4	125	3	0	0.10	3.84	2.81	1.37	7.2	209	151							3	pos	pos				1.98	
				14 Sept '71						5	0	24						7.5					0			0	pos					14		
C 6	Calcutta		193 -202	15 Jan '72						140	5	286						9					0.3	0	0		0				0			
					76	34	7.5	9.3	13	103	3	156	0.2	5.0	3.20	8.72	0.37	8.7	325.8	687			1.1	trace				neg	neg	pos			5.48	
	Sur. River (at Carolina)	Cp		5 Aug '71						2.5	27	12						5.6					0.15	0							0			
				17 Aug '71						7.5	0.25	15						6.9																
GMD D1	Kampong Baroe	C		22 Mar '71	30	104	9.9	7.1	15	96	118	33	0.1	1.0	6.36	6.27	1.01	6.5	383	389			3.0	0.2		?	0.2	pos	pos	pos			16.02	
				28 Aug '70	13 c					96	106							6.8		380				neg										
GMD 22	Koewarasan	C		20 Jul '71						188	200	54						6.3					2.9											
					42	68	7.6	17	43	163	125	30	0.2	0.8	7.54	8.20	0.92	5.9	453.6	586	39	282	1.1	1.0				pos	pos	pos			2.01	
				28 Aug '70	12 c					165	115							6.9		556				neg										
SWM	Lelydorp	Z	30 - 31	6 Apr '29				13.5		7.8								6.5													30			
			48 - 49	22 Apr '29				11		29	12							6.5													25			
		C	63 - 64.4	25 Apr '29				16	15	60	41							6					16								17			
GMD 7	Meerzorg	A		23 Jul '71						177.5	2	48						6.7																
					43	119	7.6	10	14	184	14	39	0.2	1.1	8.77	6.78	1.29	6.7	387.6	366	53	79	0.8	0.3				neg	neg	pos			18.1	
	Melk Centrale	Cw		5 Mar '71	25	108	11	21	32	179	147	21	0.6	0.1	8.66	8.81	0.98		519	574	64	206	10	0.5	0	?	0.4	neg	neg	pos			3.47	
500SW	Republiek	Z	9.3 - 17.3	28 Feb '30				0.8	0.3	14.5								5.5		62			0.4											
1000 S			5.6 - 11.6	10 Mar '30				0.2	0.2	6.0								5.0		28			0.05											
1500W			12.7 - 18.7	3 Feb '30				0.3	0.2	5.1								5.0		23			0.1											
1000 N			9.5 - 13.6					0.5	0.4	8.0								5.5		54			1.0											
Centre			6.2 - 14.9					0.2	0.2	4.4								5.0		30			0.03											
				13 Mar '29				0.3	0.2	4.2								5.0		29														
				18 Jun '70	7					9.0	15							6.4					1.3	neg				neg	neg	neg				
				13 Oct '71						12.5		6						5.5					3	0.5	0.2	0.4					16			
				13 Oct '71	63	6	<4	<3	<3	6	15	3	0	0.1	0.76	0.58	1.31	5.6	40	66	6	9	0.2	neg			0	neg	neg	neg			1.86	
GMD37	Santo Boma	Cw		29 Aug '70	14 c					70	70							6.9		310				neg										
	Spieringshoek			26 Jun '70	9					355	128							8.8		1126			0.6	0.18										
	Suralco (at Paranam)	Z		7 Oct '71						15								3.8					0.35	0.75	0	0					0			
					69	7	<4	<3	<3	13	5	15	0	0.5	0.80	0.97	0.83	5.5	50	37	11	11	0.2	neg			neg	pos	neg	neg			2.14	
										30													0.3	0.5	<0.1	0					14			
					60	15	<4	<3	<3	22	8	6	0	0.2	1.15	0.99	1.16	6.0	61	46	8	8	0.1	trace			0.1	neg	neg	neg			4.64	
0-5	Zorg en Hoop	Cw		15 Febr'72	83	81	7	10	21	82	88	45	0	1.5	5.93	5.64	1.05	6.2	253	402	75	107	2.0	0.4			neg	pos	neg	pos			3.36	
SWM II	Nickerie			20 Jan '72	78	69	7.5	18	39	264	17	9	0	0.3	9.03	8.09	1.09	7.0	423.5	685	15	221	1.3				neg	pos	neg	pos			2.10	
	Wageningen	Cp		12 Aug '70						279	53							6.6		650			0.7	neg										

Annex III - 4 , Chemical analyses (continued)

ANNEX 5

RIJSDIJK AQUIFER TEST

SETTING

Rijsdijkweg is located in the Bauxite Belt west of the Onverdacht bauxite mines and east of the Saramacca River about 20 km SSW of Paramaribo.

The Zanderij aquifer extends throughout the area, topping at a depth of about 25 m. It is composed of coarse-grained kaolinitic sand from 10 to 30 m thick. The floor is irregular, coinciding with the post-Middle Miocene erosion surface, which features a N-S oriented buried spur of low relief in the center of the test area (Enclosure 4 and Figure A). The spur contains Coesewijne sand aquifers interbedded with clay, which are apparently hydraulically connected with the Zanderij aquifer, forming one aquifer system. A Lower Coesewijne clay layer forms the base of the aquifer system.

The aquifer is confined beneath Coropina sediments, shown as the Lelydorp (sandy) member on the "Fotogeologische Kaart van Suriname." In sections it appears as clay, silt and sandy clay, and sand lenses.

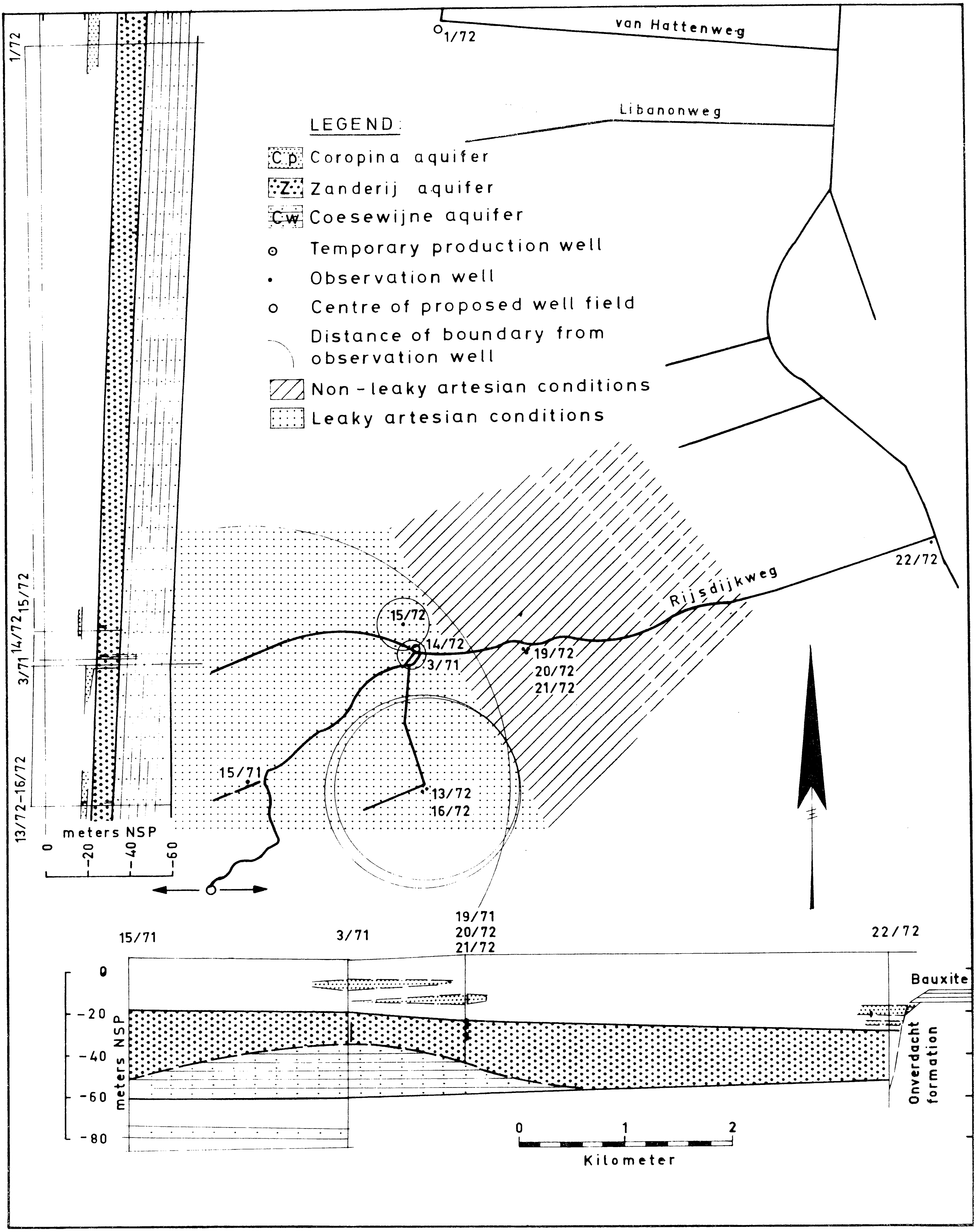
PUMPED WELL 14/72

Well 14/72 was constructed with nominal 12-inch diameter PVC casing cemented at a depth of 31.27 m BCL, and with a string of nominal 6-inch diameter screen and casing to a depth of 52.09 m BCL, adjacent to Zanderij and Upper Coesewijne aquifers. The 40-slot screens were at depths of 32.21 to 36.78 m, 39.90 to 43.92 m, and 45.20 to 49.77 m BCL, for a total exposed length of 13.16 m.

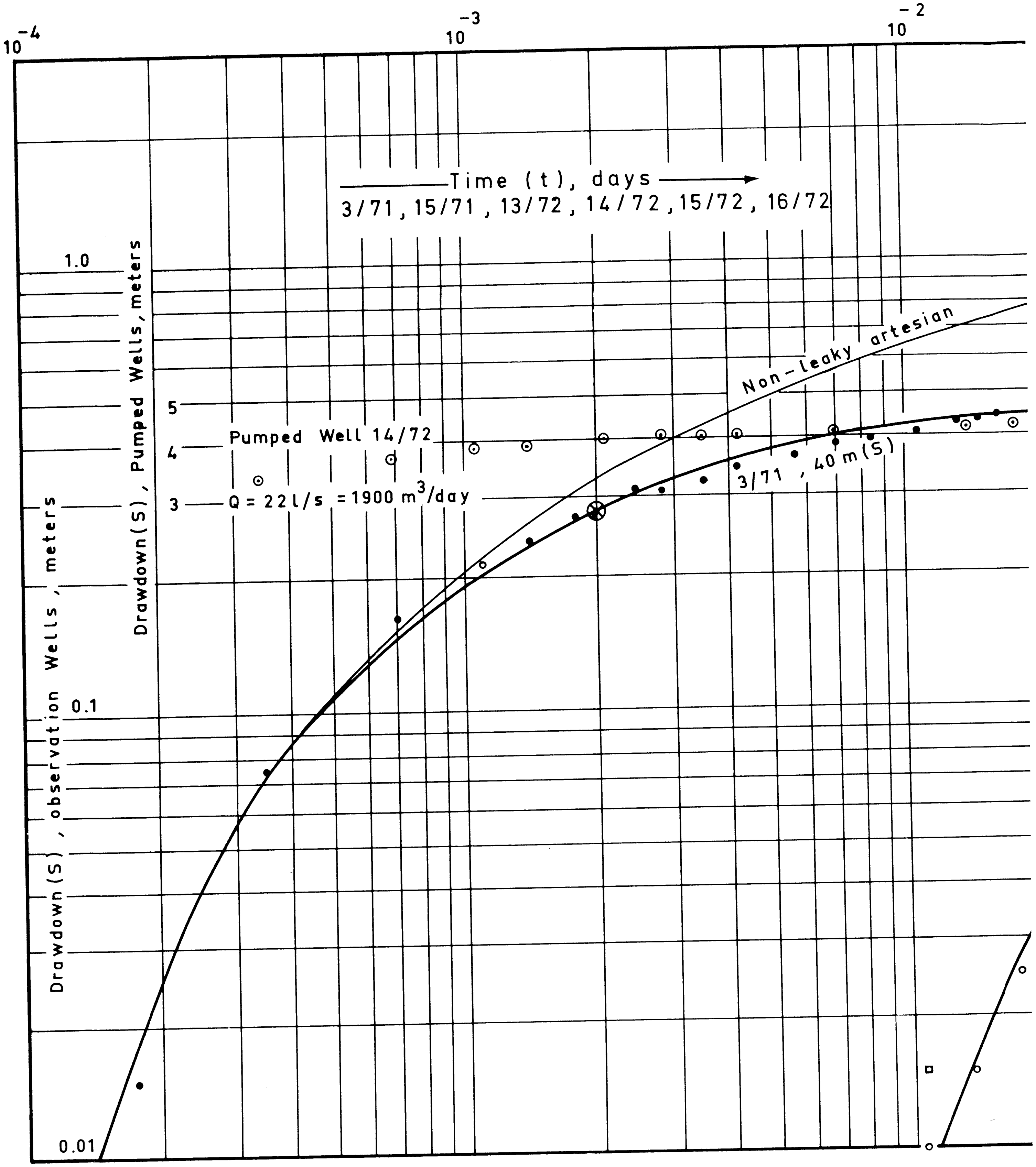
The well was pumped continuously for two days at 22 l/s (1,900 m^3/day)(Figure B). A second test at the same rate was run for 12 hours to check some early drawdown data and to monitor the water levels in additional wells.

OBSERVATION WELLS

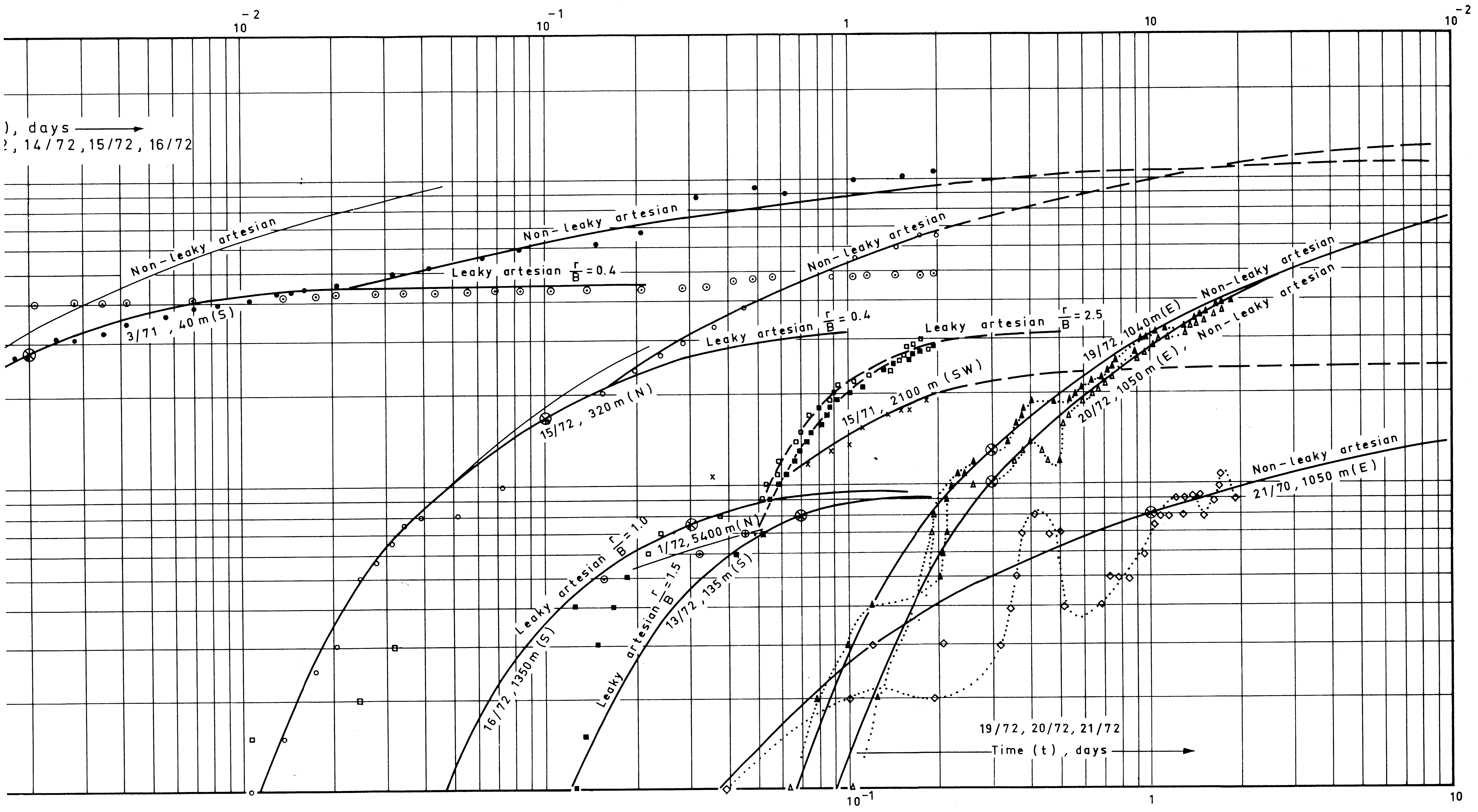
Water levels were observed in eight observation wells at five sites and at distances from 40 to 2,100 m. Most of the observation wells were constructed with nominal 3-inch diameter PVC casing saw-slotted adjacent to the aquifers at depths shown in Table A5-A. Three of the wells were equipped with automatic water-level recorders. It was reported that water levels were lowered in a number of local dug wells during the first test and an automatic water level recorder was installed over one of them for



Annex 5, Figure A, Well locations and sections in the Rijsdijk area



Annex III - 5, Figure B, Rijsdijk aquifer te



III - 5, Figure B, Rijsdijk aquifer test - graph of drawdown versus time for the pomped and observation well

TABLE A5-A

RIJSDIJK TEST - PARAMETERS OF THE AQUIFER AND THE OVERLYING AQUITARD, AND MATCH POINT VALUES (FIGURE A)

Well	15/72	3/71	13/72	16/72	19/72	20/72	21/72
r, meter	320 (N)	40 (S)	1,350 (S)	1,350 (S)	(1,040 (E)	1,050 (E)	1,050 (E)
Screen, meter	29-32	30.9-40.2	35-38	21-23	34-41	31-34	17-20
m, meter	19	18	18	21)	20	20	25 (5+20)
m', meter	30	25	27	22	30	30	
$\frac{r}{B}$	0.4	0.4	1.5	1.0			
s, meter	0.165	0.28	0.08	0.076	0.13	0.1	0.8
t, day	0.1	0.002	0.7	0.3	0.3	0.3	1
$\frac{1}{u}$	5.4	7.8	3.0	10	2.55	1.7	40
$W(u)$, $W(u\frac{r}{B})$	1.25	1.35	0.37	0.68	0.7	0.48	3.2
T m^2/day	1,150	720	700	1,450	830	725	608
Av, k, m/day	60	40	39	69	41	36	24
S	$8.3x10^{-4}$	$4.3x10^{-4}$	$3.5x10^{-4}$	$2.0x10^{-4}$	$3.6x10^{-4}$	$4.5x10^{-4}$	$5.5x10^{-5}$
k' m/day	0.046	1.8	0.023	0.00134			

the second test. Water levels were also measured in OW 1/72, at a distance of 6 km N, during the second test.

AQUIFER PARAMETERS

The transmissivities, hydraulic conductivities, and storage coefficients listed for the observation wells in the table were calculated using the formulae:

$$T = \frac{Q\,W(u)}{4\pi s} \qquad k = \frac{T}{m} \qquad S = \frac{4\,T\,u\,t}{r^2}$$

where T = Transmissivity in m^2/day
k = Hydraulic conductivity in m/day
S = Storage coefficient
Q = Discharge of pumped well in m^3/day
s = Drawdown in meters
t = Elapsed time of pumping in days
r = Distance from pumped well in meters
m = Aquifer thickness in meters
u and its well function W(u) are obtained from type curves as the points matching s and t

The transmissivity averages 880 m^2/day and the hydraulic conductivity averages 44 m/day, which is intermediate between the lower values at Republiek to the south and the high values estimated for the coastal area.

The low storage coefficient, in the order of 10^{-4}, reflects artesian conditions, and the matching type curves indicate leaky artesian conditions in the vicinity of the pumped well, to the west and south.

AQUIFER BOUNDARIES

The aquifer extends throughout the area, with the nearest boundary possibly the Onverdacht sediments to the east. Even this may not be an effective boundary because the formation is in part aquiferous. During two days of pumping, interference did not appear to extend to it.

Aquifer boundaries are evident from the drawdown-time data matched against the type curves of $\frac{1}{u}$ and $W(u\frac{r}{B})$. The calculated distances of the boundaries from the observation wells are shown in Figure A as circles with equivalent radii. The configuration of the circles suggests a boundary passing in a NNW-SSE direction close to the east of the pumped well. It must reflect a change eastward from leaky to non-leaky artesian conditions.

HYDROGEOLOGICAL PROPERTIES OF THE CONFINING COROPINA FORMATION

The hydrograph of OW 3/71 (Fig. 29), with seasonal water-level fluctuations of about 0.5 m, establishes hydraulic connection of the aquifer with the surface through the confining Coropina. The low but significant tritium content of water from this well (Annex 10) also establishes such a connection.

Further evidence of leakage through the Coropina is provided by the leaky artesian type curves, which match the drawdown data of some of the wells. In the previous section it is suggested that leaky conditions are apparent to the west and that non-leaky conditions are apparent to the east; however, it has not been established that non-leaky conditions continue eastward much beyond OW 21/72.

The lithology of the Coropina formation is heterogeneous, with clay, sandy and silty clay, and lenses of sand, indicating that leakage is irregular. It probably takes place mainly through "windows," where sand lenses are in direct contact with the underlying aquifer.

The hydraulic conductivities listed in the table for this layer were calculated using the formula:

$$k' = \frac{T\, m' \left(\frac{r}{B}\right)^2}{r^2}$$

where k' = Hydraulic conductivity of the aquitard (confining Coropina formation) in m/day

m' = Thickness of the aquitard in meters

$\frac{r}{B}$ is from the matching type curve of $\frac{1}{u}$ and $W(u\frac{r}{B})$ (Walton, 1970)

r and T are as previously defined

The heterogeneous nature of the confining Coropina is reflected by the differences in calculated hydraulic conductivity. The relatively high value of 1.8 m/day for OW 3/71 suggests a high leakage potential locally. In this regard it is interesting that a hydraulic conductivity of 2 m/day was measured by permeameter for a fine sand exposed at the surface near OW 13/72. The lower values listed for the more distant observation wells indicate regional averages.

Leakage through the Coropina established from the test should be regarded as a potential. Some leakage probably takes place naturally through "windows," but it is not fully realized until the water level in the aquifer is lowered by pumping.

No evidence of lowering water levels caused by pumping during the test was found in the dug well over which a water level recorder was installed for the second test; however, the water level in the open well did fluctuate because of rainfall.

ANNEX 6

WELL FIELD AT RIJSDIJK

PROPOSED WITHDRAWALS

For practical purposes a well field is considered that will supply 32,200 m^3/day. The flow is equivalent to the proposed Santigron Project, which involves the treatment of Saramacca River water to supply coastal communities, and thus is a basis for a comparison of costs using surface water and ground water as alternative sources of supply (Volume IV).

AVAILABILITY OF GROUND WATER

It is known that the Zanderij aquifer is recharged as far north as Rijsdijkweg, and from the Rijsdijk aquifer test (Annex 5) that leaky artesian conditions prevail throughout much of the area.

The recharge has been estimated at 200 mm/year (Chapter 5), which is equivalent to 0.3 million m^3/yr/km^2. The operation of wells in the area would lower the water level in the overlying Coropina formation (aquitard), and the recharge, which presently is lost as evapotranspiration and effluent stream flow, would be available for use.

It is recognized that the aquifer contains brackish water to the north; however, this water should remain to the north as long as withdrawals do not exceed the local recharge. Recharge to approximately 60 km^2 of aquifer would be required to sustain the proposed yield of 32,200 m^3/day. Such an area is outlined in Figure 31.

LOCATION OF THE WELL FIELD

From the Rijsdijk test, leaky artesian conditions are known to prevail in the vicinity of Well 14/72, to the south and southwest, whereas non-leaky conditions are known to the north and at least close to the east. Because the withdrawals must be sustained by local recharge, the well field must be located in the leaky artesian area to the southwest of Well 14/72, leaving an area with such conditions to the north and avoiding significant flows from the non-leaky area in that direction.

A line of wells oriented approximately E-W, centered about 3 km to the SW of Well 14/72, would be suitable, with the required 60 km^2 recharge area falling within 4.5 km of the center. Non-leaky artesian conditions are known only in the NE fringe of this area, but may exist along the N and NW fringe; however, this probably is offset by higher recharge to the south.

WELLS

Wells constructed with nominal 12-inch diameter PVC casing and 6- or 8-inch stainless steel screen in the manner of Well 14/72 would be ideally suited to the prevailing conditions. The corrosion-resistant materials should ensure a life as long as the system design.

On the basis of the Rijsdijk test, drawdown and yield characteristics of individual wells are assumed the same as for Well 14/72. This well contained 13.18 m of screen and, pumped at 22 l/s, had a specific capacity of 4.4 l/s/m, amounting to 0.34 l/s/m per meter of screen. The yield of 22 l/s was the approximate maximum for the well to maintain an entrance velocity of less than 3 cm/sec.

Where possible, additional screen should be added to either decrease the drawdown or increase the yield. The drawdown discharge relationships for various lengths of screen are given in Figure A.

With yields of 22 l/s each, a total of 17 wells would be needed to obtain 32,200 m^3/day.

EXTENT OF INTERFERENCE AND INDUCED LEAKAGE THROUGH THE AQUITARD

The interference after one year was obtained by extrapolating the drawdown-time curves in Figure B (Annex 5) to one year. Because of the distribution of observation wells, it is only possible to draw an interference curve to the SW; however, this is the direction of leaky artesian conditions and is valid for purposes of estimation.

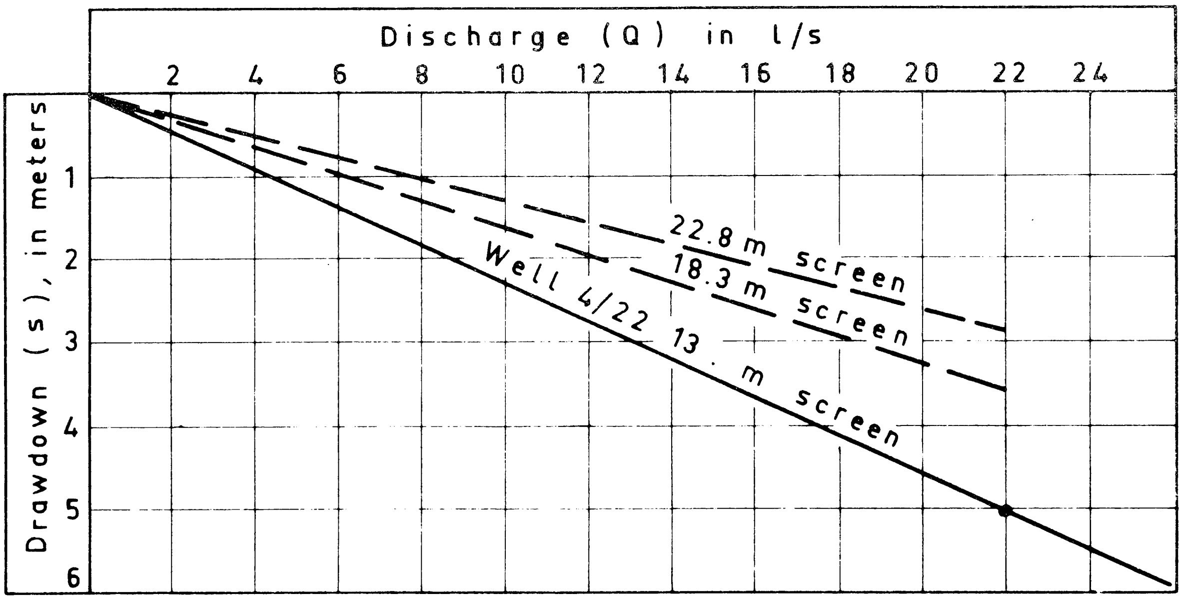
Interference extended to approximately 6 km to the S and SW during the test and, assuming recharge at the rate of 0.2 million m^3/year/km^2, it should not extend to more than 6 km with the proposed withdrawals of 32,200 m^3/day from 17 wells. The extent of interference is more than the 4.5 km indicated above for a 60 km^2 circular area necessary to provide sufficient recharge to sustain the withdrawals; however, at distances greater than 5 km the interference is estimated at less than 0.5 m. This is less than the head difference required to induce the full amount of recharge through the aquitard. The approximate head difference required may be calculated by the equation:

$$\Delta h = \frac{Q\,m'}{k'A}$$

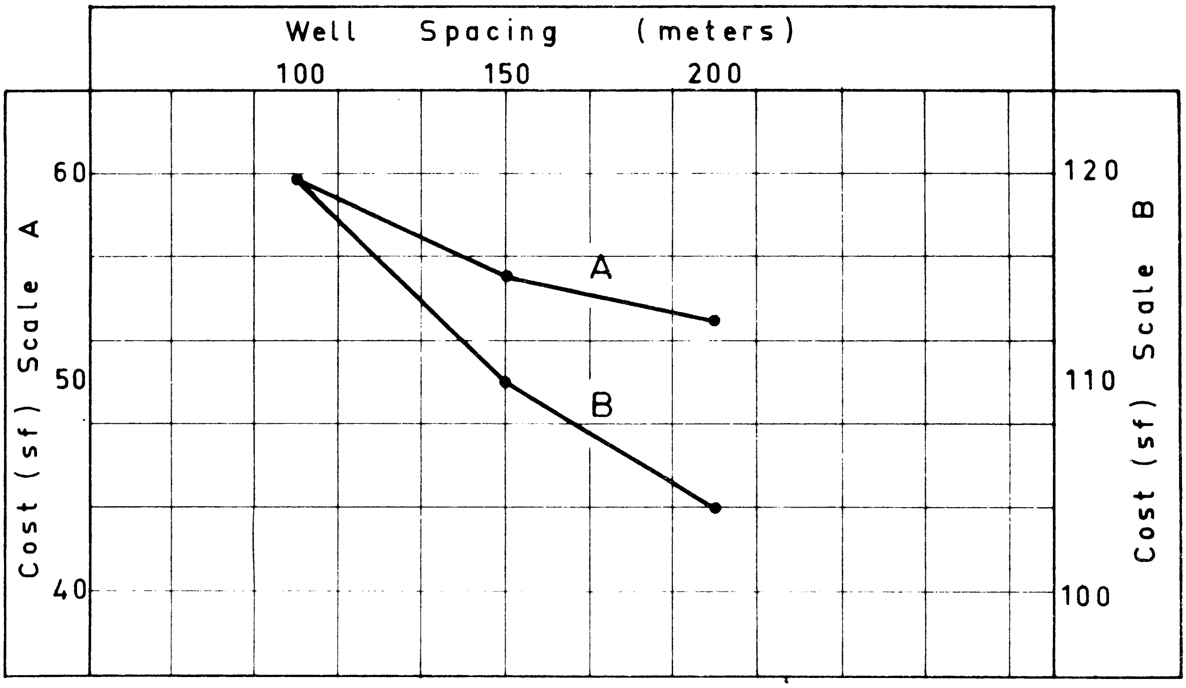
where: Δh = Difference in head between the aquifer and aquitard in meters

Q = Available recharge in m^3/day/km^2 (550 m^3/day/km^2)

m' = Saturated thickness of the aquitard in meters (25 m)



Annex 6, Fig. A, Drawdown - discharge relationship of Well 14/72 and for similar wells with additional screen



Annex 6, Fig. B, Rijsdijk Project - cost to lift water to the surface for different well spacings. A = 19,000 m^3/day in 1987, and B = 32,000 m^3/day in 2000, (Cost based on sf 0.07/Kwh, and 1 m^3 lift 1 m = 2.73 x 10^{-3} Kwh).

k'= Vertical hydraulic conductivity of the aquitard in m/day (0.025 m/day)

A = Area (1 km^2)

The 0.025 m/day indicated as the hydraulic conductivity of the aquitard is the average of the three low values listed in Annex 5, Table A, and the approximate value obtained for OW 13/72.

Substituting the values in the equation, a Δh of 0.55 m is obtained.

WELL SPACING

The drawdown expected as an average and at the center and outside wells of a line of 17 wells, each pumping 22 l/s, are listed in Table A6-A. The values represent the interference after one year for well spacings of 100, 150, and 200 m. The optimum spacing should be within this range and may be calculated by comparing the savings in power for increased spacing against the cost of additional feeder main.

COSTS

From Annex 9 (Well 14/72) the cost of each well should be about Sf.16,000 plus pump. The estimated power costs to operate the wells are given in Figure B for different well spacings.

TABLE A6-A

RIJSDIJK PROJECT - DRAWDOWN AND BELOW-GROUND HEAD ESTIMATED FOR VARIOUS WELL SPACINGS

Well spacing	100 m	150 m	200 m
Year 1987 - 10 Wells at 22 l/s (19,000 m^3/day)			
Drawdown (m)			
Center wells	11.9	11.0	10.45
Outside wells	10.75	9.85	9.25
Average	11.75	10.57	9.99
Average static water level	4.63	4.63	4.63
Average below-ground head (m)	16.38	15.20	14.62
Year 2000 - 17 Wells at 22 l/s (32,200 m^3/day)			
Drawdown (m)			
Center wells	15.6	14.10	13.10
Outside wells	13.35	11.85	10.75
Average	14.82	13.26	12.27
Average static water level (m)	4.63	4.63	4.63
Average below-ground head (m)	19.45	17.89	16.90

ANNEX 7

ASPECTS OF WELL DESIGN

MATERIALS

Virtually all ground water in Surinam is corrosive, and the life of deep wells has generally been considered at about five years on this account. At Paranam well pumps have been known to corrode after six months of use.

There is an awareness of the problem, and attention is being turned towards the construction of wells where corrosion is at a minimum.

Casing of unplasticized PVC offers one of the best possibilities. It is available in a large variety of diameters and wall thicknesses (British Standard 3505: 1968), and the price is attractive. The material is not as strong as steel, and therefore it is most attractive for relatively shallow installations. Well 14/72 was constructed as a demonstration during the project using 32 m of nominal 12-inch diameter PVC pipe (Annex 8).

In selecting metals for well construction, the galvanic series provides a guide. It is assumed that steel casing is to be used for deep wells and that the screen should be most resistant to corrosion. Stainless steel in an active state appears to be the most suitable material available for the screens (when removed from wells, stainless steel screens are bright and shiny and therefore it is assumed that there is no oxide coating to render the metal passive). The corrosion-resistant EVERDUR bronze commonly used for screens is higher than active stainless steel in the galvanic series and therefore is less suitable. An EVERDUR screen removed from a well in Zorg en Hoop was seriously corroded, with enlarged slot openings, although the screen should be cathodic in relation to the casing and therefore more protected against corrosion. This probably is because of hydrogen sulphide.

Even with all steel and stainless steel construction there will be a galvanic cell at the base of the casing where it is adjacent to the screen string. For further protection the casing would best be grouted in position and PVC used for an extension tube. Low flow velocities should also minimize corrosion.

Similar considerations should be given to the pump. The SWM is now specifying pumps constructed entirely with iron.

SIZE OF CASING

The diameter of the casing is normally selected according to the size of pump to be used.

It has been the general practice to use nominal 8-inch diameter casing for production wells in the coastal area. This was continued during the project. The size ideally receives a pump with nominal 6-inch diameter bowls. It will receive nominal 8-inch bowls, but this is marginal, particularly if the well is out of line and not plumb. Recommended casing diameters are one to two diameters larger than the pump bowls; thus, 10-inch casing would best be used to receive an 8-inch pump. The size may be reduced to 8-inch from about 20 m, below which depth drawdown is unlikely. The small difference in friction loss between 8- and 10-inch casing would not justify the extra cost of using 10-inch casing throughout.

SCREENS

Most wells are equipped with JOHNSON wire-wound screens of stainless steel or EVERDUR bronze, which have a high proportion of open area, while maintaining a high degree of strength. Number 40 slot size generally suits most conditions.

Mechanical analyses have been run to select slot sizes, but with disturbed samples the analyses are not representative of the conditions. A visual comparison with standard grain sizes generally is adequate, bearing in mind a need for about 40% retention. This has been the practice during the project for making a choice between the 30 and 40 slot sizes available. The sands are generally graded and therefore suited for natural pack construction.

It has been the practice to install only one 4.57 m (15-ft) length of screen in a well, but during the project longer screens were placed to obtain better drawdown-yield characteristics. Six-inch pipe size screens (6 5/8-inch OD) were used instead of 8-inch telescope size (7 1/2-inch OD) to allow more annular space for handling the longer lengths.

A maximum entrance velocity of 3 cm/sec was designed, after recognizing that coarse sand with an assumed porosity of 35% is packed around the screen. This gives a transmitting capacity of 1.6 l/s per meter of 6 5/8" OD 40-slot screen (4.8 l/s for the open screen).

The use of additional lengths of screen must be considered in relation to cost. One 15-foot length of 6 5/8-inch OD stainless steel screen costs about Sf.1,000, which must be saved to justify its inclusion. The local cost of electricity is 10 ct per Kwh and the power required to lift 1 m^3 of water 1 m is 2.73 x 10^{-3} Kwh (Walton, 1970, p. 489). Thus, the drawdown in wells with a life of five years pumping 25 and 10 l/s for 20 hrs/day must be reduced by at least 1.1 and 2.8 m, respectively, to write off the cost of an additional 15-foot length of screen.

Specific capacities and specific capacities per meter of screen are listed in Table A7-A for project and other wells. From these data it can be computed whether the amount of screen was justified and whether an additional length would have been justified. As an example, assume a pumping rate of 20 l/s from Well 40/71 in Zorg en Hoop. A reduced drawdown of 1.4 m would be required to write off the cost of 15 feet of screen in five years. Using the specific capacity per meter of screen, the drawdown should be about 1.9 m more if only one screen had been used and a decrease of about 0.6 m should occur by adding a third length. Thus, the second length was justified but a third length would not be justified. A similar conclusion is reached for Well 41/71 and the Leysweg wells. The 13.8 m of screen were justified in Well 14/72, but an additional length would not be justified. On the other hand more screen would be justified in the Paradise well.

From the discussion, it may be concluded that for high capacity wells two 15-foot lengths of screen (9.2 m) are justified and desirable, and a third (13.8 m) and even a fourth length (18.4 m) may be justified where the hydraulic conductivity is low. It is assumed that there is additional aquifer to screen, which is not necessarily the case. Where the aquifer thickness is limited, consideration should be given to increasing the diameter of the screen and gravel packing.

WELL HEAD

Surinam receives heavy rains, drainage in the Young Coastal Plain is not good, and the water table is high; therefore, wells should be finished with the casing above ground level and grouted all around. The practice of finishing wells below ground level under these conditions is unsanitary. Even with a protective roof, water inevitably seeps into the well pit contaminated and, together with aquatic wildlife, may at times spill over the top of the casing into the well. The least protection under the circumstances would be the provision and maintenance of effective well seals to include facilities for water-level measurements by airline (non-corrosive material). A well finished with the pump below ground level may permit the simplest feeder main connection without elbows, but it is inconvenient for pump handling.

TABLE A7-A

SPECIFIC CAPACITIES OF WELLS AND PER METER OF SCREEN FOR PROJECT AND OTHER WELLS

Well		Q/s 1/s/m	Screen m	Q/s/m 1/s/m/m
1/69	Stolkslust	1.8	4.6	0.39
2/69	Houttuin	0.54	4.6	0.12
2/70	Groningen	0.8	4.6	0.17
8/70	Magenta	1.3	4.6	0.28
9/70	Morico	1.0	9.2	0.11
3/71	Rijsdijk	3.0	9.2	0.33
10/71	Morico	2.9	9.2	0.32
16/71	Meerzorg	1.1	9.2	0.12
31/71	Helena Christina	2.0	9.2	0.22
36/71	Zorg en Hoop	4.8	6.1	0.79
37/71	Groot Henar	0.62	9.2	0.07
40/71	Zorg en Hoop PO	10.5	9.2	1.14
41/71	Zorg en Hoop	4.5	9.2	0.49
44/71	Sidodadie	5.6	13.8	0.4
5/72	Paradise	3.0	12	0.25
7/72	Tigre Kreek	2.0	9.2	0.22
14/72	Rijsdijk	4.4	13.8	0.32
26/72	Livorno	6.0	18.4	0.32
32/72	La Vigilantia	10.0	9.2	1.08
	Leysweg 3	6.3	4.6	1.37
	Leysweg 4	7.1	4.6	1.54
	Wageningen	1.05	4	0.26

ANNEX 8

WELL CONSTRUCTION WITH NOMINAL 12-INCH DIAMETER UNPLASTICIZED POLYVINYL CHLORIDE (uPVC) CASING: A CASE HISTORY

INTRODUCTION

Steel casing is subjected to severe corrosion by the aggressive ground waters in the coastal basin to the extent that it may be corroded within five years. Casing made of uPVC was considered as a likely solution to this problem and was used in several small-diameter wells prior to the project. Its use could reduce costs and extend the life of wells, and consequently the construction of a well using 12-inch diameter uPVC casing was included as a demonstration in the activity of the project. The demonstration was in the construction of the relatively shallow Well 14/72, but it was intended to use it to depths of 90 m and more.

SPECIFICATIONS

The pipes used were nominal 12-inch diameter CHEMIDUS 3000 class C and D, in 6 m lengths, with a socket on one end conforming to BS 3505/1968. The minimum outside diameter of the 12-inch pipes is 12.732 inches, and the specific gravity of the material is 1.42. Details are listed in Table A8-A.

TABLE A8-A

CHARACTERISTICS OF CHEMIDUS uPVC PIPES

Class	B	C	D	E
Min. wall thickness (in.)	0.307	0.453	0.598	0.736
Max. working pressure (head) in feet	200	300	400	500
Weight kg/m	11.55	16.85	21.91	26.68
lb/yd	23.28	33.96	44.16	53.78

A cleaner and a solvent cement is used to join the pipes.

DRILLING

A truck-mounted FAILING 1250 rotary rig was used to construct Well 14/72. A 1-meter diameter concrete pipe was placed as a cellar and concreted poured in the base with an orifice to take 18-inch surface casing. An 8 5/8" OD steel conductor box was cemented in the bottom of the cellar, and a steel channel was provided to the settling pit.

Regular bentonite mud was used; a 5 7/8-inch diameter hole was drilled to 32 m using a wing bit. Samples were taken every meter. These and a gamma-ray log indicated that a positive shutoff could be made with the casing set at 32 m BGL.

The 8-inch conductor box was removed, the top of the hole was reamed, and 3 m of 18-inch steel casing was squeezed in to control the surface sand and sandy clay. The hole was reamed to 32 m using an 11 1/2-inch diameter wing bit and finally a 16 1/2-inch diameter pilot bit.

INSERTION OF CASING

Class C pipes were used, excepting the uppermost 2.5 m, where an odd length of class D pipe was used.

Preparations included:

1. Reinforcing with class D pipe to form a shoe on the bottom.
2. Centralizers around the bottom near the shoe using class D pipe for reinforcing.
3. The construction of a pressure head to fit in the top of the pipes in order to circulate much through the annular space as the casing was run, and to place the cement. The head was made of hard wood bound around the outside with rubber and with a rubber seal ring on the bottom. A 2-inch pipe was inserted through the center, and a steel plate with angle iron extensions was attached to the top to facilitate handling. The 2-inch pipe was fitted with a spreader for cement on the lower end and was supported with pipe fittings and a valve on the upper end.
4. Lugs were attached to the casing lower than the section to be occupied by the pressure head. These were to keep the casing clamps in position, thereby forming an anchor to which the angle-iron extensions of the pressure head could be secured.

The rig was moved forward to permit the installation of the pipe clear of the rotary table. An angle-iron frame supporting a single rope sheave had been attached to the mast just below the crown sheaves to deflect the hoisting cable clean of the mast.

The pipes were run male end upward and hoisted by means of a rope sling attached to steel clamps tightened to the pipes. The joints were quickly cleaned and cemented, and, as an additional safeguard permitting the pipes to be run immediately, three stainless steel self-tapping screws were placed equidistant but on different levels round the joint.

The annulus was circulated with mud, utilizing the pressure head, and the pipe was surged from 23 m to the final depth of 31.27 m BCL. The pressure head was weighted down with a 3/4-ton drill collar.

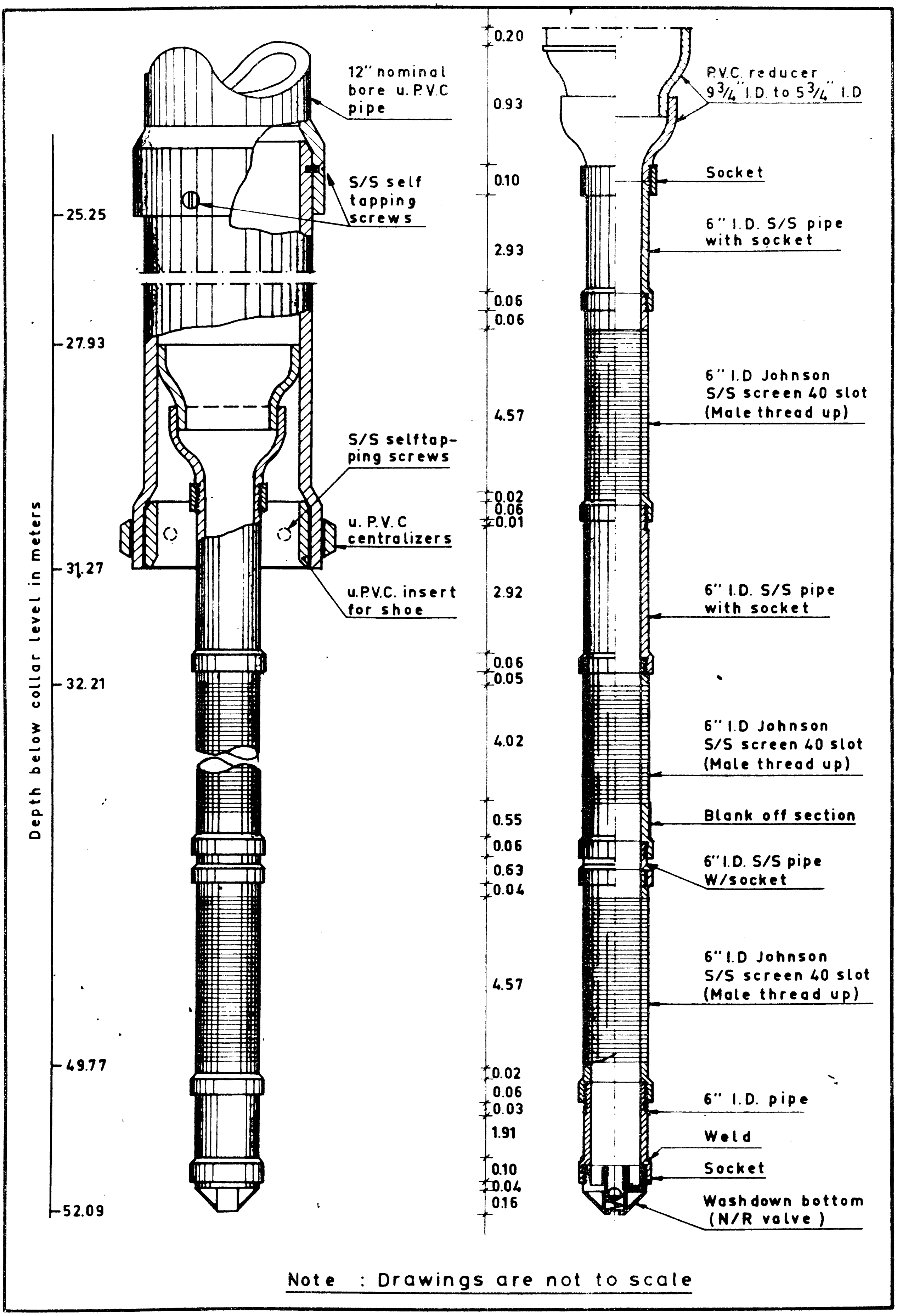
CEMENTING

Seventeen bags of Portland cement were mixed and pumped into the pipes through the pressure head. A cement plug was inserted on top of the cement; after the pressure head was replaced a measured amount of water was pumped into the pipes above the plug; and finally the 2-inch valve was closed. The cement was allowed to set for 20 hours. It was drilled out and the cement in the annulus was allowed to set for a further 48 hours, during which time the 18-inch surface casing was removed and the annulus was filled from the top with gravel followed by concrete.

COMPLETION OF WELL

A 5 7/8-inch diameter wing bit was used to drill with fresh mud through the aquifer to a clay layer at 52 m BCL. Samples were taken every meter, and the section from 32 to 52 m was logged. On this basis, a screen was designed using three 15-foot long, 6-inch ID, JOHNSON 40 slot, stainless steel screens, interspaced with stainless steel pipe, a plastic reducer with rubber packing ring, 6-inch ID sump, and a washdown bottom for a total length of 24.16 m. After reaming the hole to 9 7/8 inch diameter, the string was run using the drill pipes and a left hand threaded back-off joint attached to the top of the washdown bottom.

The well was developed by jetting with clean water and by pumping. The pumping test is described in Annex 5.



Note : Drawings are not to scale

Annex III - 8, Construction details of Well 14/72, Rijsdijk

ANNEX 9

WELL CONSTRUCTION COSTS

The costs to construct nine production wells are listed with details in the table. They are for the items listed only and do not include amortization of the rig, transport, and plant.

Work was normally for eight hours per day, which forms the basis for calculating the wages as Rig Crew Units (RCU's). Any round-the-clock work as two 12-hour shifts is charged as four RCU's per day, a simplification to cover overtime and allowances.

Operating costs per shift for the rig, plant, and light transport attached to the rig were calculated by dividing the total annual cost for these items by the number of working days. Drivers' wages were added.

Shutdowns listed as category A, Line 23, were on account of holidays, to receive pay at head office, and waiting for material to be either manufactured or delivered. Shutdowns listed as category B, Line 24, were for mechanical reasons only, such as servicing of engines and breakdown of equipment.

The listed costs show the advantage of shift work. Wells 36/71, 40/71, and 41/71 at Zorg en Hoop were all drilled on shift. They cost less than the shallower wells (4/70, 14/72, and 31/71), with the exception of Well 44/71. It is reflected also by the lower relative costs for wages and operating. These items amount to 46% of the total for the Zorg en Hoop wells, whereas for the other wells it is 62 to 71%, with the exception of Well 44/71 where it is 53%.

The cost for wages and operating amounts to 70% and 71% of the total for the deep wells 37/71 and 5/72 near Nickerie. This reflects the long shutdowns because of extended trips to Paramaribo every month for pay, amounting to about 40% of the RCU's.

COSTING OF COMPLETED BOREHOLES

N.B. All these production wells were drilled slim hole, electric logged, then reamed and cased. Failing rigs were used to drill in each case.
All costs are in Surinam Guilders

	1250 RIG Leiding 9A TW 4/70 From: 23/6/70 To : 27/10/70 4 man R.C.U.	12 Sidoc T From: 1 To : 6 ma
Average cost:		
1. Per tour (shift) Rig Crew Unit	46.01	
2. Each rig operating tour for consumable items	4.30	
3. Each rig operating tour for fuel and serviceing	7.44	
4. Per Labourer Day Unit	5.00	
Cost of:		
5. Rig crew wages, accomodation, etc.	106 RCU's = 4,877	49 RCU
6. Consumable items	46 " = 198	20 "
7. Fuel, oil & serviceing for rig	46 " = 342	20 "
8. Preparing access, site & cellar	60	
9. Casing	1779	
10. Screens and fittings	3136	
11. Mud chemicals, in-filling, etc.	436	
12. Light transport attached to rig	1244	
13. Heavy transport for moving equipment	100	shortm
14. Additional Labour as L.D.U.'s	920	
15. Workshop charges, spareparts, etc.	825	
16. Fuel, oil, & serviceing for tractor (test pumping)	113	
17. TOTAL COST	14,030	

+) Crew were deployed: 2 to 17 Oct.'71 on TW 36/71 and 24 Oct. to 13 Nov. on TW 41/71 15-18 Nov. re-positioning rig.

	Daywork			
	Labourer Day Unit	Rig Crew Unit	No. of calendar days	Labourer Day Unit
18. Site preparation	46	-	-	15
19. Moving	9	8	-	1
20. Rigging up	8	7	-	1
21. Drilling, casing, screens, etc.	36	27	-	15
22. Developing & testing	32	21	-	18
23. Shut-down - A	24	18	-	28
24. Shut-down B	29	25	-	-
25. TOTAL	184	106	127	78
26. Rig operating tours			46	

Annex 9, Costing of Wells

	1250 RIG	SWM 1500 RIG	SWM 1500 RIG	1500 RIG	1500 RIG	2500 RIG	2500 RIG
	Rijsdijkweg TW 14/72 From: 18/4/72 to $ 6/8/72 6 man R.C.U.	Oorantijnstraat TW 36/71 From: 1/10/71 To : 15/10/71 6 man RCU	Post Office TW 40/71 From: 20/10/71 To : 6/11/71 6 man RCU	Corantijnstraat TW 41/71 From: 24/10/71 To : 11/11/71 6 man RCU	Helena Christinaweg TW 31/71 From: 31/8/71 To : 8/2/72 5 man RCU	Groot Henar Polder TW 37/71 From 3/9/71 To : 8/2/72 5 man RCU	Paradise TW 5/72 From: 9/2/72 To : 12/6/72 8 man RCU
	72.62	72.80 (SWM) 66.50 (DenD)	62.80 (SWM)	55.50	61.42	53.90	107.70 (Rig crew) 66.15 (single tour)
	4.30	4.95	4.95	4.30	4.30	6.84	6.84
	7.44	13.68	13.68	7.11	7.11	17.12	17.12
	5.00	7.76	7.76	7.76	5.00	5.00	5.00
		28 RCU's = 2038					
48	91 RCU's = 6,608	25 RCU's = 1650	53 RCU's = 3328	64 RCU's = 3558	95 RCU's = 5856	187 RCU's = 10,079	192 RCU's = 12,701
86	38 " = 163	32 " = 158	30 " = 149	129	37 " = 150	64 " = 438	60 " = 410
49	38 " = 283	32 " = 438	30 " = 410	213	37 " = 263	64 " = 1,096	60 " = 1,027
17	386	57	57	74	80	350	148
63	915	3,714	3,731	3,744	2,040	5,597	5,750
00	3,786	1,755	2,562	2,155	2,475	2,155	3,891
07	297	424	306	275	123	729	793
79	1,256	498	571	491	1,820	2,185	3,149
1	125	100	60	60	230	3,550	226
90	1,105	435	435	147	950	1,845	1,760
50	875	110	495	190	678	1,200	1,197
13	120	75	75	75	120	280	327
02	15,919	11,452	12,179	11,111	14,944	29,504	31,379

	Daywork			24 hrs. Daily			24 hrs. Daily			24 hrs. Daily			Daywork			Part Daywork/Part 24 hrs.			Part Daywork/Part 24 hrs.		
o. of alendar ays	Labourer Day Unit	Rig Crew Unit	No. of calendar days	Labourer Day Unit	Rig Crew Unit	No. of Calendar Days	Labourer Day Unit	Rig Crew Unit	No. of Calendar Days	Labourer Day Unit	Rig Crew Unit	No. of Calendar Days	Labourer Day Unit	Rig Crew Unit	No. of Calendar Days	Labourer Day Unit	Rig Crew Unit	No. of Calendar Days	Labourer Day Unit	Rig Crew Unit	No. of Calendar Days
-	64	-	-	18	-	-	18	-	-	18	-	-	19	-	-	19	-	-	44	-	-
-	9	3	-	-	2	-	7	4	-	1	4	-	4	4	-	67	17	-	26	7	-
-	9	4	-	1	2	-	12	5	-	-	2	-	3	2	-	9	5	-	12	6	-
-	40	29	-	26	34	-	14	24	-	-	30	-	58	33	-	96	59	-	71	57	-
-	34	26	-	10	14	-	4	19	-	-	16	-	26	16	-	20	15	-	46	31	-
-	28	17	-	-	-	-	-	-	-	-	2	-	55	28	-	122	71	-	128	77	-
-	37	12	-	1	1	=	1	1	-	-	10	-	25	12	+)	12	6		25	14	-
57	221	91	111	56	53	15	56	53	18	19	64	19	190	95	120	345	173	142	352	192	125
20			38			32			30			30			37			59			60

ANNEX 10

ENVIRONMENTAL ISOTOPE STUDIES

(From Report of the International Atomic Energy Agency,
September 1972)

ISOTOPE APPROACH

The isotopes involved in this study were the stable isotopes ^{18}O and ^{13}C and the radioactive isotopes tritium and ^{14}C, all of them belonging to a group of isotopes termed "environmental isotopes" because of their natural existence in the hydrologic cycle. Oxygen-18 ($H_2{}^{18}O$) is one of the principal heavy stable isotopic components of water and constitutes a tool for studying the origin of water bodies, or can be used as a trace element to differentiate between water bodies because of its conservative property in a closed system. The stable isotopic composition of a water sample is expressed in terms of per mil deviation of the isotope ratio from that of a standard. The standard in general use is SMOW (Standard Mean Ocean Water), and thus data for oxygen-18 concentrations of a given water sample are expressed as delta (δ) value defined by

$$\delta = \frac{R - R_{SMOW}}{R_{SMOW}} \cdot 10^3 \text{ o/oo}$$

where R is the isotope ratio $\frac{^{18}O}{^{16}O}$.

During the natural processes occurring in the hydrologic cycle, causing changes of the state of water through condensation or evaporation, isotope fractionation occurs. One of the main factors for fractionation during condensation is the temperature at the time of condensation. Consequently, variations in the stable isotopic composition of precipitation with latitude and altitude are observed. In a given location, there are also seasonal variations of stable isotopic composition similar to that of the precipitation recharging them, depending on the area and time of recharge.

Tritium is useful for dating purposes due to the fact that it is a radioactive isotope and its disappearance in a closed system is governed by the law of radioactive decay. Thus, it enables the study of transit times involved in the movement of ground water. With the present accuracies of available measurement techniques, tritium (with a half-life of 12.26 years) can be used for dating of ground waters up to about [illegible] years. The tritium concentrations in precipitation at the latitudes of the project area reached their maximum value in 1963 as a result of detonations of thermonuclear devices started in 1952. The maximum tritium concentration of precipitation was 420 T.U. (Tritium Units)* in 1963 for the

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*1 TU = 1 tritium atom per 10^{18} hydrogen atoms

WMO/IAEA network station San Juan, which is the closest available to the project area. From that time onward, a steady decrease in the tritium concentration of precipitation is observed, with seasonal variations, the last few years being almost constant at about 10-20 T.U. Thus, the tritium concentration in precipitation forms a valuable input of trace elements into the ground water, and its known time variation also enables evaluations of the dynamics of the system and transit times involved in the flow of ground water.

Similar to tritium, carbon-14 is also a radioactive isotope with a half-life of 5,730 years. In cases where the movement of water is relatively slow, it is a useful dating tool covering a time span of 40,000 years. It should be mentioned that disappearance of ^{14}C in a closed system can involve complicated chemical exchange processes with the solid matrix, in addition to radioactive decay, thus making it more difficult to be used in dating applications. However, methods are developed for applying necessary corrections based on the ^{13}C measurements and water chemistry data.

Periodic samples collected from selected wells in the project area enabled the determination of isotopic compositions of different water-bearing zones in the project area. The findings of the isotope study are given in the following sections.

The isotopic analyses of the collected samples were performed in the Isotope Laboratory of IAEA in Vienna.

The accuracy of the results of oxygen-18 analysis given in this report is ± 0.2 o/oo. The analytical errors associated with tritium and carbon-14 analysis are given, together with the result of each analysis.

RESULTS OF THE ISOTOPIC ANALYSES - INTERPRETATIONS AND EVALUATIONS

Results of all isotope analyses performed for the samples collected from wells are given in Tables A10-A, -B, and -C. Data belonging to each aquifer zone are given in separate tables: Table A10-A includes all isotope data from the "Zanderij Aquifer," Table A10-B from the "Coesewijne Aquifers," and Table A10-C from the "A Sand Aquifer" and the "Onverdacht Aquifer." In the last columns of the tables, some of the available water chemistry data are also included. The sampling dates given in the tables refer to the collection of isotope samples but not necessarily to the samples for chemical analysis.

Oxygen-18 Results

The $\delta^{18}O$ values for each zone are shown in Figure A.

The values of the Zanderij aquifer vary between -2.1 and -3.4%. Significant variations in $\delta^{18}O$ from one well to another are observed in

TABLE A10-A

DATA FOR THE ZANDERIJ AQUIFER

Well No.	Well Location	Screen Depth (m)	Code No.	Sampling Date	Results of Isotopic Analyses				Chemical Analyses				Remarks
					$\delta^{18}O$ (%o SMOW)	Tritium (T.U.)	^{14}C (% Modern)	$\delta^{13}C$ (%o PDB)	Cl ppm	SO_4 ppm	Total CO_3 ppm	pH	
6/71	Zanderij	12-15	SUR-5	2.8.71	-2.4	1.0±0.3							
7/71	Zanderij	3-6	SUR-6	2.8.71	-3.0	17.8±1.1			33	0	9	3.7	
			SUR-33	14.7.72	-2.9	11.5±0.5							
3/71	Rijsdijkweg	31-40	SUR-7	8.4.71	-2.8	2.7±0.4							pH 8.0 likely in error. pH 5.7 later determined within 1 hour of sampling
			SUR-24	10.4.72		2.3±0.4	57.9±1.5	-19.2	28	5	51	8.0	
			SUR-29	11.7.72	-2.6	0.6±0.2							
3/71	Rijsdijkweg	54-64	SUR-8	19.4.71	-2.7	1.6±0.4			48	13	33	7.2	Same well as above sampled at different depth
	Republiek	Appr. 10-30	SUR-9	13.10.71	-3.3	10.6±0.8			6	15	3	5.6	Raw water, average of 26 wells
			SUR-32	12.7.72	-2.8	10.1±0.5							
5	Paranam Well (East)	23-28	SUR-10	7.10.71	-3.3	1.1±0.4			13	5	15	5.5	
7	Paranam Well (West)	23-28	SUR-11	7.10.71	-3.2	3.5±0.6			22	8	6	6.0	
32/71	de Crane Weg	50-56	SUR-12	8.10.71	-2.8	0.4±0.2			27	67	48	6.9	
35/71	Tawajari Weg	46-52	SUR-13	18.10.71	-3.2	1.0±0.3			73	50	33	6.4	
17/71	Pad v. Wanica	36-48	SUR-26	17.4.72	-2.6	2.3±0.3	16.8±0.9	-18.1	850 411	175 117	51 15	6.5 6.0	pH = 5.7 lab. measurement after ^{14}C sampling
28/71	de Crane Weg	45-51	SUR-27	18.4.72	-2.6	2.3±0.3	18.5±1.1	-17.4	31	26	27	5.7	pH = 7.2 lab. measurement after ^{14}C sampling
15/72	Rijsdijk-N	29-32	SUR-28	10.7.72	-2.6	1.5±0.2							

TABLE A10-A (cont.)

DATA FOR THE ZANDERIJ AQUIFER

Well No.	Well Location	Screen Depth (m)	Code No.	Sampling Date	Results of Isotopic Analyses				Chemical Analyses				Remarks
					$\delta^{18}O$ (‰ SMOW)	Tritium (T.U.)	^{14}C (% Modern)	$\delta^{13}C$ (‰ PDB)	Cl ppm	SO_4 ppm	Total CO_3 ppm	pH	
15/71	Rijsdijk-SW	24-30	SUR-30	11.7.72	-2.2	0.6±0.2							
11/72	Hwy at Coropina Creek	20-23	SUR-31	11.7.72	-2.9	2.4±0.2							Coropina zone ?
9/71	Zanderij-Matta	5.5-8.5	SUR-34	14.7.72	-2.3	16.0±0.7							
19/72	Rijsdijk-E	37-41	SUR-35	18.7.72	-2.7	0.9±0.4							Samples from the same site at different depths collected during drilling
20/72		31-34	SUR-36	18.7.72	-2.8	1.3±0.3							
21/72		17-21	SUR-37	18.7.72	-2.7	1.1±0.2							
13/72	Rijsdijk-S	35-38	SUR-38	27.7.72	-2.8	0.6±0.2							Samples from the same site at different depths collected during drilling
16/72		21-23	SUR-39	27.7.72	-2.9	1.1±0.2							

TABLE A10-B

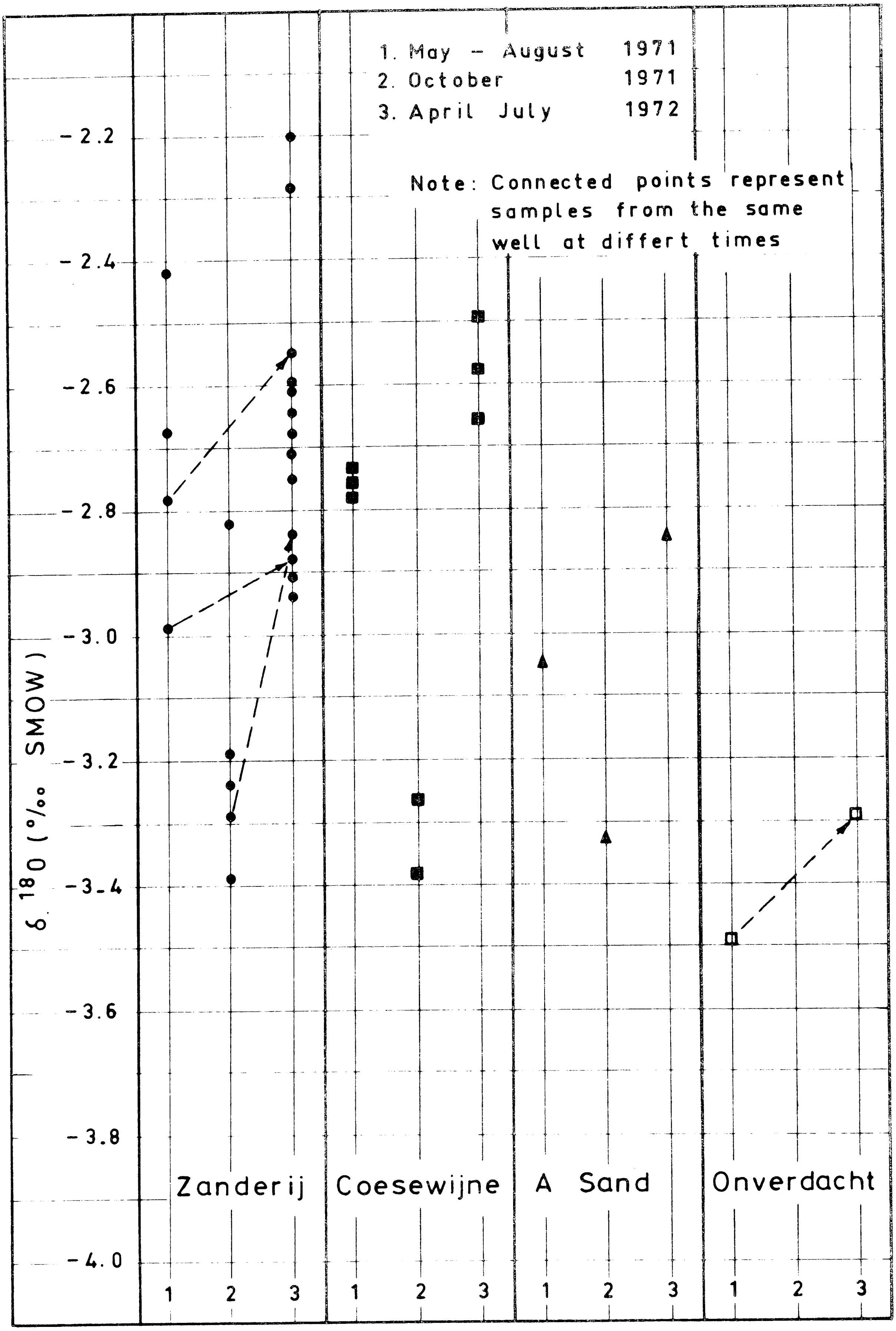
DATA FOR THE COESEWIJNE AQUIFERS

Well No.	Well Location	Screen Depth (m)	Code No.	Sampling Date	Results of Isotopic Analyses				Chemical Analyses				Remarks
					$\delta^{18}O$ (%o SMOW)	Tritium (T.U.)	^{14}C (% Modern)	$\delta^{13}C$ (%o PDB)	Cl ppm	SO_4 ppm	Total CO_3 ppm	pH	
10/71	Morico	80-88	SUR-2	7.5.71	-2.8	1.7±0.3							
	Alliance Well	103-108	SUR-3	11.5.71	-2.8				197	179	30	7.7	
1/69	Stolkslust	87-91	SUR-4	11.6.71	-2.8	1.3±0.4			150	194	3	8.1	
2/70	Groningen	133-138	SUR-14	19.10.71	-3.3	0.3±0.3			88	108		8.3	
GMD-2	Kampong Baroe	123-129	SUR-15	19.10.71	-3.4	0.9±0.3			96	118	33	6.5	
4/70	Leiding	73-87	SUR-20	23.3.72	-2.5		17.0±0.7	-17.6	106	177	81	6.8	pH = 6.4 t = 27°C Field measurement during ^{14}C sampling
31/71	Helena Christina Weg	85-95	SUR-21	24.3.72	-2.6		17.0±0.8	-18.8			36	5.4	pH = 6.2 t = 27°C Field measurement during ^{14}C sampling
23/71	de Crane Weg	64-72	SUR-25	12.4.72	-2.7		18.9±0.9	-16.4	36	62	30	6.7	pH = 7.3 Lab measurement after ^{14}C sampling

TABLE A10-C

DATA FOR THE A SAND AND ONVERDACHT AQUIFERS

Well No.	Well Location	Screen Depth (m)	Code No.	Sampling Date	Results of Isotopic Analyses				Chemical Analyses				Remarks
					$\delta^{18}O$ (‰ SMOW)	Tritium (T.U.)	^{14}C (% Modern)	$\delta^{13}C$ (‰ PDB)	Cl ppm	SO_4 ppm	Total CO_3 ppm	pH	
2/69	Houttuin	126-131	SUR-1	1.6.71	-3.1	1.5±0.6			141	45	48	8.3	pH = 6.1 Lab measurement after ^{14}C sampling
			SUR-23	29.3.72			9.0±0.7	-21.6					
36/71	Zorg en Hoop	155-161	SUR-16	15.10.71	-3.3	0.6±0.4			190		42	6.8	pH = 6.6 t = 29°C Field measurement during ^{14}C sampling
			SUR-18	21.3.72			20.3±0.7	-19.3					
GMD-19	Uitvlugt	?	SUR-19	22.3.72	-2.9		8.5±0.8	-12.7					pH = 6.7 t = 29°C Field measurement during ^{14}C sampling
2	Onverdacht	(Appr.) 30-35	SUR-17	8.10.71	-3.5	1.0±0.3			19		6	6.0	pH = 5.5 Lab measurement after ^{14}C sampling
			SUR-22	29.3.72	-3.3		57.2±1.3	-18.8					



Annex 10, Figure A, Oxygen - 18 values from different aquifers

the Zanderij area ($\delta^{18}O$ = 2.3 for 9/71 and $\delta^{18}O$ = -2.9 for 6/71) should be due to the rapid response of the aquifer to seasonal inputs, which is supported by high tritium values observed in these shallow wells in the recharge area. Similar considerations apply to the well at Republiek, with $\delta^{18}O$ values of -3.3 and -2.8% observed in the same wells at different sampling times, which is also in agreement with the high tritium value observed. Further to the north, the stable isotopic composition of the Zanderij aquifer is quite uniform, with a typical value of $\delta^{18}O$ = 2.7‰, the only exceptions being the two wells in Paranam (-3.3 for No. 5 and -3.2 for No. 7).

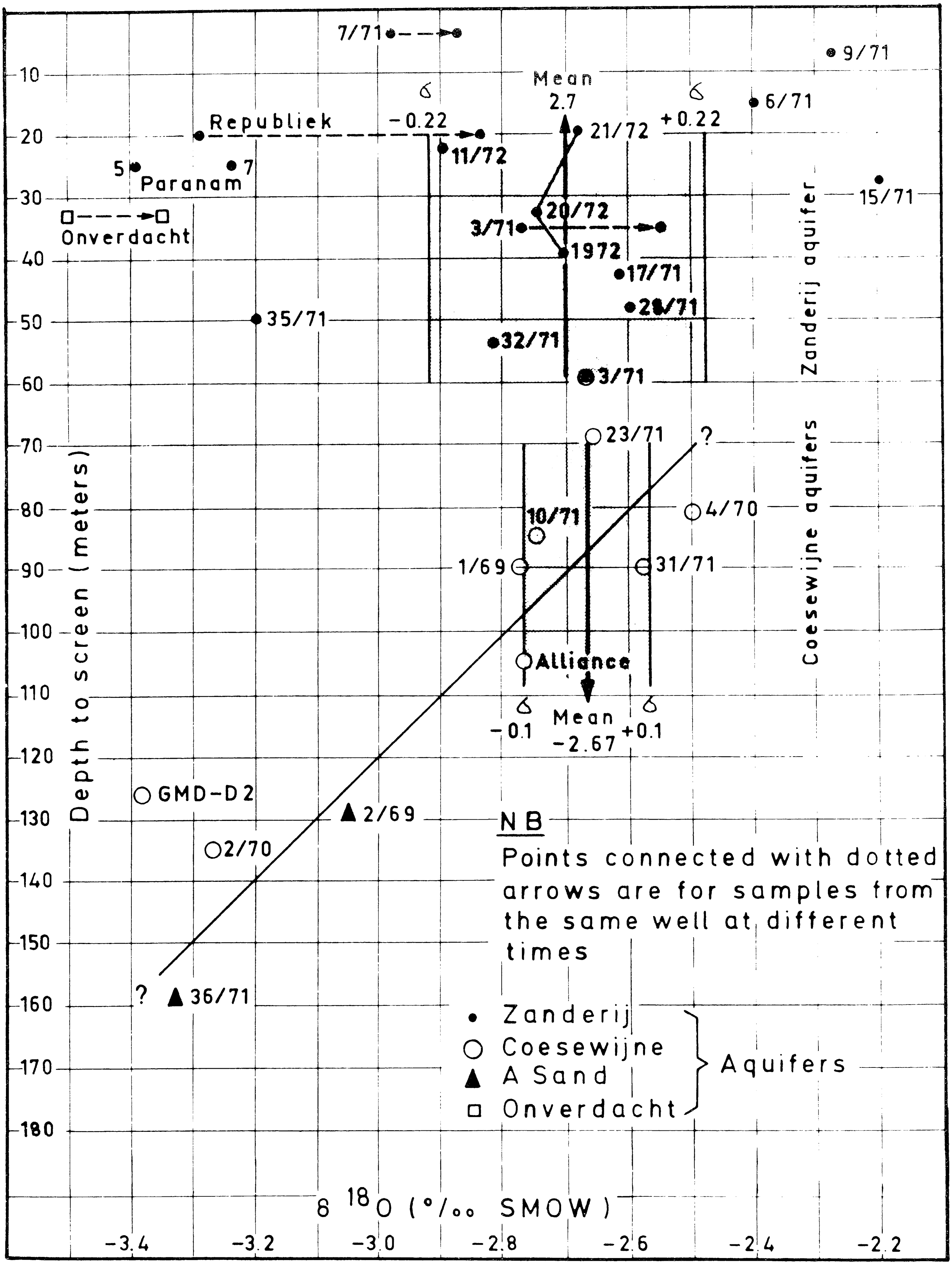
The Coesewijne aquifers have also quite a uniform stable isotopic composition, with a typical value comparable to that of the upper zones. The two wells located west of the Saramacca River (2/70 and GMD-2), however, have slightly depleted values of -3.3 and -3.4‰.

Three samples available from the A Sand Aquifer have slightly depleted $\delta^{18}O$ values (-2.9 for GMD-19, -3.3 for 36/71, and -3.1 for 2/69), as compared to the upper zones.

The two samples available from the same well in Onverdacht have ^{18}O values of -3.5 and -3.3.

As can be seen from Figure A, the range of $\delta^{18}O$ values in the Zanderij and Coesewijne aquifers is quite similar. A plot of ^{18}O vs. depth to well screen is given on Figure B. Excluding the shallow wells in the Zanderij area, where the response of the aquifer is rather rapid, and also excluding the two wells in Paranam, all samples from the Zanderij aquifer in the central part of the basin have a mean $\delta^{18}O$ value of -2.70 ± 0.21. For all the samples from the Coesewijne aquifers in the central part of the basin (that is, excluding 2/70 and GMD-D2), the mean value is $\delta^{18}O = -2.67 \pm 0.10$. Thus, the Zanderij and the Coesewijne aquifers have the same stable isotopic composition in the central part of the basin, as can be clearly seen on Figure B. Therefore, it is not possible to distinguish between Zanderij and Coesewijne aquifers using their stable isotopic composition.

Relatively depleted values of the wells in Paranam (-3.3 for No. 5 and -3.2 for No. 7) and the wells west of the Saramacca River (-3.3 for 2/70 and -3.4 for GMD-D2) might be indicative of a recharge source which is different to that between the two. Considering that the values observed in these wells are similar to those of the Onverdacht and the A Sand, and taking into account their location and proximity to the main rivers, the possible contributing source of recharge could perhaps be the rivers. Drainage areas of these rivers extending to higher altitudes would normally result in a more depleted $\delta^{18}O$ composition for the rivers. Thus, one may consider a possible contribution of the Suriname River, for example, infiltrating into the aquifers in the Savannah area or further south through the alluvium river bed and then flowing through Paranam



Annex 10, Figure B, - Plot of $\delta^{18}O$ versus depth

wells and Onverdacht down to the A Sand aquifer. Considering that the number of samples is very limited and the difference in $\delta^{18}O$ values is not too significant, this is only a hypothesis suggested by the isotope data.

As regards a possible interconnection between different aquifer zones, the similar stable isotopic composition of the Zanderij and the Coesewijne aquifers does not allow any firm conclusions. Similar stable isotopic composition of these aquifers would not necessarily indicate any hydrodynamic relation or interconnection between these aquifer zones, although it does not exclude the possibility of such an interconnection.

With slightly depleted values observed in the A Sand aquifer, a possible different origin of waters in this aquifer or probable different recharge mechanism can be suspected, but the very limited number of samples available from this zone and the relatively small difference observed in the $\delta^{18}O$ content does not allow any further conclusive interpretations.

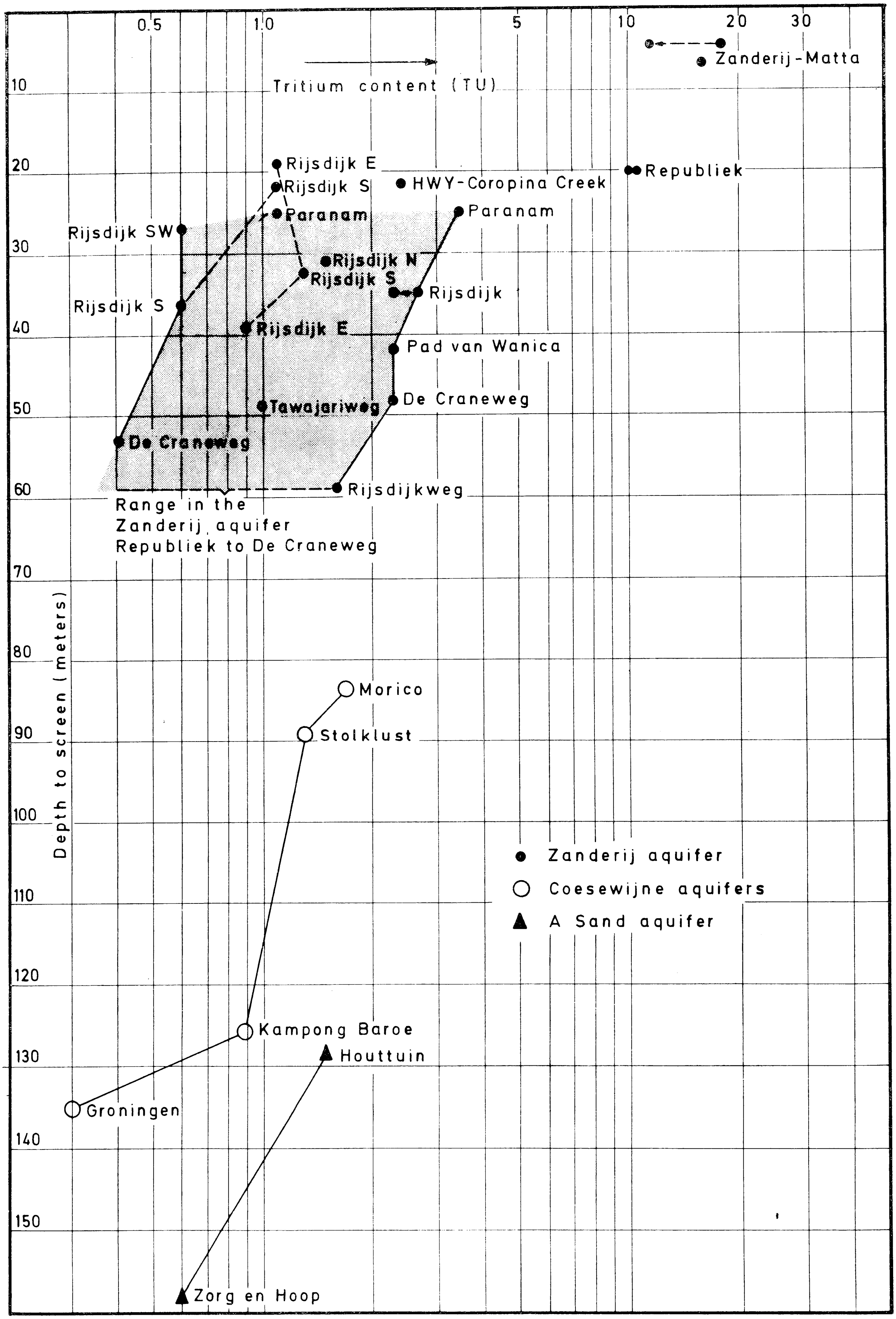
Tritium Results

The tritium content of the wells in the Savannah Belt near Zanderij is quite significant (17.8 ± 1.1 T.U. for 7/71, 16.0 ± 0.7 for 9/71), and the tritium levels observed in these relatively shallow wells are comparable to the present level of tritium concentrations of precipitation at the latitudes of the project area. Thus, the observed tritium values certainly indicate recent recharge in this area, which is also supported by the seasonal water level fluctuations observed in these wells which are caused by seasonal variations of rainfall. The considerably lower tritium value observed in a nearby well in the same area (1.0 ± 0.3 T.U. for [illegible]/71) is apparently due to the overlying impermeable clay layer as found from the drillings.

Similarly, the tritium content of the well in Republiek (10.6 ± 0.6, 10.1 ± 0.5) is evidence for recent recharge occurring in this area, which can be either laterally from the Savannah recharge area or as a direct vertical recharge through the overlying younger sediments, or a combination of both. Therefore, at the Savannah area and the Republiek area, the Zanderij aquifer is being actively recharged.

To the north of Republiek, the tritium content of all the wells in the project area decreases to very low values.

At de Crane Weg and further to the north, the tritium values observed in the Zanderij aquifer range between 0.6 and 2.7 T.U. and should be considered as evidence of the rather slow movement of ground water in this zone between Republiek and de Crane Weg further to the north. The tritium content of Well 1/72 (2.4 ± 0.2 T.U.), which is only a few kilometers north of Republiek, indicates that immediately north of the Republiek area the flow of ground water in the Zanderij aquifer is very slow. In view of the very low tritium values observed, both in



Annex 10, Figure C, - Tritium content versus depth to screen

individual wells and at different depths of the same wells (3/71, 19, 20, 21/72, 13, 16/71), detailed quantitative evaluations for estimating the residence time of flow in the Zanderij aquifer are rather difficult. However, considering the tritium levels observed in precipitation at the latitudes of the project area, such low values of tritium would indicate the average residence time of water to be in the order of 40 years. Simplifying assumptions of the mean residence time indicated by tritium to be equal to a Volume/Discharge $(\frac{V}{D})$ ratio of the system, and the system to be in a steady state condition (that is Discharge = Recharge = Constant), 40 years of residence time would result in

$$\frac{\text{Volume}}{\text{Recharge}} = \frac{\text{Volume}}{\text{Discharge}} = 40$$

for the Zanderij aquifer to the north of Republiek. This can be possible either by an increase of volume of the system to the north of Republiek by a factor of 40 as compared to the volume in the Savannah Belt and the Republiek area, or a decrease in the discharge of the aquifer by the same factor. Considering the physical size of the aquifer, one would hardly expect the volume to the north of Republiek to increase by a factor of 40, and, on the other hand, it is most probable that the discharge of the aquifer decreases considerably from Republiek further to the north. For the estimated annual recharge depth of 500 mm in the Savannah Belt area, the annual recharge volume (for the whole recharge area between the Saramacca and Suriname Rivers) would be $3x10^8$ m^3. For a decrease in discharge by a factor of 40, only $7.5x10^6$ m^3 would be flowing further to the north, and the rest has to be discharged from the aquifer. The withdrawals at Republiek well field are about $3.4x10^6$ m^3/year, and there remains a considerable amount of water to be discharged from the aquifer. One possible explanation would be the hypothesis that aquifers are full, that natural discharge to the ocean is small, and that most of the recharge is being discharged back to the many permanent streams draining the Savannah area. With such a hypothesis, the remaining volume to be discharged from the Zanderij aquifer to the streams would be about $2.9x10^8$ m^3 per year, which would result in an average discharge rate of 9.4 m^3/sec, a value which is not unreasonable. It should be pointed out that all the above evaluations are very rough estimates aimed only at shedding some light on the dynamics of the system, and the values given should be considered as a rough indication of the order of magnitude suggested by the tritium results. As mentioned earlier, any attempt to achieve further detailed quantitative estimates is unwarranted in view of the very low tritium values observed in the project area. The most obvious and convincing evidence from the tritium values is that, while the Zanderij aquifer is being recharged in the Savannah area, the discharge of the aquifer to the north of Republiek is comparatively low and the movement of ground water is relatively slow. Thus, all the above quantitative estimates should be considered as supporting evidence of such a conclusion rather than as absolute values.

The tritium values observed in the Coesewijne and the A Sand aquifers indicated that these aquifers are practically free of tritium. This would indicate that the age of the water in these aquifers is at least 40 years. Thus, recharge (if there is any) to these aquifers must be at a rather slow rate. This is why ^{14}C sampling has been carried out with the aim of studying both the age differences between different aquifer zones and a possible age gradient in each aquifer zone, to shed some more light on the dynamics of the aquifer system in the project area.

Carbon-14 Results

Results of computations of the corrected ages based on ^{13}C analysis and on the available water chemistry data are given on Table A10-D. The biogenic $\delta^{13}C$ value is assumed to be 025.0% in all the correction computations. It should be pointed out that even lower (more depleted values than -25%o) have been observed for biogenic $\delta^{13}C$ in measurements made in some tropical regions. Furthermore, taking also into account rather depleted $\delta^{13}C$ values observed in the project area, the use of a lower (more depleted) value, say -28%o, for biogenic $\delta^{13}C$ might be considered. This would make all ages slightly younger than those given in Table D, but the overall picture would remain the same and interpretations based on the relative difference of the age between sampling points will not change. It should also be mentioned that only part of the pH and temperature values used in the computations are field measurements during ^{14}C sampling, and the rest of the pH values are laboratory measurements after ^{14}C sampling. Due to the fact that the correction of ^{14}C data to estimate the age of water depends much on pH values, a possible deviation of the laboratory measurement of pH from the true field pH value, which is quite common, should be taken into account, and therefore the computed ages should be interpreted accordingly.

Zanderij Aquifer

In the Zanderij Sand aquifer, the ^{14}C content decreases from south to north in the expected general flow direction. A significant difference in the ^{14}C content and, accordingly, in the computed ages between Rijsdijkweg (57.9 ± 1.5% for 3/71) and de Crane Weg (18.5 ± 1.1% for 28/71) would indicate this part of the aquifer to be relatively active in comparison to that farther north of de Crane Weg, where the difference is quite small. As is given in Table D, the age difference between the Rijsdijkweg area and de Crane Weg would result in an estimated mean flow velocity of up to 1 m/year in this part of the Zanderij Sand aquifer. This assumes that the observed age difference is due to the radioactive decay without any mixing, that is, no direct recharge occurs to the aquifer between these two areas. Considering any possible direct recharge to the aquifer in the Rijsdijkweg area, the above estimated value of the mean flow velocity should be an upper limit value. Farther to the north of the de Crane Weg area, there is no significant difference in the age of water, and thus this should be considered as evidence of very slow movement of water (if there is any)

TABLE A10-D

CARBON-14 AGES OF GROUND WATER

Aquifer Zone	Well No.	Code No.	HCO_3	pH	Temp. (°C)	Measured		Biogenic	Estimated	Corrected Age (years)
						$\delta^{13}C$	^{14}C	$\delta^{13}C$ (assumed)	^{14}C (initial)	
Zanderij Sand Aquifer (Zone CI-CII)	3/71	SUR-24	0.82	8.0	(27)	-19.2	57.9	-25.0	111.52	5,419
	17/71	SUR-26	0.24	5.7	(27)	-18.1	16.8	-25.0	68.61	11,631
	28/71	SUR-27	0.44	7.2	(27)	-17.4	18.5	-25.0	96.82	13,682
Coesewijne Sand Aquifer (Zone CIII)	4/70	SUR-20	1.31	6.4*	27*	-17.6	17.0	-25.0	82.80	13,088
	31/71	SUR-21	0.48	6.2*	27*	-18.8	17.0	-25.0	85.16	13,320
	23/71	SUR-25	0.48	7.3	(27)	-16.4	18.9	-25.0	91.79	13,064
"A" Sand Aquifer (Zone CIV)	36/71	SUR-18	0.68	6.6*	29*	-19.3	20.3	-25.0	97.90	13,006
	GMD-19	SUR-19	0.72	6.7*	29*	-12.7	8.5	-25.0	59.53	16,090
	2/69	SUR-23	0.77	6.1	(29)	-21.6	9.0	-25.0	100.77	19,969
Onverdacht	2	SUR-22	0.10	5.5	(27)	-18.8	57.2	-25.0	70.24	1,698
	3/71	SUR-24	0.82	(5.5)	27	-19.2	57.9	-25.0	73.04	1,921

* Field measurements during ^{14}C sampling

( ) Assumed values

in this part of the aquifer. The difference in the computed ages between Wells 28/71 and 17/71 is not significant, considering the analytical error on ^{14}C measurements and also overall simplifying assumptions involved in the correction procedure.

Coesewijne Aquifers

Samples collected from the Coesewijne aquifers have similar ^{14}C values, and the corrected ^{14}C ages are all practically the same (Table D). This would indicate that a significant flow of water in this aquifer should not be expected and, under the present dynamic conditions, the water in this aquifer seems to be rather stagnant. This would also suggest that there is no significant recharge occurring to this zone. Thus, it is quite probable that any withdrawals from the aquifer could result in mining of the ground water available in this zone.

A Sand Aquifer

Considering similar ^{14}C values observed in the Houttuin (9.0 ± 0.7% for 2/69) and the Uitvlugt (8.5 ± 0.8 for GMD-19) areas, there seems to be no age gradient in this zone also. A significant difference in the corrected ages between these two wells (Table D) is due to the very enriched $\delta^{13}C$ value (-12.7) observed in well GMD-19. Considering the rather uniform $\delta^{13}C$ values of about -19‰ observed in all the other wells in the project area, one should doubt the validity of the very enriched $\delta^{13}C$ value observed in well GMD-19, or, at least, further sampling would be most useful. Thus, although the difference in the corrected ages indicates an inland age gradient, the observed discrepancy in $\delta^{13}C$ values would not allow any conclusive interpretation in this regard, and, in view of similar ^{14}C values of these two wells, it is also quite probable that there exists no age gradient, which would mean no significant flow occurs in the aquifer. The third sample from this zone in the Zorg en Hoop area (20.3 ± 0.7% for 36/71) has a significantly higher ^{14}C content as compared to the other two samples, thus indicating younger water in this part of the aquifer. Normally, one would not expect such variations to occur in the ^{14}C content of the confined A Sand aquifer, considering both the depth of the wells and available hydrogeological data. The ^{14}C value and the age of water observed in the Zorg en Hoop area being comparable to that of the above Coesewijne aquifers might suggest an interconnection between these two zones in this part of the area, and a significant contribution from the Coesewijne aquifer to the A Sand may be suspected. However, the existence of a thick, impermeable clay layer between these two zones and the piezometric head in the lower Zone C-IV being generally higher than that of all above zones, it is most unlikely to have such a downward leakage of water into the A Sand. Therefore, it is very difficult to interpret the ^{14}C value observed in the Zorg en Hoop area, and further detailed sampling would be required to reach a reasonable interpretation.

Onverdacht Aquifers

The only ^{14}C sample available from Onverdacht (57.2 ± 3% for Well No. 2) is evidence of relatively younger water in this series. Its ^{14}C content being quite similar to that observed in the Zanderij aquifer at comparable depths in the Rijsdijkweg area (57.9 ± 5% for 3/71) would suggest that the movement of water through Onverdacht takes place at a similar rate as in the Zanderij aquifer surrounding it, and there is no apparent retardation of the water movement in the Onverdacht series. The difference in the corrected ages between Well No. 2 in the Onverdacht aquifer and Well 3/71 in the Zanderij aquifer is due to the high pH value (8.0) of 3/71. Corrected ages would be similar for these two wells if pH = 5.5, equal to that of Onverdacht well, is used for 3/71, as given in the last line of Table D.

Comparison of ^{14}C Age between Different Zones

The results of ^{14}C sampling and computed ^{14}C ages indicate that Zanderij aquifer in the Rijsdijkweg area and the Onverdacht series contain quite young waters, as compared to all others further north, and thus there is evidence of recharge occurring at a certain rate to this part of the aquifer, which is most probably from the southern recharge area in the Savannah Belt. At de Crane Weg and further to the north, the ^{14}C content and the age of water in the Zanderij and the Coesewijne aquifers it practically the same, and it is not possible to distinguish between the two aquifers. The A Sand aquifer is older than the above two zones, excluding the sample in the Zorg en Hoop area (Well 36/71). Thus, should there be any recharge occurring to this deep zone, it must be at a lower rate as compared to the above zones. As already mentioned in earlier paragraphs, in all of the aquifer zones to the north of the de Crane Weg area the flow of water is not really significant, and, thus, if there is any recharge occurring, it must be at a very low rate. However, older ages observed in the A Sand lead to the further conclusion that this is the zone where the recharge to the aquifer is most insignificant (if there is any).

CONCLUSIONS

The results of the environmental isotope study conducted in the coastal aquifers of the project area have proved to be useful to allow interpretations and evaluations as regards the hydrogeology of the ground water basin and its dynamics.

1. Stable isotope data indicate that the Zanderij and the Coesewijne Sand aquifers have the same stable isotopic composition. Thus, the waters in these two aquifers have the same origin or similar source of recharge. Relatively depleted values observed in the A Sand aquifer suggest the origin of waters in this aquifer zone to be different from the above zones;

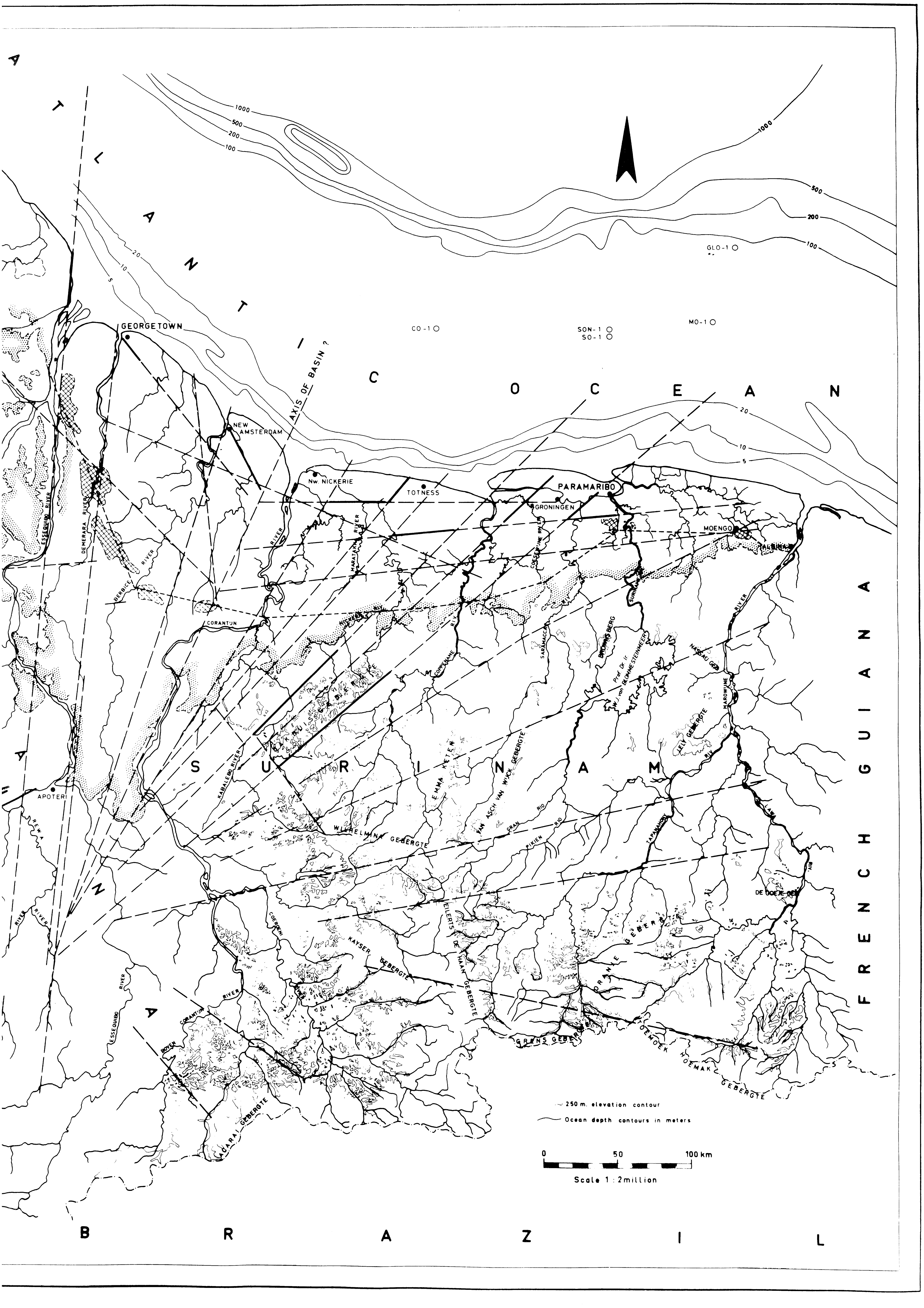
however, the limited number of samples available would not allow any conclusive interpretations in this regard. The similar stable isotopic composition of the Zanderij and the Coesewijne aquifers does not allow any conclusive interpretations as regards a possible interconnection between them. The similar stable isotopic composition of these aquifers would not necessarily indicate any hydrodynamic relation or interconnection between them, although it does not exclude such a possibility.

2. The tritium data clearly indicate that the Zanderij Sand aquifer is being recharged in the Zanderij and Republiek area and that the aquifers in this part are active. However, only a small portion of the recharge should be flowing to the north of the Republiek area, and the movement of water is rather slow between Republiek and Rijsdijkweg and farther to the north.

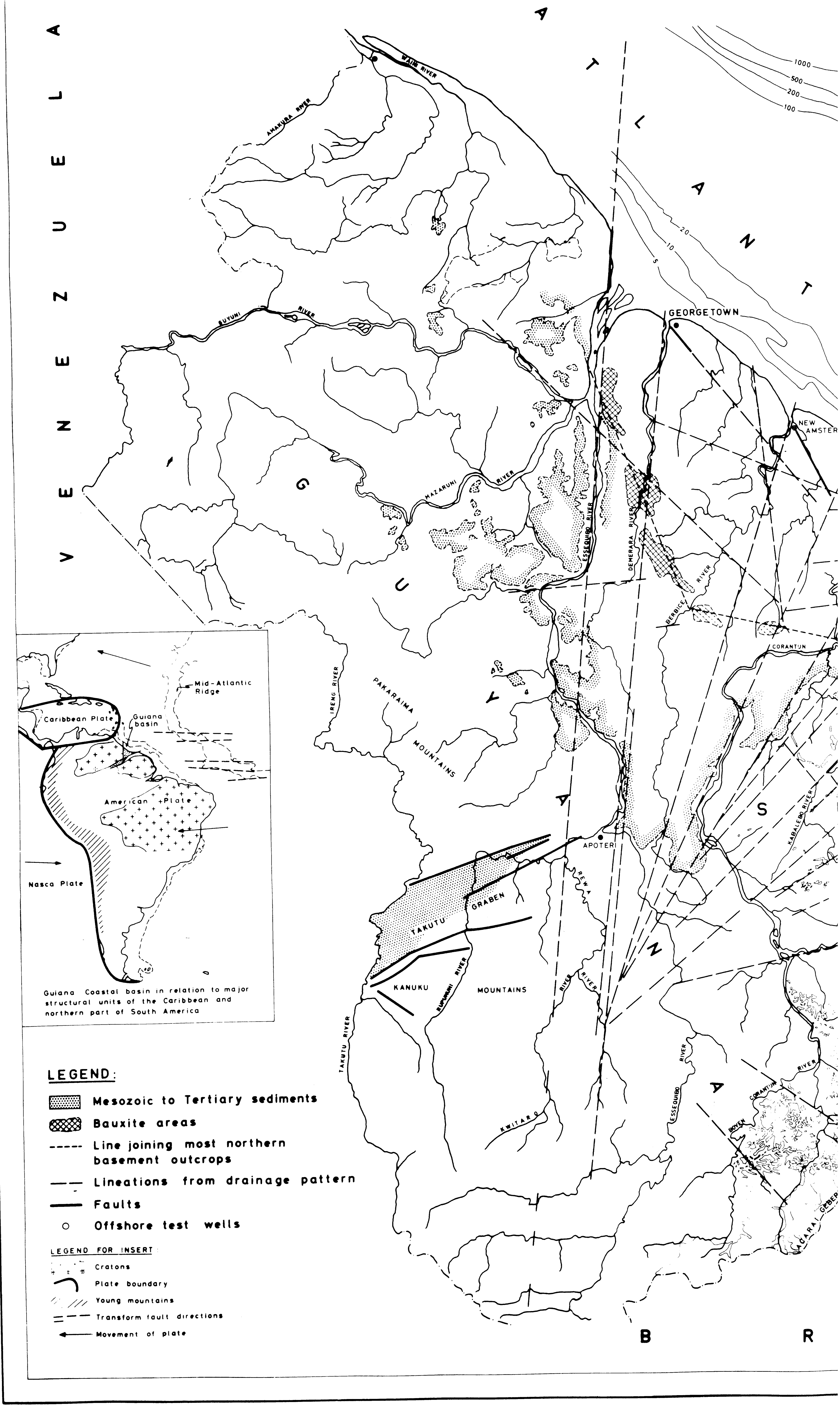
3. Carbon-14 data and computed corrected ages indicate rather young waters in the Zanderij aquifer at the Rijsdijkweg area and, as suggested by tritium as well, would be an evidence of certain recharge occurring to this zone at Rijsdijkweg, which is most probably a lateral contribution from the Savannah Belt. The ^{14}C age gradient between Rijsdijkweg and de Crane Weg in the Zanderij aquifer indicates a mean flow velocity of about 1 m/year in this part of the Zanderij aquifer. Similar ^{14}C content and age of the water farther to the north of de Crane Weg indicate that the flow of water to the north of de Crane Weg is not significant in the Zanderij aquifer.

Similar ^{14}C content of the samples from the Coesewijne aquifers should be considered as evidence for the flow of water being very slow (if any) in this aquifer, which would also indicate that any recharge to this aquifer is most unlikely or at a very slow rate. Similar considerations apply to the A Sand aquifer, and, the water in this aquifer being oldest, the movement of water is least significant (if any) and the possibility of this zone being recharged is a minimum.

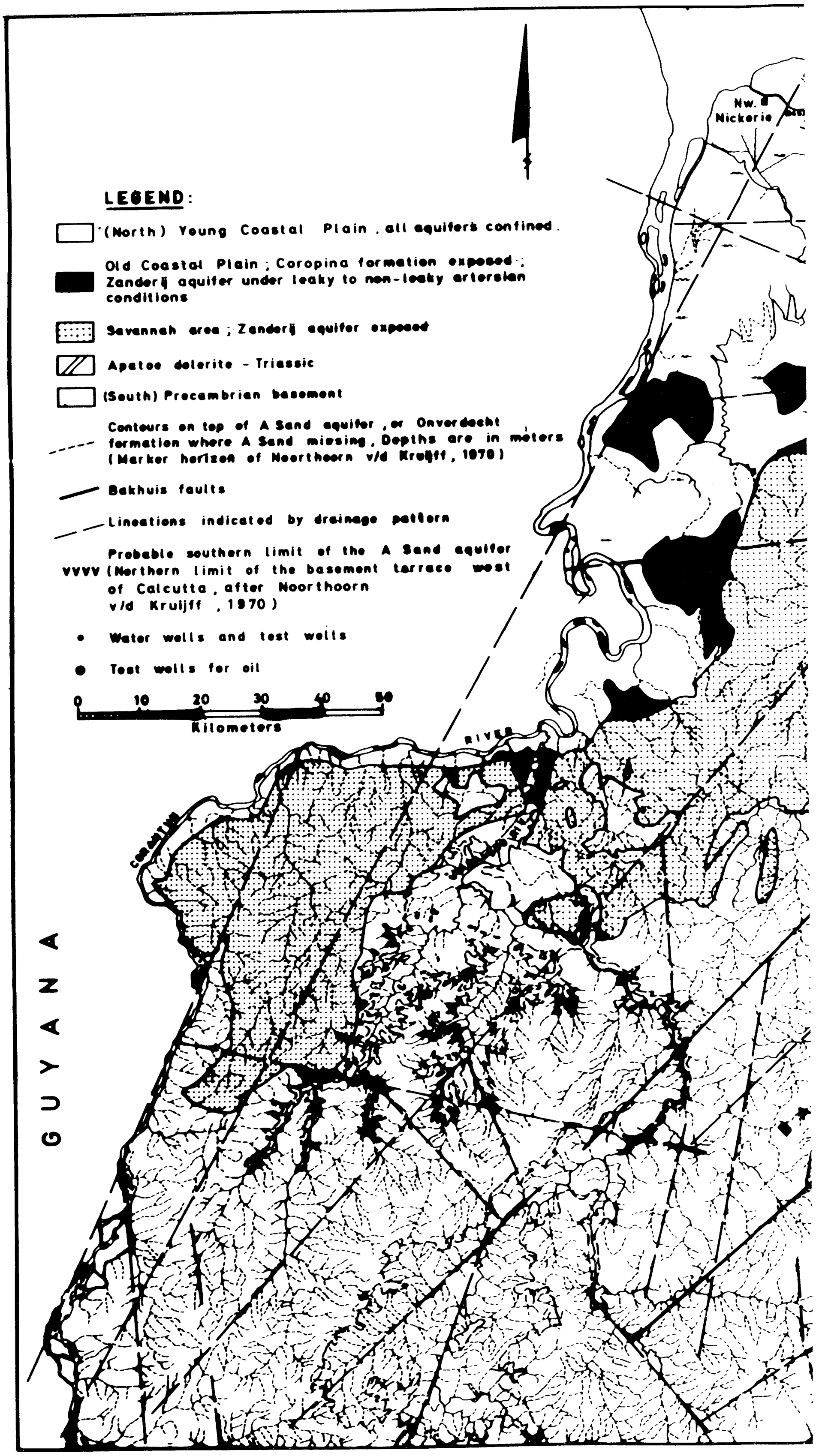
From the environmental isotope study it seems to be the case that in all of the aquifer zones north of de Crane Weg, there is no significant flow of water through the ground water basin under the present hydrodynamic conditions, and it is unlikely that significant recharge occurs to the aquifers. However, in the Zanderij and Republiek area, where only the Zanderij aquifer exists, the aquifer is being recharged actively and a small portion of recharge flows down to the Rijsdijkweg and de Crane Weg area.

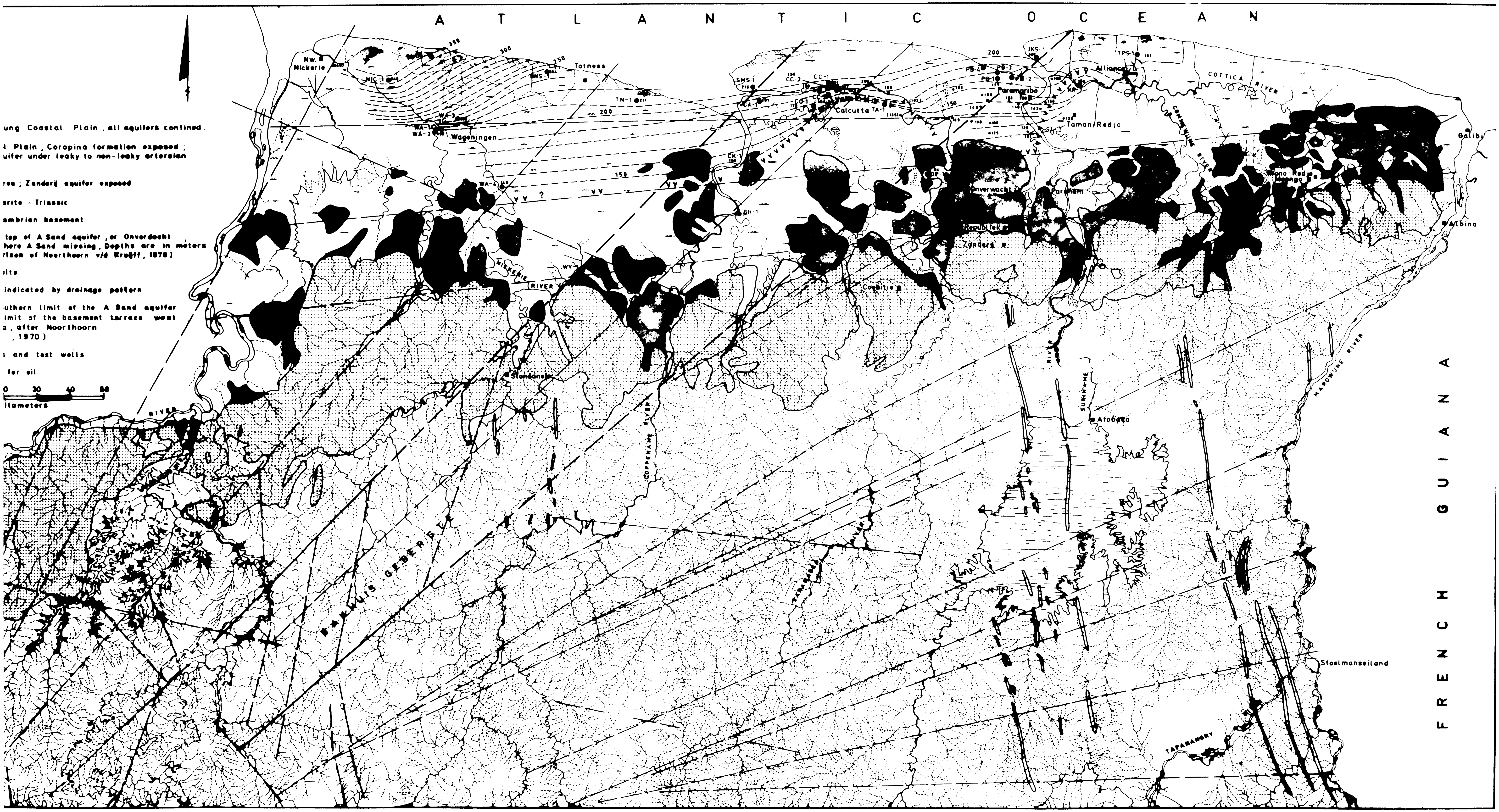


-1, The coastal basin of Surinam and Guyana

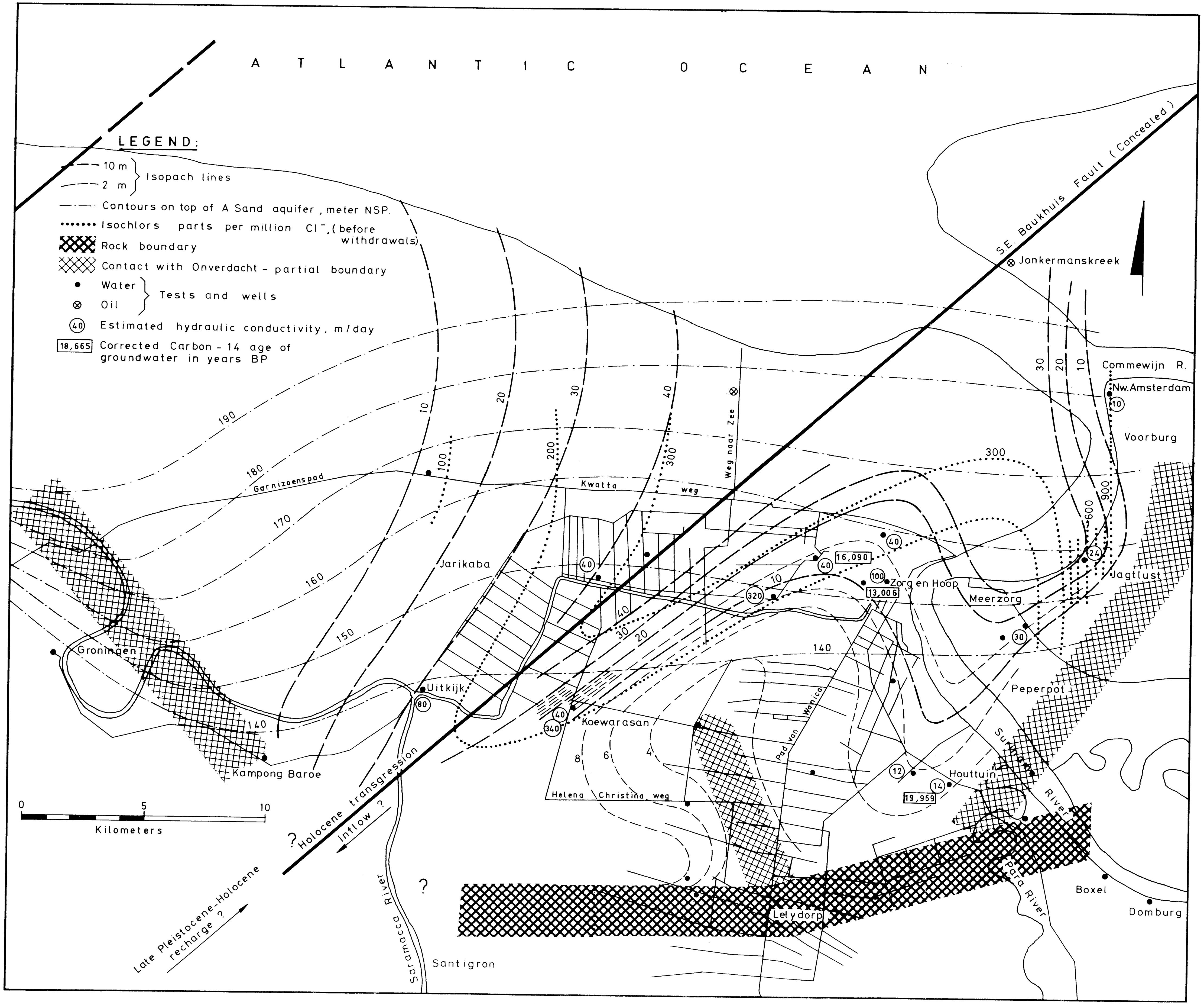


Enclosure III-1, The coastal basin of

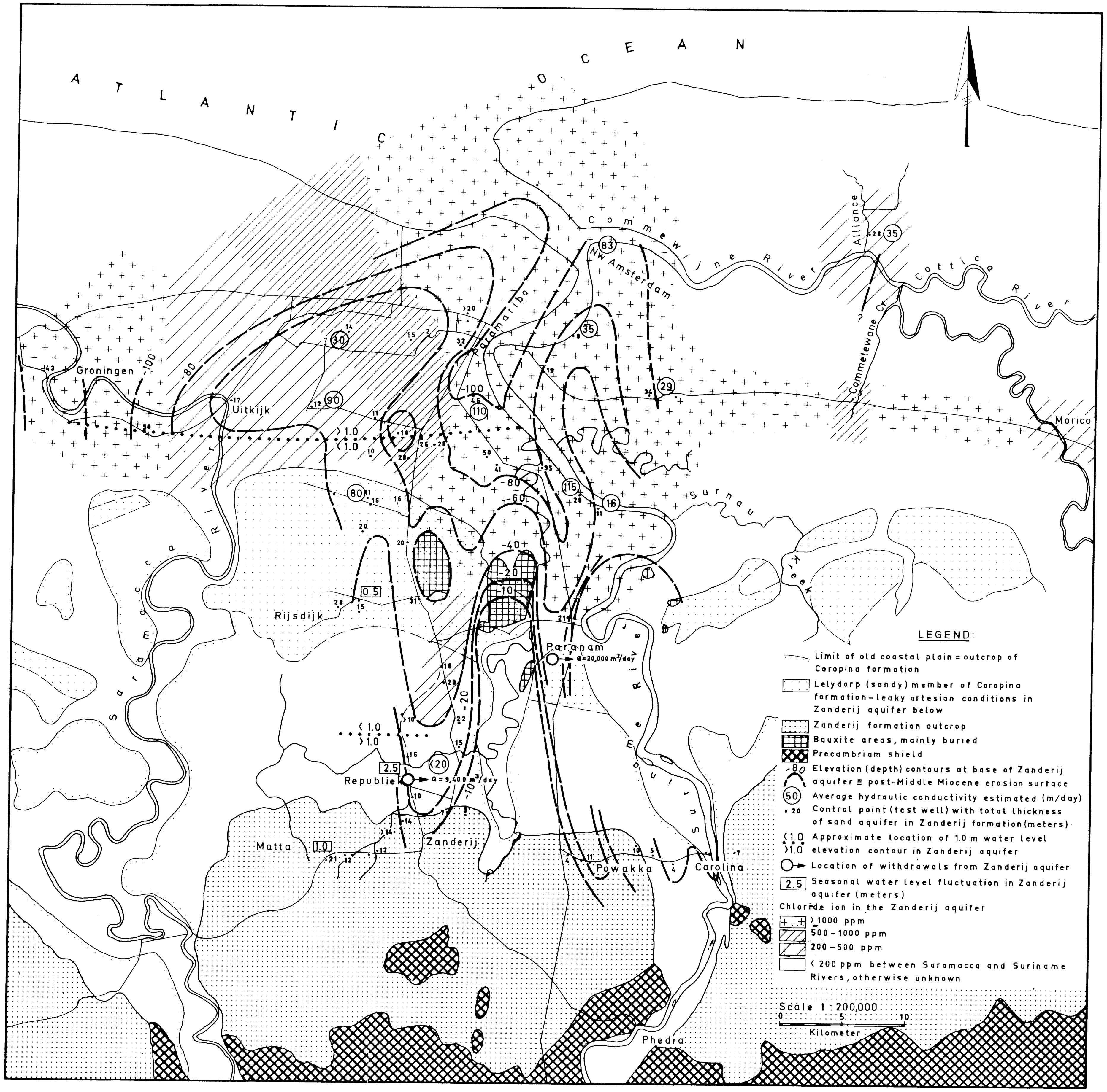

LEGEND:
(North) Young Coastal Plain, all aquifers confined.
Old Coastal Plain; Coropina formation exposed; Zanderij aquifer under leaky to non-leaky artesian conditions
Savannah area; Zanderij aquifer exposed
Apatoe dolerite - Triassic
(South) Precambrian basement
Contours on top of A Sand aquifer, or Onverdacht formation where A Sand missing, Depths are in meters (Marker horizon of Noorthoorn v/d Kruijff, 1970)
Bakhuis faults
Lineations indicated by drainage pattern
VVVV Probable southern limit of the A Sand aquifer (Northern limit of the basement terrace west of Calcutta, after Noorthoorn v/d Kruijff, 1970)
Water wells and test wells
Test wells for oil
0
10
20
30
40
50
Kilometers
Nw. Nickerie
RIVER
CORANTIJN
GUYANA



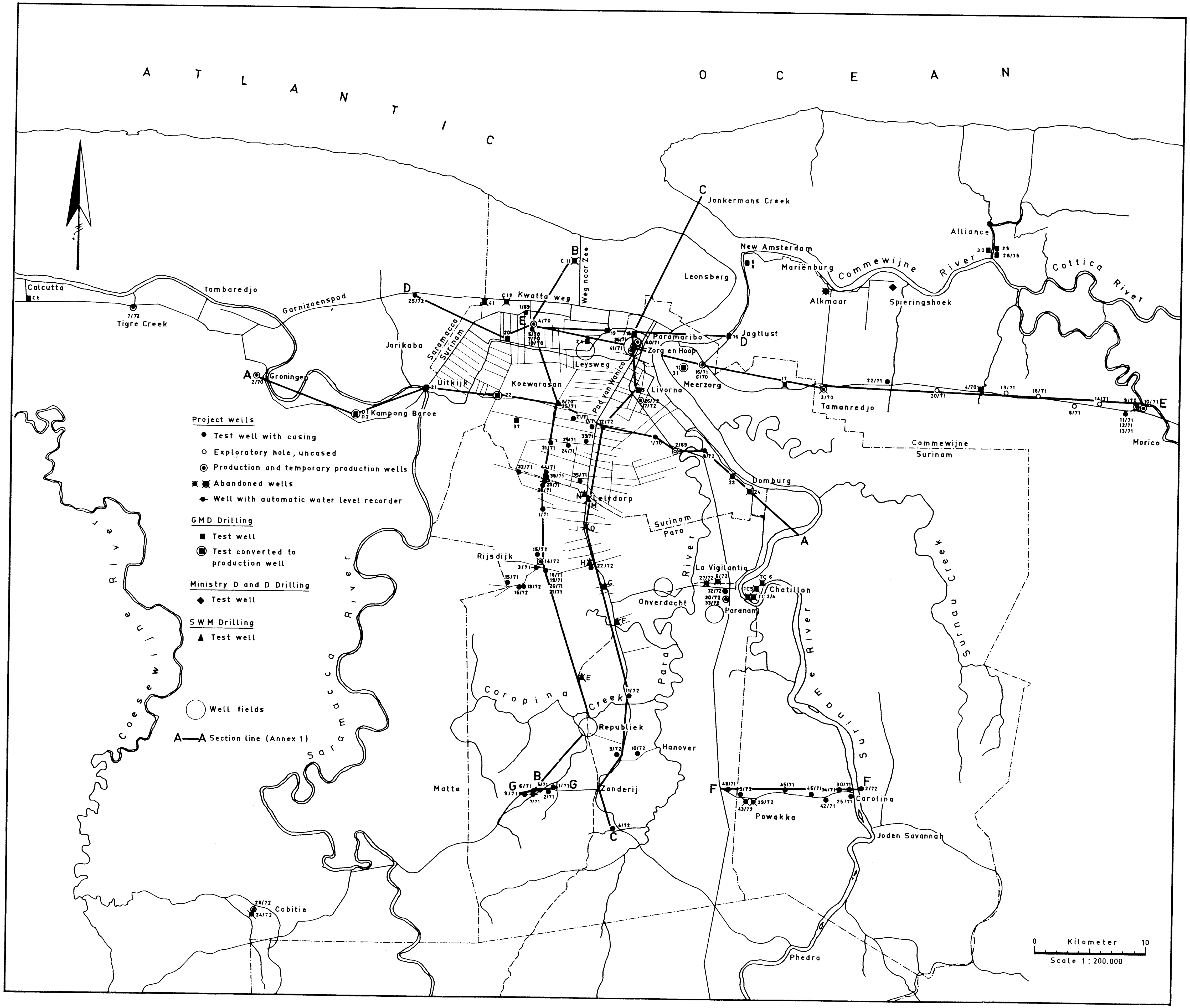
Enclosure ~~2~~ III-2, Northern Surinam showing limits and features of the coastal artesian basin



Enclosure III -3, Hydrogeological features of the A Sand Aquifer



Enclosure III-4, Hydrogeological features and salinity distribution in the Zanderij aquifer in the vicinity of Paramaribo and Zanderij



Enclosure III-5 ,Well locations section lines in the Paramaribo - Zanderij area

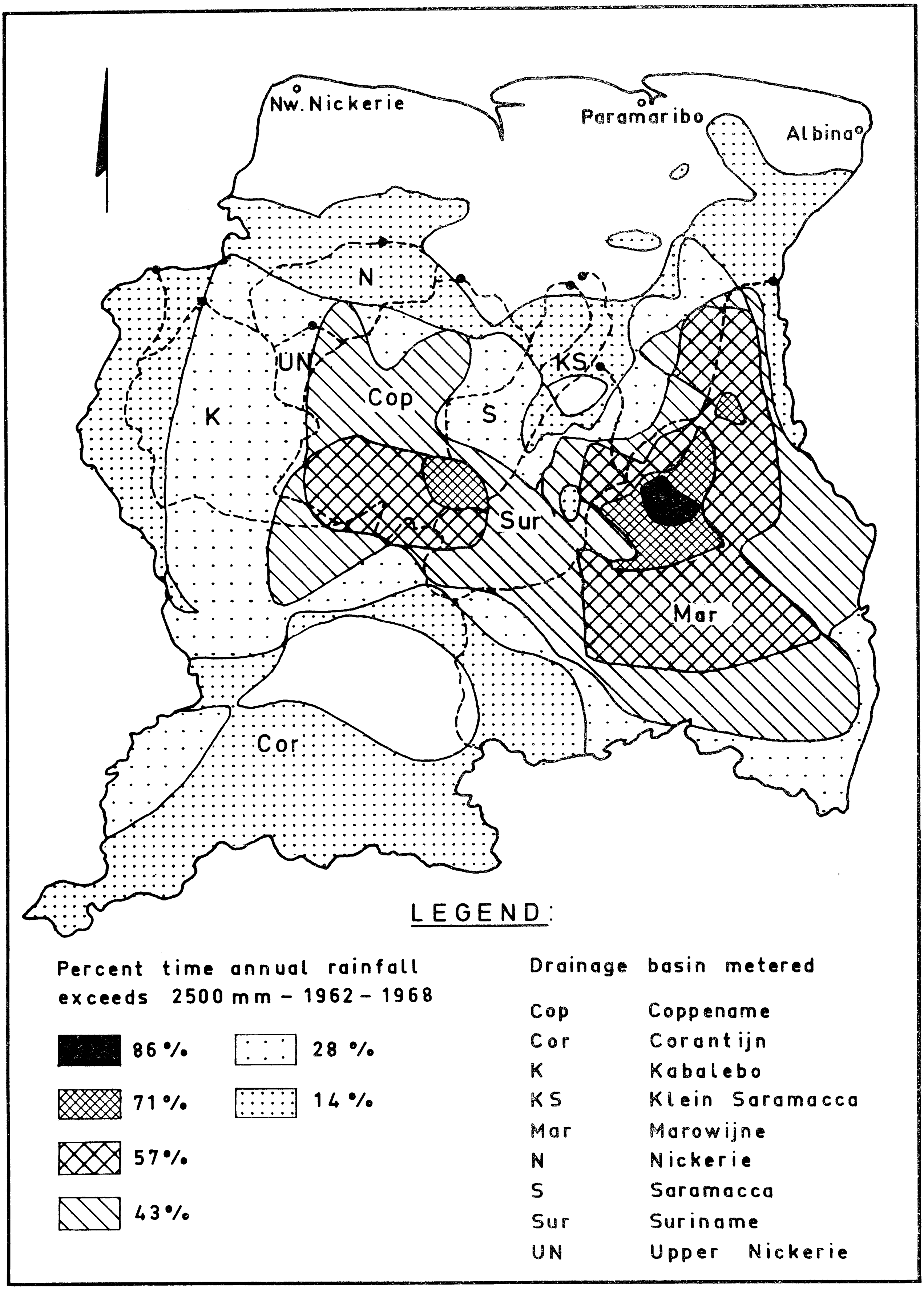


Figure III - 1 , Distribution of rainfall over 2500mm/year, and locations river basins with gauging stations

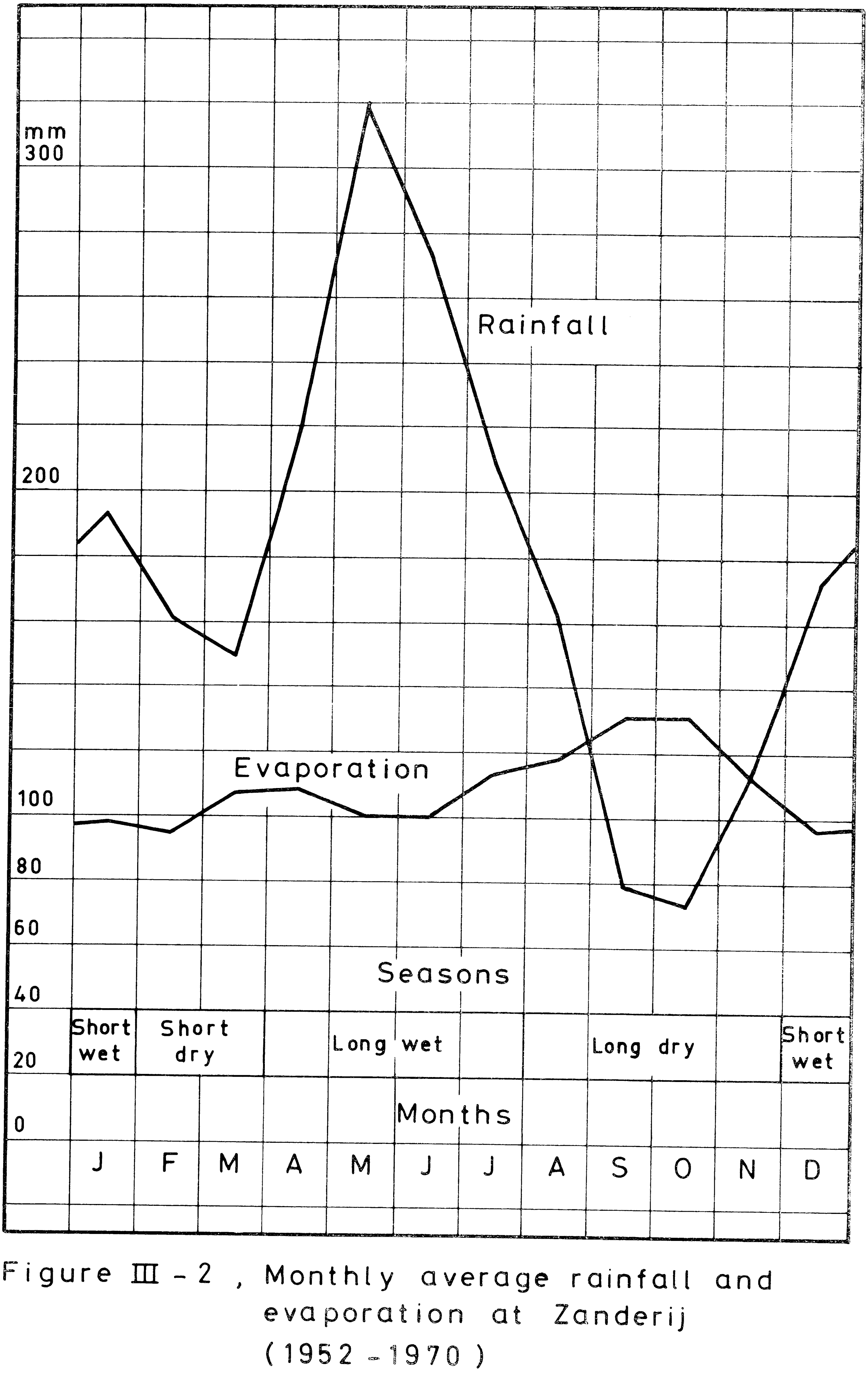


Figure III - 2 , Monthly average rainfall and evaporation at Zanderij (1952 - 1970)

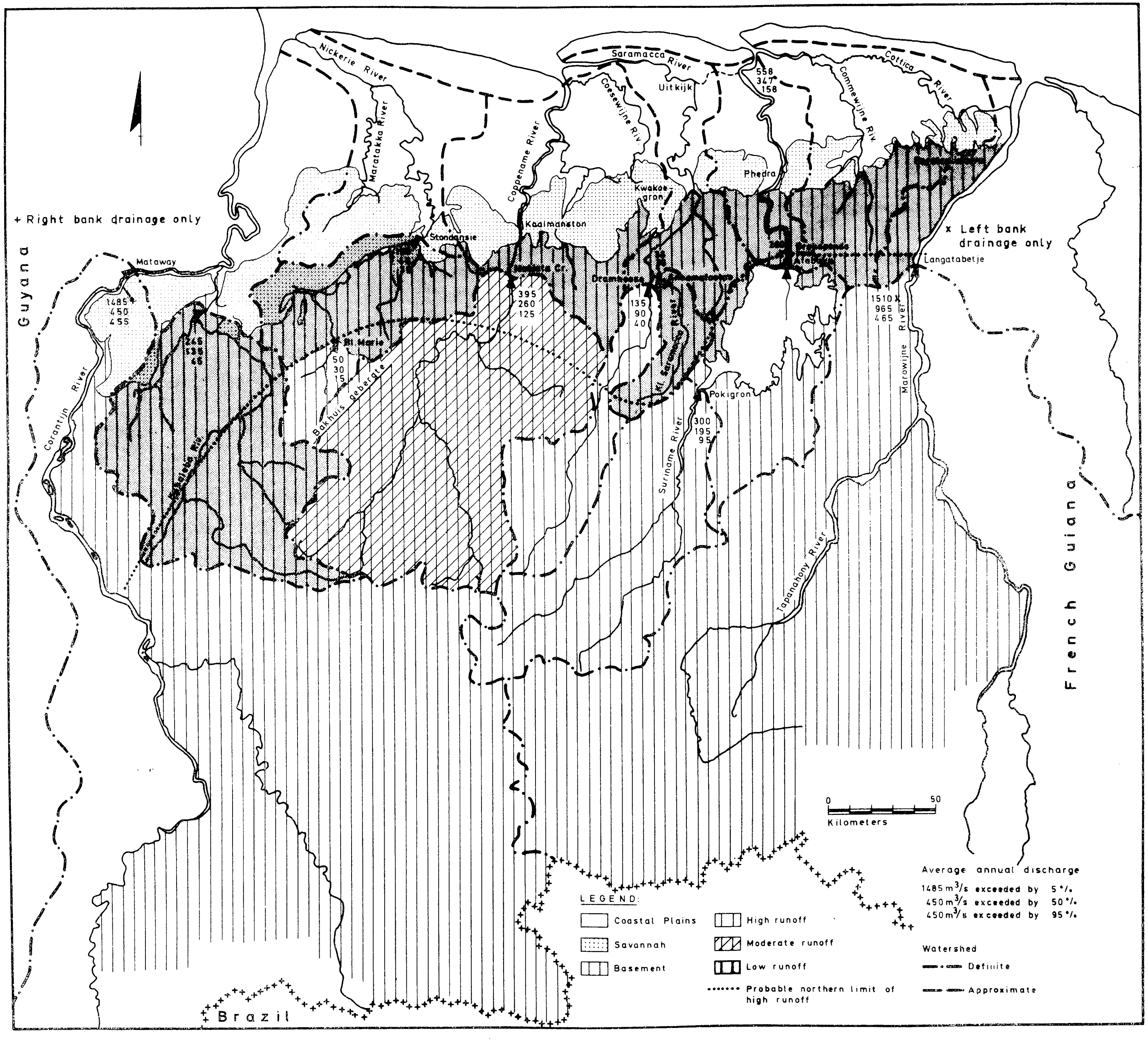


Figure III-3, Drainage basins of Surinam

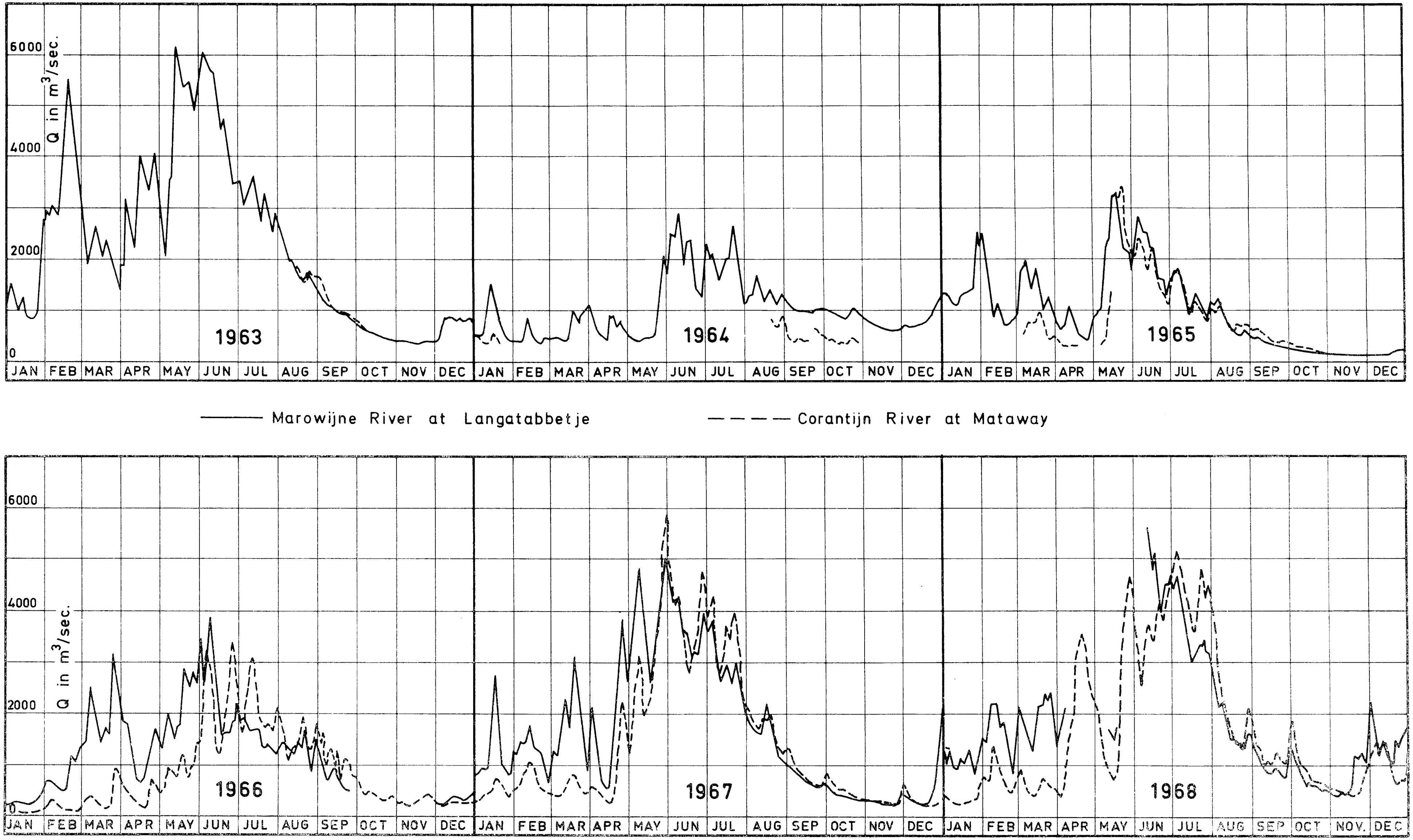


Figure III - 4, Hydrographs of the Marowijne and Corantijn Rivers

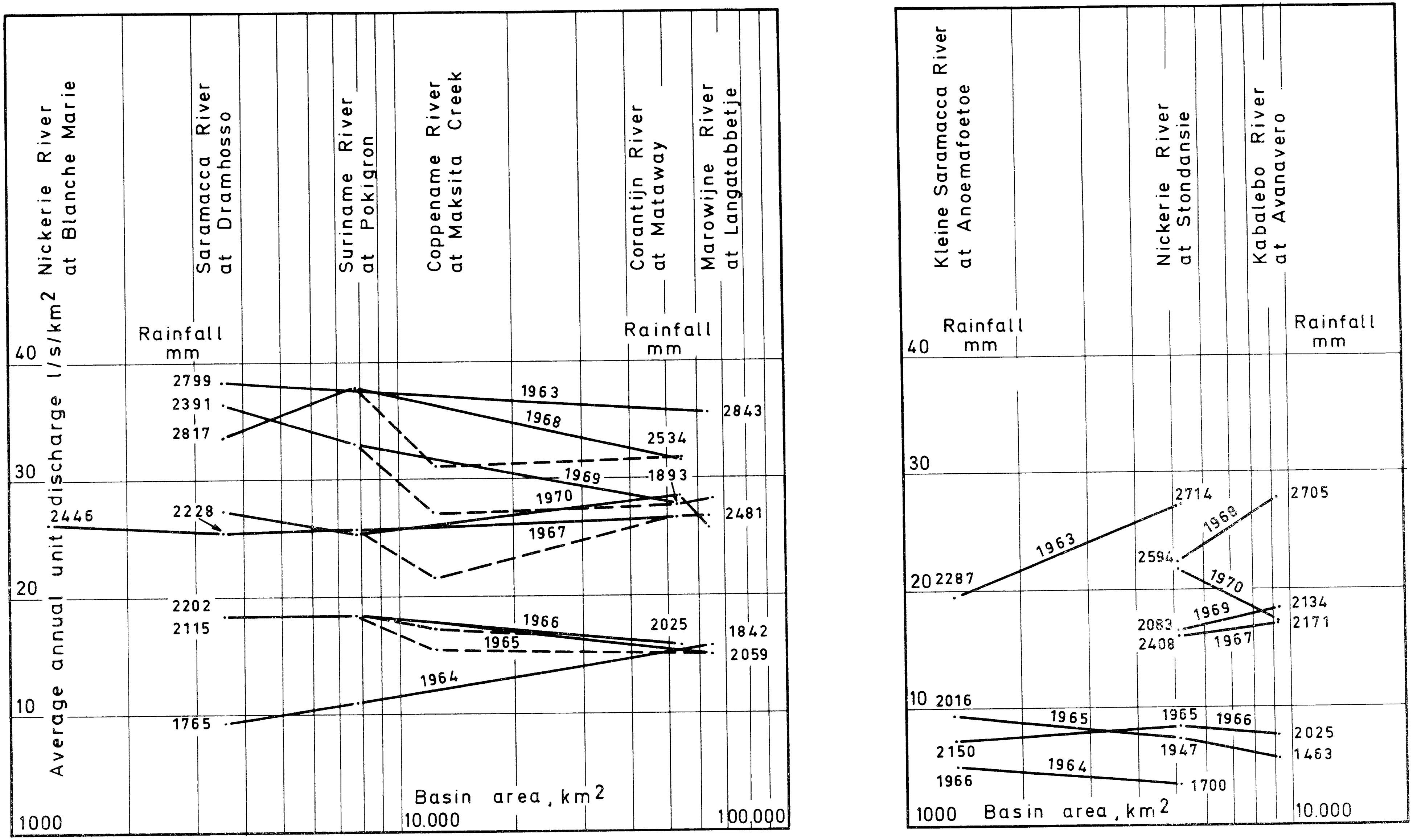


Figure III - 5, Average annual unit discharges and basin areas

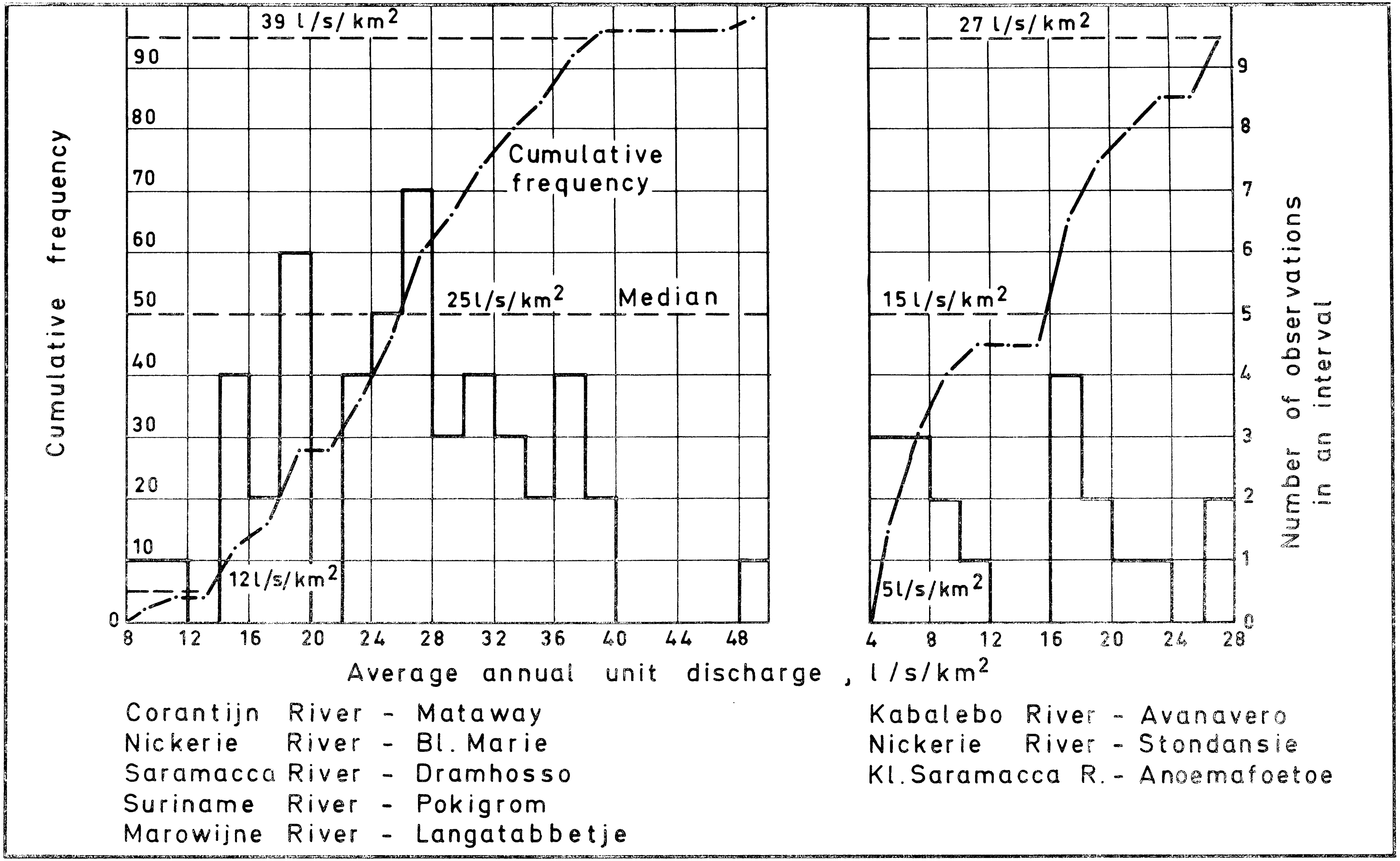


Figure III - 6, Distrubution of average annual unit discharge for the years 1952 - 1970 inclusive

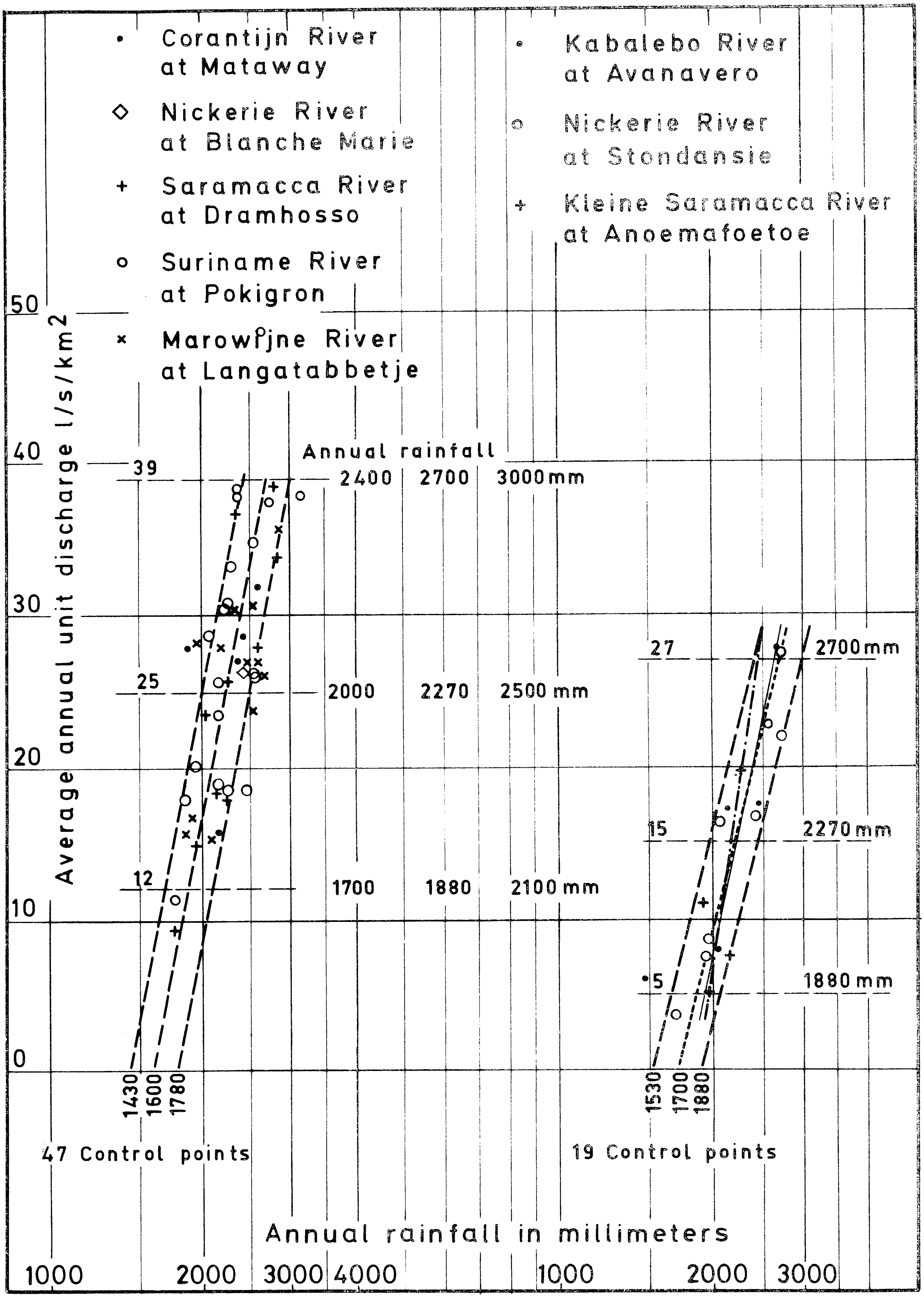
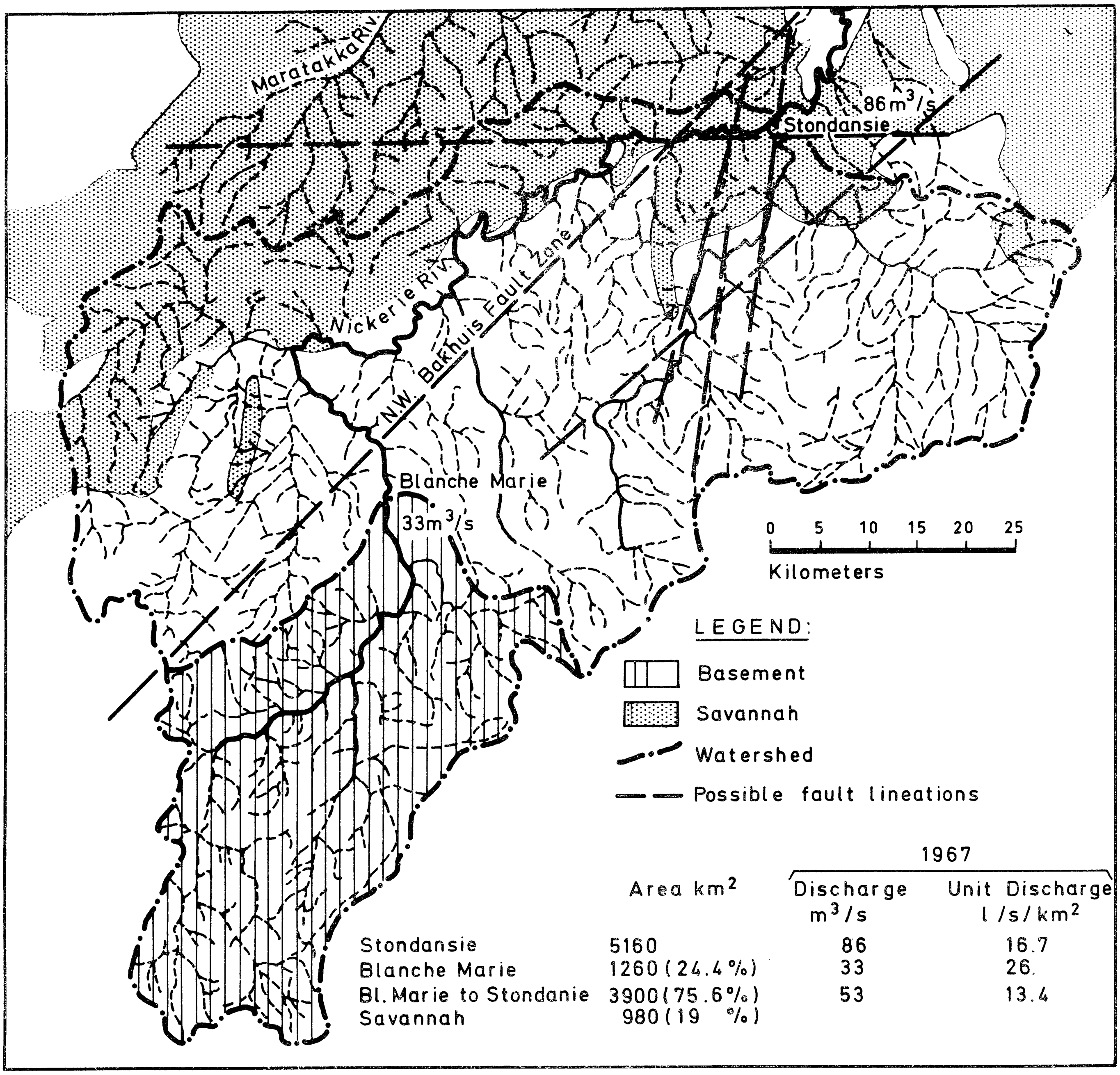


Figure III - 7, Relationship between annual rainfall and average annual unit discharge



	Area km^2	1967	
		Discharge m^3/s	Unit Discharge l /s/km^2
Stondansie	5160	86	16.7
Blanche Marie	1260 (24.4 %)	33	26.
Bl. Marie to Stondanie	3900 (75.6 %)	53	13.4
Savannah	980 (19 %)		

Figure III - 8, The Nickerie River basin

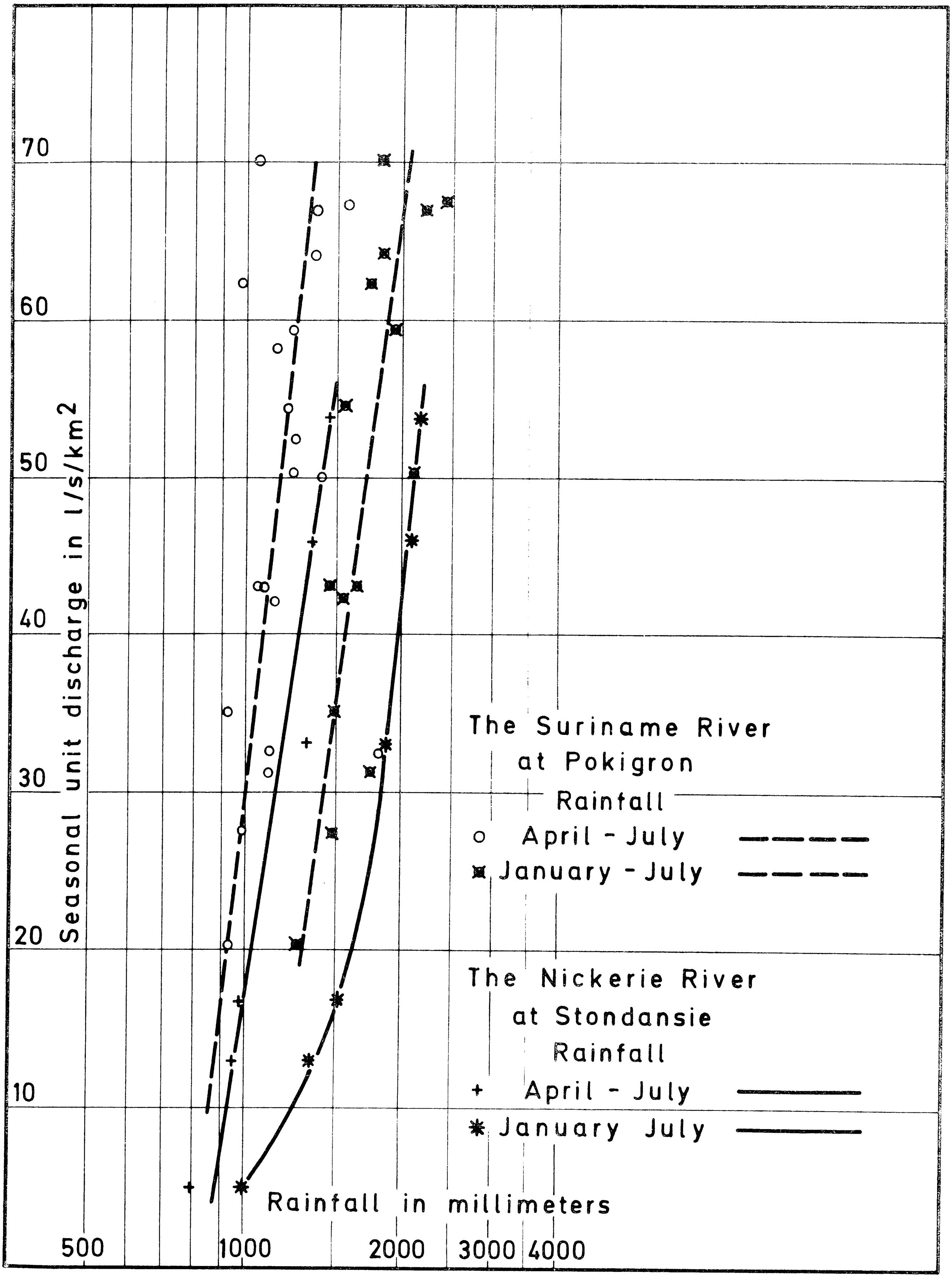


Figure III-9, Relationship of rainfall and unit discharge for the long wet season

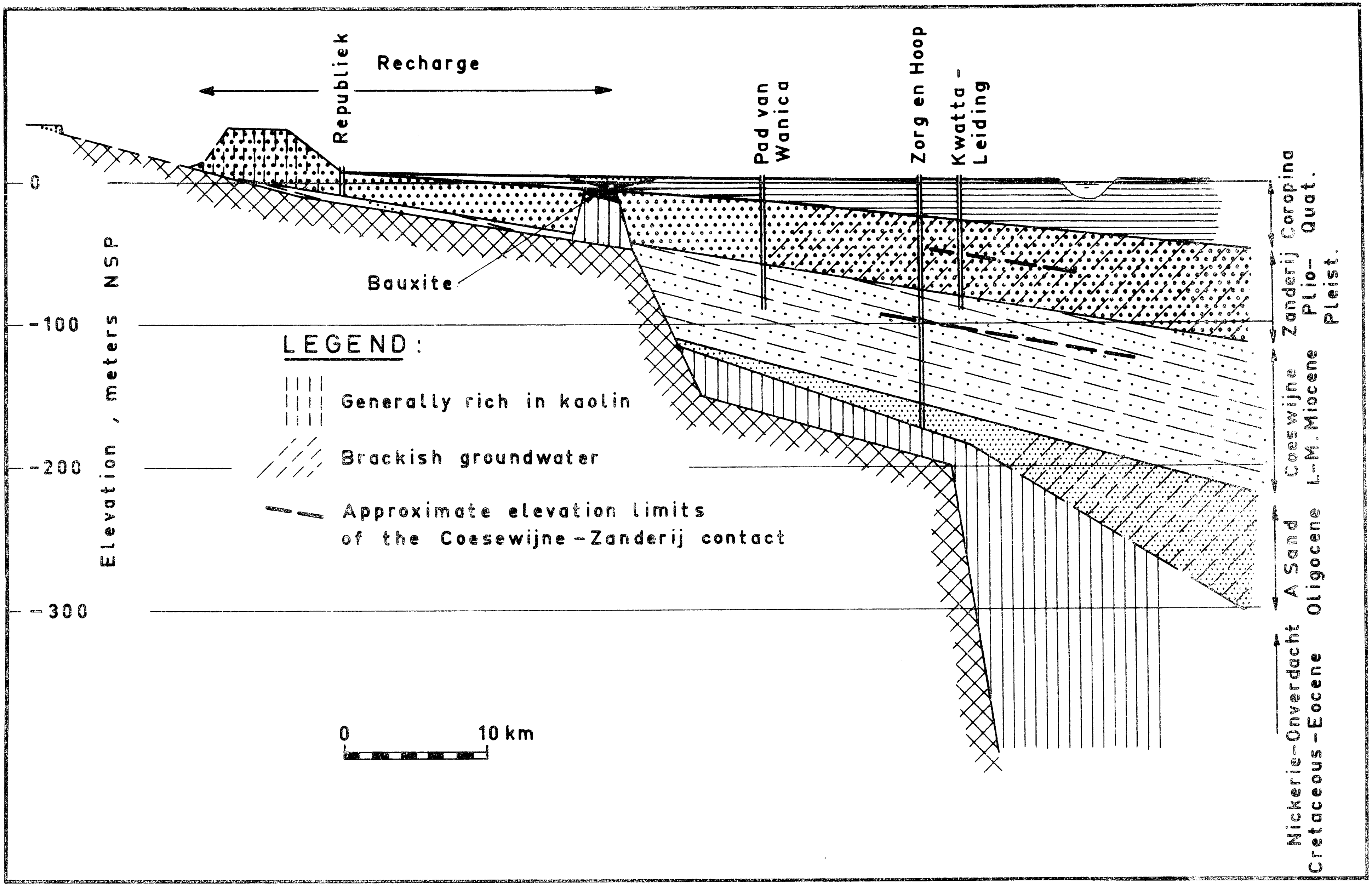


Figure III-10, Idealized N-S section of the onshore coastal basin near Paramaribo

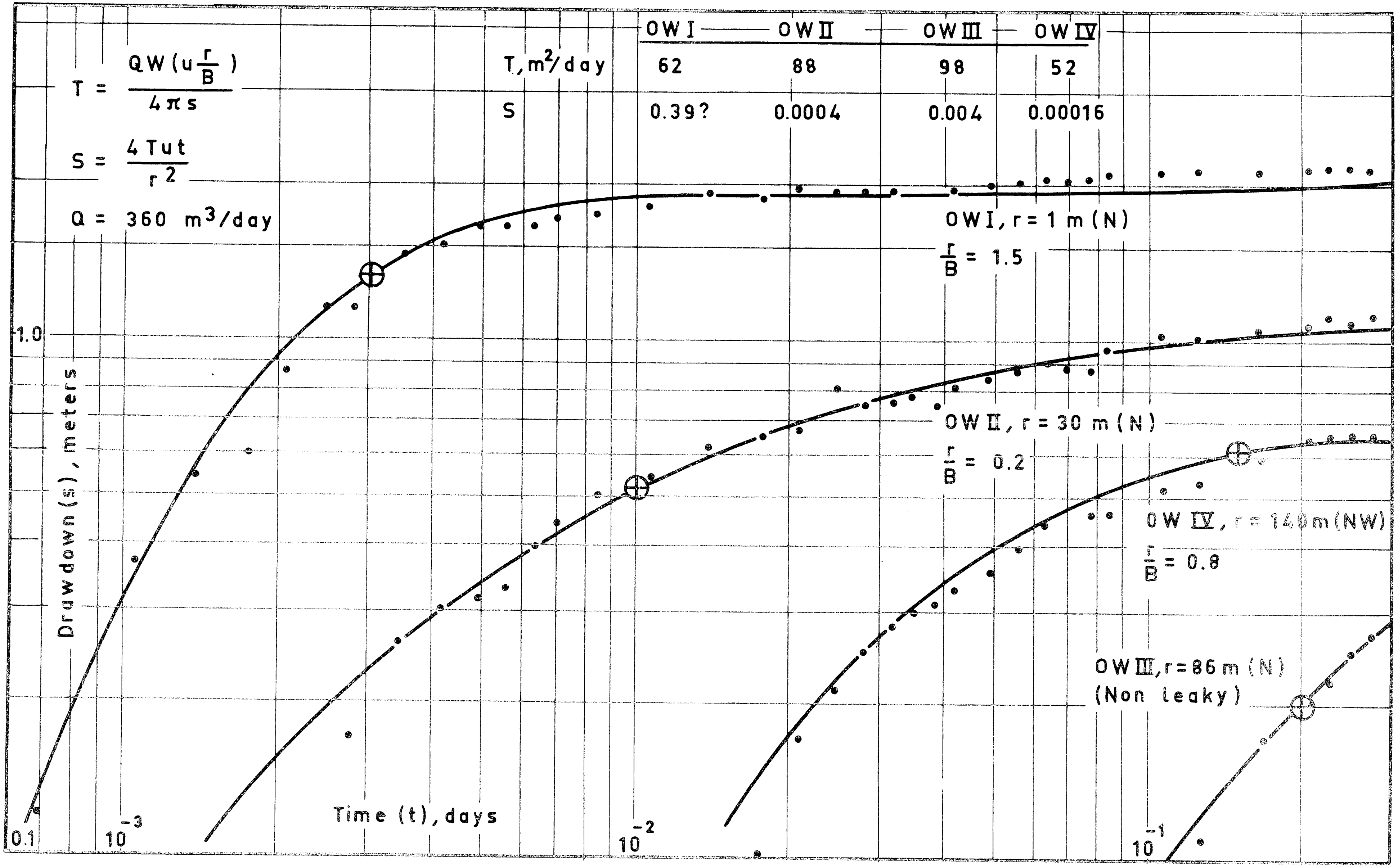


Figure III- 11 , Aquifer test at Onverdacht (Billiton Mine), 17 December 1962 - Upper Onverdacht formation aquifer. (Data from Surinam Water Company)

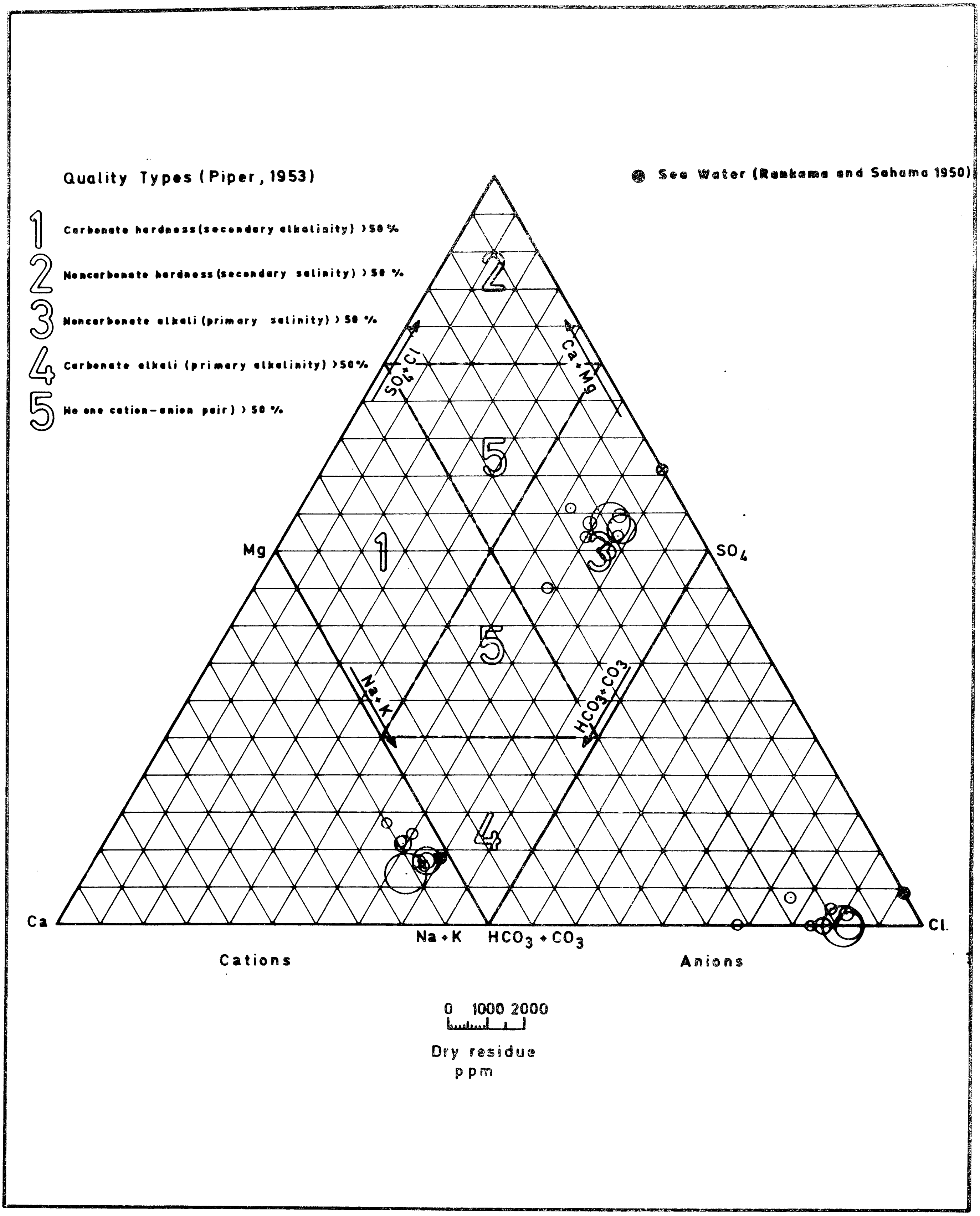


Figure III-12, Trilinear diagram representing percent of total equivalents per million of cations and anions in samples taken from the A Sand aquifer

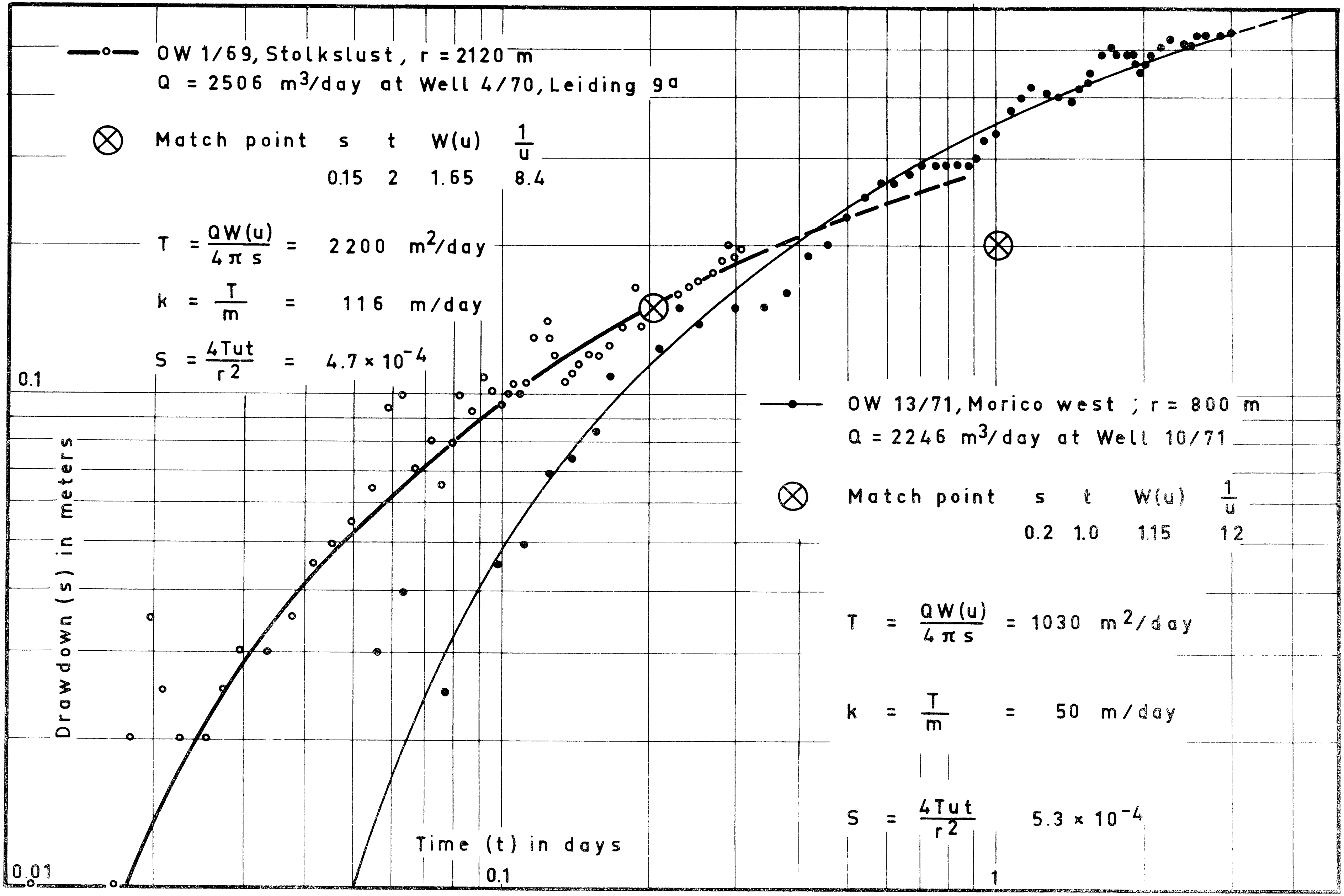


Figure III-13 , Coesewijne aquifer tests at Kwatta and Morico

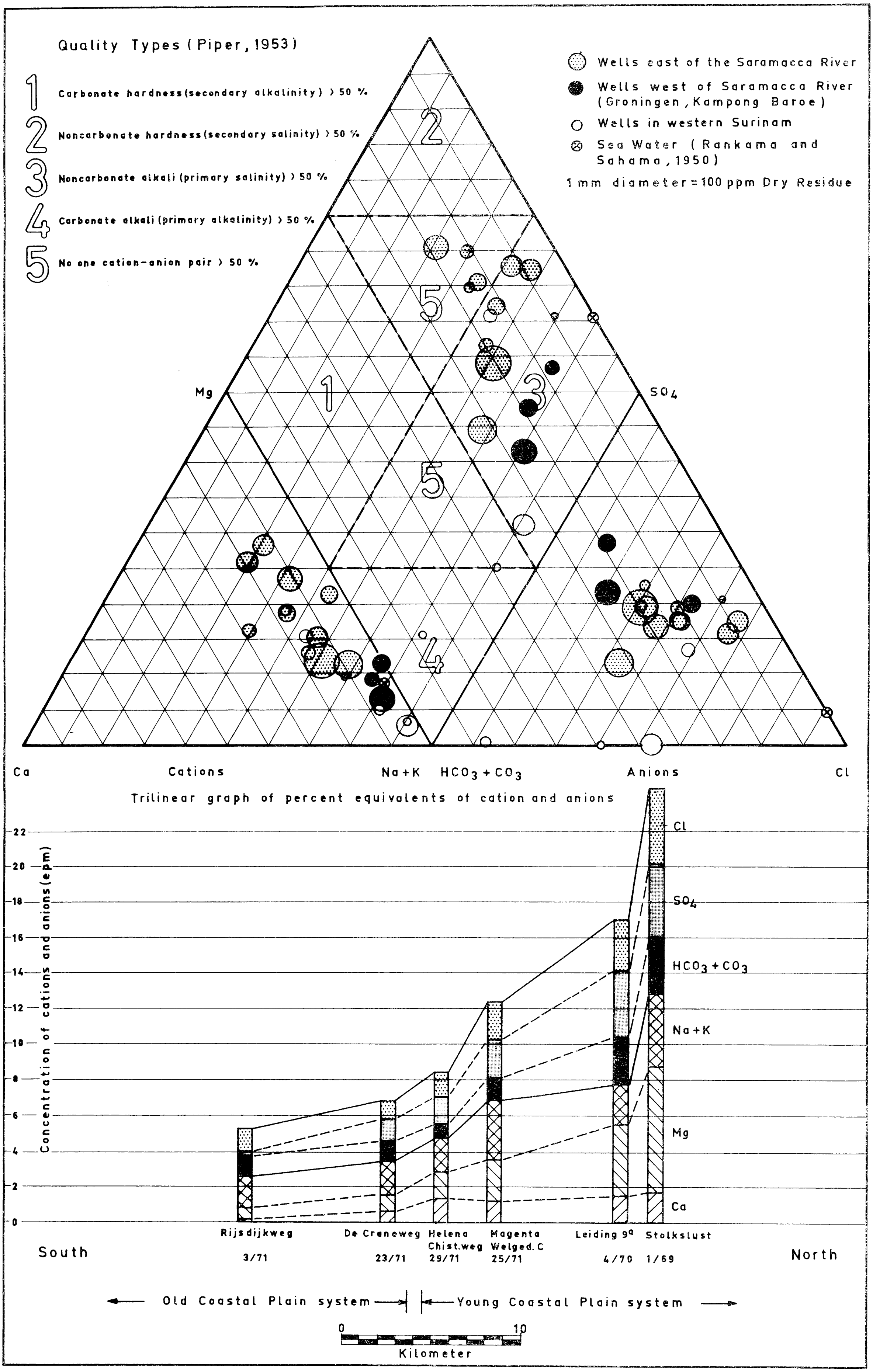


Figure III-14 ,Chemical quality of water from the Coesewijne aquifers

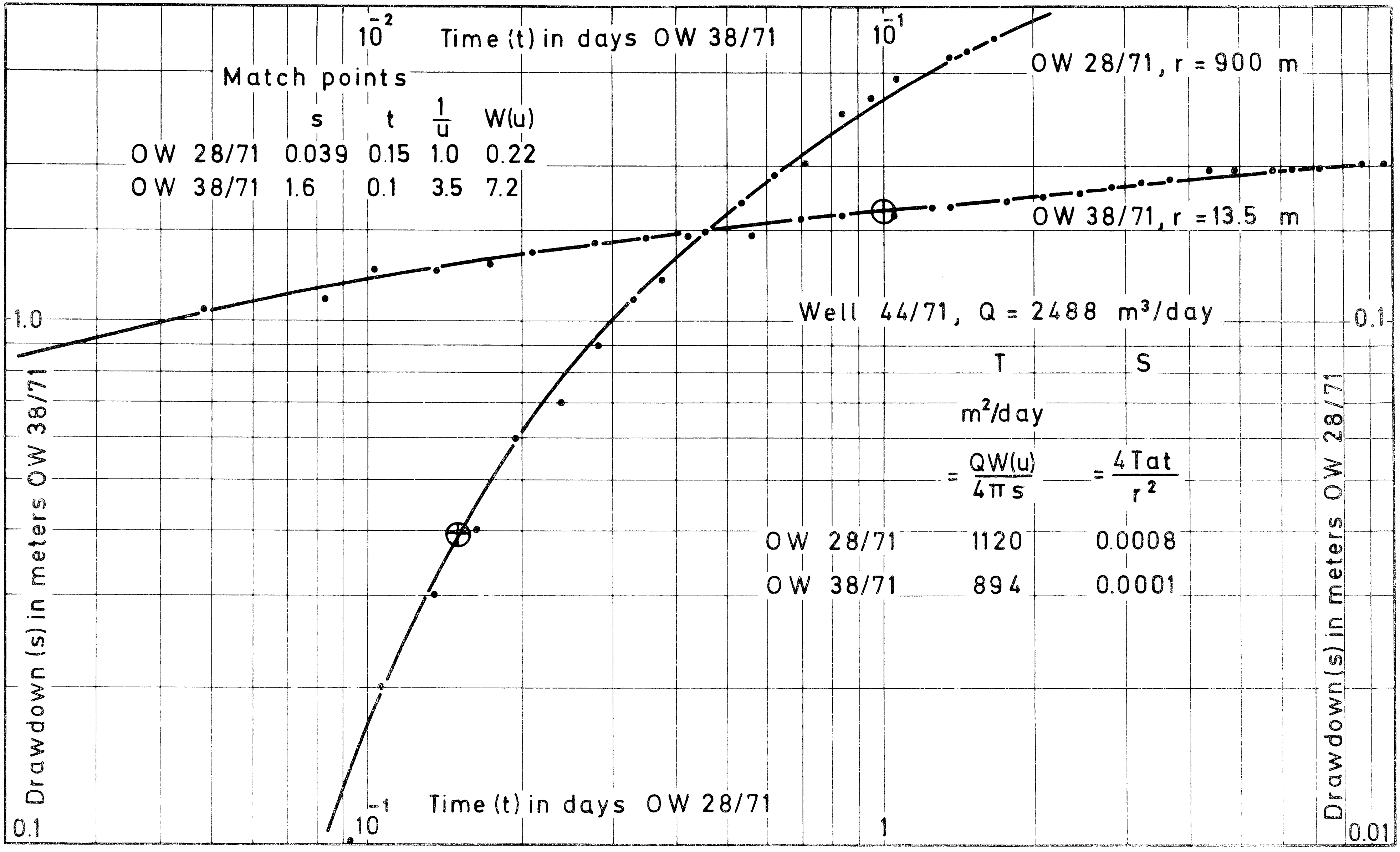
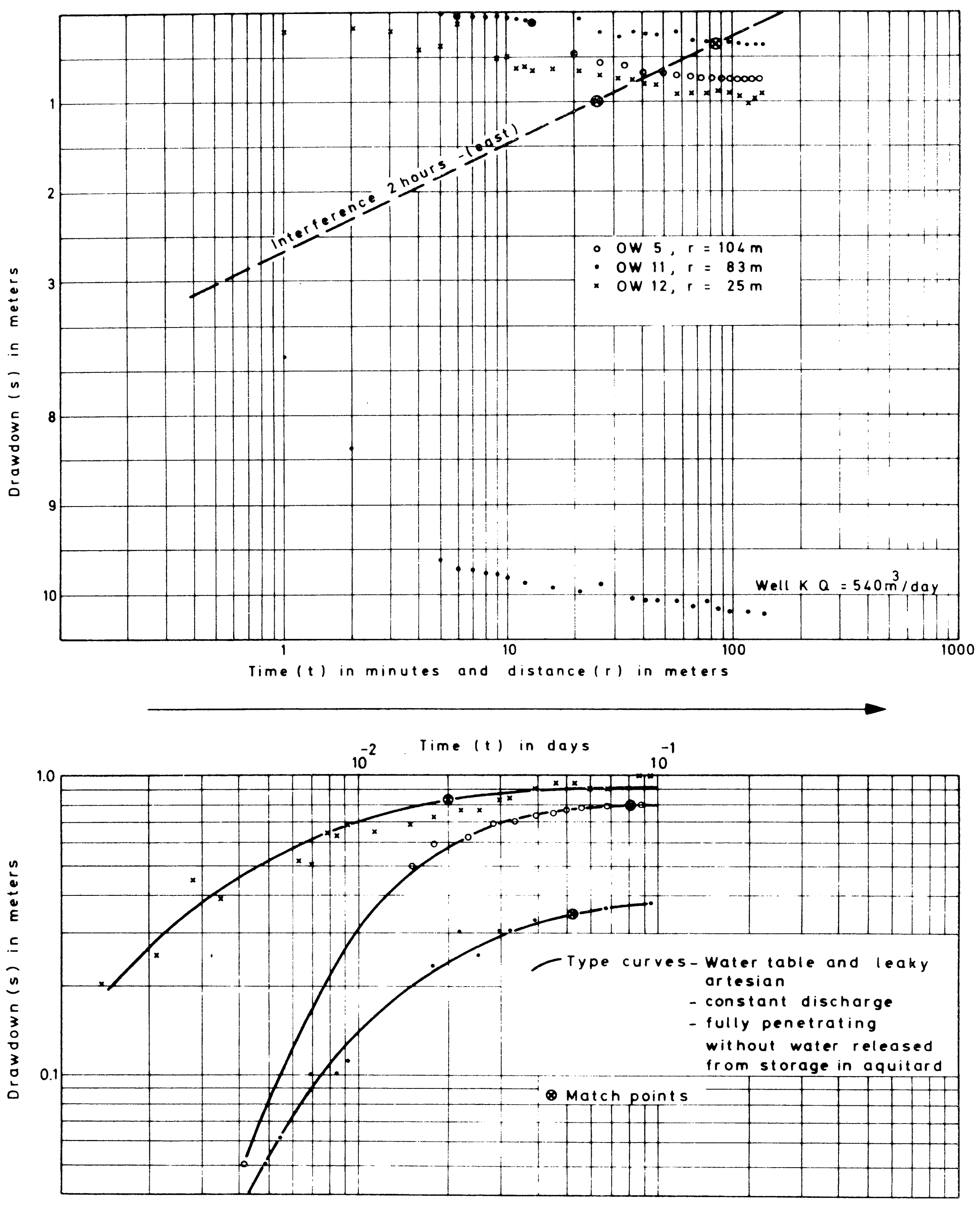


Figure III-15, Zanderij aquifer test in the area of Sidodadie and de Crane wegs, with well 44/71 pumping at 28.8 l/sec.



	r	$\frac{r}{D_t}$	s	t	$\frac{1}{u_a}$	$\frac{1}{u_y}$	$W\left(u_{ay}\frac{r}{D_t}\right)$	$T\,(m^2/day) = \frac{QW\left(u_{ay}\frac{r}{D_t}\right)}{4\pi s}$	$S = \frac{4Tu_{at}}{r^2}$ (leaky artesian)	$S = \frac{4Tu_{yt}}{r^2}$ (water table)
OW 5	104	1.5	0.79	8×10^{-2}	8.4	8.4×10^{-3}	0.44	24	8.5×10^{-5}	0.085
OW 11	83	0.8	0.34	5.2×10^{-2}	9.2	9.2×10^{-3}	1.00	126	4.0×10^{-4}	(0.4) ?
OW 12	25	0.4	0.82	2.0×10^{-2}	24.8	2.48×10^{-2}	1.95	100	5.0×10^{-4}	(0.5) ?

Figure III-16, Aquifer test at Republiek, December 1963, with Well K discharging at 540 m³/day.

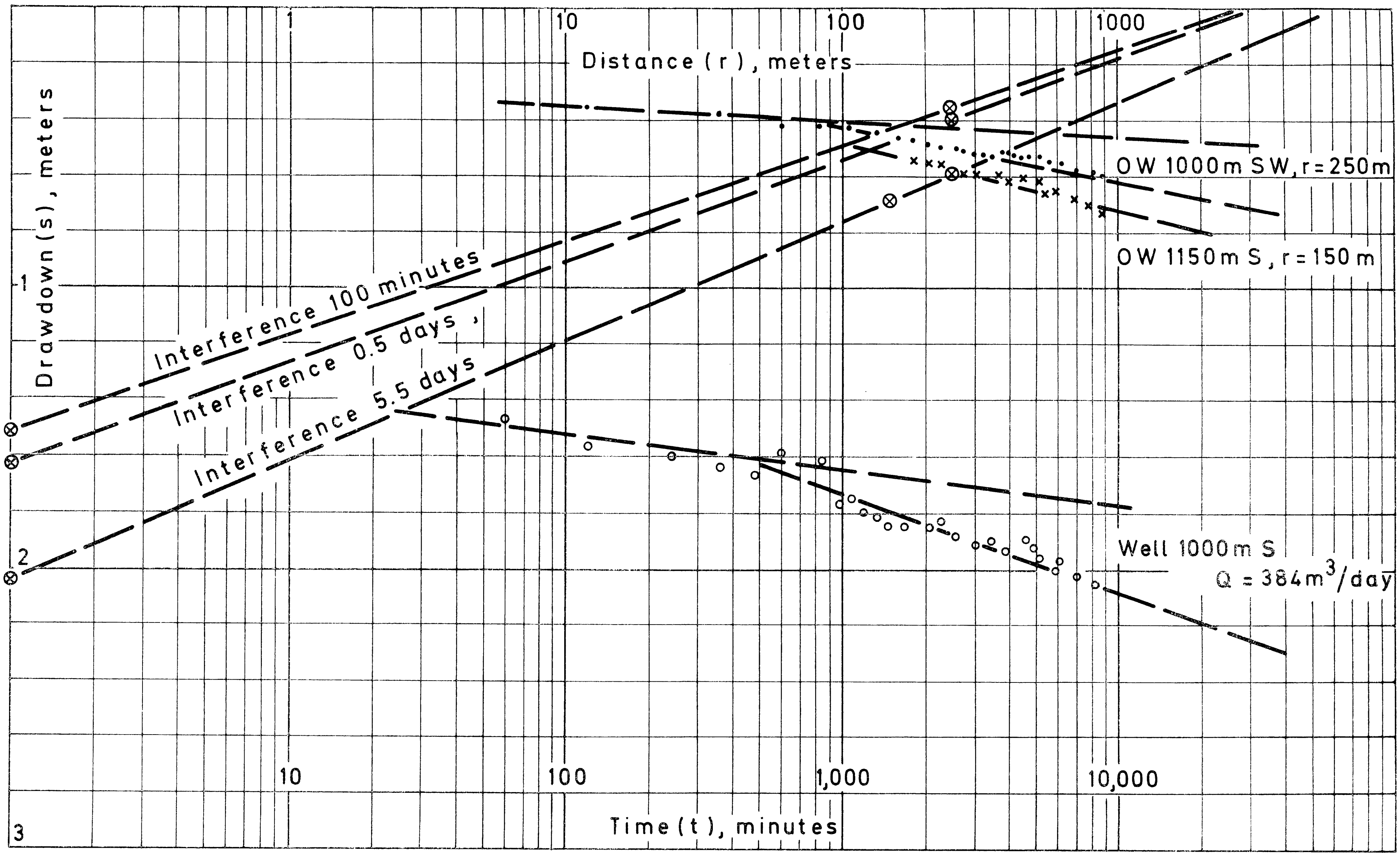


Figure III-17, Aquifer test at Republiek 4 - 10 March 1930, showing the influence of an aquifer boundary. (Data from Weyerman, 1930)

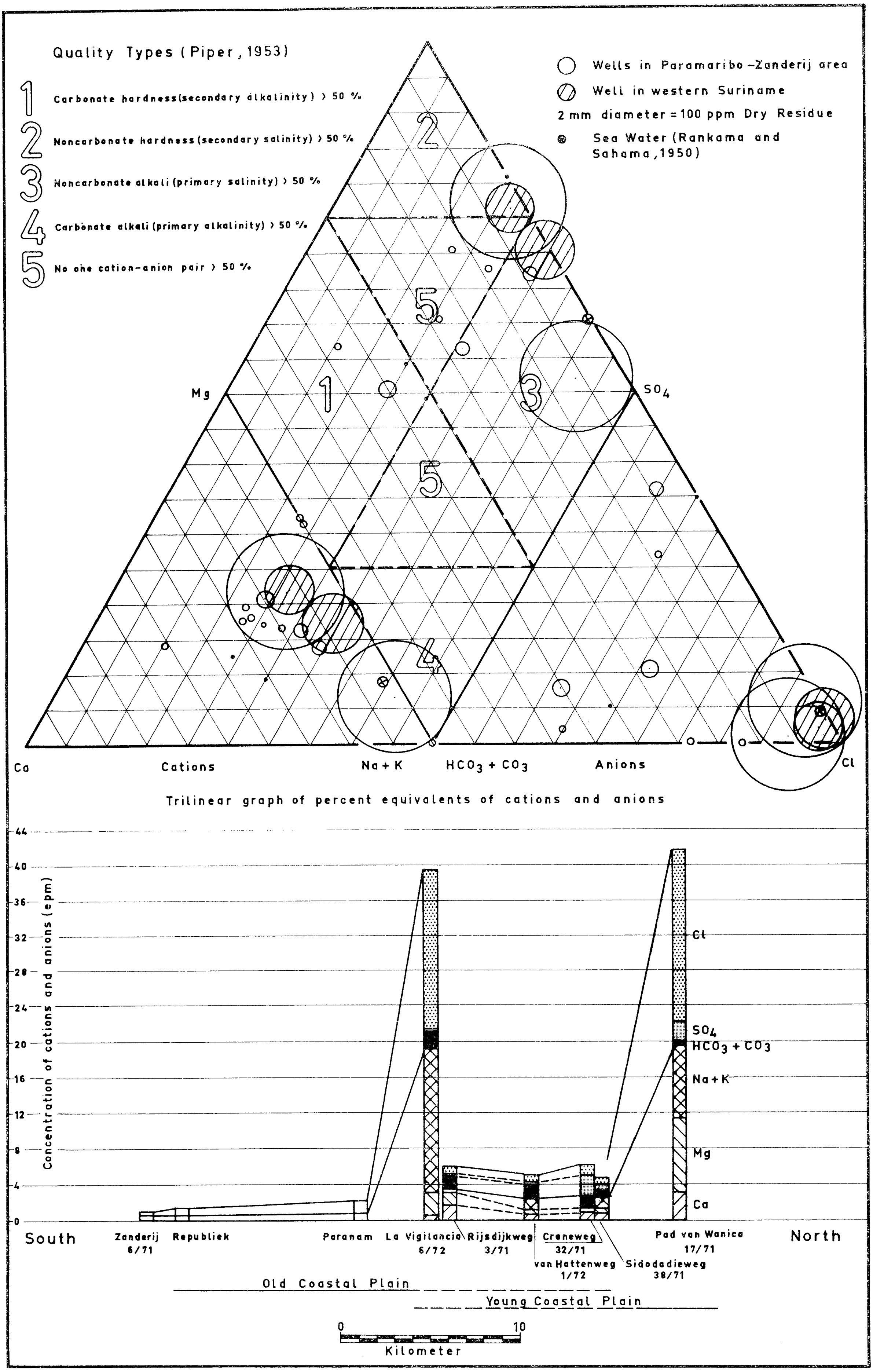


Figure III-18 ,Chemical quality of water from the Zanderij aquifer

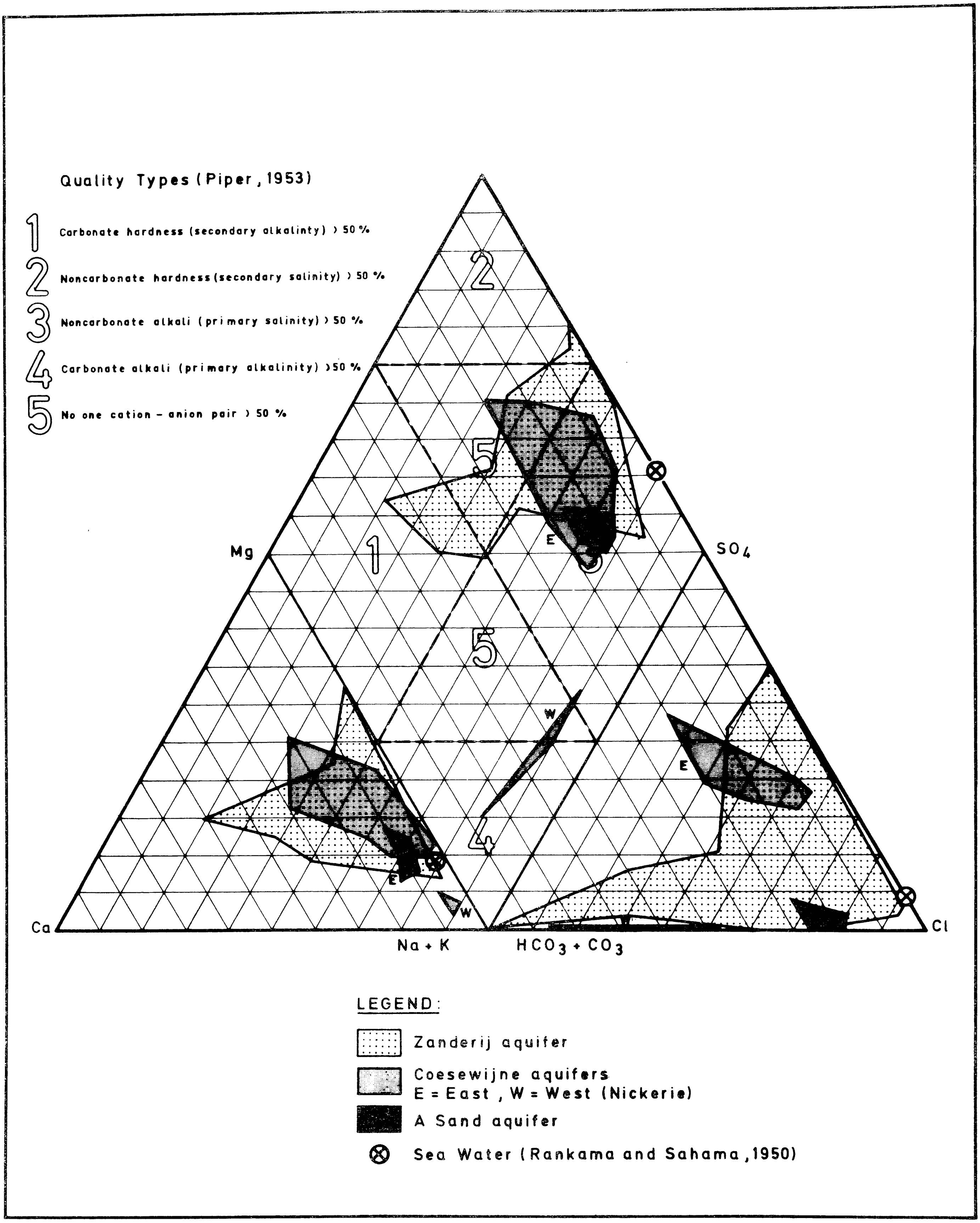


Figure III-19, Water quality characteristies of the upper Tertiary aquifers

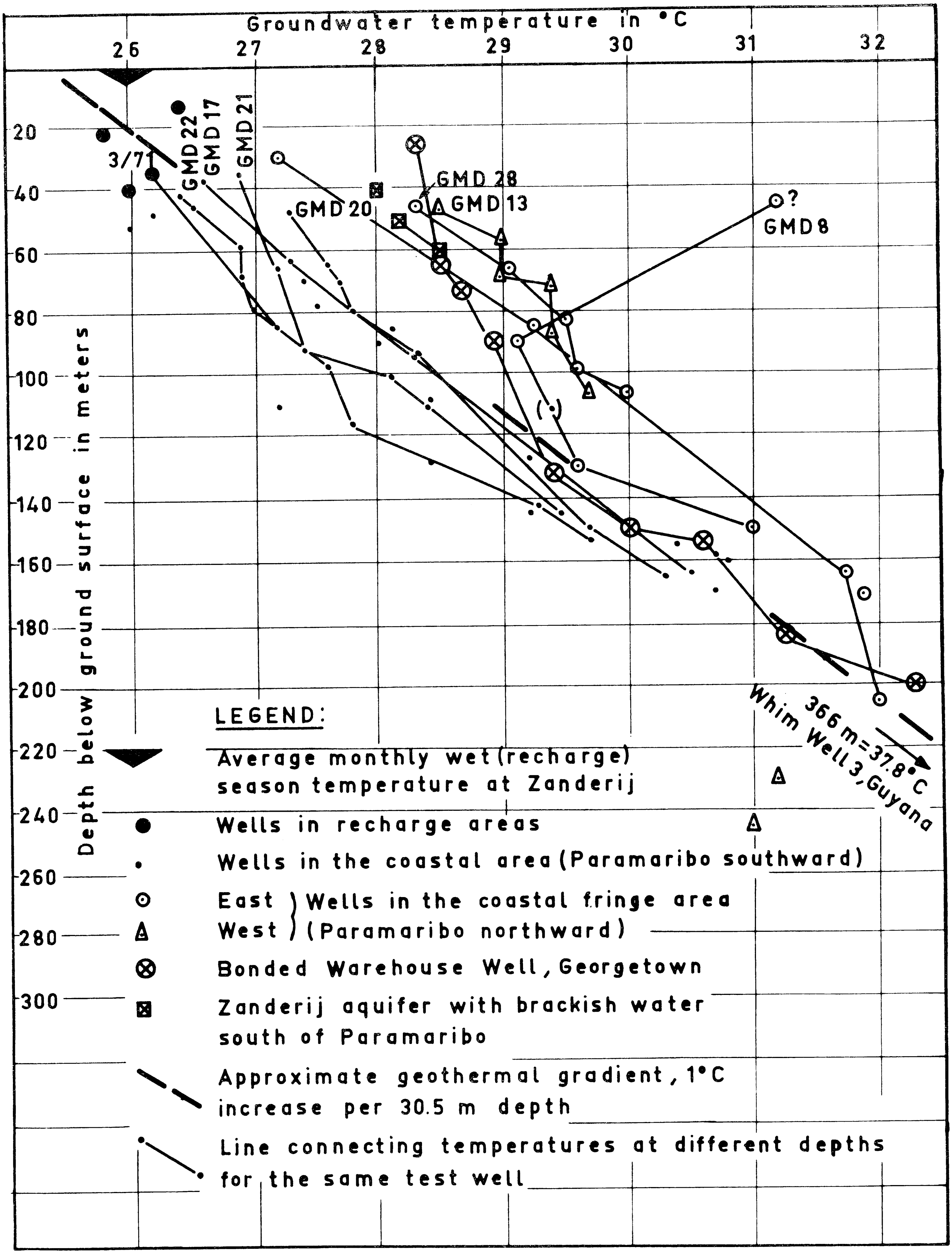


Figure III-20, Relationship of groundwater temperature and depth

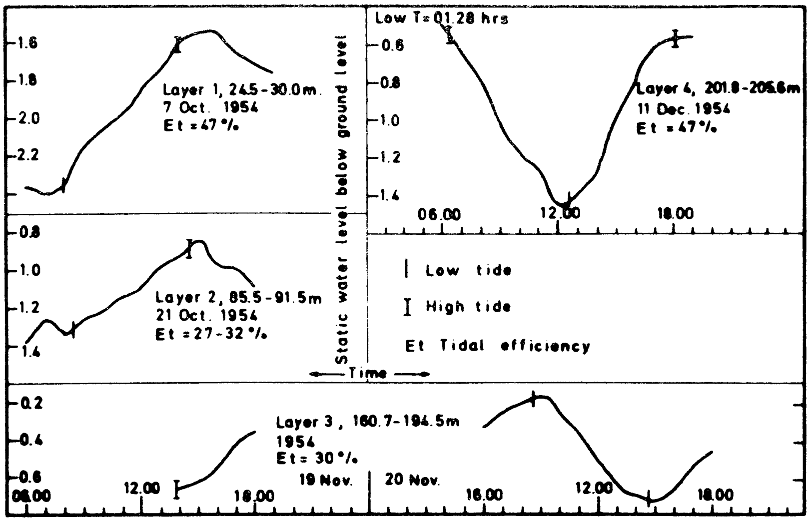


Figure III - 21, Static water level variations caused by tides at Well GMD 16

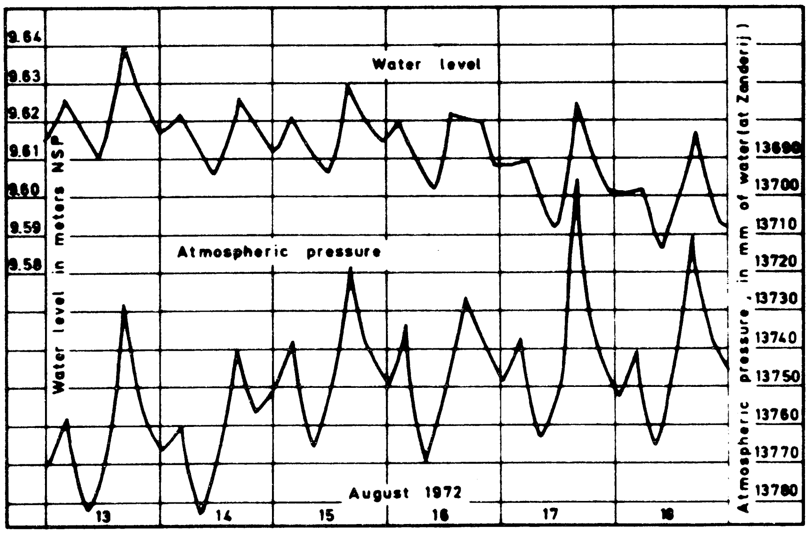


Figure III - 22, Relationship between atmospheric pressure and water levels in OW 9/71

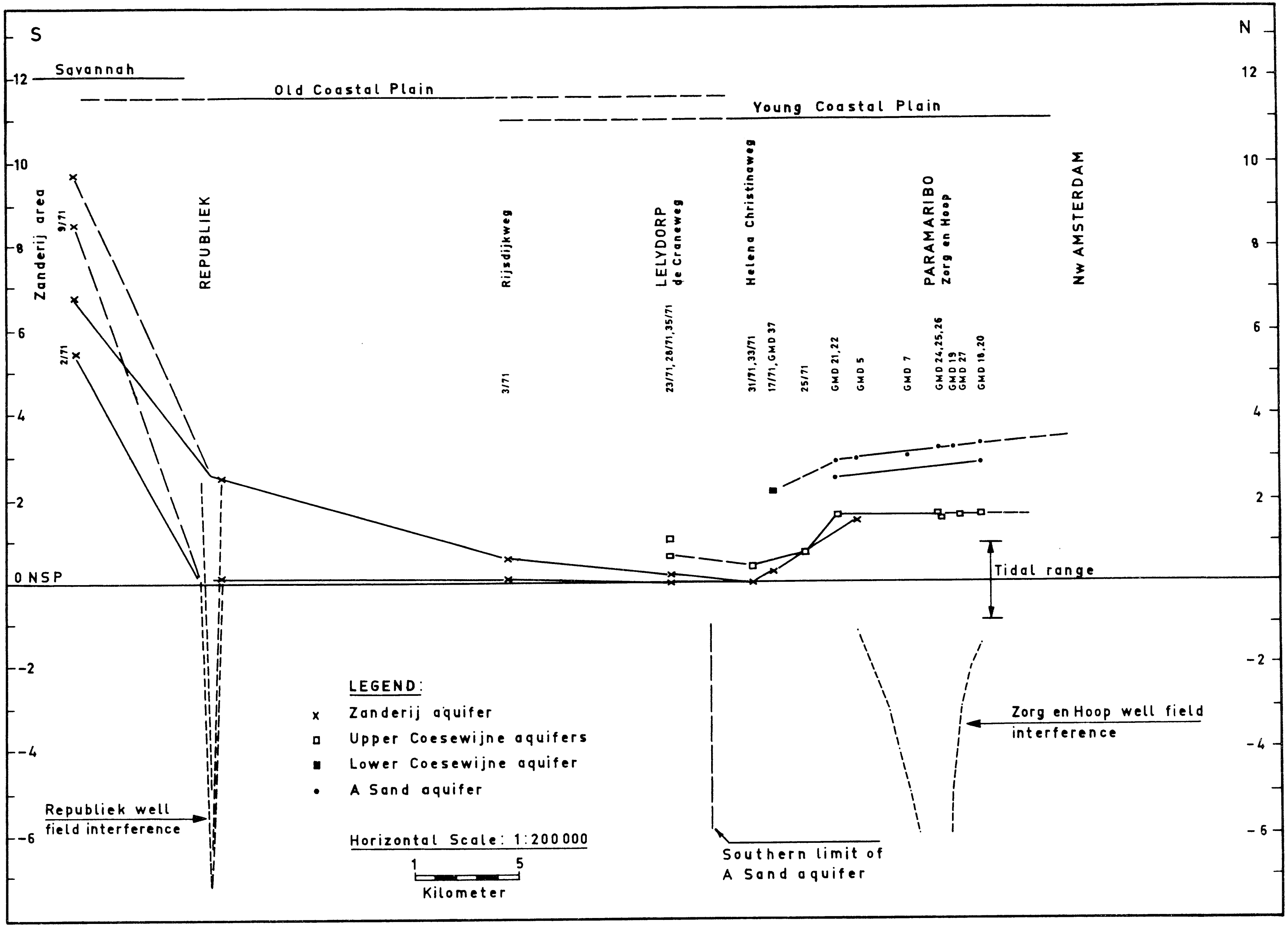


Figure III-23, Water levels of aquifers in the coastal basin from the Savannah area near Zanderij to the Young Coastal Plain near Paramaribo

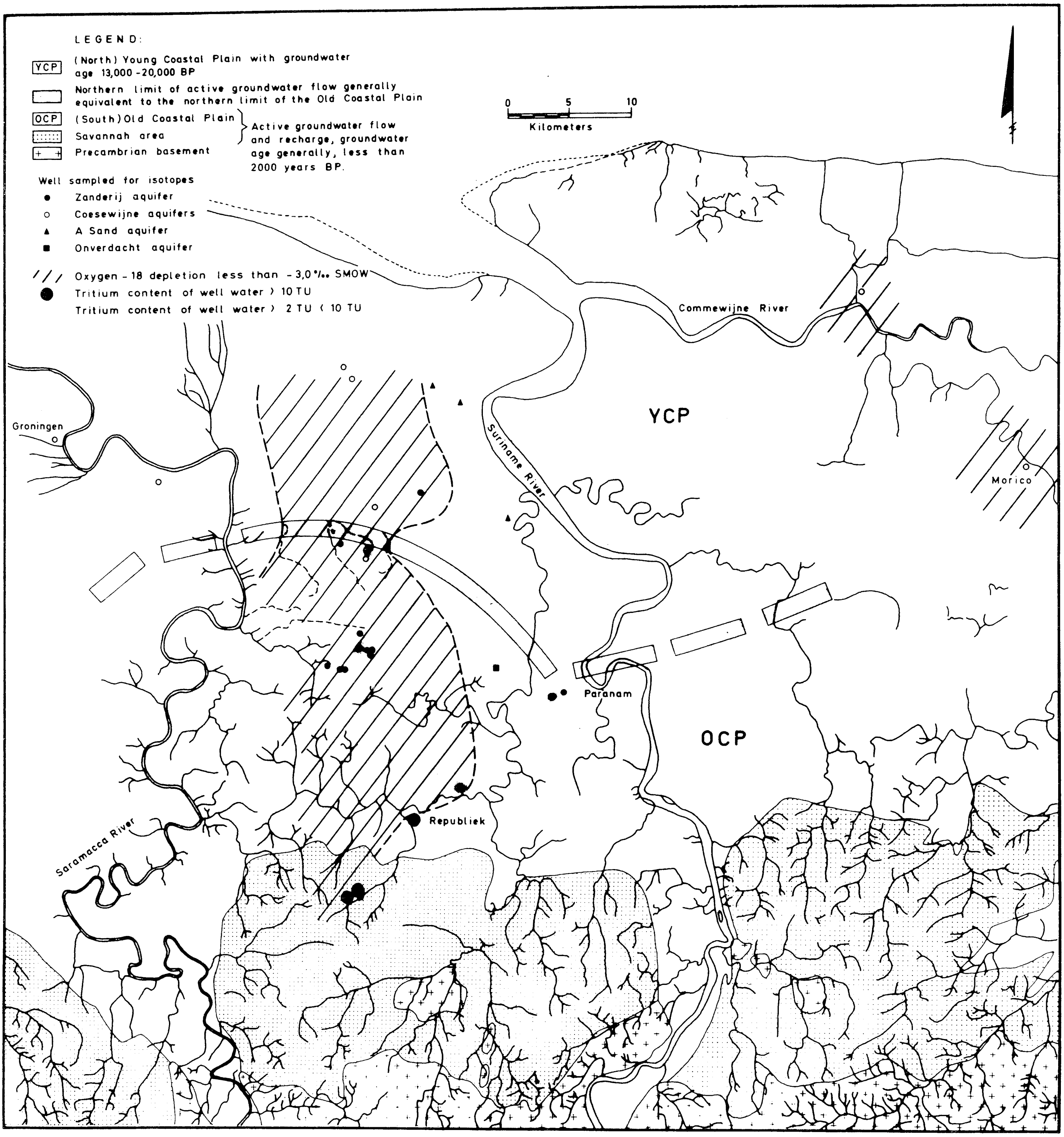


Figure III - 24, Groundwater flow systems

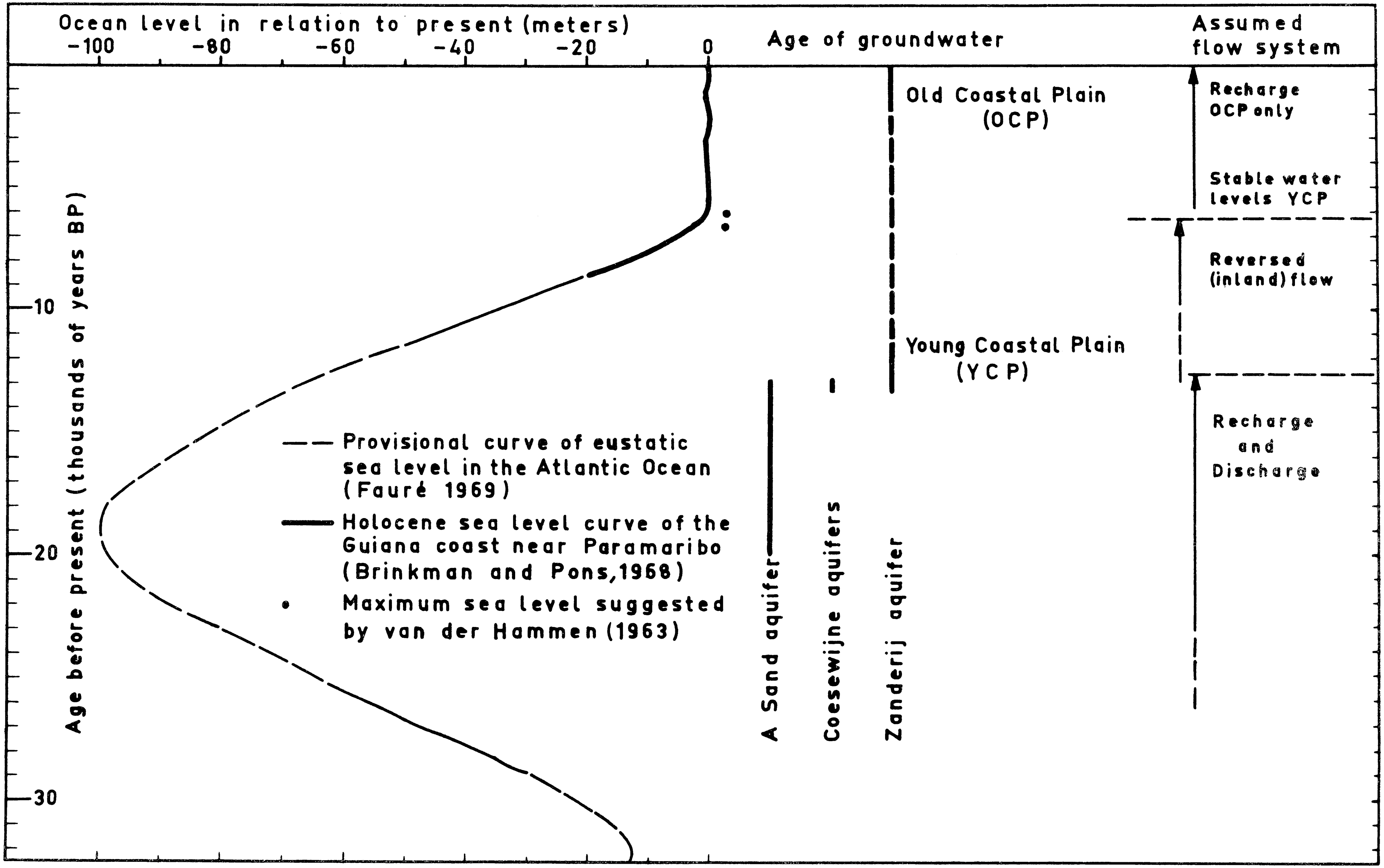


Figure III-25 , Groundwater age in relation to Holocene and late Pleistocene ocean levels

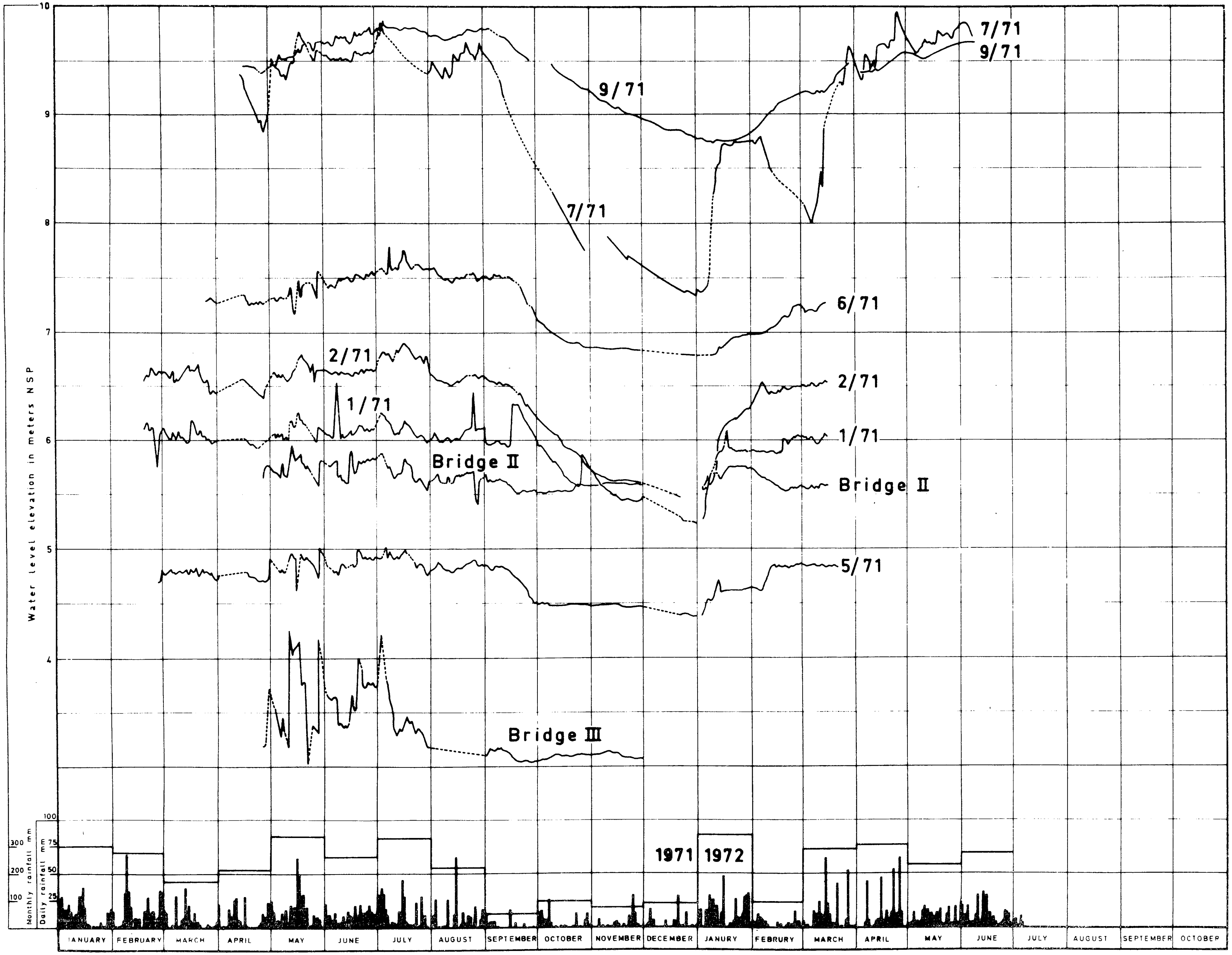


Figure III -26, Hydrographs of wells and streams in the Zanderij - Matta area, and rainfall at Zanderij.

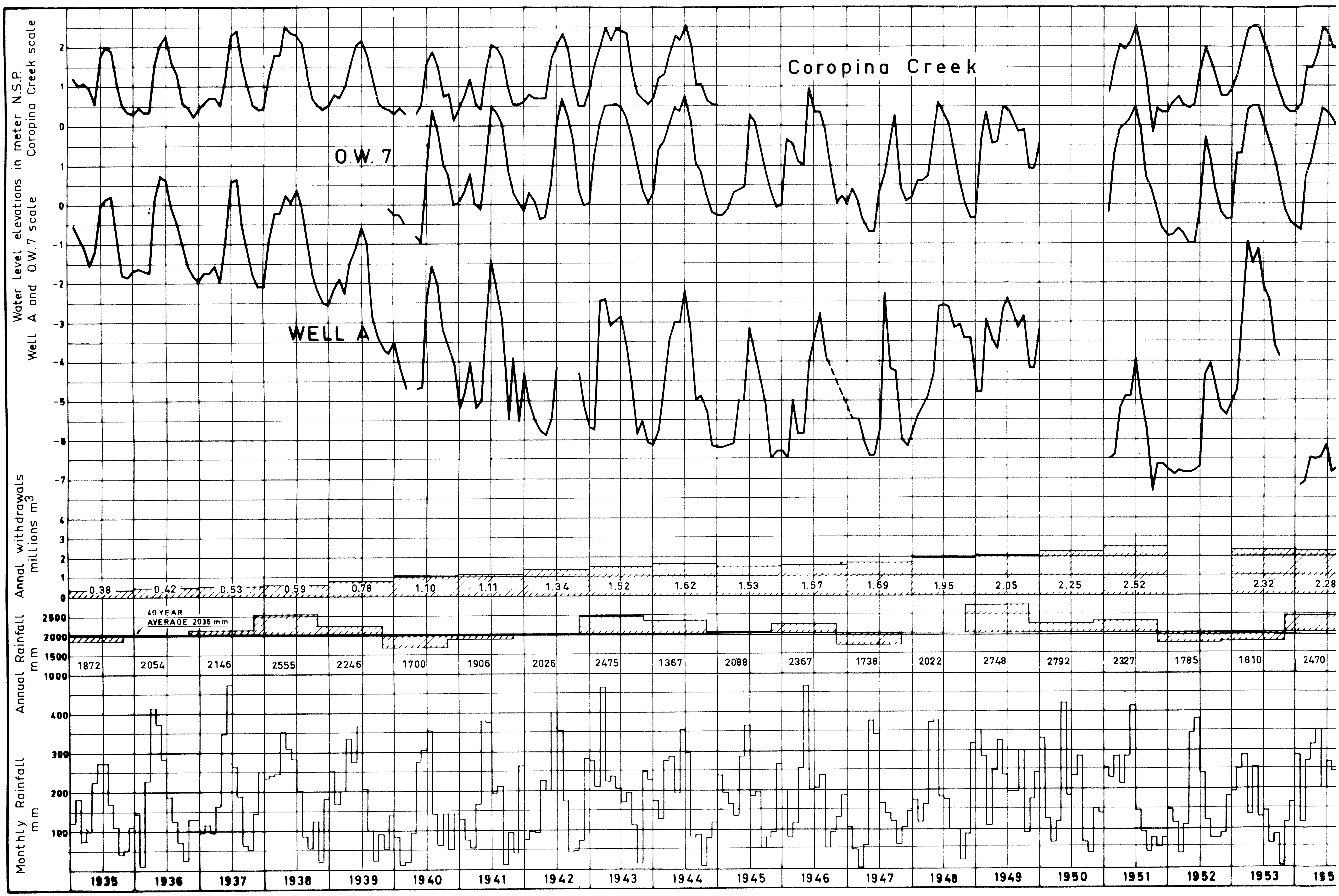
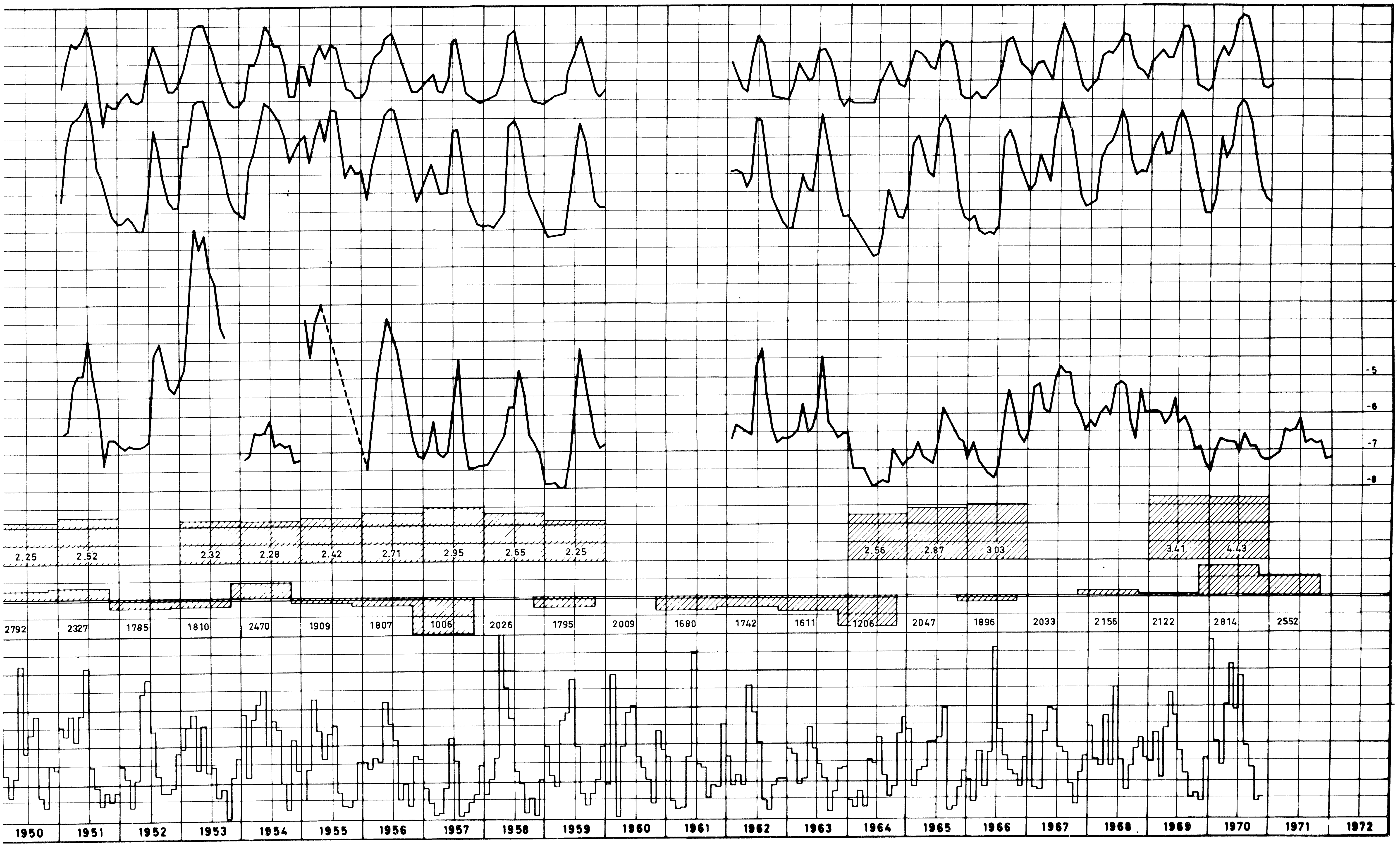


Figure III-27, Water levels, groundwater withdrawals, and ra



er withdrawals, and rainfall at Republiek for the year 1935 – 1971

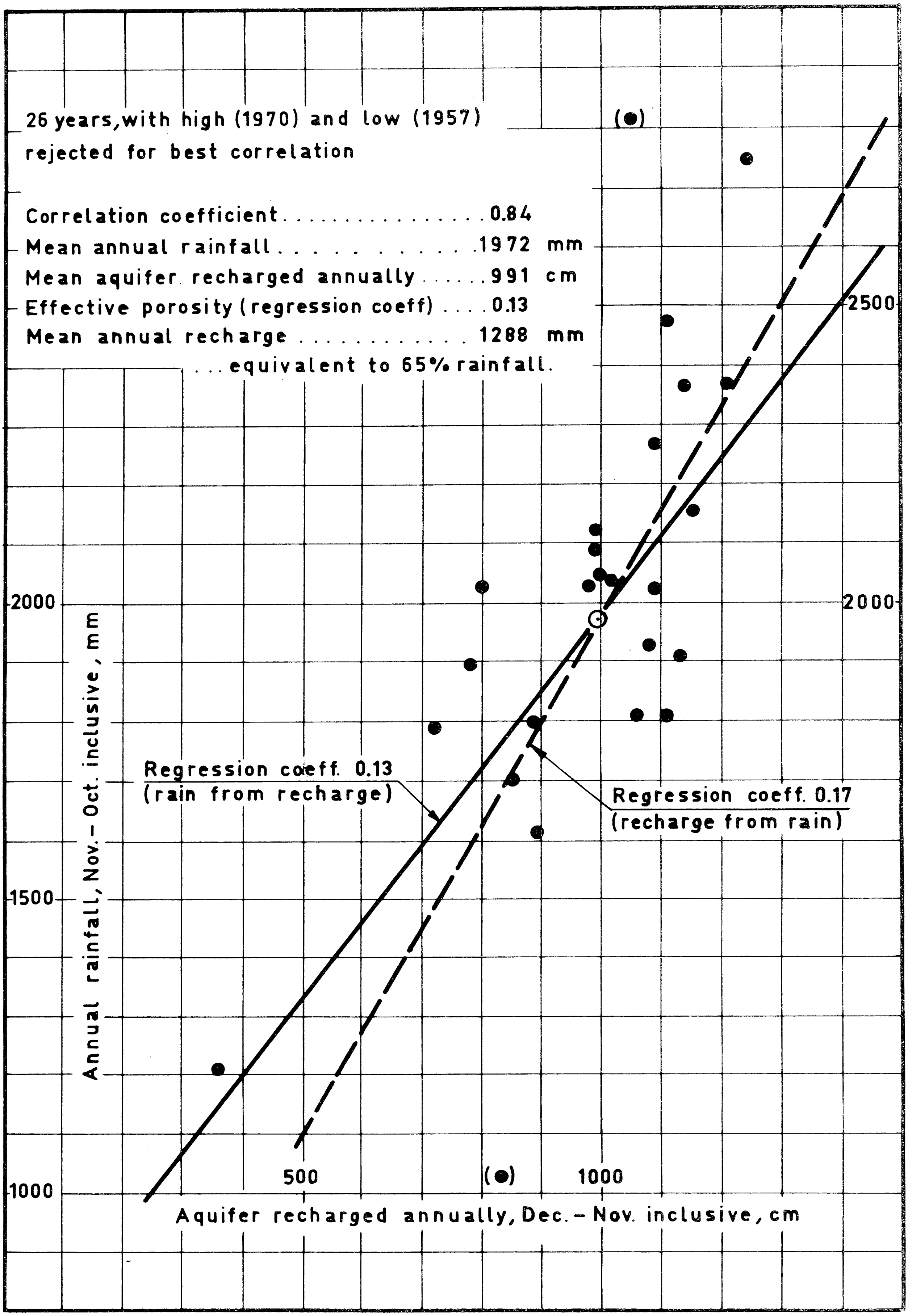
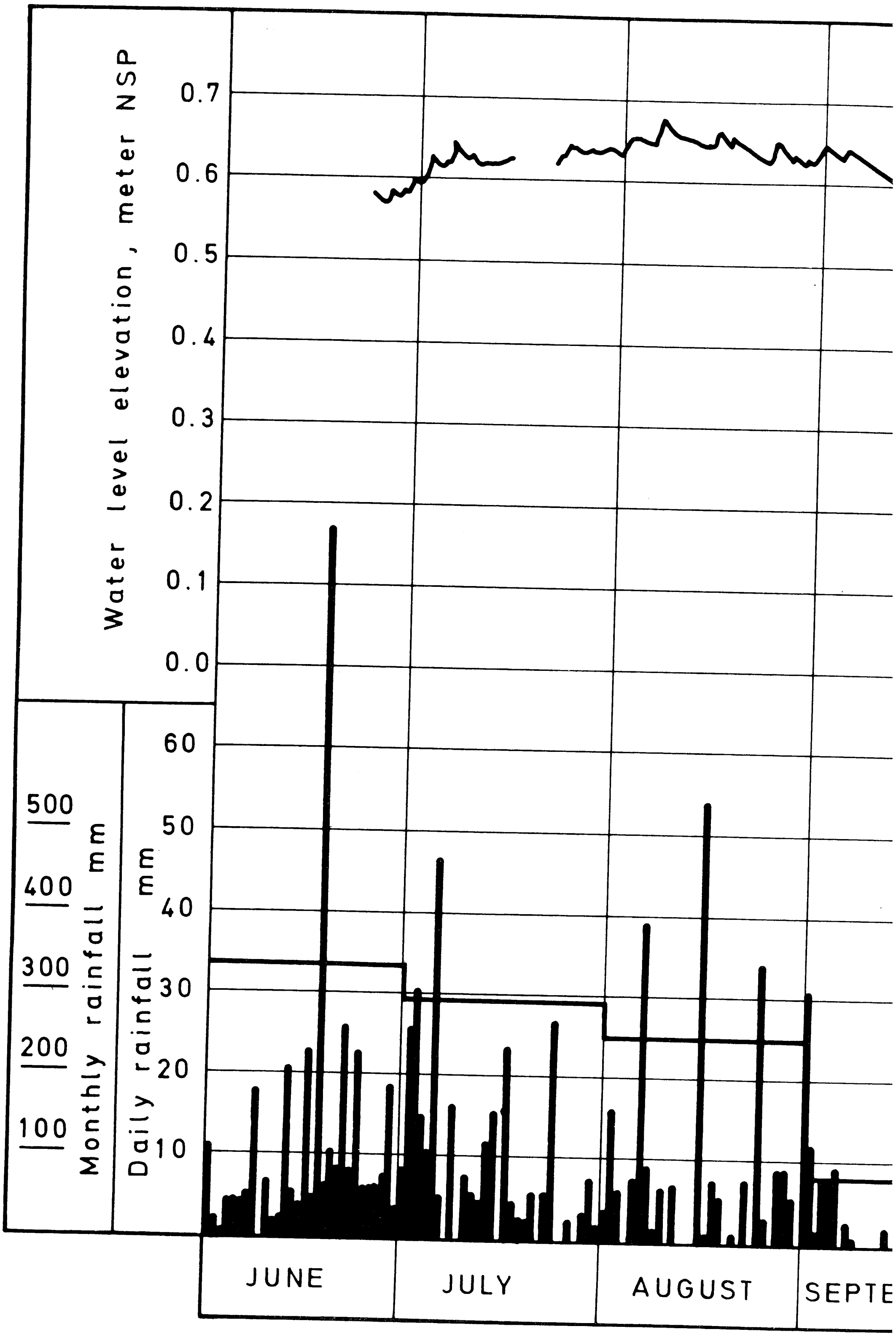


Figure III - 28, Correlation of rainfall and recharge at Republiek SWM Observation Well № 7


Water level elevation, meter NSP
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Monthly rainfall mm
500
400
300
200
100
Daily rainfall mm
60
50
40
30
20
10
JUNE
JULY
AUGUST
SEPTE

Figure

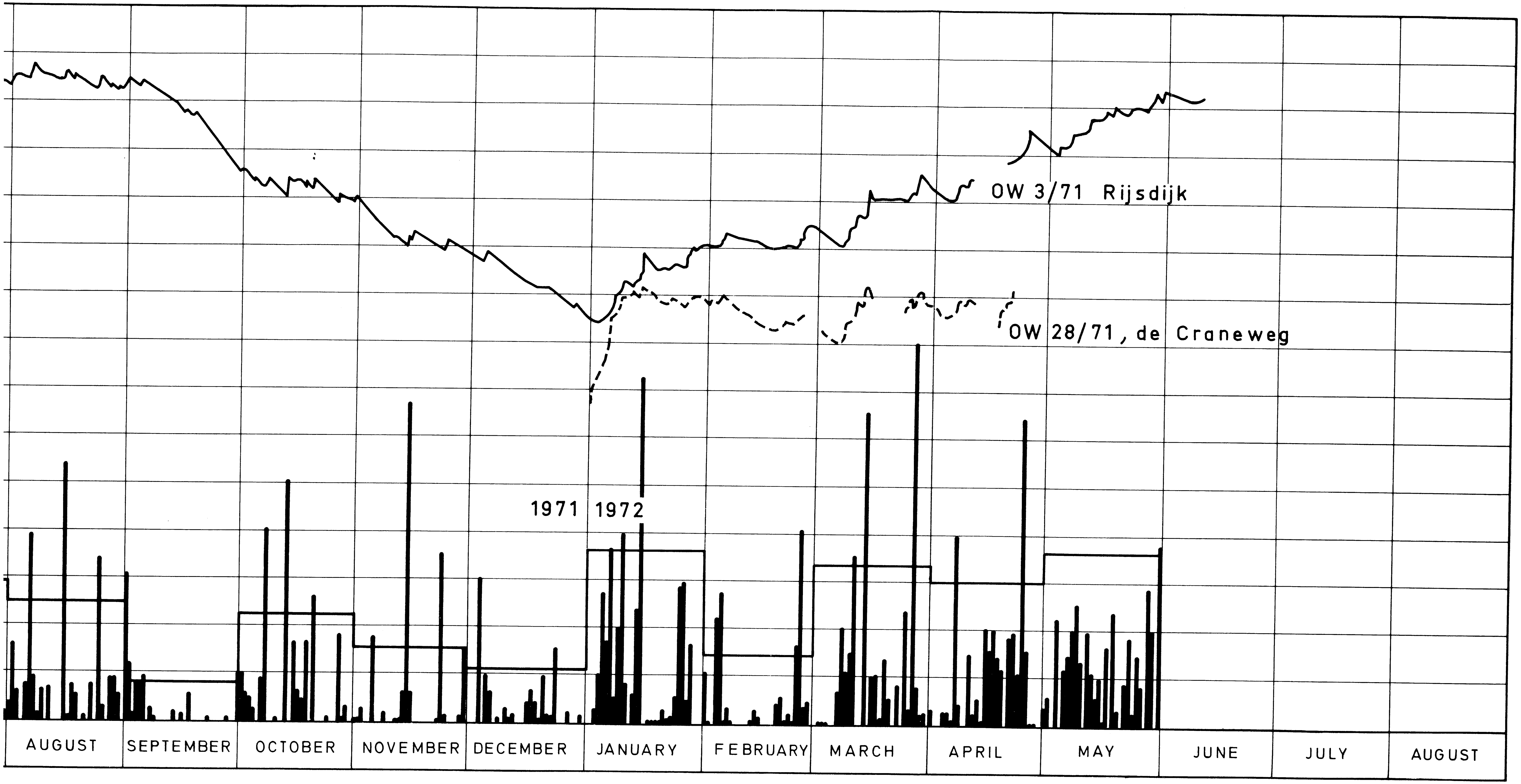


Figure III - 29, Hydrographs of Observation Wells 3/71, Rijsdijkweg, and 28/71, de Craneweg and rainfall at Oema (Rijsdijkweg)

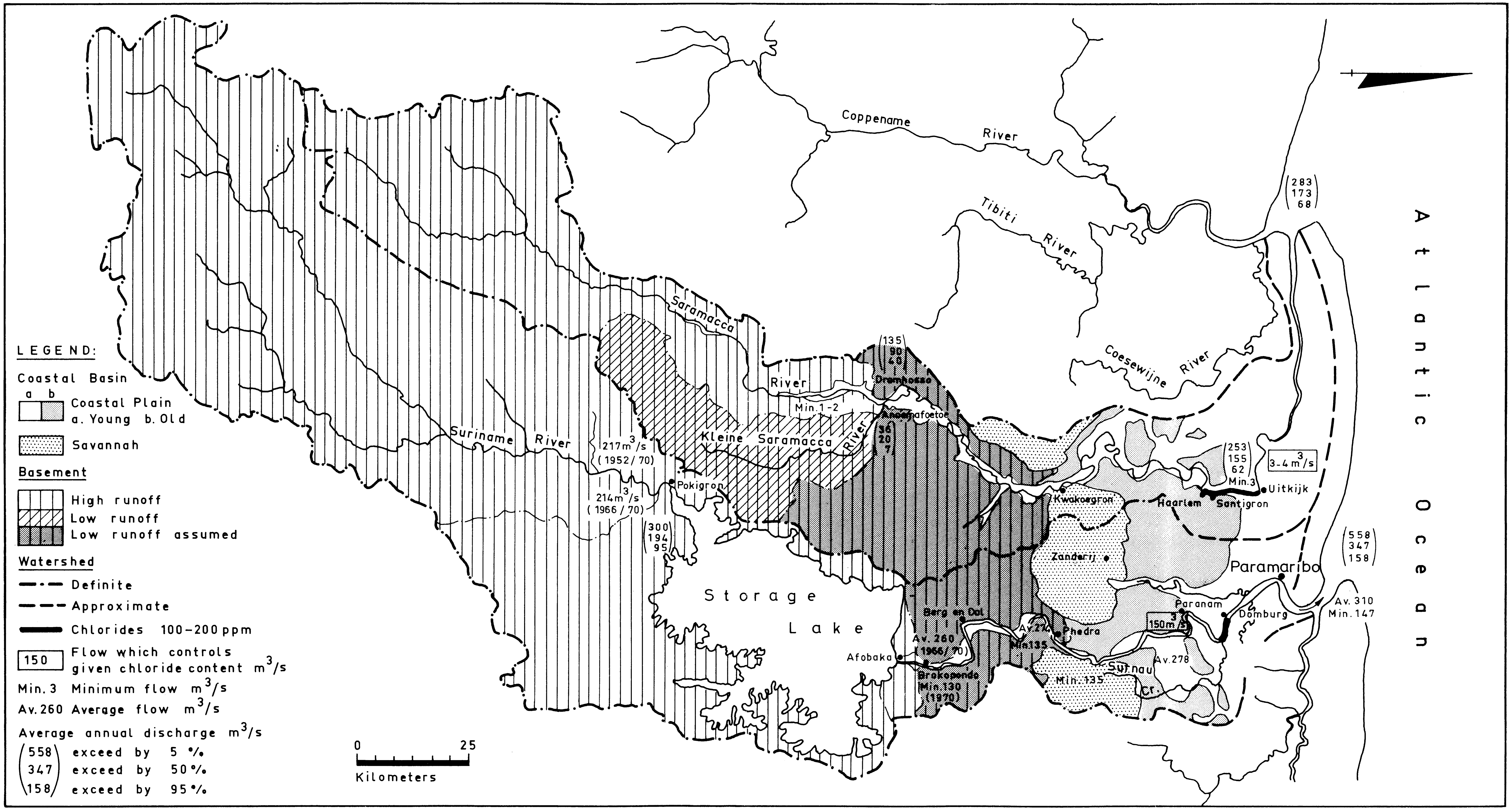
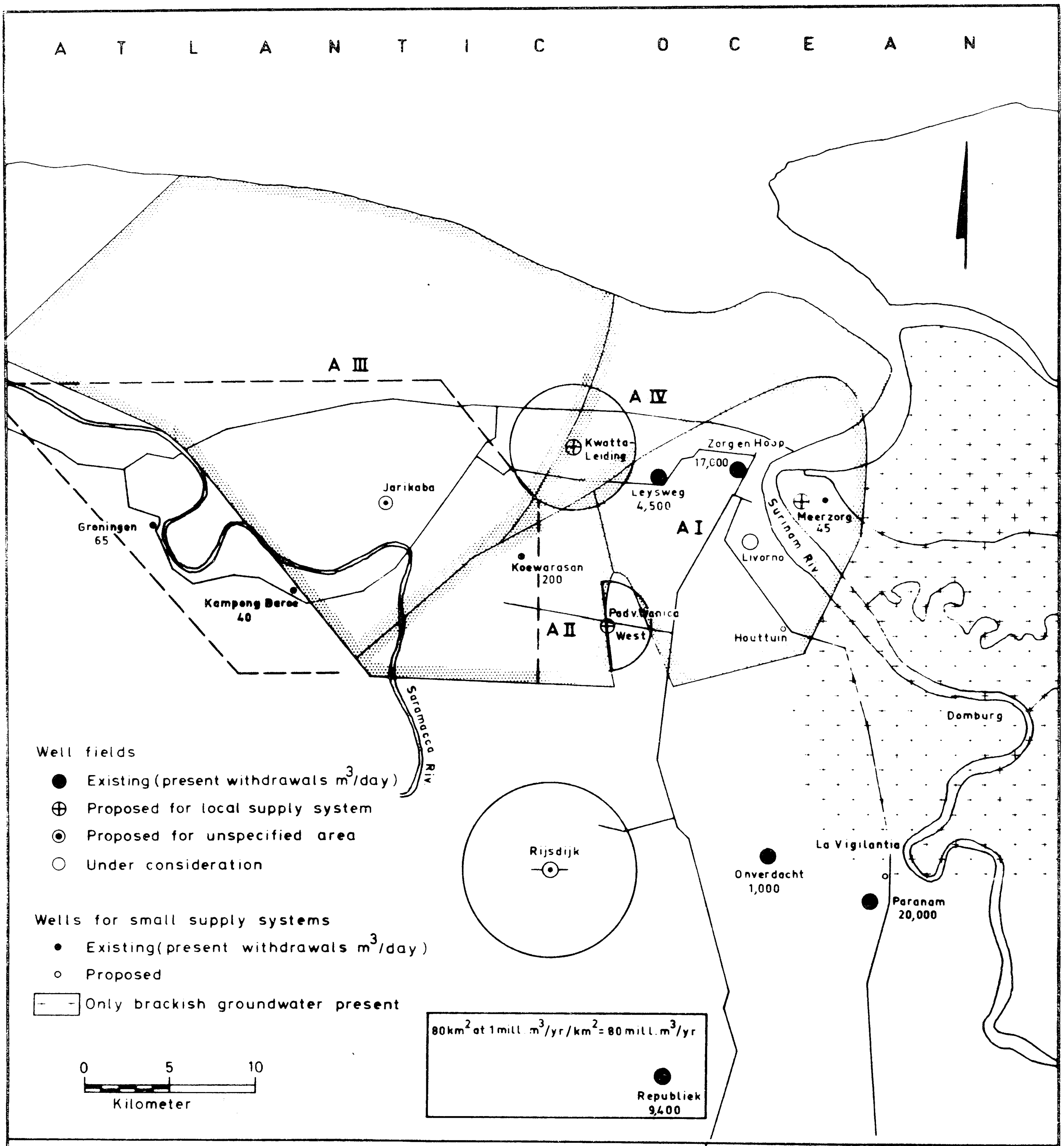


Figure III - 30, Discharges of the Suriname and Saramacca Rivers



Young Coastal Plain

Fresh groundwater storage areas with estimated volumes in million m^3

A Sand aquifer

A I = 230 , A II = 190 , A III = 748

A IV (300 - 400ppm Cl) = 420

Zorg en Hoop
Leysweg
Meerzorg
Houttuin
Livorno
Jarikaba

Coesewijne aquifer

Koewarasan - Groningen area 593

Kwatta - Leiding = 53

Pad van Wanica West = 20

Kwatta - Leiding
Pad van Wanica West
Koewarasan
Kampong Baroe
Groningen

Old Coastal Plain

Estimated perennial supplies of fresh groundwater in suggested future withdrawal areas

Zanderij aquifer

Republiek 2,740 m^3/day / km^2

Rijsdijk 32,000 m^3 / day

Republiek
Rijsdijk
Paranam
La Vigilantia
Onverdacht -
(Onverdacht aquifer)

Figure III -31 , Availaibility of water in the Coastal Plain near the Suriname and Saramacca Rivers

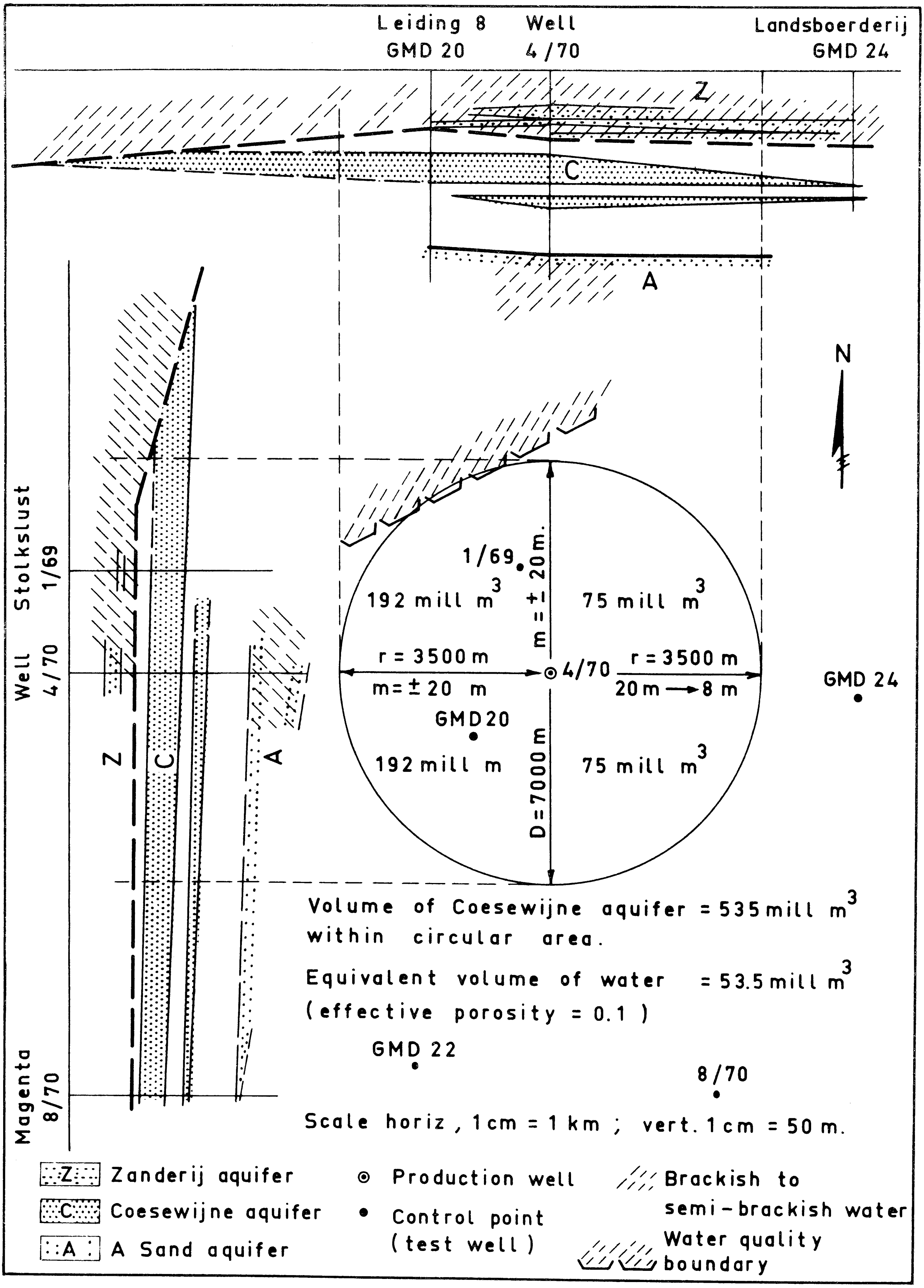


Figure III -32 , Schematic representation of the aquifer system in the Kwatta - Leidingen area .

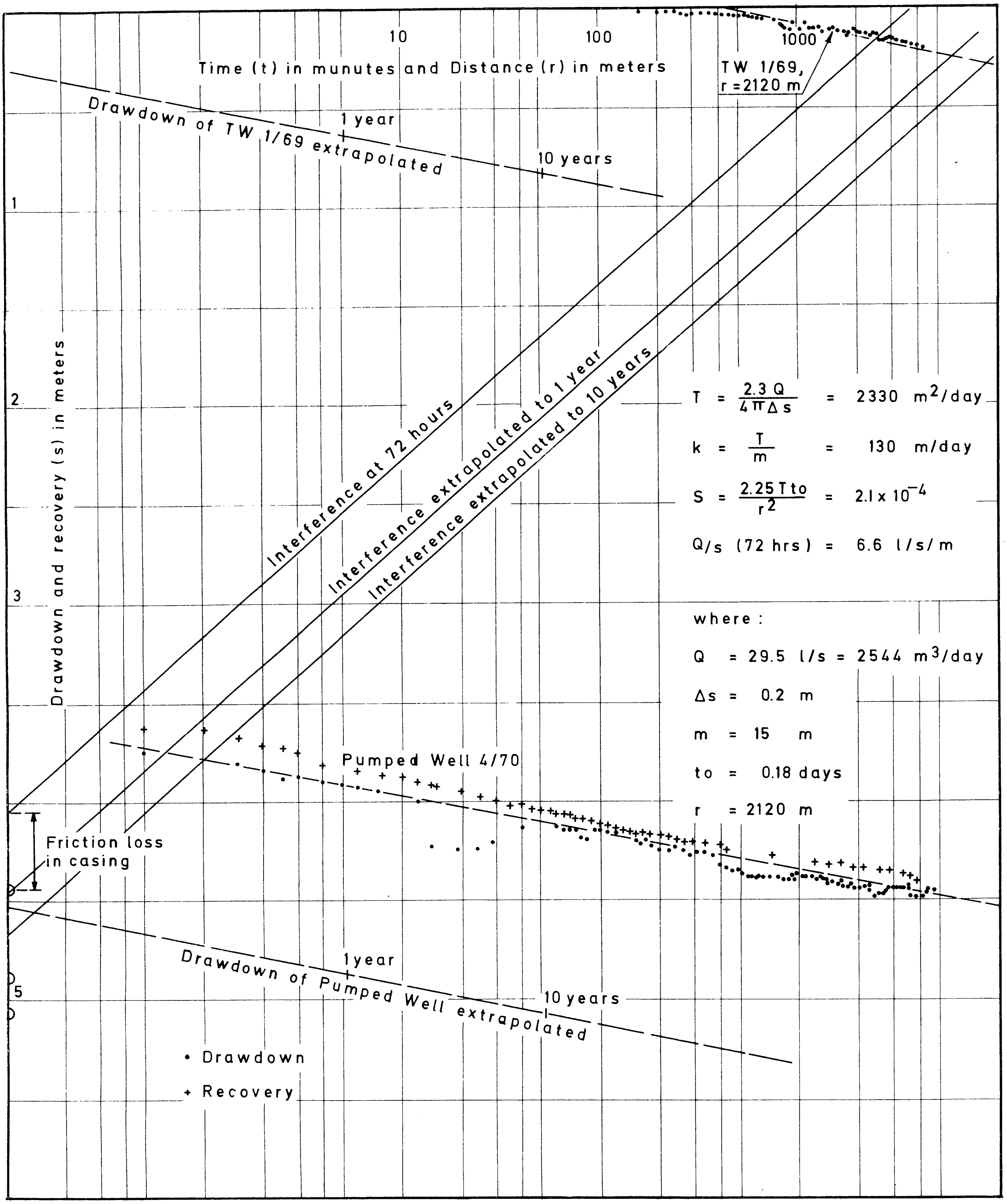


Figure III-33, Aquifer test at Kwatta - Leidingen 14-17 january 1970

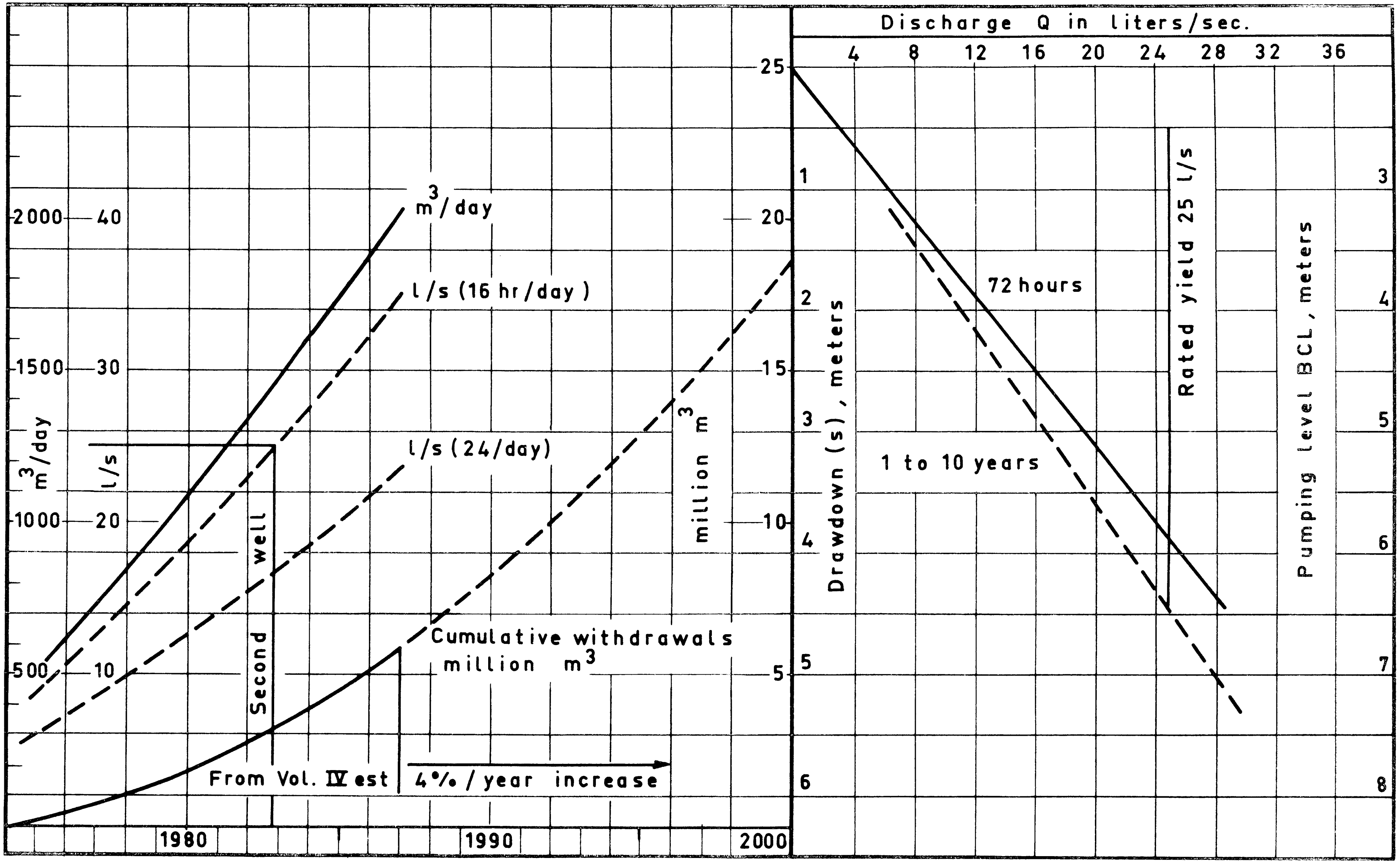


Figure III-34, Water requirements for the Kwatta - Leidingen water distribution system and the drawdown-discharge relationship of **Well** 4/70

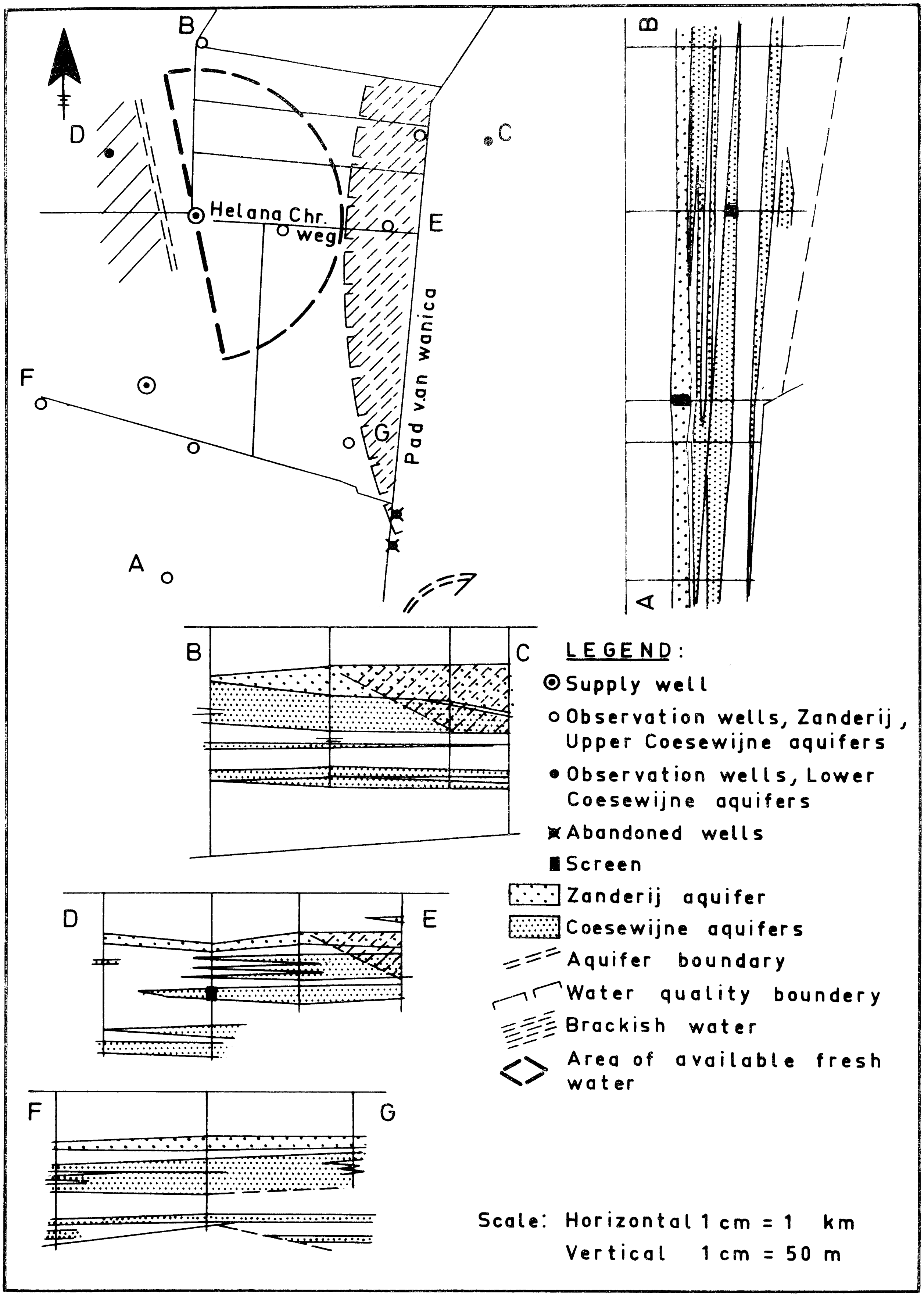


Figure III - 35, Schematic representation of the aquifer system in the Pad van Wanica West area

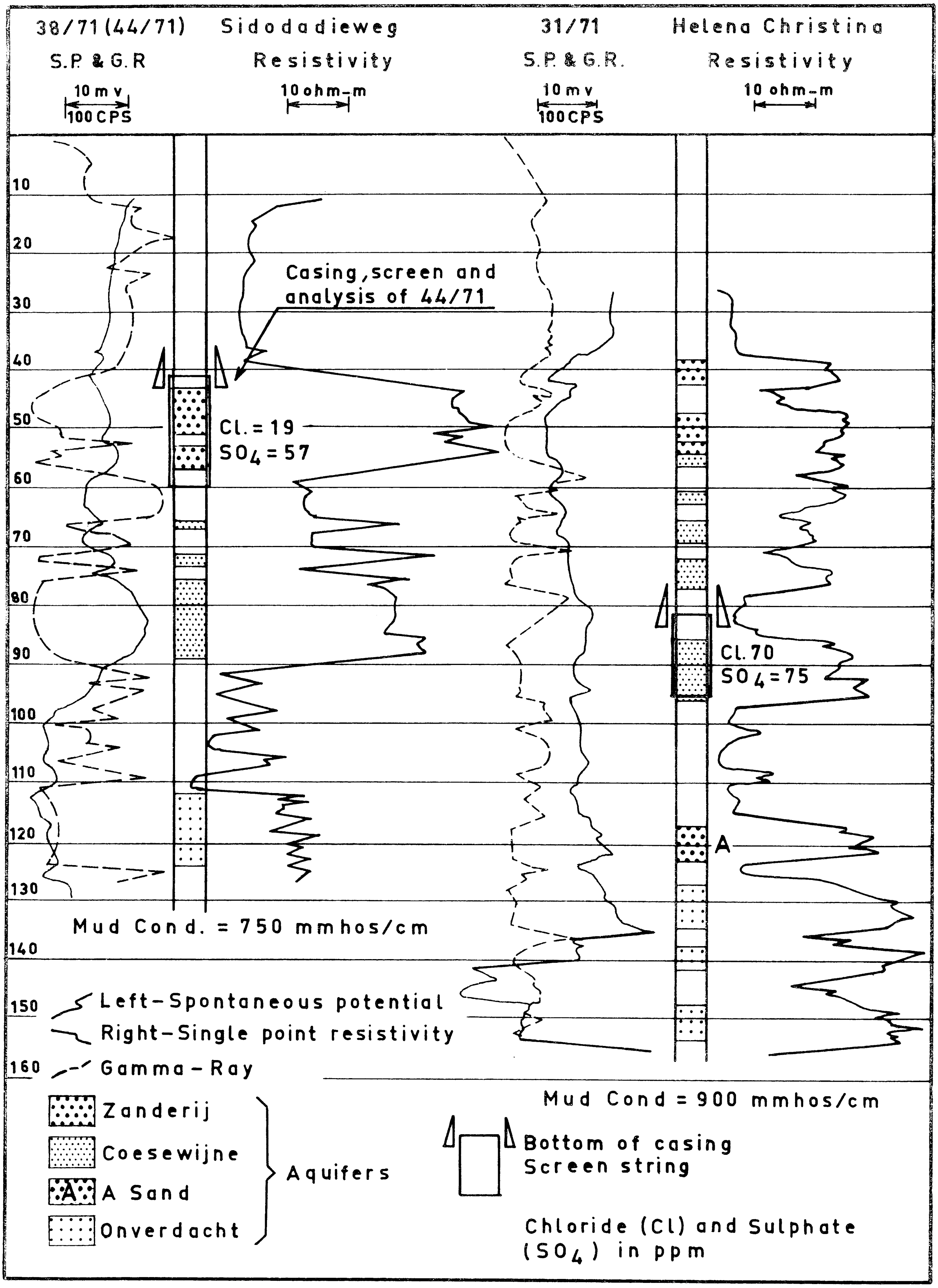


Figure III-36, Logs of wells 38/71, Sidodadieweg and 31/71 Helena Christinaweg

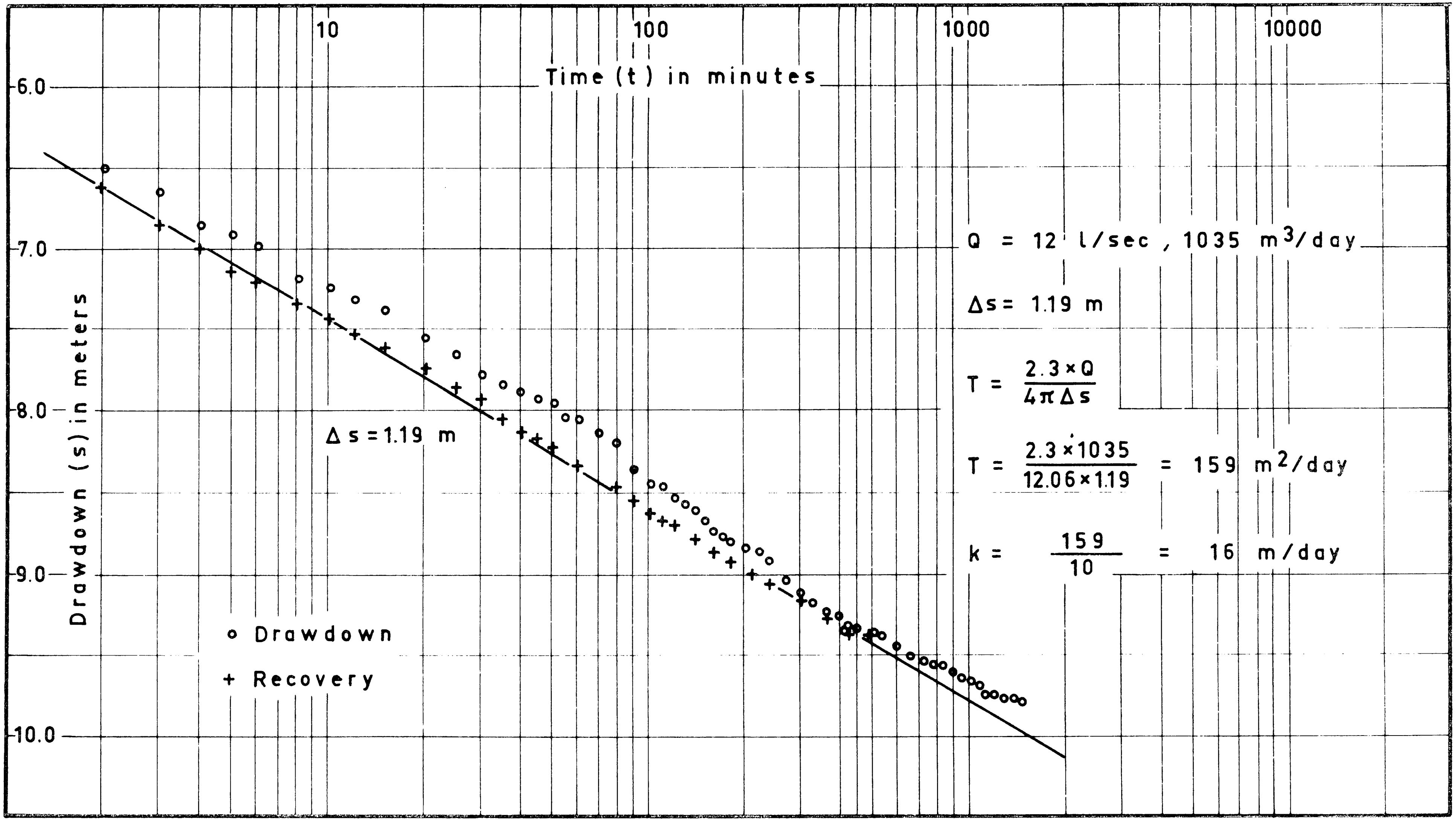
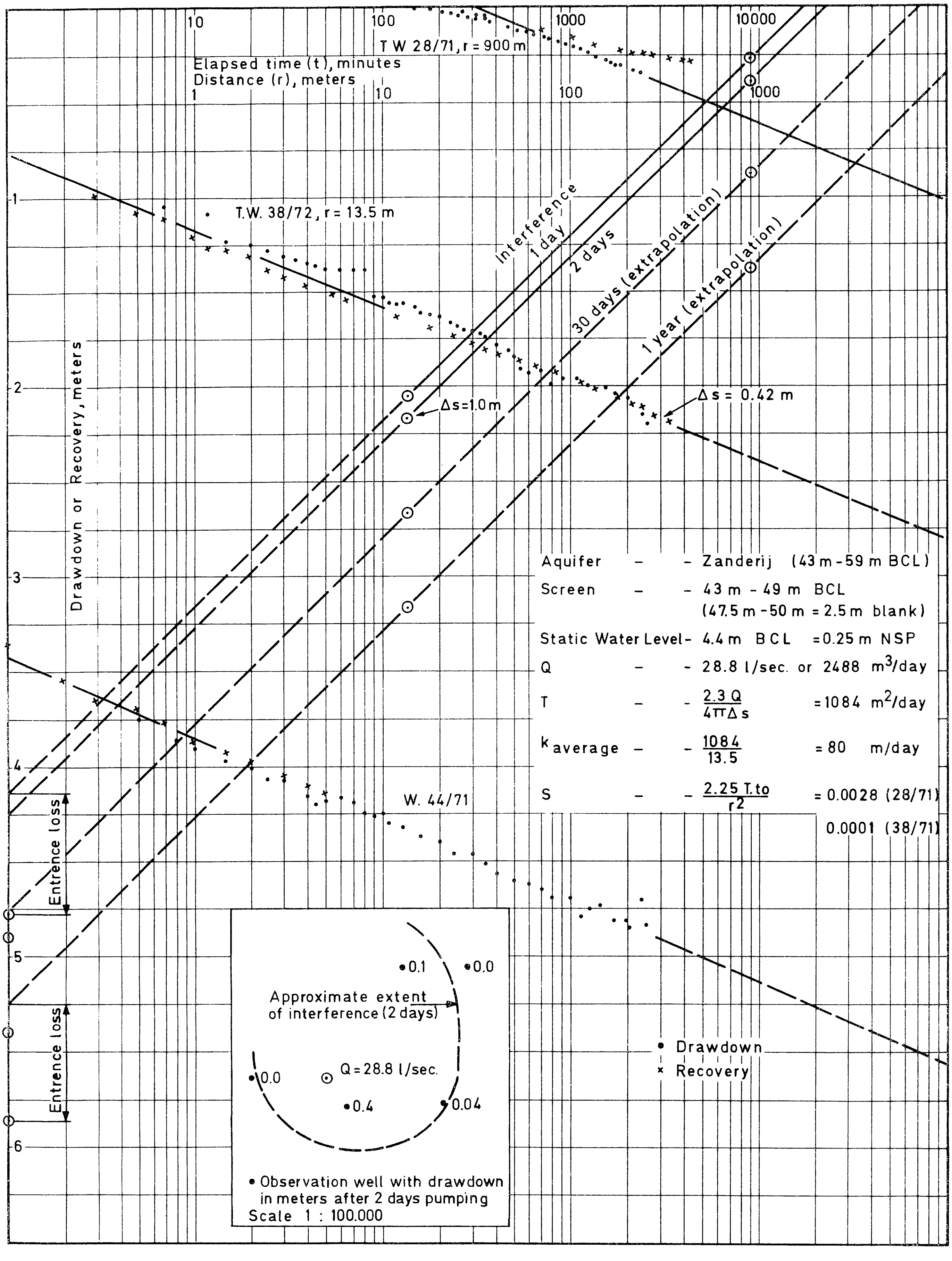


Figure III-37 , Pumping test on Well 31/71, Helena Christinaweg 13-14 September 1972



Aquifer - - Zanderij (43 m - 59 m BCL)
Screen - - 43 m - 49 m BCL (47.5 m - 50 m = 2.5 m blank)
Static Water Level - 4.4 m BCL = 0.25 m NSP
Q - - 28.8 l/sec. or 2488 m^3/day
T - - $\frac{2.3\,Q}{4\pi\Delta s}$ = 1084 m^2/day
$k_{average}$ - - $\frac{1084}{13.5}$ = 80 m/day
S - - $\frac{2.25\,T.t_o}{r^2}$ = 0.0028 (28/71)
0.0001 (38/71)

Figure III-38, Well 44/71, Sidodadieweg – Pumping test

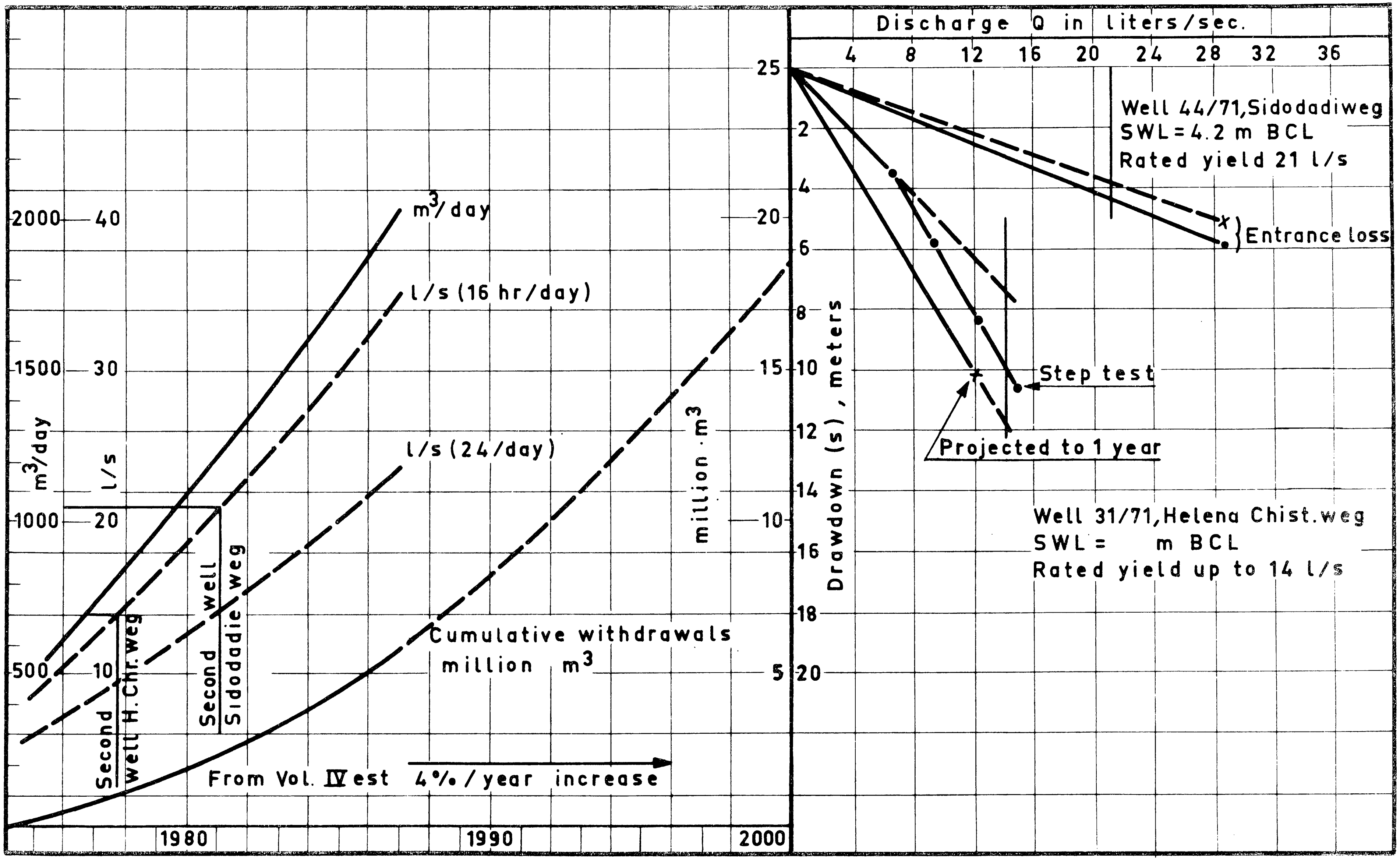


Figure III-39 ,Water requirements for the Pad van Wanica-West water distribution system and the drawdown-discharge relationship of Wells 31/71, Helena Christinaweg and 44/71, Sidodadieweg

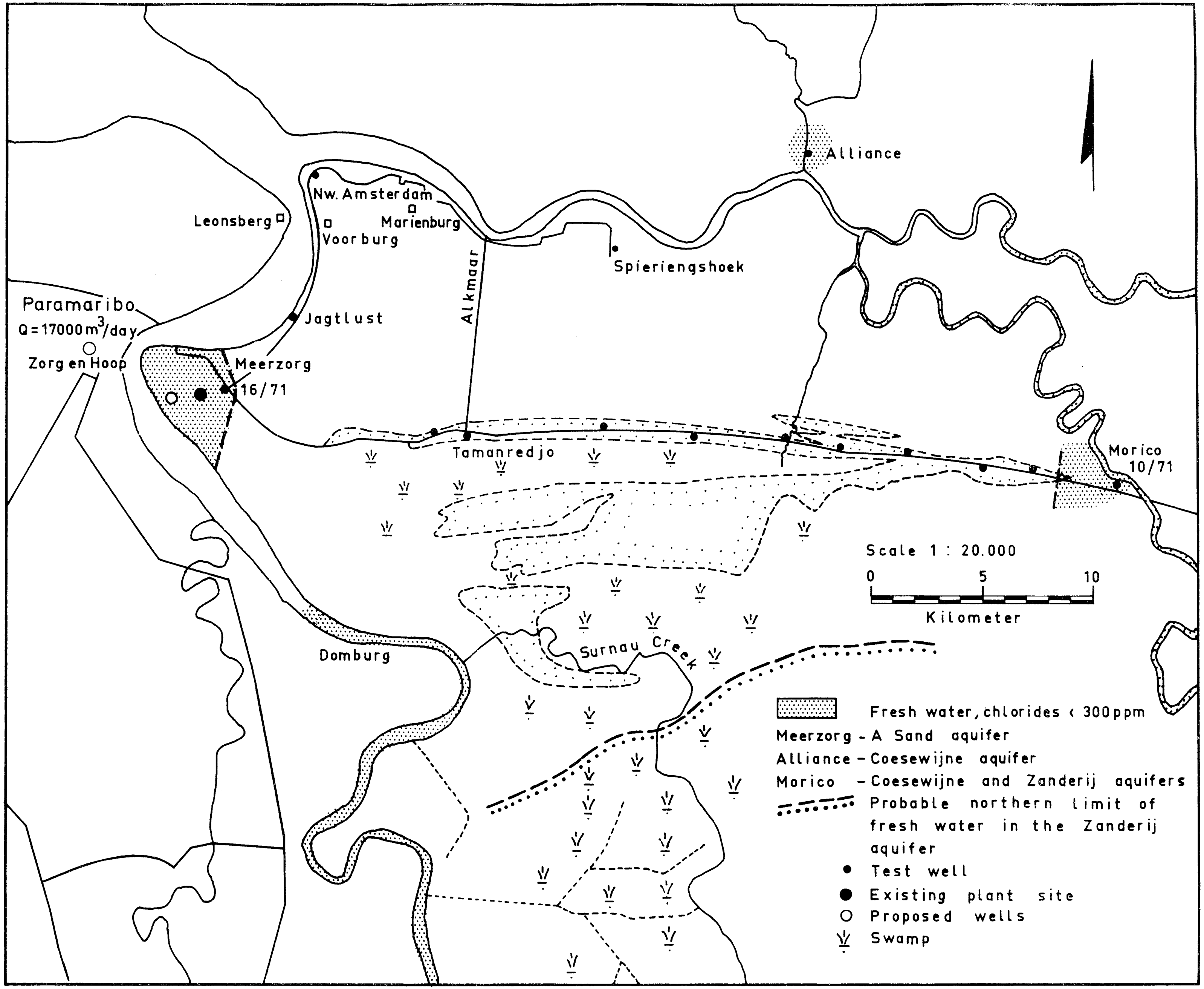


Figure III -40, Sources of fresh water in the Commewijne area.

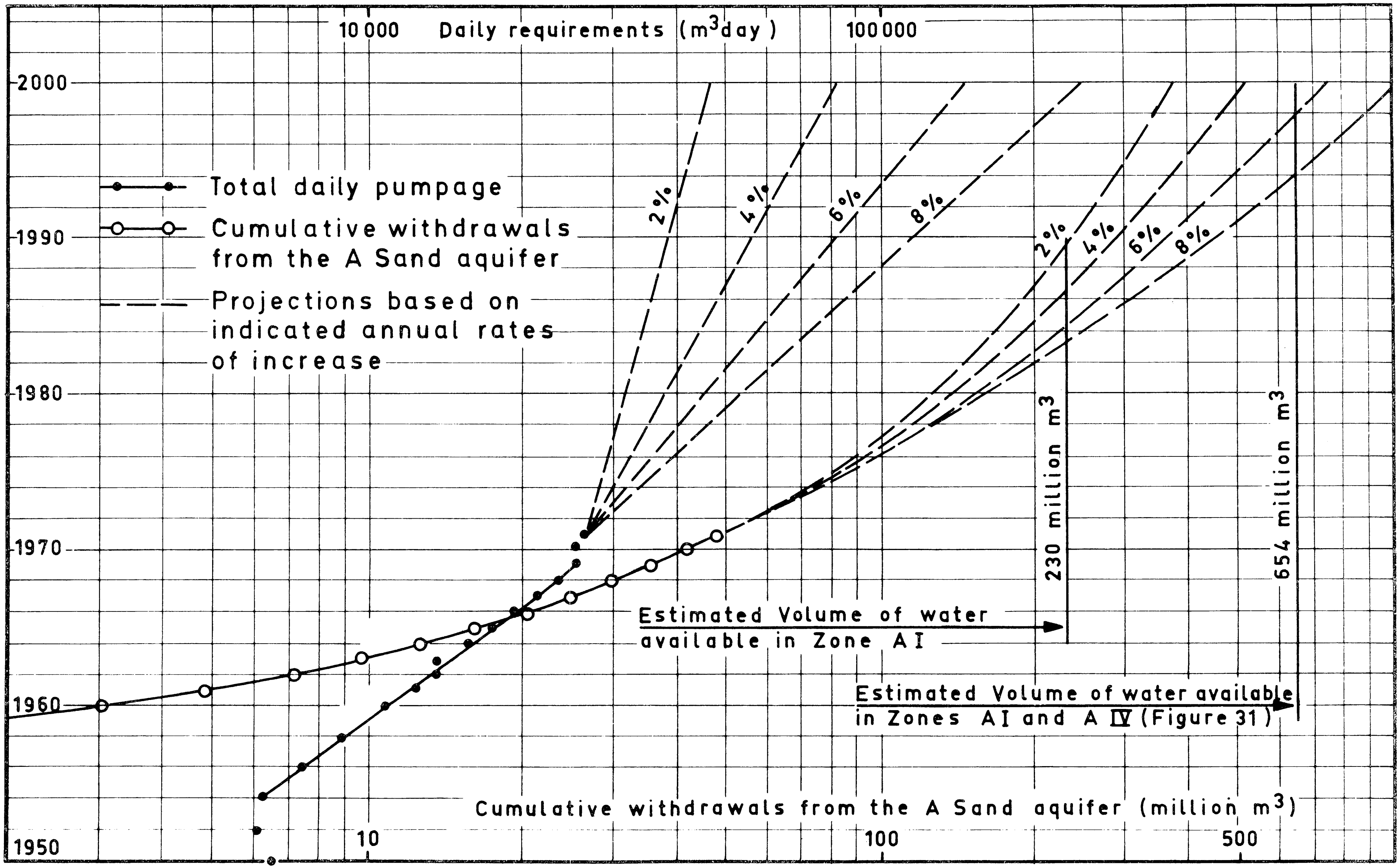


Figure III-41, .-Estimated water requirements for Paramaribo, and cumulative withdrawals from the A Sand aquifer

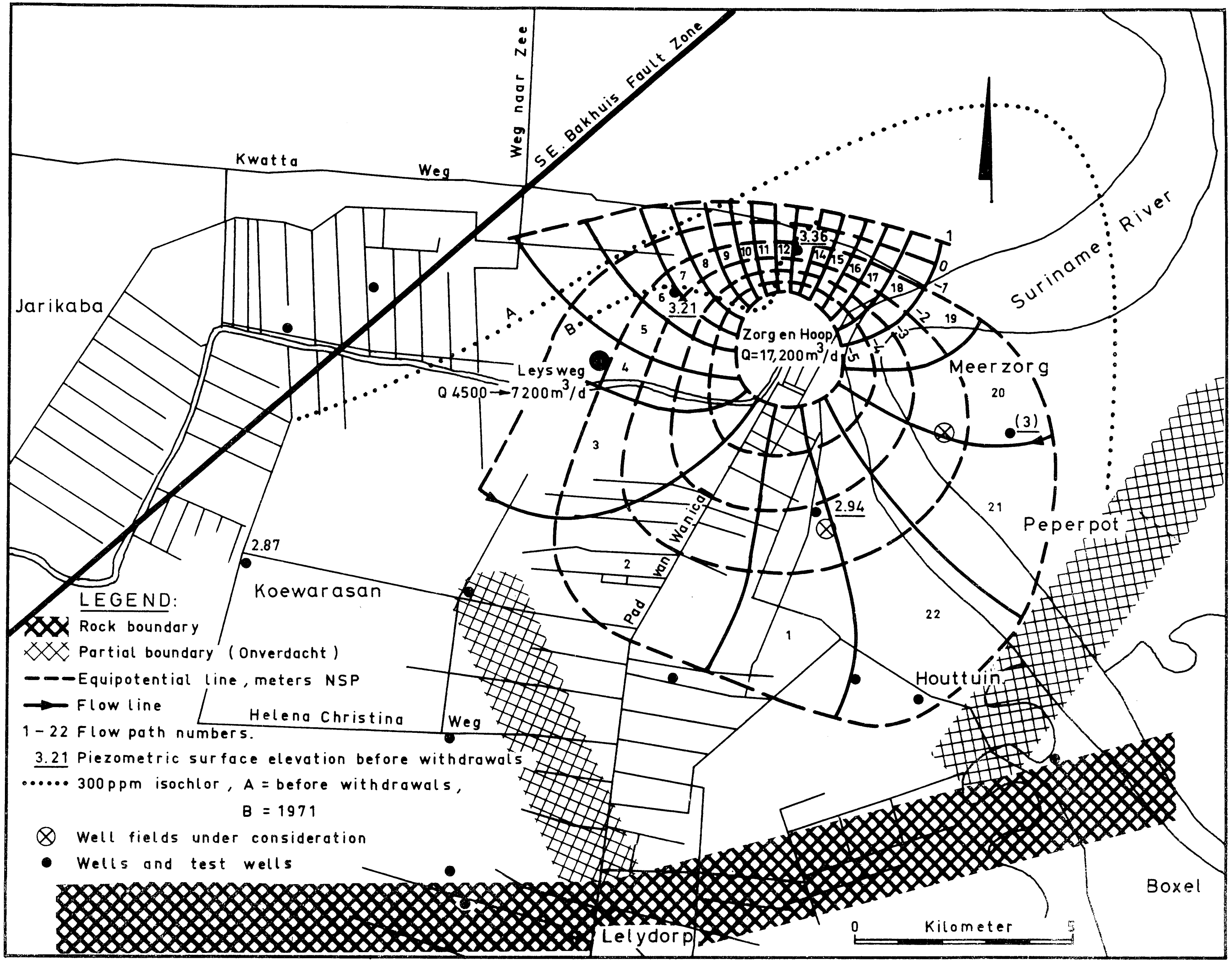


Figure III -42, Interference of the Zorg en Hoop well field in the A Sand aquifer, Paramaribo, 1971

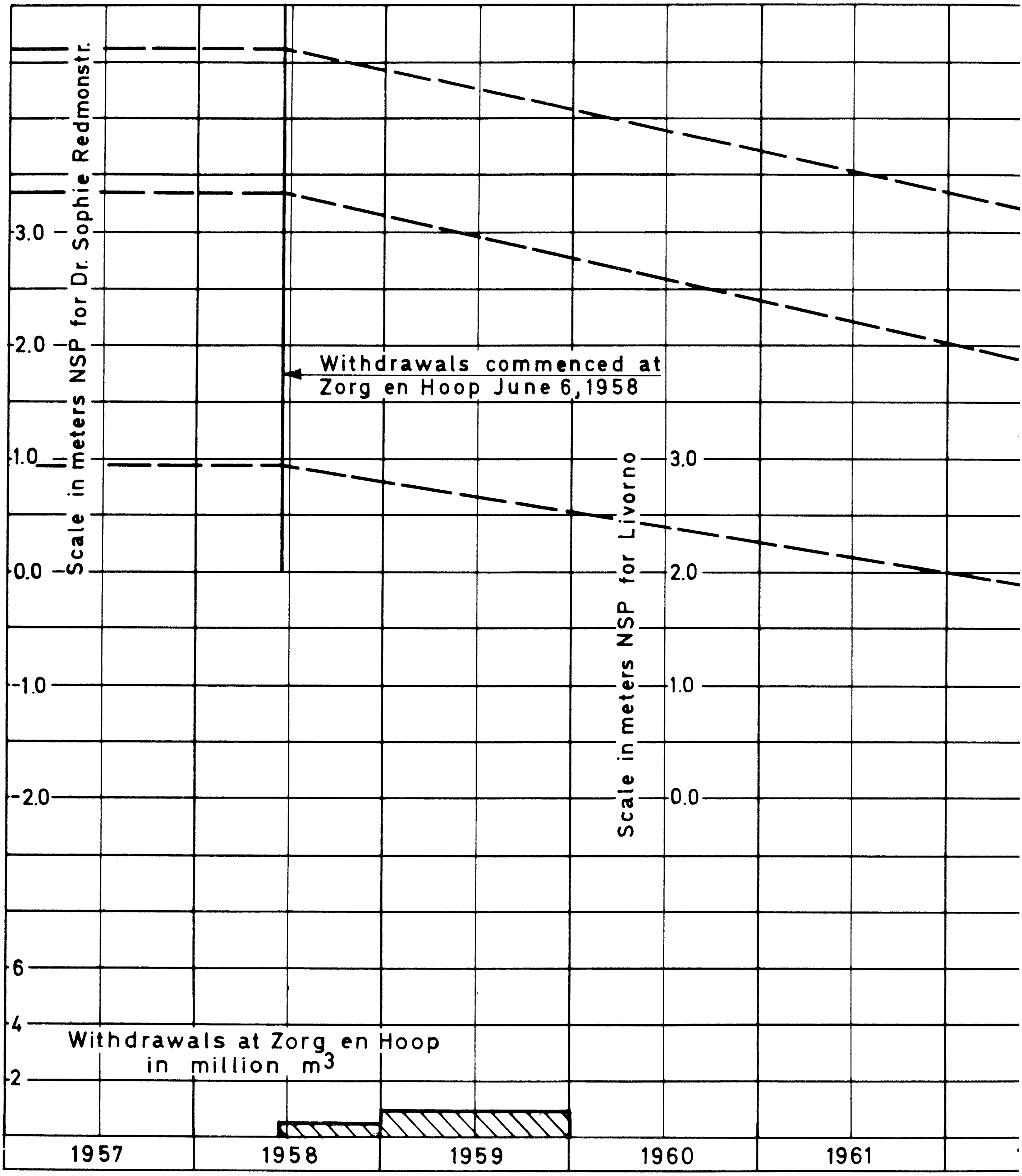
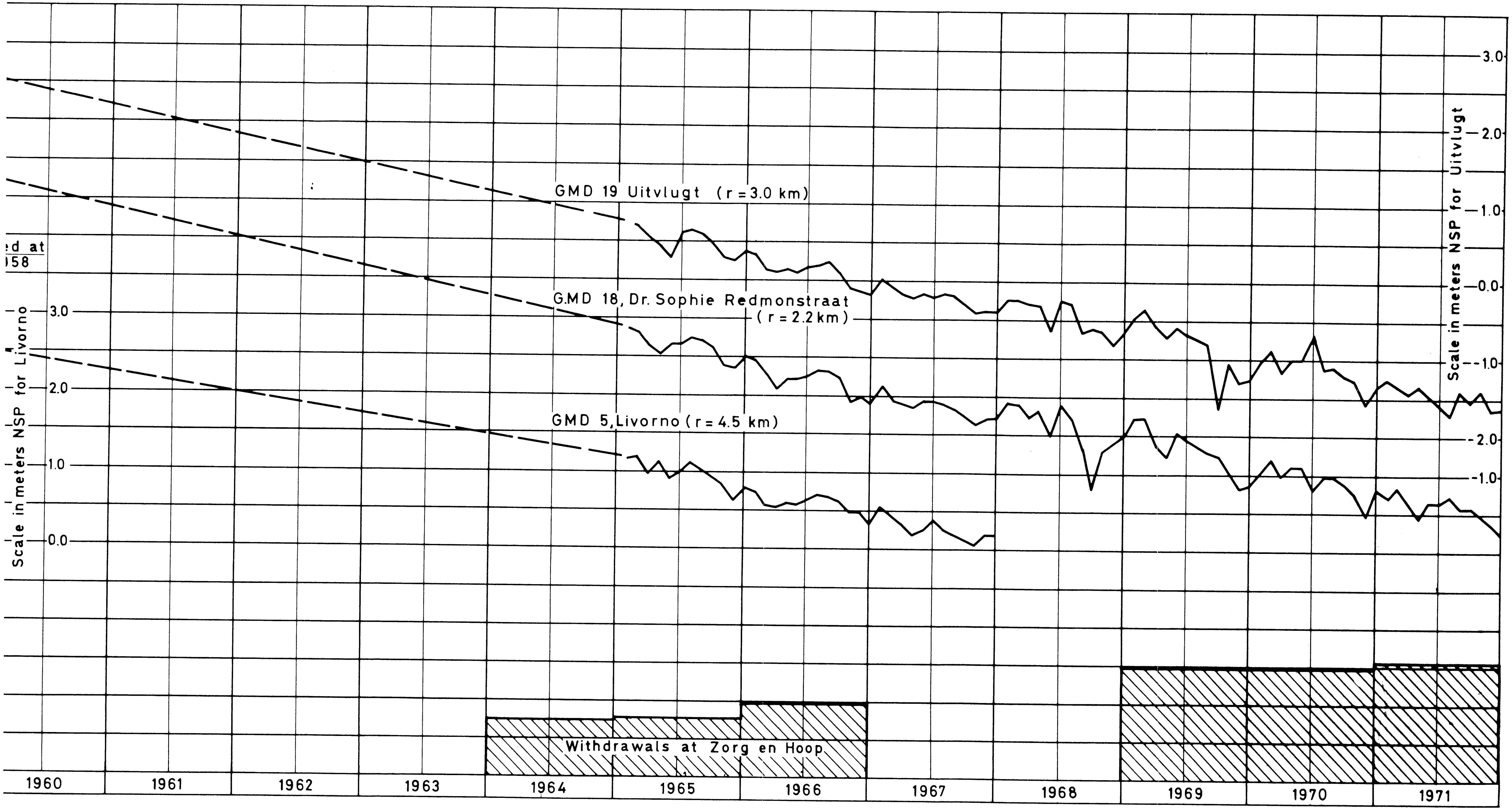
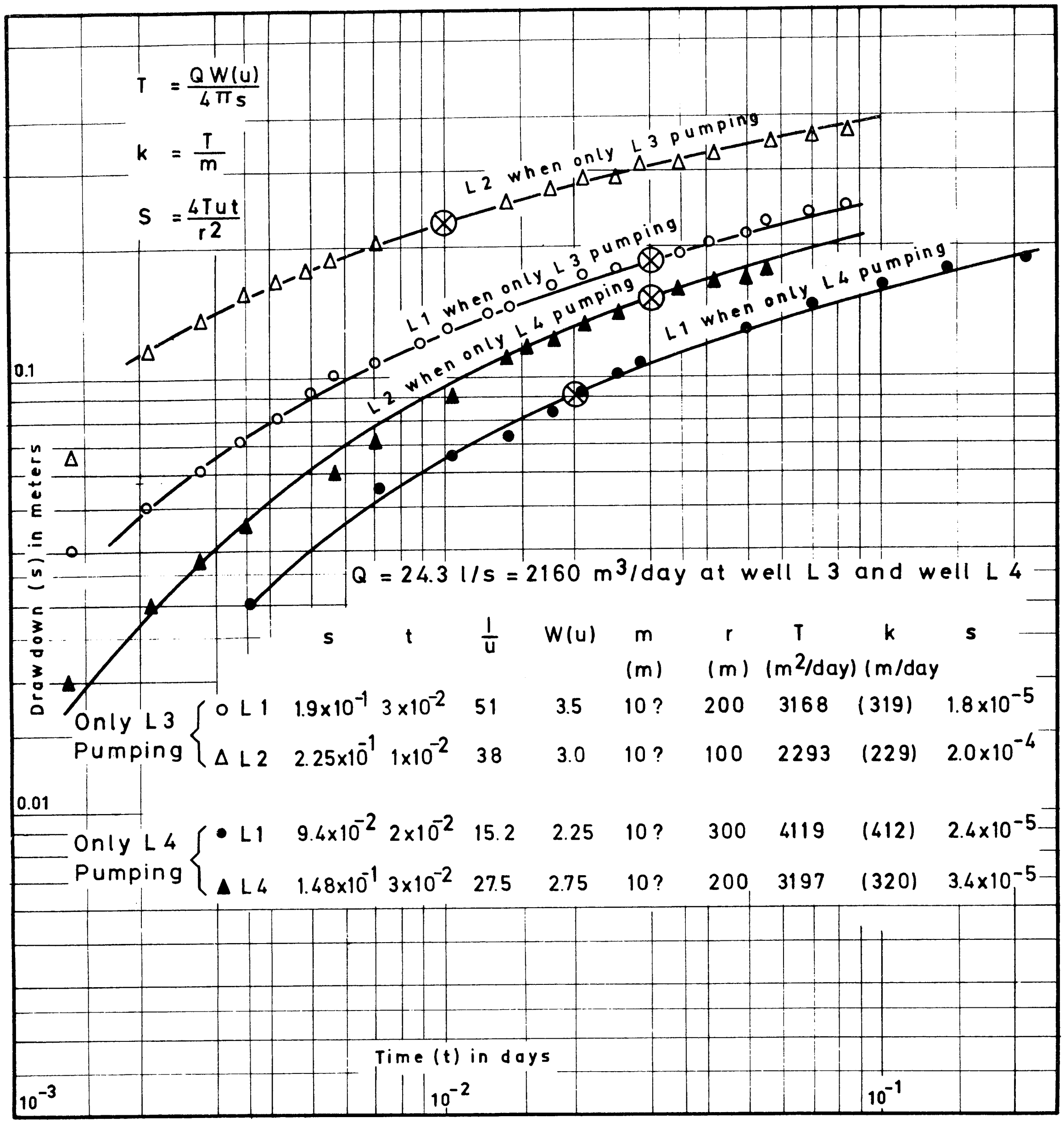


Figure III -43, Hydrographs of wells in th



-43, Hydrographs of wells in the A Sand Aquifer showing interference caused by groundwater withdrawals at Zorg en Hoop



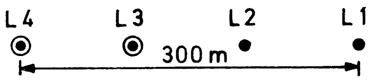
$T = \frac{QW(u)}{4\pi s}$

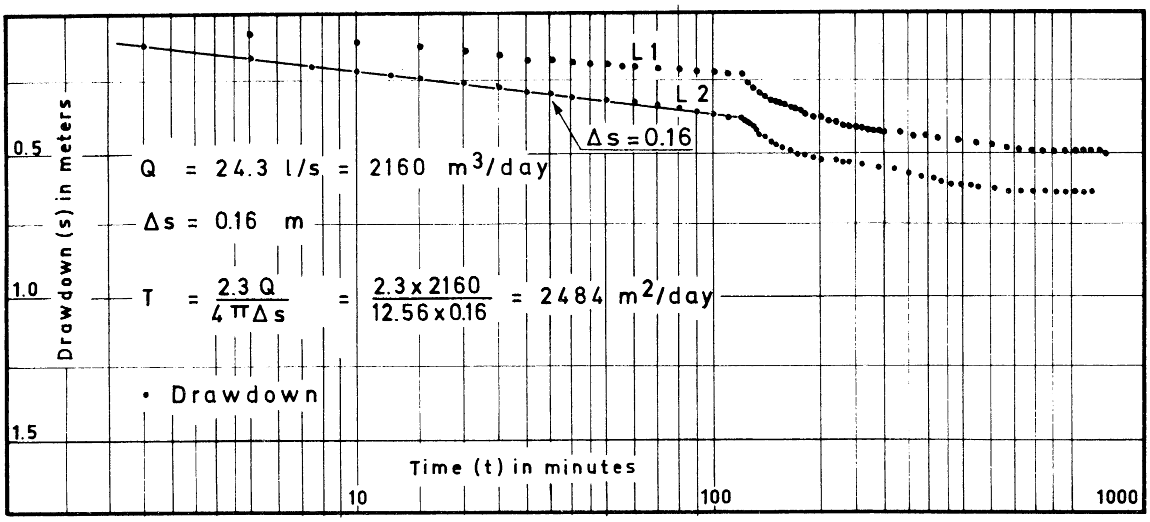
$k = \frac{T}{m}$

$S = \frac{4Tut}{r2}$

Q = 24.3 l/s = 2160 m³/day at well L 3 and well L 4

		s	t	$\frac{1}{u}$	W(u)	m (m)	r (m)	T (m²/day)	k (m/day)	s
Only L 3 Pumping	○ L 1	1.9×10^{-1}	3×10^{-2}	51	3.5	10 ?	200	3168	(319)	1.8×10^{-5}
	Δ L 2	2.25×10^{-1}	1×10^{-2}	38	3.0	10 ?	100	2293	(229)	2.0×10^{-4}
Only L 4 Pumping	• L 1	9.4×10^{-2}	2×10^{-2}	15.2	2.25	10 ?	300	4119	(412)	2.4×10^{-5}
	▲ L 4	1.48×10^{-1}	3×10^{-2}	27.5	2.75	10 ?	200	3197	(320)	3.4×10^{-5}





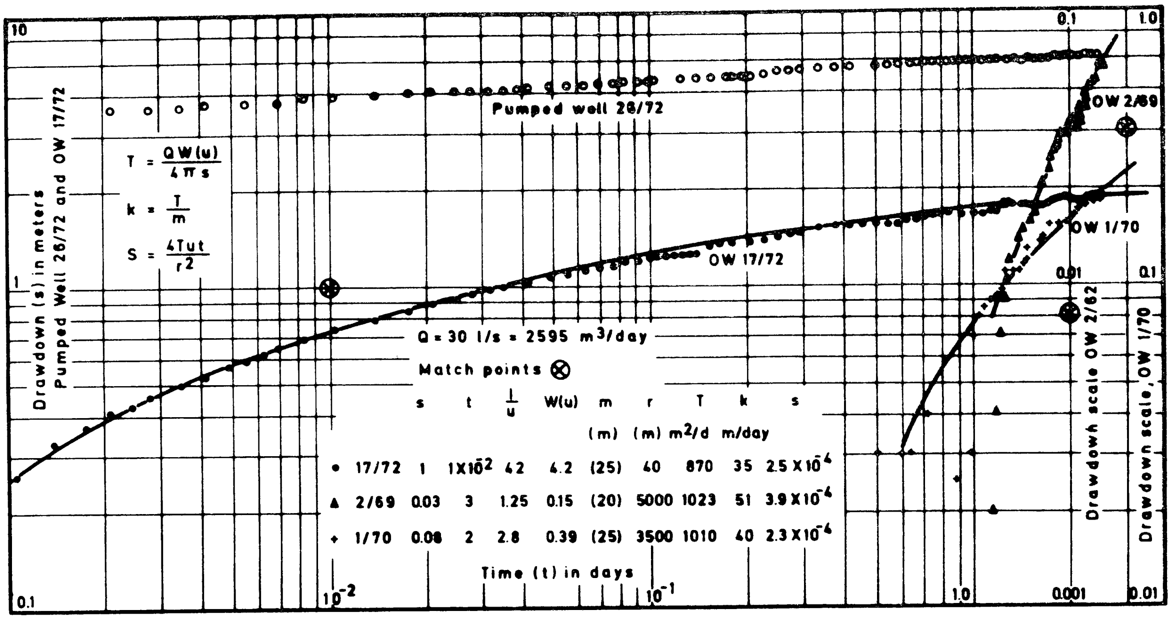
Q = 24.3 l/s = 2160 m³/day

Δs = 0.16 m

$T = \frac{2.3\,Q}{4\pi\Delta s} = \frac{2.3 \times 2160}{12.56 \times 0.16} = 2484\ m^2/day$

• Drawdown

Figure III-44, A Sand aquifer test at Leysweg



$T = \frac{QW(u)}{4\pi s}$

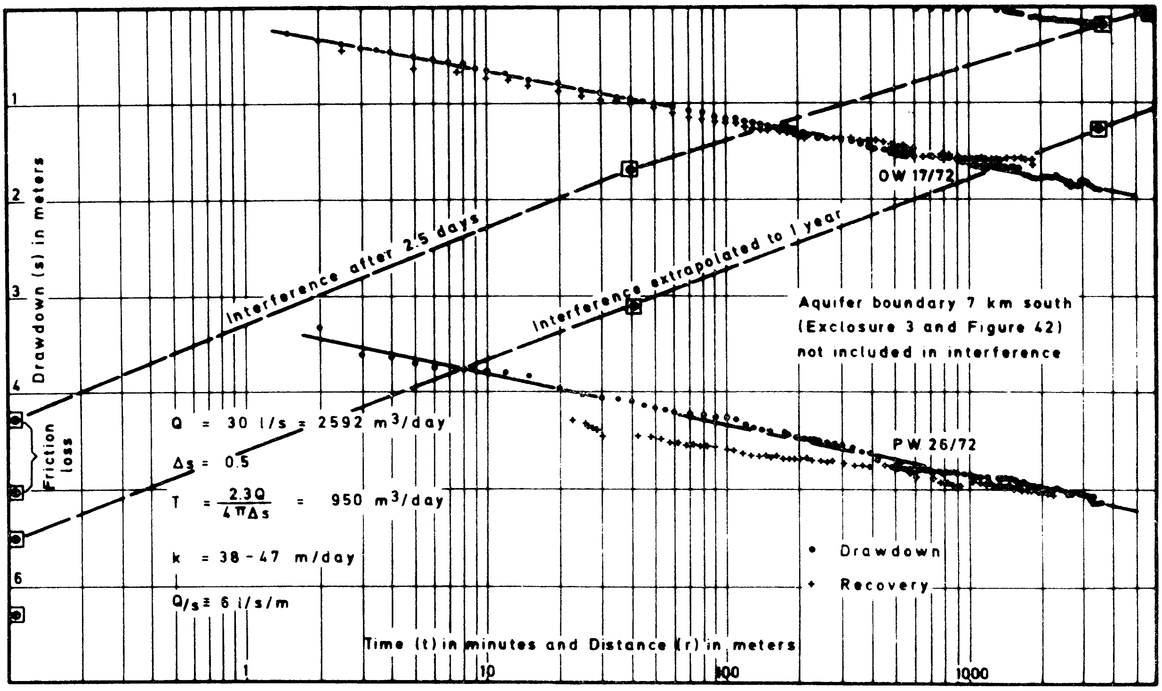
$k = \frac{T}{m}$

$S = \frac{4Tut}{r^2}$

Q = 30 l/s = 2595 m^3/day

Match points ⊗

		s	t	$\frac{1}{u}$	W(u)	m (m)	r (m)	T m^2/d	k m/day	s
●	17/72	1	1×10^{-2}	42	4.2	(25)	40	870	35	2.5×10^{-4}
▲	2/69	0.03	3	1.25	0.15	(20)	5000	1023	51	3.9×10^{-4}
+	1/70	0.08	2	2.8	0.39	(25)	3500	1010	40	2.3×10^{-4}



Aquifer boundary 7 km south (Exclosure 3 and Figure 42) not included in interference

Q = 30 l/s = 2592 m^3/day

$\Delta s = 0.5$

$T = \frac{2.3Q}{4\pi\Delta s} = 950$ m^3/day

k = 38 - 47 m/day

$Q/s \cong 6$ l/s/m

● Drawdown

+ Recovery

Figure III - 45, "A Sand" aquifer test at Makkaholo Weg (Livorno)

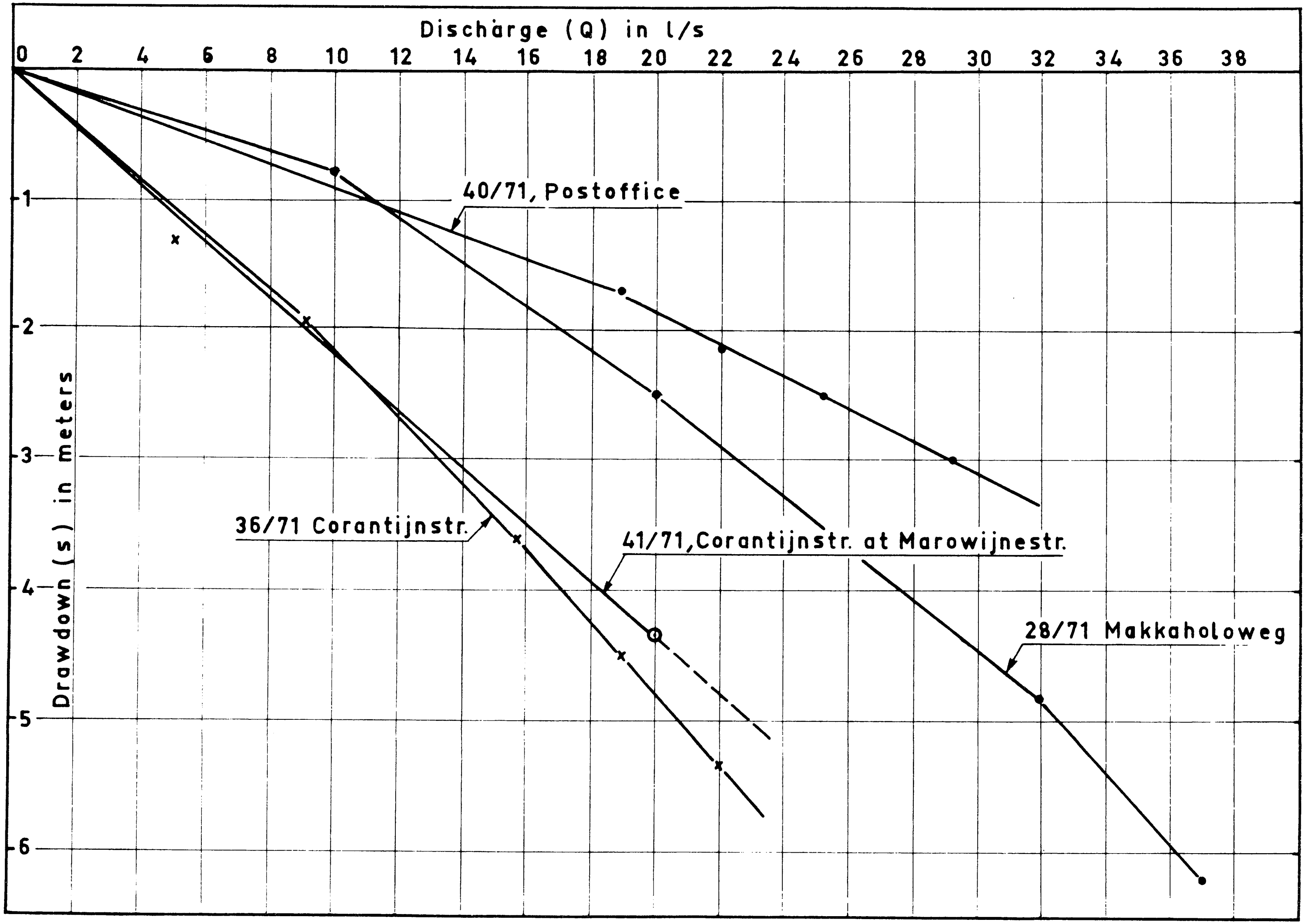


Figure III-46 - Drawdown-discharge relationship of wells drilled for Paramaribo

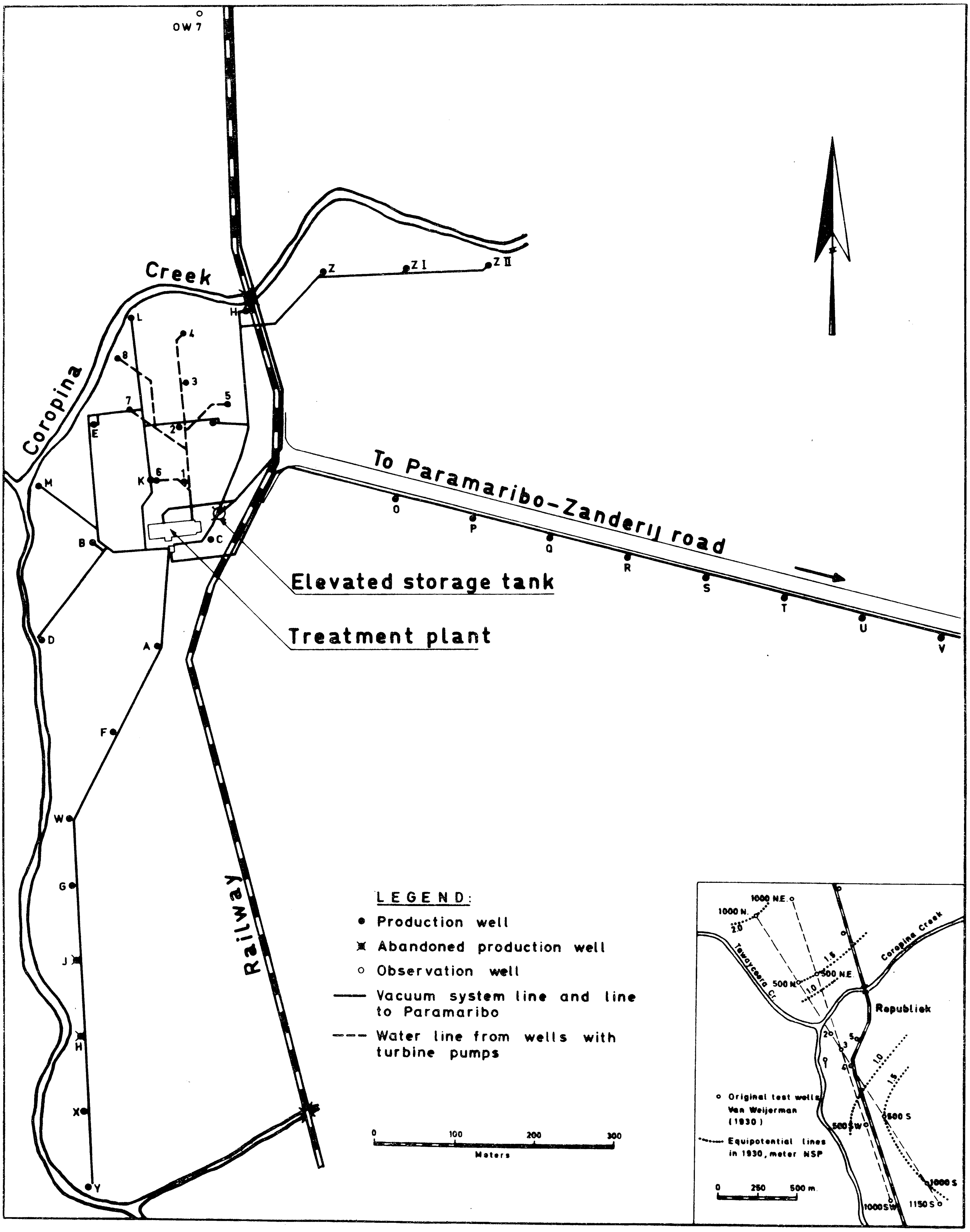
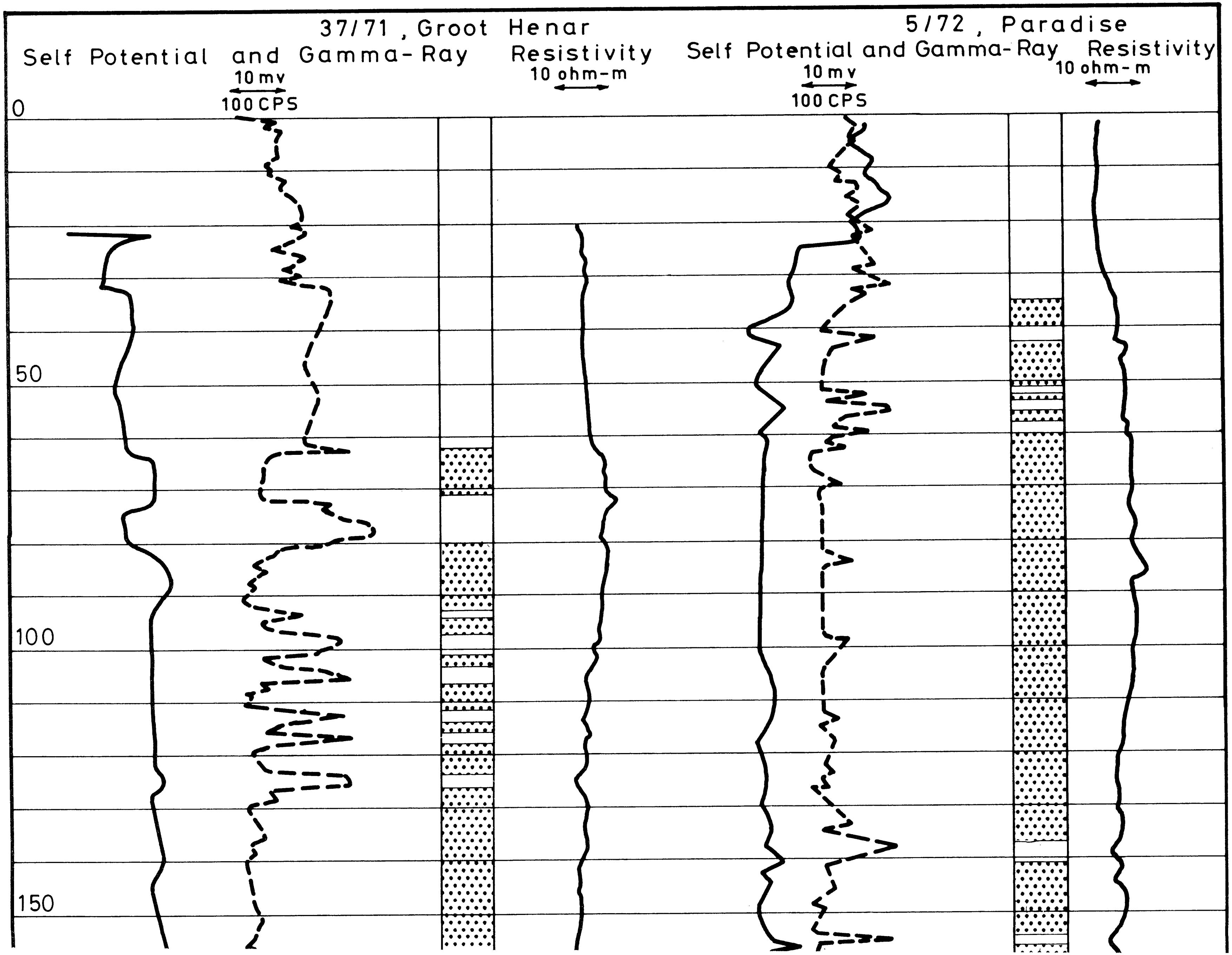


Figure III-47, Republiek well field

37/71 , Groot Henar
Self Potential and Gamma-Ray
10 mv
100 CPS
Resistivity
10 ohm-m
5/72 , Paradise
Self Potential and Gamma-Ray
10 mv
100 CPS
Resistivity
10 ohm-m
0
50
100
150

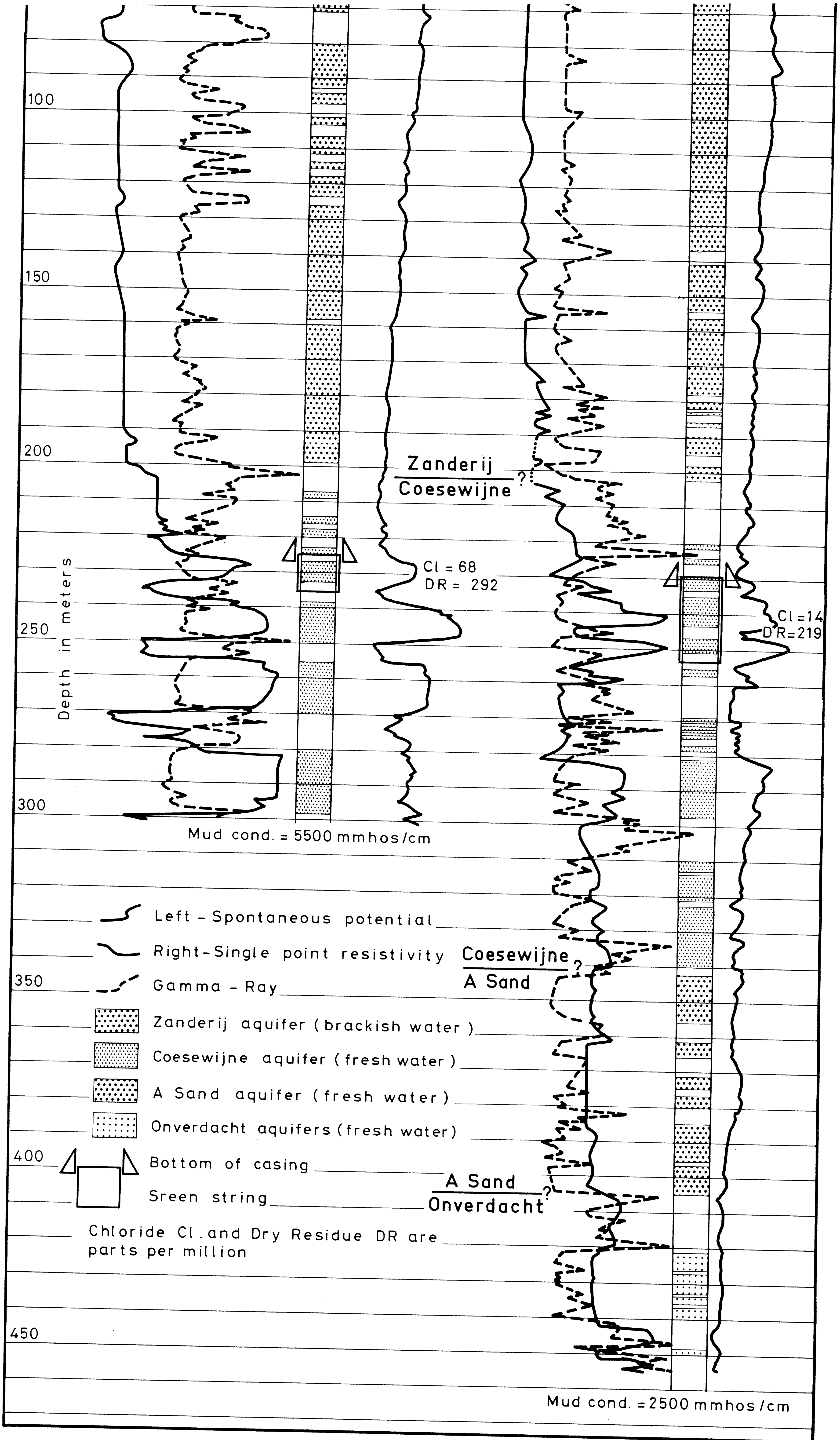


Figure III -48 , Logs of Wells 37/71 , Groot Henar , and 5/72 Paradise