Station Number	Station Name	River Name	Catchment Area (Km^2)	Latitude (D. M. S)	Longitude (D. M. S)	Period of Record (47–80)	Nos yrs	State
6402434	Titi Jln. Arau	Gial	21.8	06 26 45	100 15 40		5	Perlis
6402435	Titi Jln. Arau	Arau	88.6	06 25 45	100 16 25		5	Perlis
6502401	Titi Tampang	Jerneh	23.5	06 32 20	100 16 15		6	Perlis
6502402	Kg. Batu Tangkup	Buloh	6.2	06 33 15	100 17 20		1	Perlis
6502431	Titi Konkerit Baru	Timah	57	06 35 15	100 12 40		6	Perlis
6502432	Titi Konkerit Baru	Tasoh	117	06 35 20	100 13 50		6	Perlis
6502433	Titi Hutan Duri	Jerneh	29.7	06 31 10	100 16 00		5	Perlis
6503401	Ldg. Tebu Felda	Arau	7.9	06 30 15	100 21 25		1	Perlis
5606410	Jam. Syed Omar	Muda	3330	05 36 35	100 37 35		11	Kedah
5608418	Kuala Pegang	Ketil	704	05 38 20	100 48 45		6	Kedah
5806414	Janiang	Muda	1740	05 49 10	100 37 55		34	Kedah
6007415	Nami	Muda	1220	06 03 20	100 46 00		13	Kedah
6204421	Langkuas	Pdg. Terap	1270	06 12 45	100 27 15		21	Kedah
5204422	Jam. Jln. Raya	Jawi	41.4	05 12 10	100 29 55		2	Pinang
5303401	Jalan Kurau	Jelutong	2.8	05 23 40	100 18 40		6	Pinang
5403401	Jam. Jln. Scotland	Air Itam	33	05 24 40	100 18 10		6	Pinang
5403402	Western Road	Air Terjun	9.2	05 25 35	100 18 10		6	Pinang
5405421	Ara Kuda	Kulim	129	05 26 10	100 30 50		20	Pinang
5505412	Ldg. Victoria	Muda	4010	05 31 55	100 34 20		20	Pinang
5506413	Batu Pekaka	Muda	3340	05 35 45	100 36 55		26	Pinang
5506416	Merbau Pulas	Sedim	440	05 34 00	100 38 20		26	Pinang
5506417	Titi Karangan	Karangan	82.9	05 31 20	100 37 10		12	Pinang

Fig. 4 Duration of Record at Hydrological Stations

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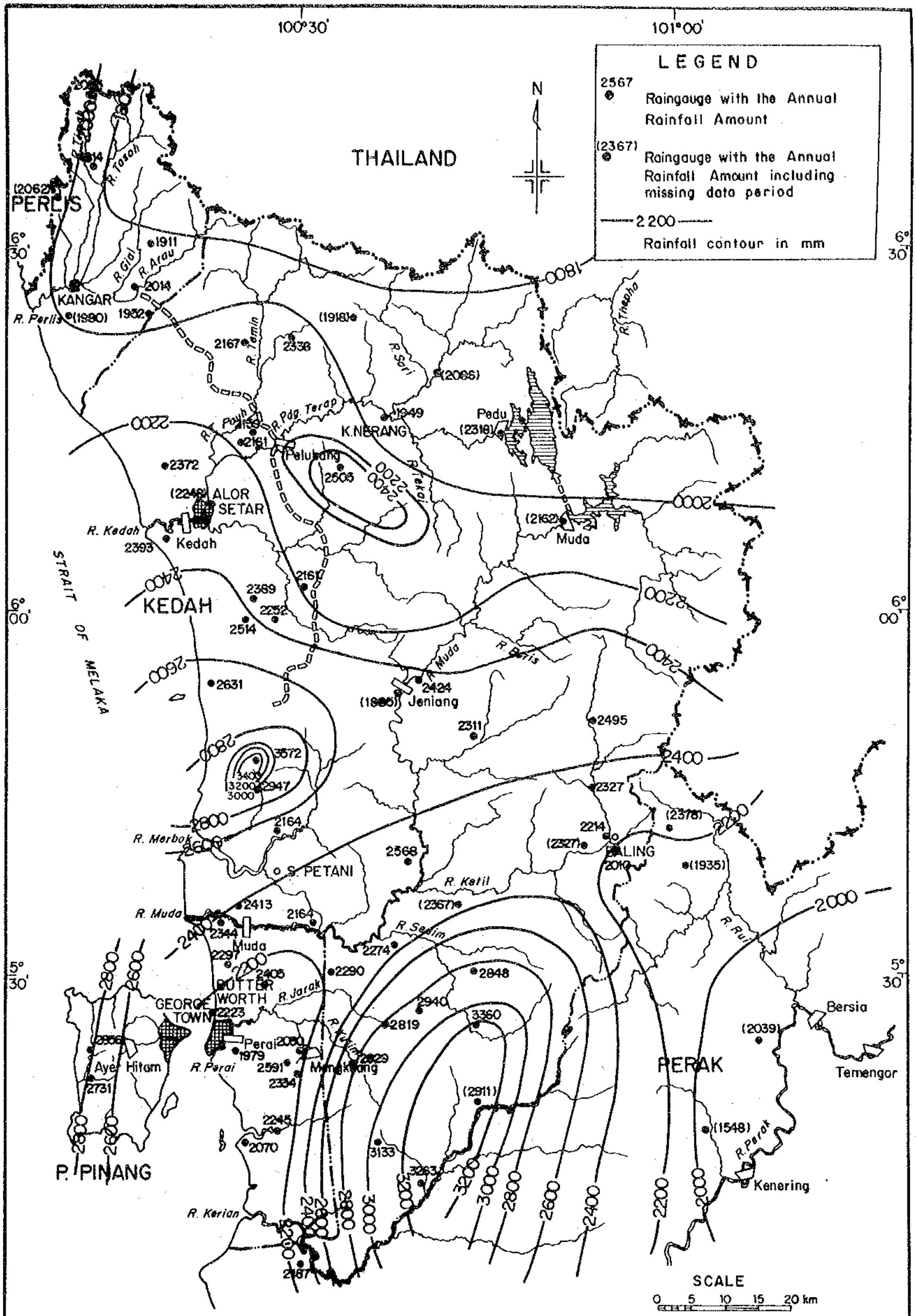

Fig. 5 Isohyetal Map of Annual Rainfall

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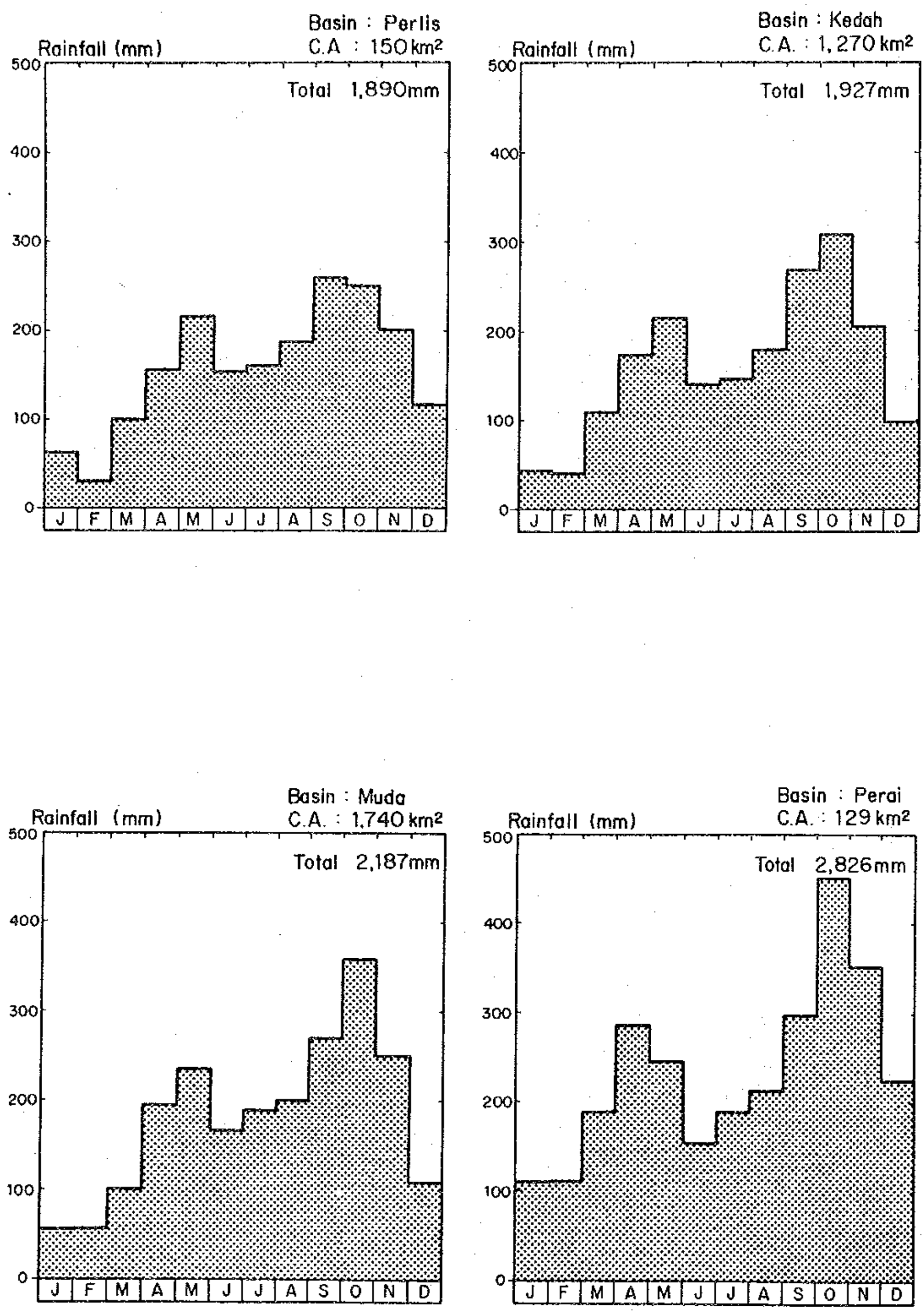

Fig. 6 Mean Monthly Basin Rainfall

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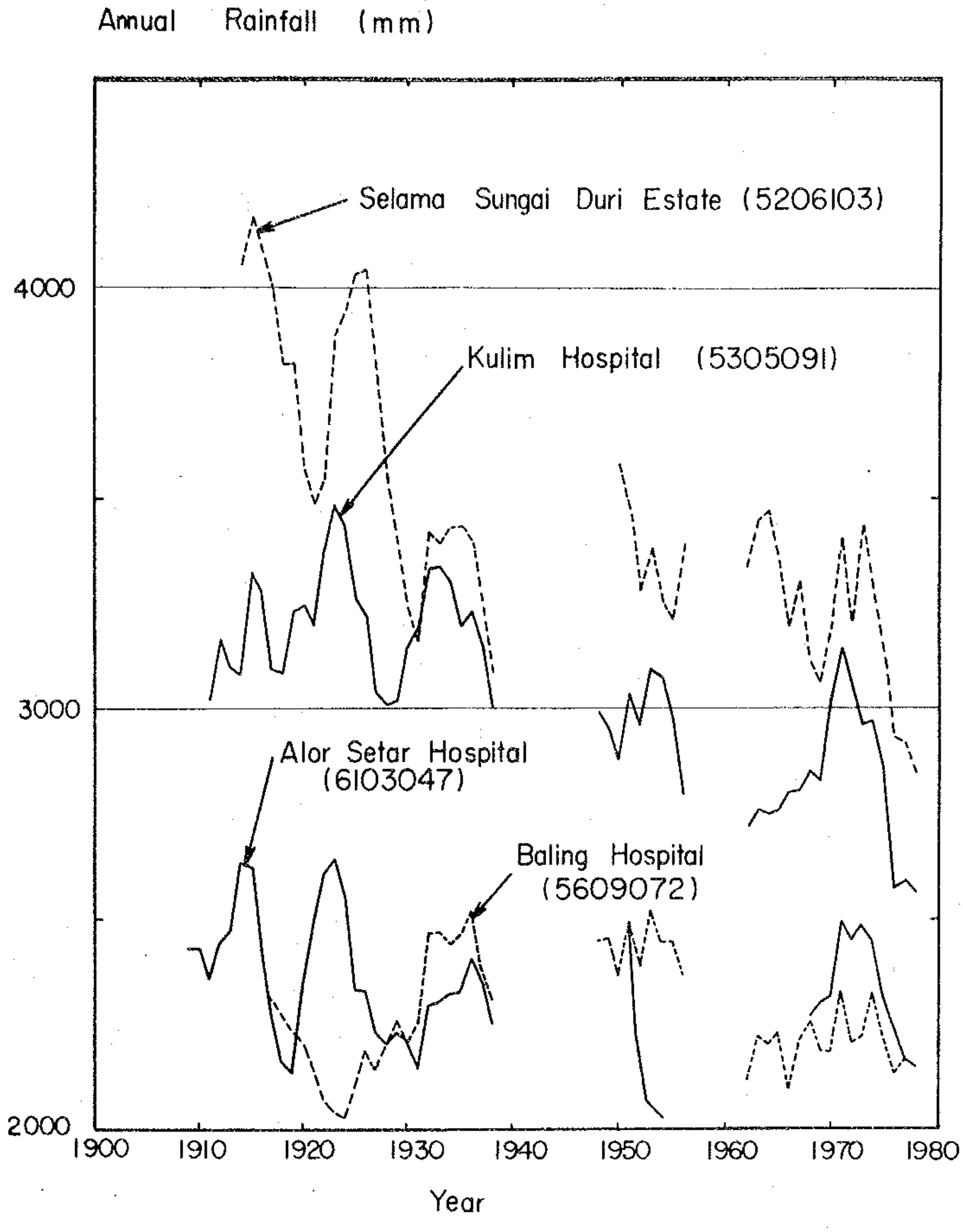

Fig. 7 5-Year Moving Average of Annual Rainfall

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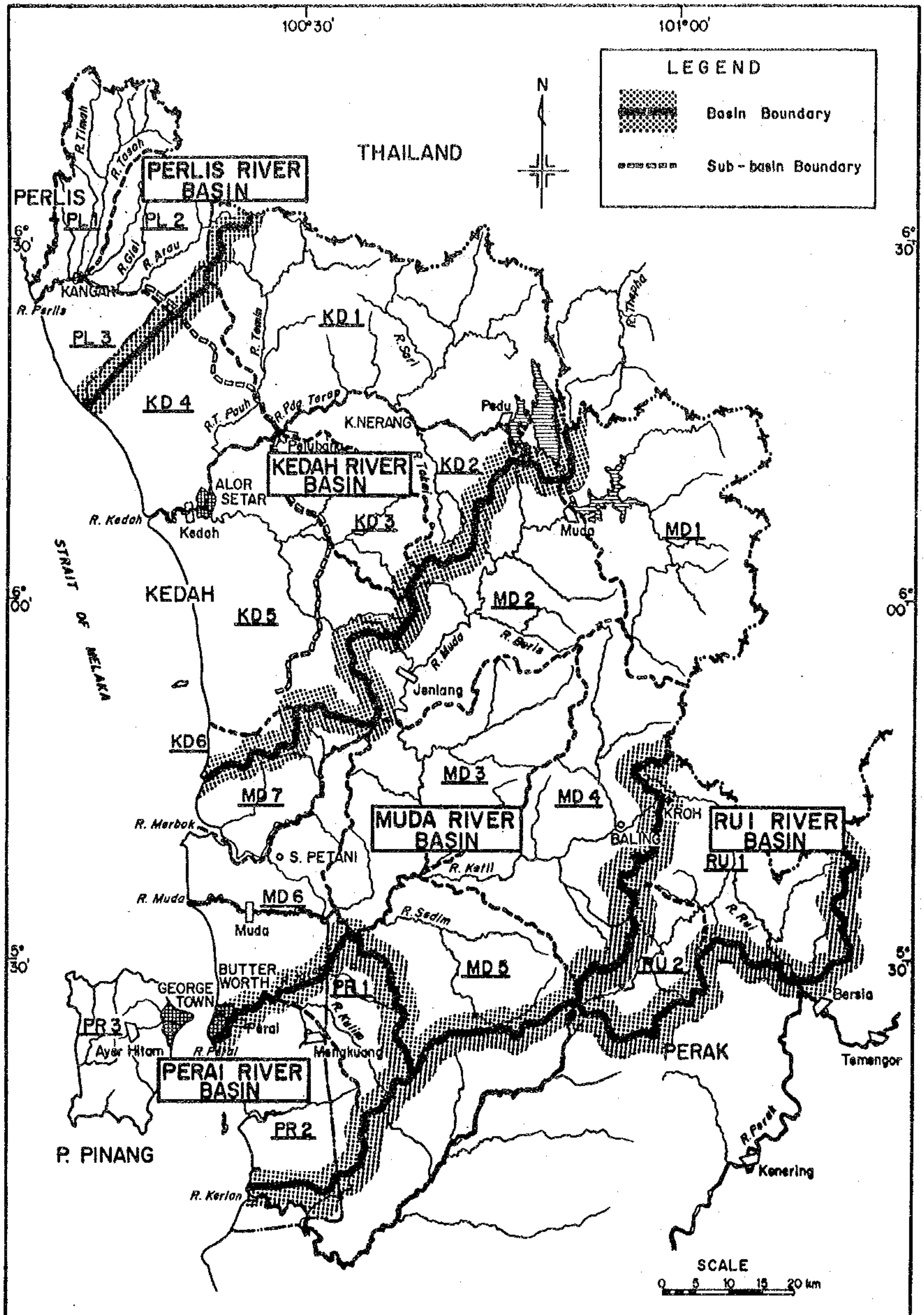

Fig. 8 Basin Division

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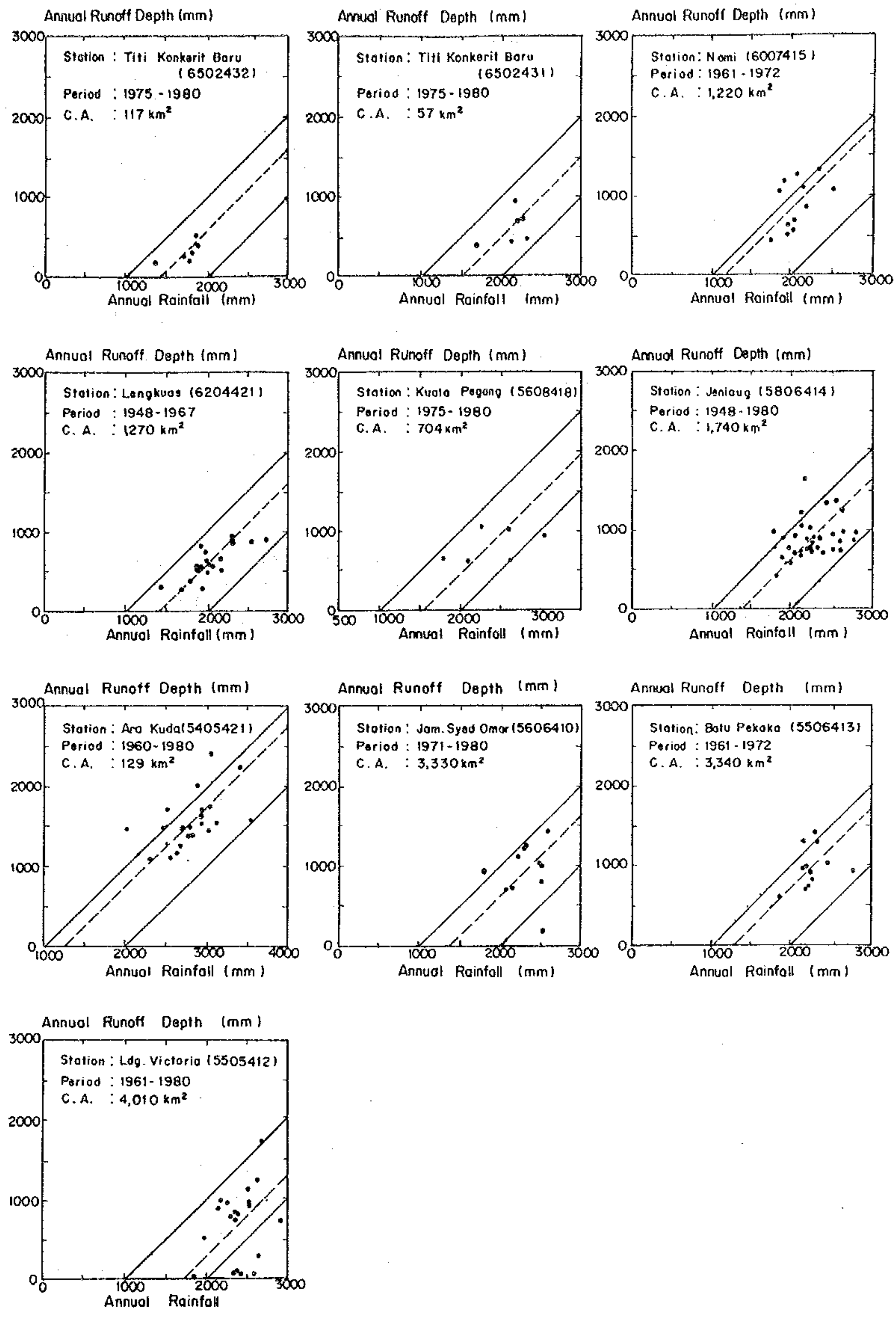

Fig. 9 Rainfall-Runoff Relationship

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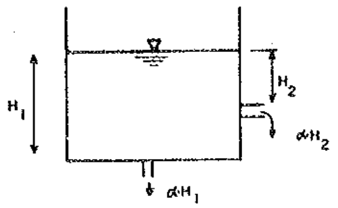
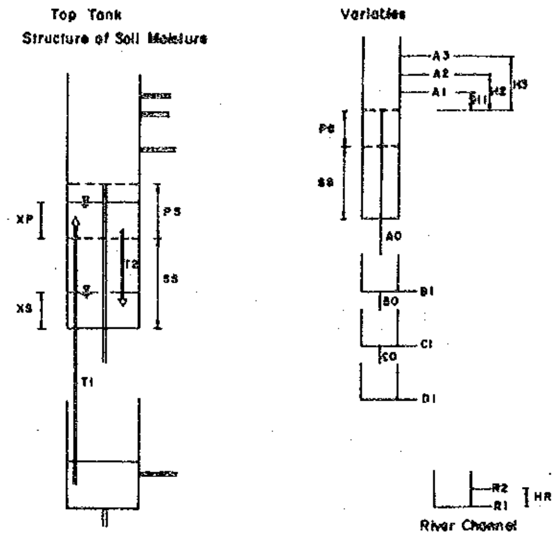


Fig. 10 Simplified Tank Model



PS Primary Soil moisture capacity
SS Secondary Soil moisture capacity

XP Primary Soil moisture depth
XS Secondary Soil moisture depth

T1 Transfer by capillary action from lower tanks.
$T1 = TB \times (1 - \frac{XP}{PS})$: TB = Constant

T2 Transfer of moisture between primary and secondary layers.
$T2 = TC \times (\frac{XP}{PS} - \frac{XS}{SS})$: TC = Constant

Fig. 12 Structure of Tank Model

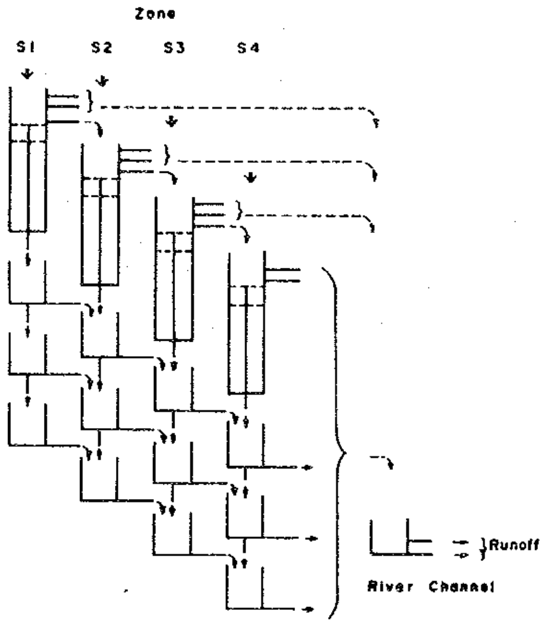


Fig. 11 Tank Arrangement for a Basin

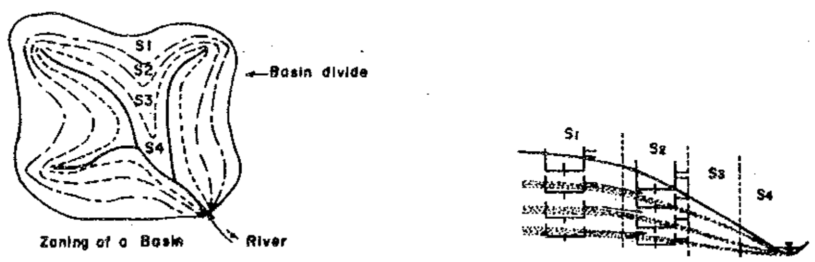


Fig. 13 Schematic Representation of Mechanism of Runoff in a Basin

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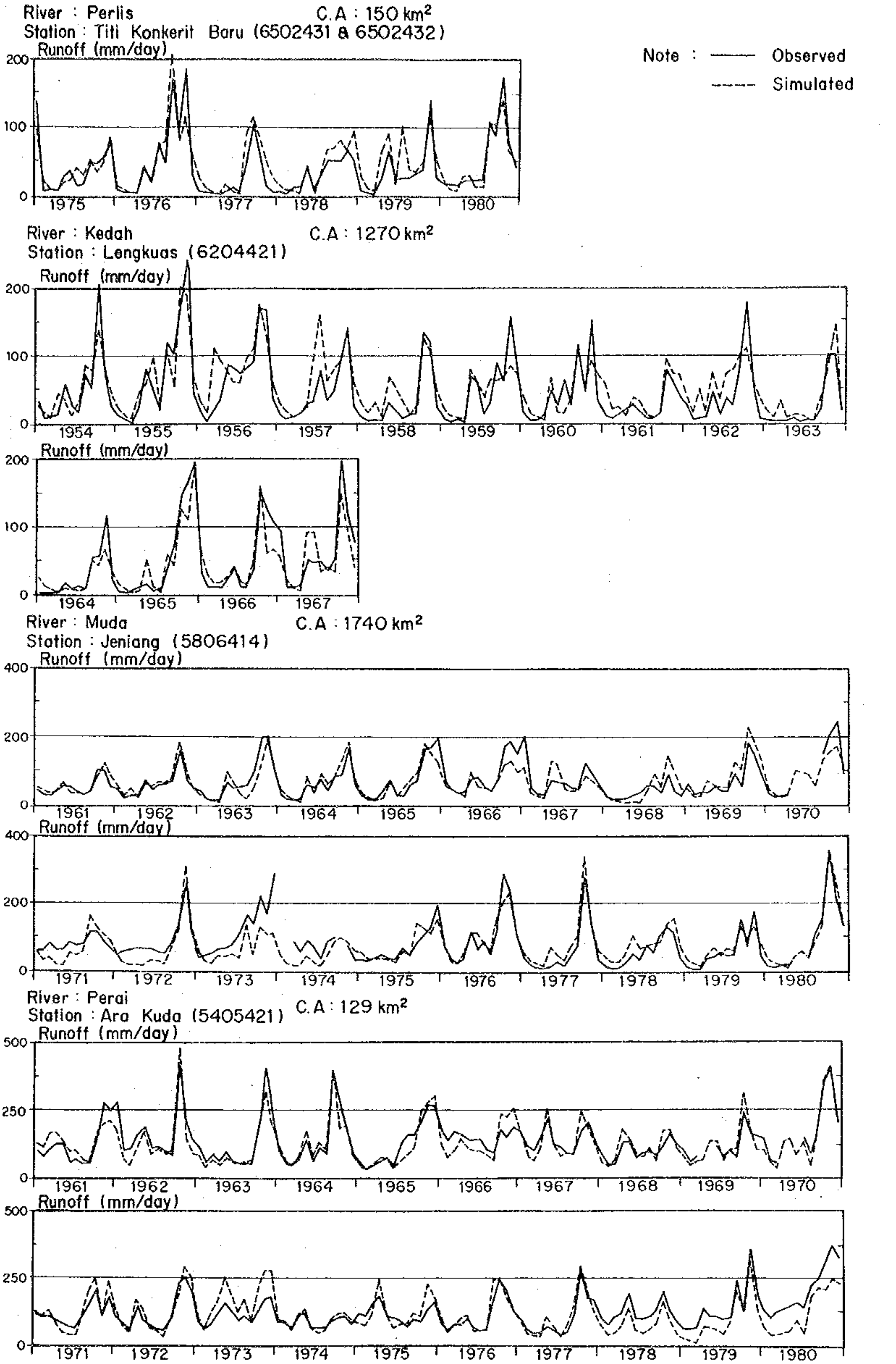

Fig. 14 Comparison of Monthly Runoff

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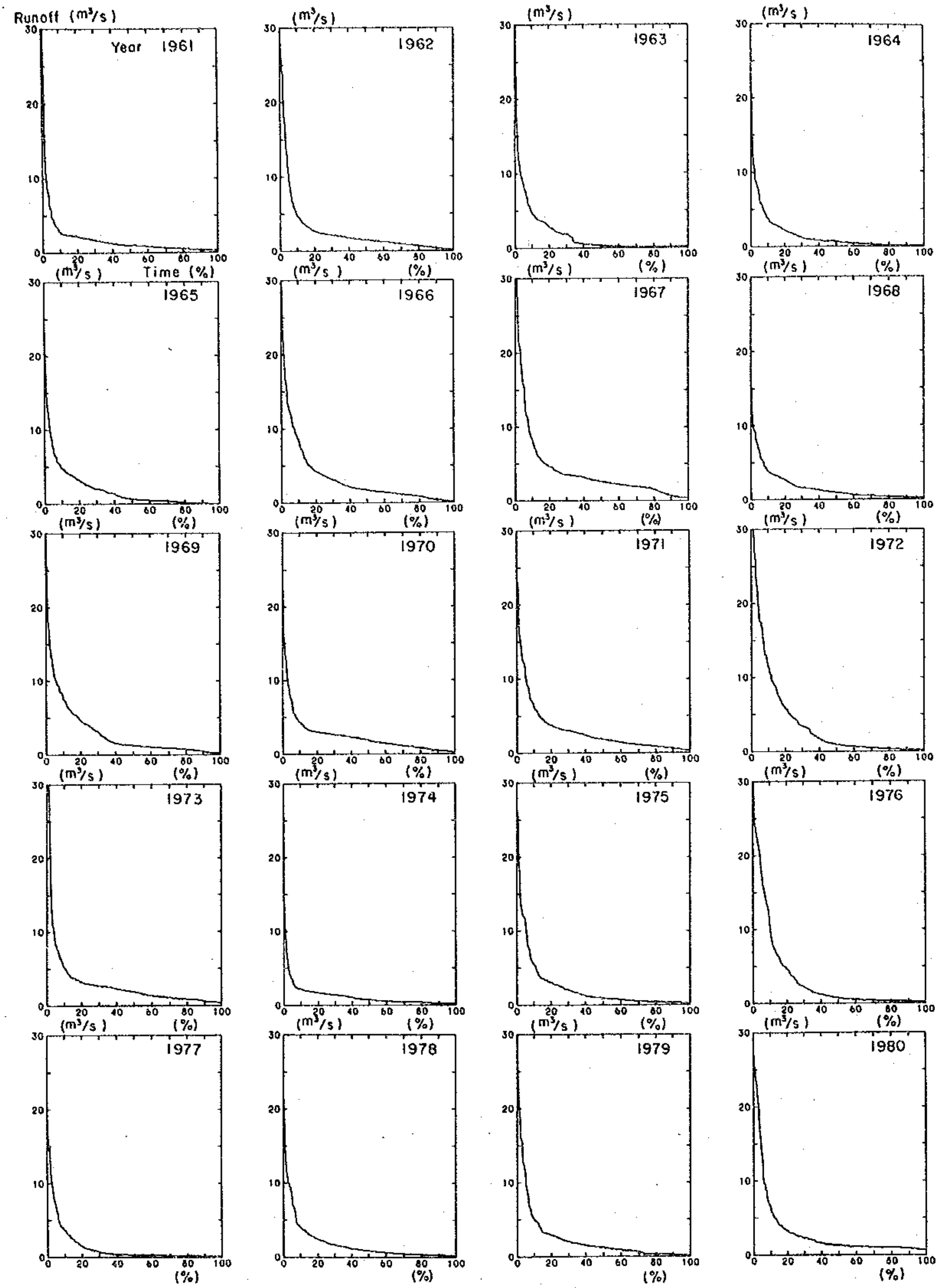

Fig. 15 Flow Duration Curves of Key Station (1/4)

(1/4)

Basin : Perlis C.A. : 150 km²

Station: Titi Konkerit Baru (6502431 & 6502432)

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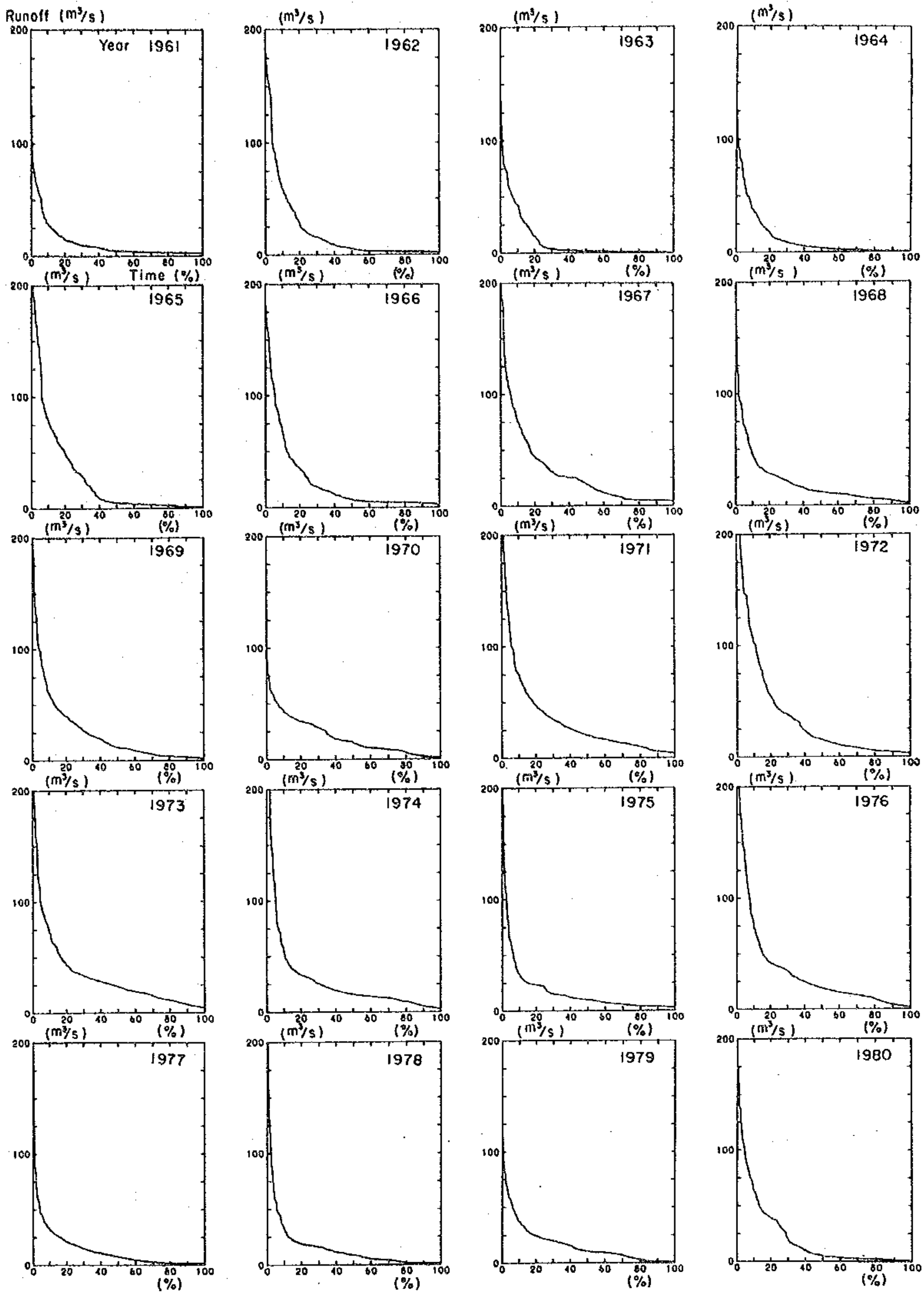

Fig. 16 Flow Duration Curves of Key Station (2/4)

Basin : Kedah

Station: Lengkuas (6204421) C.A. : 1,270 km²

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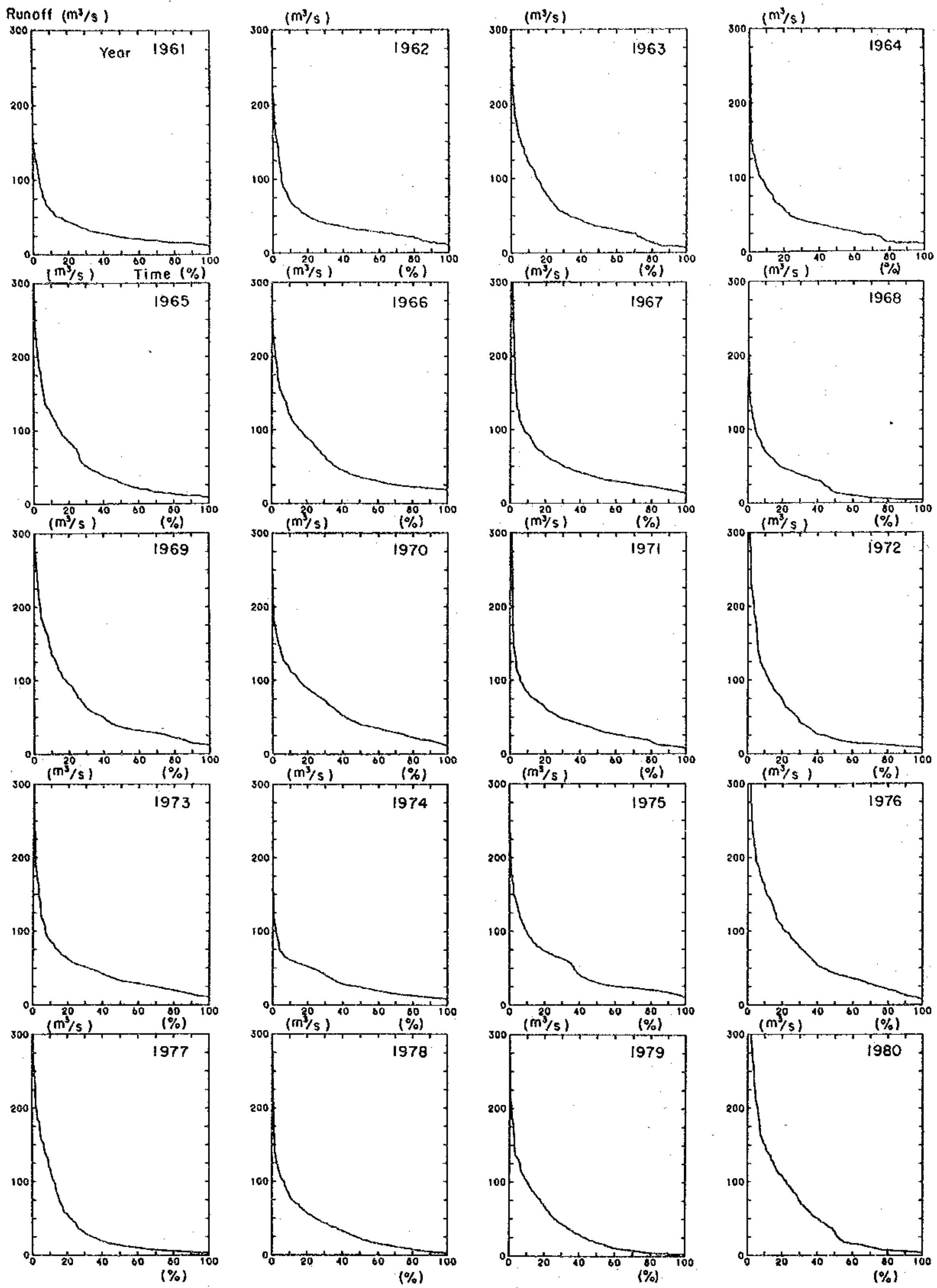

Fig. 17 Flow Duration Curves of Key Station (3/4)

Basin : Muda

Station: Jeniang (5806414) C.A. : 1,740 km²

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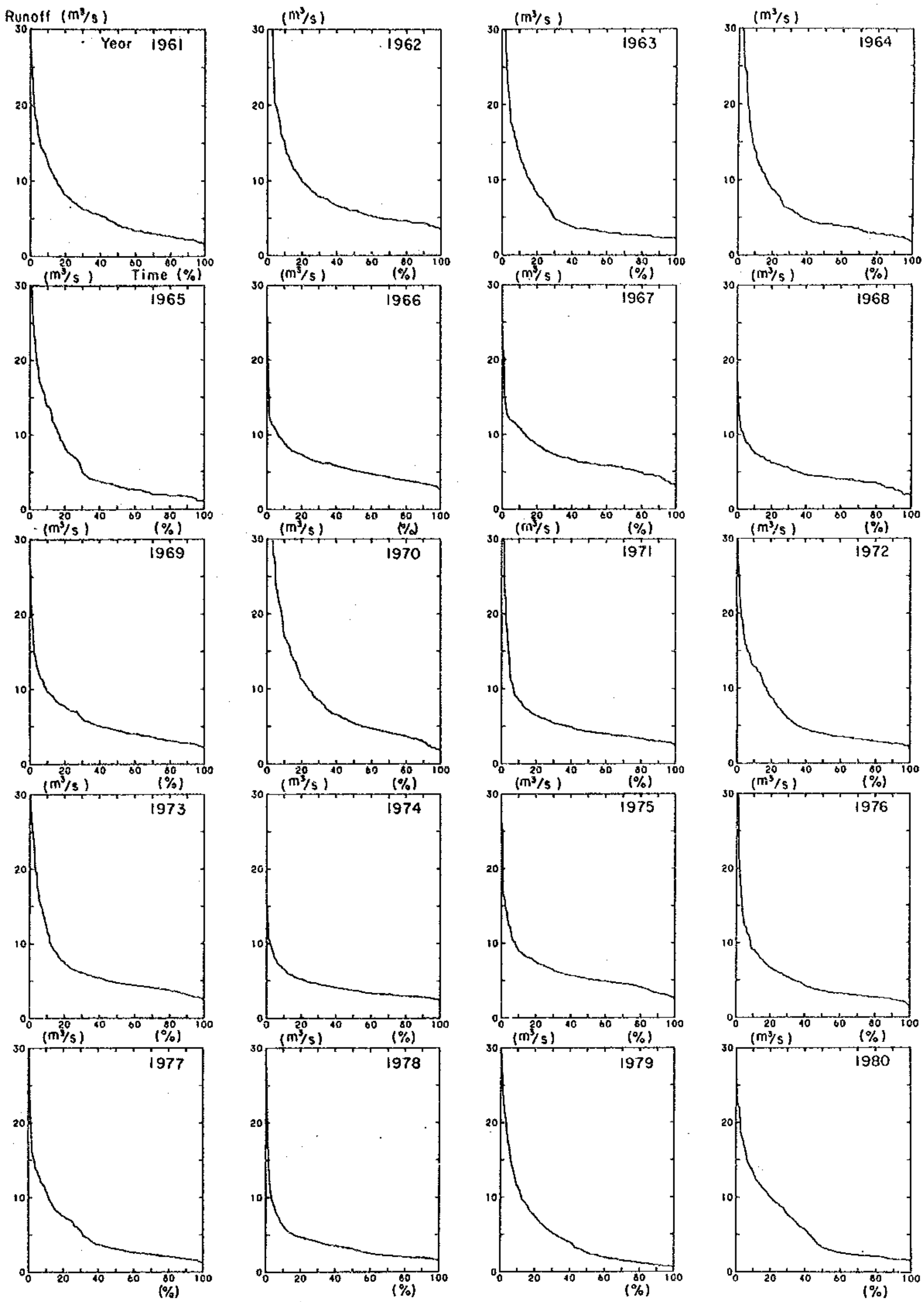

Fig. 18 Flow Duration Curves of Key Station (4/4)

Basin : Perai

Station: Ara Kuda (5405421) C.A.: 129 km²

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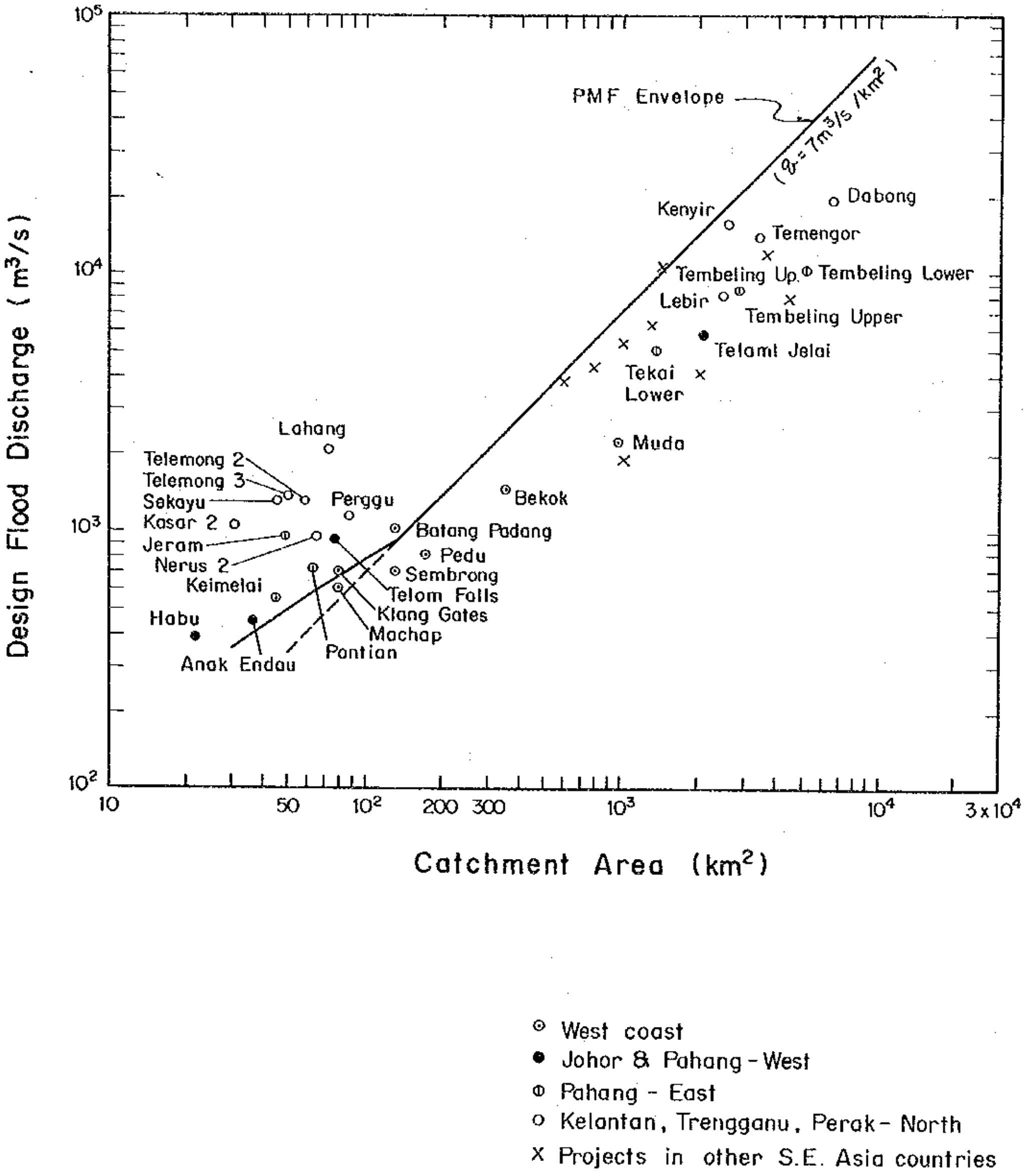

Fig. 19 Probable Maximum Flood Envelope

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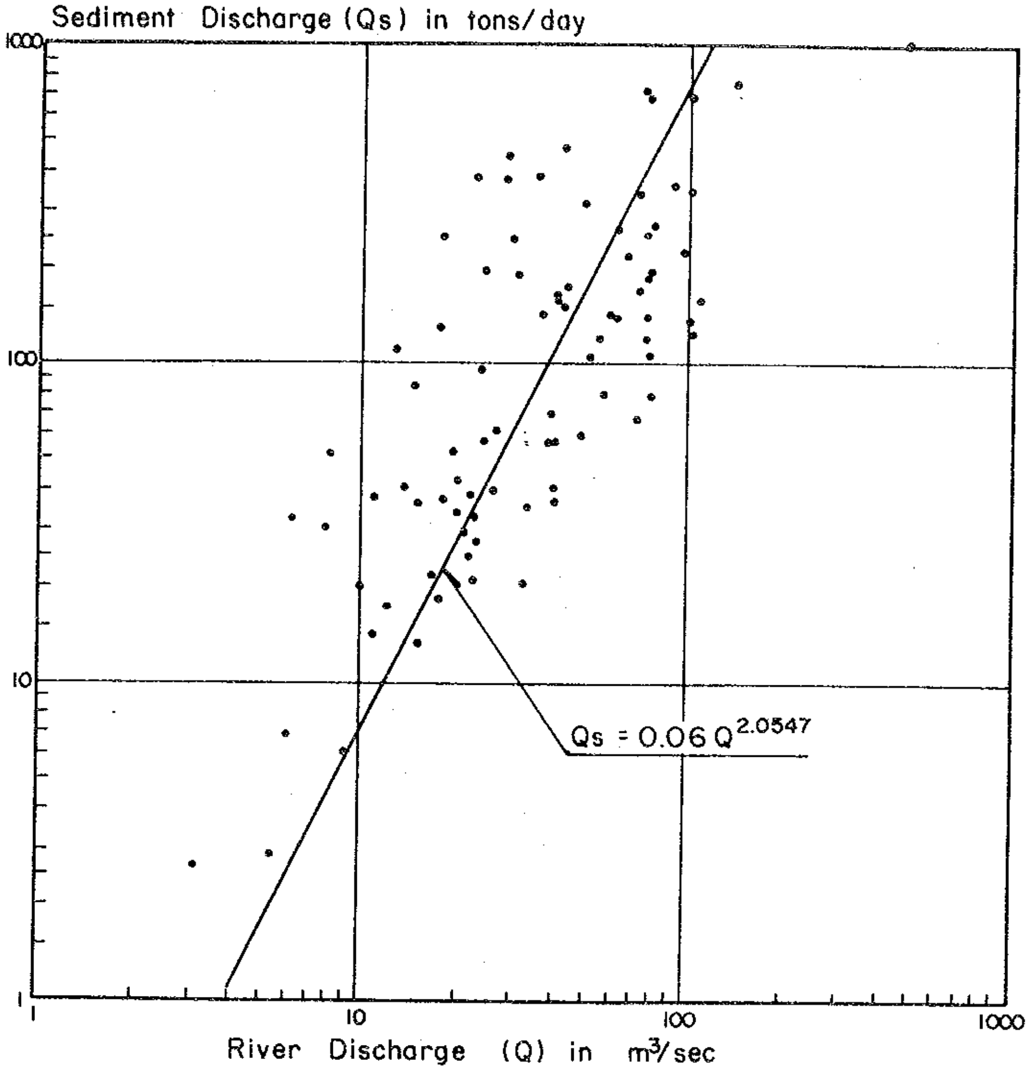
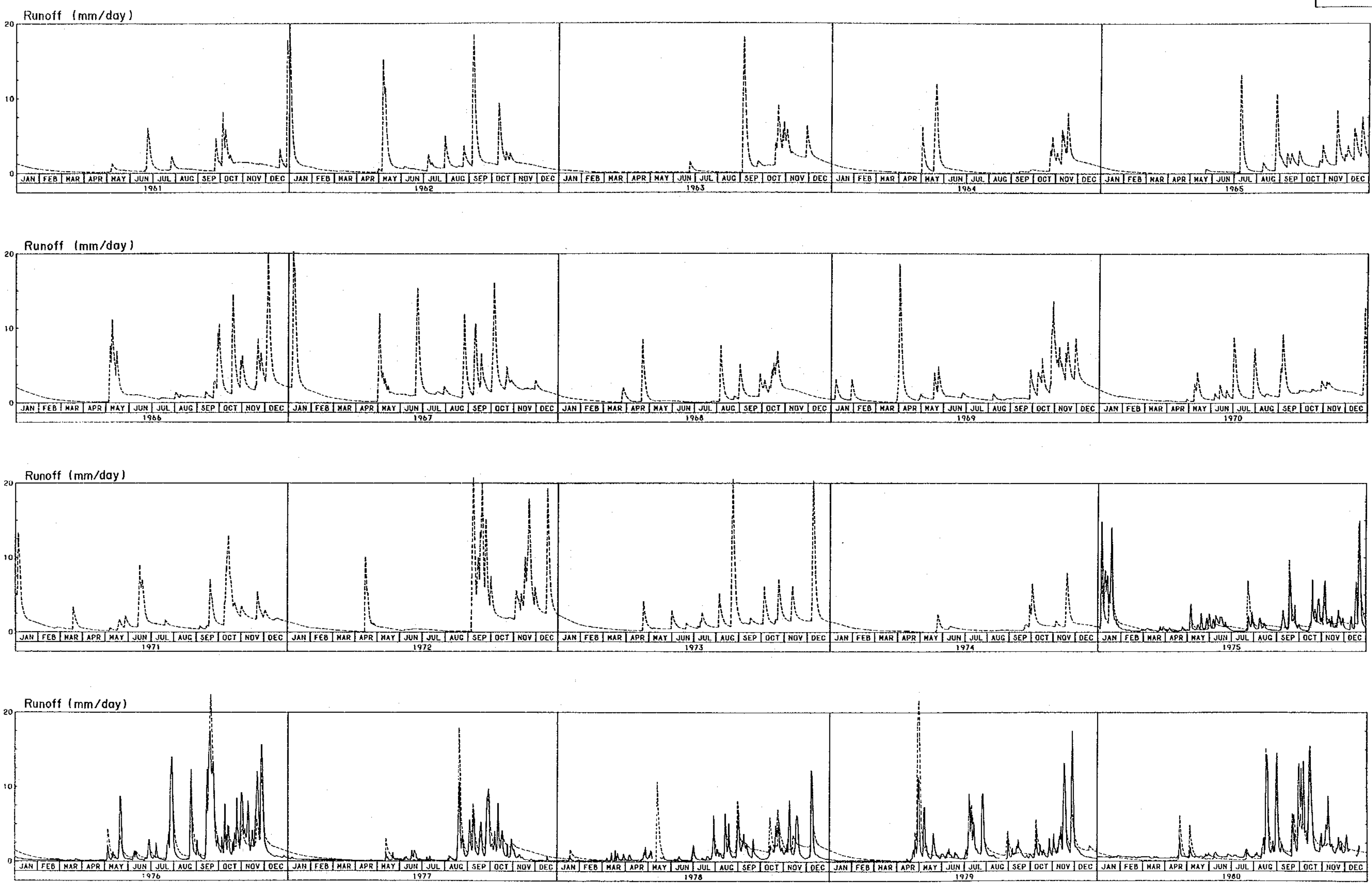


Fig. 20 Suspended Load Rating Curve at the Jam. Syed Omar Hydrological Station

PLATES

PLATE NO. 1



Daily Runoff Simulation (1/5)

Basin : Perlis Station : Titi Konkerit Baru (6502431 & 6502432)

Catchment Area : 150 km²

Note : ——— Observed

- - - - - - Simulated

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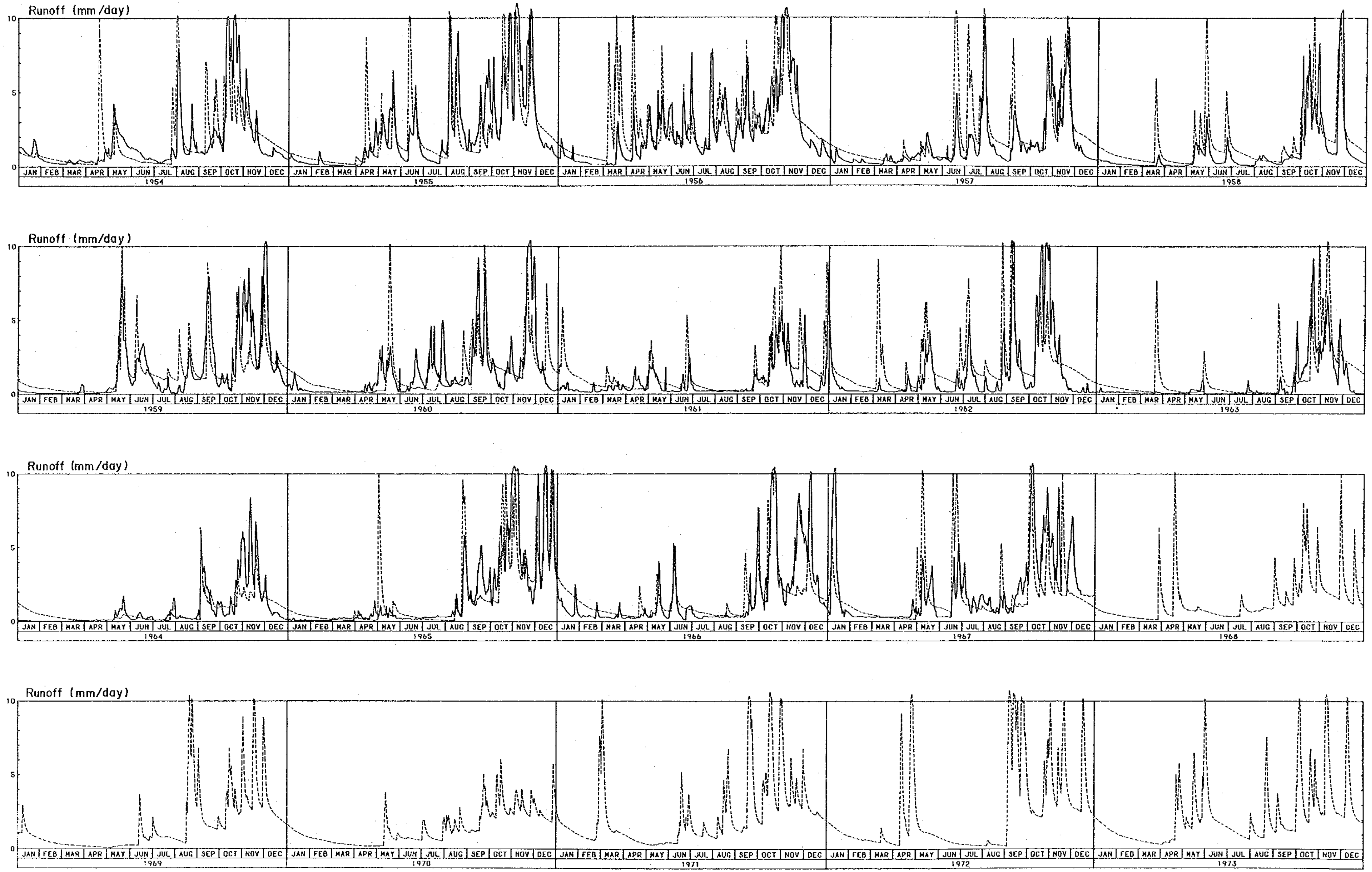
PLATE NO. 2



Daily Runoff Simulation (2/5)

Basin : Kedah Station : Lengkuas (6204421) (1/2)

Catchment Area : 1270 km²

Note : ——— Observed

------ Simulated

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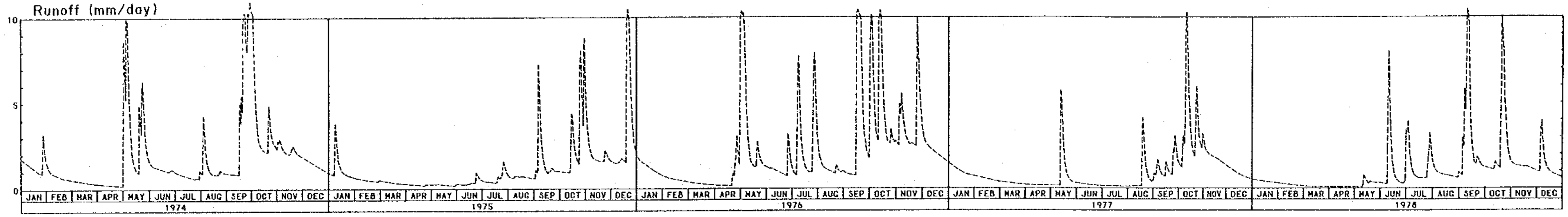

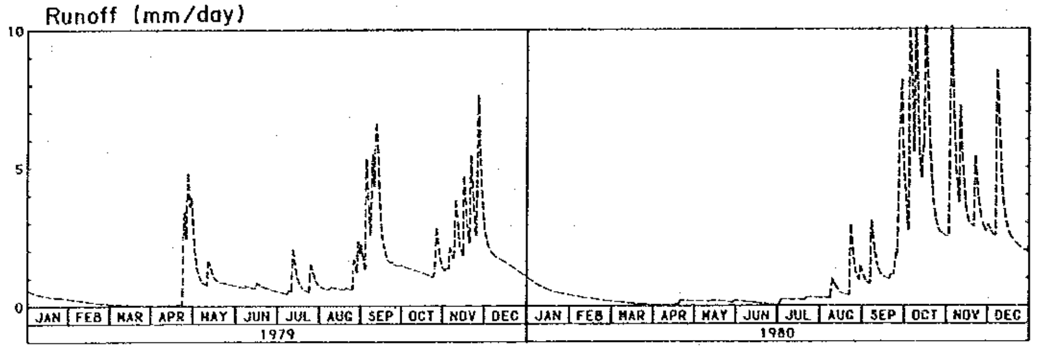

Daily Runoff Simulation (3/5)

Basin : Kedah Station : Lengkuas (6204421) (2/2)

Catchment Area : 1270 km^2

Note ; ——— Observed
------ Simulated

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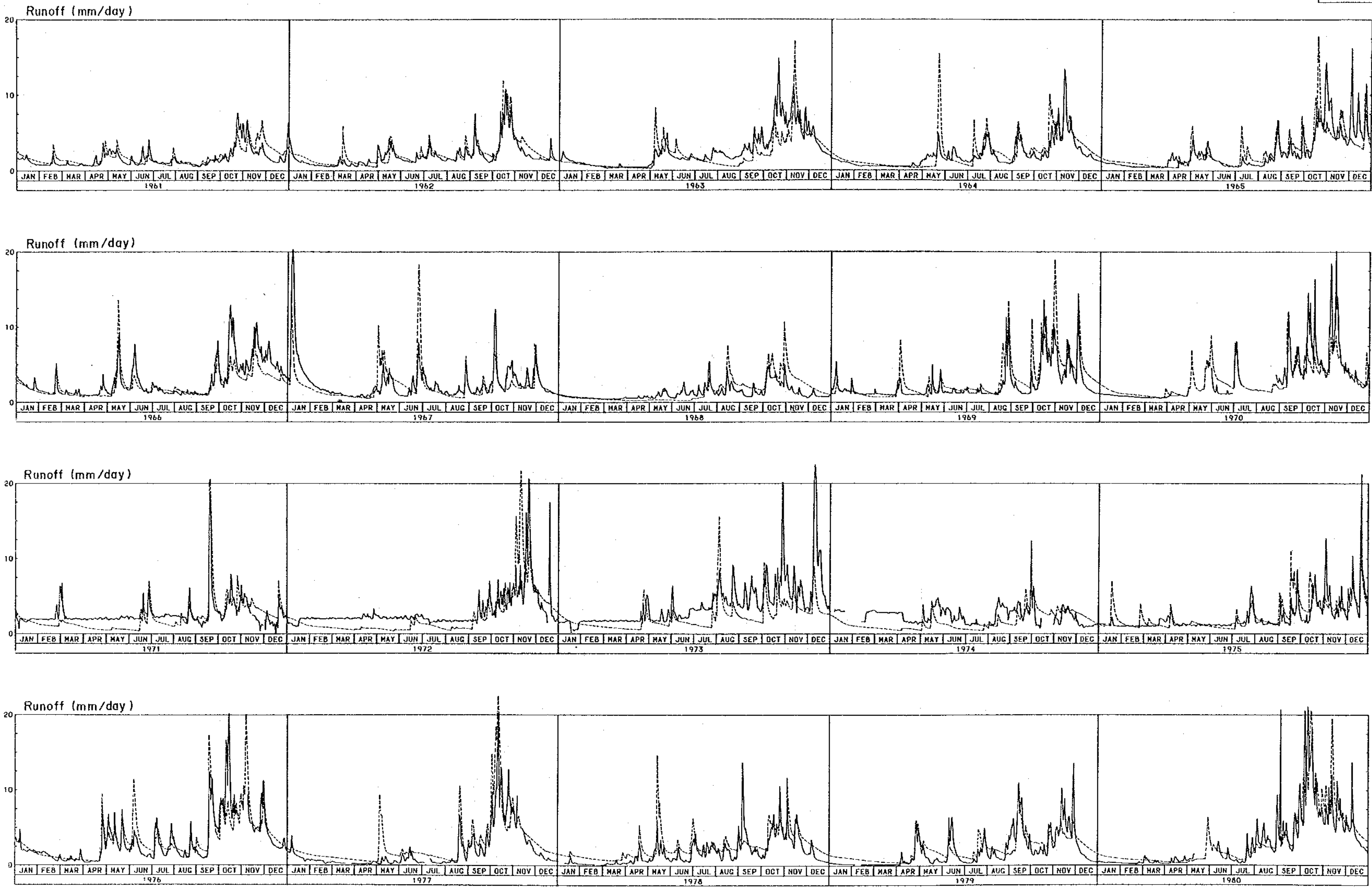

Daily Runoff Simulation (4/5)

Basin : Muda   Station : Jeniang (5806414)

Catchment Area : 1740 km²

Note : ——— Observed
- - - - - - Simulated

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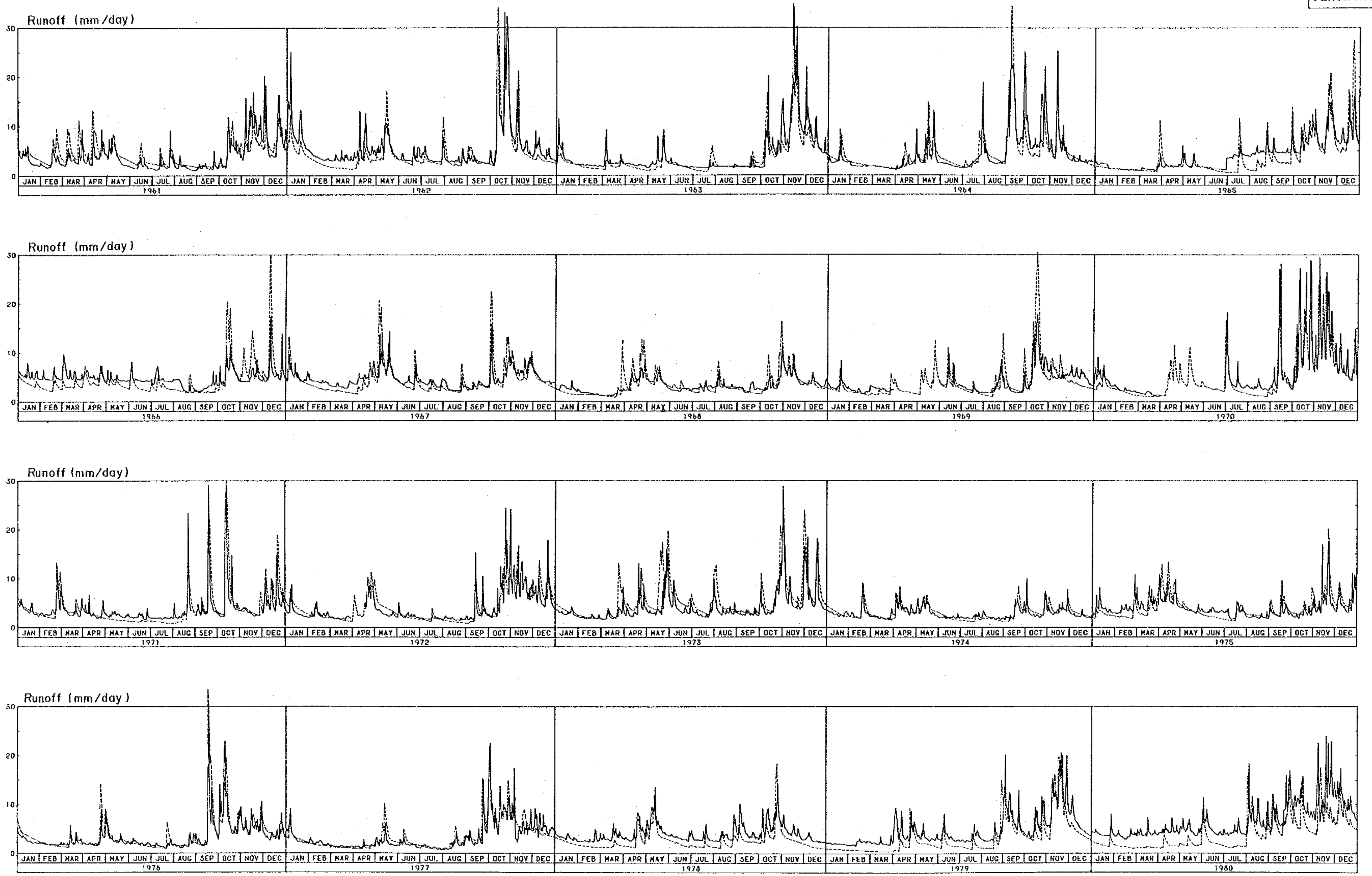

Daily Runoff Simulation (5/5)

Basin : Perai   Station : Ara Kuda (5405421)

Catchment Area : 129 km²

Note : ——— Observed
------ Simulated

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ANNEX F

GROUNDWATER RESOURCES

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1. INTRODUCTION

This ANNEX presents the results of a groundwater resources study including the present condition of groundwater use, potential analysis to estimate the safe yield, cost analysis and some comments on groundwater management for potential aquifers.

Data collection was carried out with the assistance of GSD, DID, Kedah PWD, Perlis PWD and Perlis EPU. General information on hydrogeology in the study region was provided by GSD. The study is largely based on the hydrogeologic data of geologic logs, well loggings, pumping tests, geoelectrical soundings and water quality test resulting Kedah-Perlis Water Resources Management Study by EPU, Development of Production Wells in Kedah and Perlis by PWD and Groundwater Resources for Agricultural Use in Malaysia by DID.

2. PRESENT GROUNDWATER USE

2.1 Domestic Groundwater Use

Traditional groundwater sources in most rural areas depend on dug wells, springs and streams, which are depleted during the dry season. Water shortages occur every year in most rural areas where no alternative to supply water for the village people are available except transporting truck mounted drinking water by PWD.

Eight production wells which were drilled by GSD in the Arau well field after 1955 are being used by PWD for the water supply to Kangar. All the boreholes are sunk in alluvium and Chuping limestones ranging from 18 to 27 m in depth. The main aquifer is sand layers of total thickness less than 5 m, intercalating the unconsolidated alluvial clayey deposit of 18 to 26 m in thickness. Groundwater of 5,400 m^3/d was extracted in 1982 from 7 tube wells out of the 8 wells. In response to the rapid increase of water demand in town areas, 6 additional boreholes with depths between 30 and 89 m were drilled in limestone aquifers in the Arau well field in 1982, to increase the supply capacity of the Arau water works. Four tube wells out of the 6 wells will be used for water supply to increase the capacity by about 5,000 m^3/d (Ref. 1). The Arau well field is located in the coastal plain of southern Perlis where the boundary of the fresh-salt water interface is very near, within 1 km.

Three production wells which were drilled in 1976 are being used by PWD as the water supply for settlers' families of Chuping FELDA plantation. All the boreholes were sunk in Bukit Arang Coal Beds of the upper Tertiary to the depth of 40 to 50 m, which is composed of semi-consolidated sequences of clay, sand, pebbles and gravel. Groundwater of 900 m^3/d was extracted from the 3 boreholes in 1982.

Taking account of the difficulties of constructing many small scale dams for the purpose of an extended rural water supply program, groundwater development was anticipated by EPU and PWD.

An exploratory drilling program was initiated in 1979 as a part of the Kedah-Perlis Water Resources Management Study by EPU. On the basis of the results of the EPU's study, PWD decided to intensify the drilling programs for the development of groundwater resources in the extensive drought affected areas in Perlis and North Kedah in 1981.

Fifty eight production wells out of the 85 test wells were completed by Kedah-Perlis Water Resources Management Study in 1981, which is anticipated to yield 16,400 m^3/d for the rural water supply. Eighty seven production wells out of the 109 of proposed tube wells were completed by the Development of Production Wells Project in 1982, which is believed to produce 21,800 m^3/d for reticulated water supply to 250 communities. The results of the drillings do not suggest the optimistic possibility of groundwater development for all the areas except some potential well fields in Perlis and North Kedah (See Fig. 1 & Table 1).

Some tube wells are used for rural water supply at Naka town in Kedah. However, no statistics to estimate the total number and yield of wells in the study region are available.

2.2 Agricultural Groundwater Use

Present groundwater use for irrigation in the study area is very minor or negligible compared with surface water irrigation. No statistics are available to estimate the volume of groundwater use in this area.

An extensive groundwater investigation has been carried out by DID since 1982 including test well drillings, 9 in Pulau Pinang, 12 in Kedah, and 17 in Perlis. Potential aquifer is recognized in limestone terrain in Perlis. Some tubewells in the limestone, down to a depth of 40 to 186 m, produced relatively high yields of more than 25 l/s, which may be an attractive output for irrigation purpose. Almost all the test wells drilled in other formations such as alluvium, areno-argillaceous rocks and granitic rocks in Kedah and Pulau Pinang recorded low yields on the order of less than 10 l/s (Ref. 2). In conclusion, groundwater development for agricultural purpose is not promissing except in some limestone areas in Perlis.

2.3 Industrial Groundwater Use

Some tube wells are being used in sugarcane factories and other factories. However, no statistics to estimate the yield of wells for industrial use are available.

3. DEVELOPMENT POSSIBILITIES

3.1 Geology

The geology of the project area consists of Recent to Pleistocene unconsolidated sediments, Tertiary to upper Cambrian sedimentary rocks and granites which are complicated both structually and stratigraphically. The alluvial and diluvial sediments are composed of unconsolidated clay, silts, sand and gravel and cover most of southern Perlis and the western part of Kedah and Pulau Pinang. The Tertiary to upper Cambrian sedimentary rocks, which are composed of sandstone, greywacke, siltstone, shale, mudstone, dolomite and limestone cover hilly and mountainous areas in the study region. Granitic rocks of the late Palaeozoic to Mesozoic period are found mostly in mountain ranges in east Kedah and Pulau Pinang.

Geological formations in the Region are the Machinchang/Jerai formations, Setul limestone, Mahang formation, Kubang Pasu/Singa formations, Chuping limestone, Semanggol formation, granitic rocks, Bukit Arang coal beds and Quaternary sediments (See Fig. 2).

The Machinchang/Jerai formations consist of well indurated metamorphosed sandstone and shale of the Cambrian age, and they are found in south eastern Kedah.

The Setul limestone of the Ordovician to Silurian period, which develops along the mountain ridge of western Perlis, is continental shelf deposits consisting of hard brittle crystalline limestone. This karstic limestone with some solution cavities has undergone major folding and faulting (Refs. 1 to 14).

The Mahang formation of the Silurian period is composed of metashale, siltstone and sandstone which covers the southern area of Kedah.

The Kubang Pasu/Singa formation of the Devonian to Triassic periods consists of shale and mudstone with minor siltstone and sandstone and covers the area of northwestern Kedah, and central and eastern Perlis. These argillaceous rock faces resulted from deep basin sedimentation.

The Chuping limestone of the Permian to Triassic periods is composed of massive finely crystalline limestone and dolomite with some calcareous sandstone and shale and developed in east central Perlis and northwestern Kedah. This limestone formation presents distinctive topographic features showing outcrops which have large scale solution cavities.

The Semanggol formation of the Triassic to Jurassic period is the final period of geosynclinal deposition and is composed of conglomerate, rapidly alternating sandstone, siltstone, shale and chert. This thick deposit covers northeastern Kedah.

The granitic rock is a series of undifferenciated acidic plutonic rocks which developed at intervals from the late Palaeozoic to Cretaceous period. The rock mass of the granite covers mountain ranges in part of northern Perlis and Kedah, east and south Kedah, and Pulau Pinang.

The Bukit Arang coal beds of the Tertiary period are composed of lacustrine-fluviatile semi-consolidated clay, sand and gravel with minor lignite. This local sedimentary basin is observed in limited areas along the Perlis-Thailand border.

Recent to Pleistocene period superficial formations are composed of marine and fluvial clay, silt, sand and some pebbles and gravel. The most significant alluvial deposit in the coastal plain is marine clay, which widely covers southern Perlis and the western parts of Kedah and Pulau Pinang.

3.2 Hydrogeology

Groundwater occurrence is dependent on local geological conditions of water bearing zones which are encountered in fissures or cracks in the indurated sandstone and shale, cavities in limestone and pores in sand and gravel of unconsolidated sediments. Permeabilities and porosities in aquifer of hard rocks are related to the intensity of secondary geological activities such as faulting, fracturing, weathering and solution. Such water bearing zones are conceived to be restricted to within 60 m in depth from the ground surface except in limestone. Aquifers in most of the hard rock formations occur in a semi-confined system which is directly replenished by rainfall.

Rainfall, water impounded temporarily in low areas during the flood season, and deep percolation of paddy area are the sources of groundwater recharge. Karst development is distinguished in both the Setul and Chuping limestones, and this area has the highest infiltration rate in the study region.

Rich to moderate aquifers are encountered in the karstic zone of the Chuping and Setul limestones producing high well yields in the range of zero to more than 50 l/s with an average of 8 l/s. The karst development has resulted in erosion of limestone (Ref. 1 to 8).

Fair to poor aquifers are found in indurated rocks of sandstone, greywacke and alternating shale in the Semanggol formation and some parts of the other formation where open joints and fractures have developed. Well yields are in the range of 0.4 to 18 l/s with an average of 3 l/s (Refs. 1 to 8).

Moderate to fair aquifers with well yields between 2.3 and 10.2 l/s have developed in semi-consolidated sand and gravel in the Bukit Arang coal bed formation. However, this type of aquifer is limited to two areas near the border of Thailand (Refs. 1 & 9).

Poor aquifers are encountered in argillaceous rocks such as shale and mudstone in the Mahang, Kubang and Pasu/Singa formations except in the areas where highly fractured zones have developed. The well yields are expected to be less than 3 l/s. Aquifer characteristics of granitic rocks and the Machinchang/Jerai formations, which is composed of various metasediment are believed to be very poor (Ref. 1 to 14).

Alluvial or diluvial aquifer of sand which partially intercalates relatively thick clayey layers yields variable quantities of groundwater to the wells. However, the water quality is invariably brackish, and the saline aquifer is widespread along the coast plain (Ref. 1 to 14).

3.3 Water Quality

The quality of groundwater is good to fair in the study region except for the coastal aquifers along the west coast which are influenced by sea water intrusion. Historical water quality data from the existing well field is available only at Arau, where PWD waterworks are extracting groundwater for the water supply of the Kangar area, showing excellent to good chemical properties in the raw water, requiring only chlorination treatment. This area is within 1 km of the fresh-salt water interface. However, no significant increase with time of chloride content has been found during the past 20 years. Shallow fresh water in the Chuping limestone aquifer, which is located at Gunong Keriang near Alor Setar and surrounded by marine alluvium, suffered saline water intrusion after a few months of groundwater extraction. The chloride content was increased from 13 to 700 mg/l. Groundwater in the Chuping limestone in southern Perlis and North Kedah where the aquifer is near or adjacent to areas of marine alluvial deposits with high salinity, trends towards sodium chloride type groundwater, indicating a risk of sea water intrusion by overpumping (Ref. 1).

A high concentration of arsenic ions, which exceeds the WHO limit of 0.05 mg/l, was detected in some wells which were drilled in fractured metalliferous Mahang formations in the Bukit Jamble area of Kedah. However, this is the only an exception in limited area of the traces of minerals exceeding the WHO standard (Ref. 1).

Relatively high levels of iron and manganese, which exceed the WHO limit of 1.0 mg/l, were detected in some wells which were drilled in semi-confined aquifers of sandstone, shale and their alternations in North Kedah.

The quantity of groundwater in the Chuping and Setul limestone formations is hard bicarbonate type. Hardness, expressed as $CaCO_3$ concentration, is rather high, in the range of 200 to 350 mg/l, which is not higher than WHO's maximum permissible level of 500 mg/l (Refs. 1 & 15). No treatment is required for the water supply except chlorination.

3.4 Classification of Groundwater Potential

Aquifers are mainly recognized in sandy layers of Quaternary sediments, and are composed of clay, silt, sand, and some pebbles and gravel. Thick layers of unconsolidated marine clay or silt are prominently found in coastal plains along the west coast. At present, it is difficult to estimate the maximum thickness of Quaternary sediments. However, a few exploratory borings suggest a depth of less than 30 m (Refs. 1 to 14). The aquifer of sand is limited to a thickness of less than 5 m and is intercalated in thick clayey layers.

Groundwater intruded by sea water is observed in some boreholes with chloride contents of 7,000 to 10,000 mg/l which are located on a line between K. Kedah and Alor Setar (Ref. 11). The interface of fresh-salt water is nearly located on the line connecting the boundary of Muda irrigation area with a maximum distance of more than 10 km from the seashore.

The distribution of aquifers in rocks is often limited to cracks or fissures in all type of rocks. Potential rock aquifers are classified by the type of rocks such as limestone, semi-consolidated sequence of clay, sand and gravel of the Tertiary period and areno-argillaceous rocks of the Palaeozoic to Mesozoic eras.

Rich to moderate aquifers have developed in limestone in Perlis and North Kedah, with high permeabilities and effective porosities as seen at outcrops of limestone hills. Existing production wells in the limestone are in the range of 40 to 100 m in depth, producing a relatively high yield of 5 to 50 l/s, with an average of 8 l/s. On the basis of the well pumping test, not much statistical difference in well yield has been distinguished between the wells of 40 and 100 m in depth, economical depth of the production well is estimated to be 40 to 60 m.

Moderate to fair aquifers are to be found in semi-consolidated argillaceous sand and gravel of the Tertiary period in the northern part of Perlis and Kedah. Existing wells of 40 to 60 m in depth produce a moderate yield of 3 to 10 l/s, with an average of 4 l/s.

Fair to poor aquifers have developed in the fractured zones in sandstone and shale of the Palaeozoic to Mesozoic eras and widely cover the hilly and mountainous areas. Arenaceous rocks of sandstone have a higher potential than argillaceous rocks of shale. A test well, 216 m in depth, was drilled in argillaceous shale at Kg. Sena Titi Tinggi in Perlis, producing less than a few l/s (Ref. 2). Existing production wells, 30 to 60 m in depth, were drilled in these rocks. Well yield ranged between 0.1 and 18 l/s with an average of 3 l/s. Some test wells were drilled to depths of 90 to 150 m, producing not significantly different yields compared with wells less than 60 m in depth, a depth which is considered to be an economical depth of exploitable aquifers.

Metashale of the upper Cambrian period and granitic rock are considered to be impervious rock mass. A few wells were drilled into the granite having low yields of less than 1 l/s. Very poor potential in these rock masses, which are widely developed in mountain ranges makes it difficult to exploit the groundwater resources in these areas.

On the basis of the data concerning the aquifer thickness, specific yield, pumping discharge, coefficient of transmissivity, drawdown, and water quality, which were obtained from a series of pumping tests, the Region was classified into 9 hydrogeological land classes. The specific yield in each class was estimated based on the result of pumping tests in previous studies and Ref. 16.

The probability of occurrence of aquifer is preliminary assumed, taking into account the non-homogeneity of aquifer system, surface land use condition and drilling technique.

In accordance with 19 sub-basins, which are used for water balance study on surface water resources (Ref. ANNEX E), hydrogeological land classification map is prepared as shown in Fig. 3. The area of hydrogeological land class by basin is as shown in Table 2.

(1) Alluvial class I

These are rich aquifers of large thickness with very high permeability, located in the downstream areas of large river basins. This type of aquifer is not found in the study region. Aquifer parameters are assumed as follows:

Thickness of Aquifer	:	10 - 40 m
Specific Yield (Effective Porosity)	:	15 - 25%
Pumping Discharge	:	500 - 3,000 m^3/d
Coefficient of Transmissivity	:	100 - 1,000 m^2/d
Drawdown	:	1 - 10 m
Probability of Occurrence of Aquifer	:	90%

(2) Alluvial class II

These are moderate aquifers of moderate thickness with rather high permeability, located in limited part of the coastal alluvial plains of Arau, Kedah and Muda river. Aquifer parameters are assumed as follows:

Thickness of Aquifer	:	8 - 15 m
Specific Yield (Effective Porosity)	:	10 - 20%
Pumping Discharge	:	200 - 500 m^3/d
Coefficient of Transmissivity	:	50 - 150 m^2/d
Drawdown	:	2 - 10 m
Probability of Occurrence of Aquifer	:	70%

(3) Alluvial class III

These are fair aquifers of moderate thickness less than alluvial class II with high to moderate permeability, located in limited part of the coastal alluvial plains of Arau, Kedah and Muda river and alluvials at the foothills of the highlands. Aquifer parameters are assumed as follows:

Thickness of Aquifer	:	2 - 8 m
Specific Yield (Effective Porosity)	:	10 - 15%
Pumping Discharge	:	50 - 200 m^3/d
Coefficient of Transmissivity	:	10 - 50 m^2/d
Drawdown	:	3 - 10 m
Probability of Occurrence of Aquifer	:	50%

(4) Alluvial class IVa

These are poor aquifers of very thin thickness less than 2 m with moderate permeability, located in extensive alluvial plains at inland or coast and foothills of the highland. Aquifer parameters are assumed as follows:

Thickness of Aquifer	:	0 - 2 m
Specific Yield (Effective Porosity)	:	5 - 15%
Pumping Discharge	:	0 - 50 m^3/d
Coefficient of Transmissivity	:	0 - 10 m^2/d
Drawdown	:	4 - 10 m
Probability of Occurrence of Aquifer	:	20%

(5) Alluvial class IVb

These aquifers intruded by sea water have developed in the coastal plain and will not be exploited. This alluvial class IVb was excluded from the potential analysis to estimate the safe yield.

(6) Rock class I

These are rich to moderate aquifers of large to moderate thickness with high permeability, located in limestone of crystalline and karst type in Perlis and a part of northwest Kedah. Aquifer parameters are assumed as follows:

Thickness of Aquifer	:	10 - 25 m
Specific Yield (Effective Porosity)	:	5 -10%
Pumping Discharge	:	300 - 1,500 m^3/d
Coefficient of Transmissivity	:	50 - 500 m^2/d
Drawdown	:	1 - 10 m
Probability of Occurrence of Aquifer	:	50%

(7) Rock class II

These are moderate to fair aquifers of moderate thickness with high to medium permeability, located in local patches in northern Perlis, consisting of the semi-consolidated arenaceouces of sand, pebbles and gravel of the Tertiary period.

Thickness of Aquifer	:	5 - 15 m
Specific Yield (Effective Porosity)	:	2 - 8%
Pumping Discharge	:	100 - 300 m^3/d
Coefficient of Transmissivity	:	10 - 50 m^2/d
Drawdown	:	5 - 10 m
Probability of Occurrence of Aquifer	:	30%

(8) Rock Class III

These are fair to poor aquifers of moderate thickness with medium to low permeability, located in hard rocks of areno-argillaceous of the Palaeozoic to Mesozoic eras which widely cover the study region. Aquifer parameters are assumed as follows:

Thickness of Aquifer	:	5 - 15 m
Specific Yield (Effective Porosity)	:	2 - 5%
Pumping Discharge	:	0 - 100 m^3/d
Coefficient of Transmissivity	:	0 - 15 m^2/d
Drawdown	:	10 - 25 m
Probability of Occurrence of Aquifer	:	10%

(9) Rock Class IV

These very poor aquifers are metashales of the upper Cambrian period and granitic rocks of the late Palaeozoic to Mesozoic eras, located in a part of south eastern Kedah, Pinang island and mountain ranges in the study region, having a very low permeability or probability of less than a few percent to encounter highly fractured zones. This rock class IV was excluded from the potential analysis to estimate the safe yield.

3.5 Storage Potential

Storage potential is the groundwater volume which is stored in the pores, cracks and fissures of the aquifer. It is estimated as follows:

$$SP = A \times B \times Sy$$

where, SP: Storage potential
A : Area
B : Thickness of aquifer
Sy: Specific yield (Effective porosity) of aquifer

Assuming the average thickness and average specific yield (see Ref. 17) by hydrogeological land class as shown in Table 3, the storage potential by class by basin was calculated as shown in Table 4.

3.6 Groundwater Recharge

Very few studies on deep percolation to estimate the groundwater recharge were found for use in this study. According to a recent study on deep percolation in Japan, a linear relation between deep percolation and precipitation was determined by a field investigation and water balance analysis. The deep percolation in alluvial plain and hilly land is estimated to be 15 to 25% of the annual precipitation (Refs. 18 & 19). The deep percolation in mountain areas of granitic rock is preliminarily estimated to be 3% of the annual precipitation (Ref. 20). Some rate of deep percolation have been used in previous studies to estimate the sustain yield of well fields (Refs. 21 to 23). They are assumed to be 20 to

30% of the annual precipitation in well fields of the coastal alluvial plain and 15% of the annual precipitation in well fields of the Tertiary sandstone formation.

Based on the previous studies, annual deep percolation rates are assumed to be 22% of annual precipitation in the alluvial plain, 15% of annual precipitation in limestone, 10% of annual precipitation in the hilly to mountainous areas of semi-consolidated rocks and 5% of annual precipitation in mountain areas of the other hard rocks. The deep percolation rates in 19 Basins were calculated based on the average basin rainfall which is shown in Table 5. The average yearly groundwater recharge was calculated by hydrogeological land class by basin to multiply the above percolation rates as shown in Table 6.

3.7 Preliminary Estimate of Safe Yield

In this study, the safe yield is defined to be an annual quantity of water which could be withdrawn from a groundwater basin, within the limit of annual groundwater recharge and groundwater storage. Assuming the probability of occurrence of aquifer, the safe yield is calculated by hydrogeological land class by basin and water supply area as shown in Tables 7 to 11 and Fig. 1.

3.8 Cost Analysis

The unit cost of the water sources was estimated in order to compare the cost of groundwater and surface water. Corresponding to hydrogeological land classification, 6 cases were assumed, with the aquifer type, average well depth, average pumping discharge, average drawdown, well type and pumping capacity as shown in Table 12.

To estimate the unit cost of water source, following 5 conditions were assumed:

(1) Regarding the power source and electric supply from power system, a diesel engine power generator was proposed because the groundwater development is regarded to be conducted mostly in rural areas. (Electric charge (M$/d) = M$0.25 x kW x 16 hour);

(2) Economic life of the facilities is assumed to be 25 years for a well which is cased by wire wrapped type screen with diameter of 20 cm (Ref. 24), 8 years for pump and generator which include a standby unit and 50 years for other facilities;

(3) All the costs are at price level of 1982, including 9% of assumed escalation rates of both foreign and domestic portions from 1980 to 1982;

(4) Physical contingency is assumed to be 10% of a total cost in items 1 to 7 of the investment cost;

(5) Unit cost of the chlorination is assumed to be M$0.02/m^3; and

(6) The cost is capitalized at the beginning of construction.

The estimated cost stream for 50 years of use of the assumed groundwater source facilities is shown in Table 13.

The unit cost of the water source was estimated assuming discount rates of 6 to 20% as shown in Table 14.

4. REMARKS ON GROUNDWATER DEVELOPMENT IN THE ARAU WELL FIELD

Groundwater development in the Arau well field will be continued with the increase in water demand in Kangar in the future. At present, major water source for the domestic and industrial water supply in Kangar is surface water which is diverted from the irrigation canal of the Muda irrigation project. Groundwater is produced from the Arau well field. Groundwater quality is excellent, requiring only a chlorination for drinking purpose. On the other hand, surface water needs all range of ordinary treatment.

The Arau well field is located in the coastal plain in the southern part of the State of Perlis. The existing wells penetrate into alluvium of sand containing some pebbles, and some part of the Chuping limestone. The rate of pumping is generally kept constant all the year, but the water levels change between 4 m in wet season and 8 m in dry season.

Some wells are located within only 1 km from an estimated fresh-salt water interface. It is believed that the fresh-salt water interface penetrates into fresh water side, if the piezometric head reduces by pumping, but quantitative evaluation of this relationship is still in a developing stage. The movement in the fresh-salt water can be detected by only an observation. In view that groundwater development may cause a sea water intrusion.

Arau well field in the future, it is recommended that piezometric head and salinity should be monitored in a series of observation wells between Arau town and the estimated fresh-salt water interface. The existing production well GS 716 can be utilized as one of the proposed observation wells. It is located at the corner of Arau waterworks, having a depth of 38 m. It is recommended that 3 additional observation wells should be constructed as shown in Fig. 4. Each observation well to be constructed should be 50 m in depth with diameter of 100 mm as shown in Fig. 5.

Kodiang area, which is located at 6 km southeast of Arau, is considered to be a delicate area as same as Arau. If groundwater development is to be carried out in this area, same monitoring system as proposed in Arau well field should be applied.

REFERENCES

1. DEVELOPMENT OF PRODUCTION WELLS IN KEDAH AND PERLIS, MAIN REPORT, VOL. 1, 1983, PWD

2. GROUNDWATER RESOURCES FOR AGRICULTURAL USE IN MALAYSIA, PROGRESS REPORT, 1982 - 1983, DID

3. COMPLETION REPORTS FOR NORTH KEDAH WELLS VOL. 2A, 1983, PWD

4. COMPLETION REPORTS FOR NORTH KEDAH WELLS VOL. 2B, 1983, PWD

5. DEVELOPMENT OF PRODUCTION WELLS IN KEDAH AND PERLIS, INTERIM REPORT, 1982, PWD

6. WATER SUPPLY SCHEME FOR NORTH KEDAH WELLS, VOL. 6, 1983, PWD

7. KEDAH-PERLIS WATER RESOURCES MANAGEMENT STUDY, VOL. 2 HYDROGEOLOGY, 1980, EPU

8. KEDAH-PERLIS WATER RESOURCES MANAGEMENT STUDY, EXECUTIVE REPORT, 1981, EPU

9. HYDROGEOLOGICAL INVESTIGATIONS IN CHUPING FELDA SUGAR-CANE PLANTATION/PERLIS, GPH 7, 1977, GSD

10. REPORT OF GEOELECTRICAL INVESTIGATION IN CHUPING AREA/PERLIS, GPH 8, 1975, GSD

11. HYDROGEOLOGICAL INVESTIGATIONS AT KUALA KEDAH, 1977, GSD

12. MUDA IRRIGATION PROJECT AREA, GROUNDWATER SUPPLY-PRELIMINARY REPORT, 1977, GSD

13. PULAU PINANG - GROUNDWATER INVESTIGATIONS - 1979, GSD

14. HYDROGEOLOGICAL MAP OF PENINSULAR MALAYSIA, 1975, GSD

15. INTERNATIONAL STANDARDS FOR DRINKING WATER, 1971, WHO

16. GROUNDWATER HYDROLOGY, 1959, John Wiley & Sons, Inc.

17. HYDROGEOLOGY, 1966, John Wiley & Sons, Inc.

18. HYDROGEOLOGICAL CYCLE OF HILLY LAND AND EFFECTS ON URBANIZATION ON IT, 1981, (Japanese)

19. GROUNDWATER RESOURCES STUDY, 1973, (Japanese)

20. SG. LUI REPRESENTATIVE BASIN REPORT, WATER RESOURCES PUBLICATION NO. 9, 1978, DID

21. FINAL REPORT FEASIBILITY STUDY SANDAKAN WATER SUPPLY EXTENSION SCHEME VOL. 1 to 4, 1980, PWD

22. HYDROGEOLOGICAL REPORT BELAWAI/SARAWAK, 1978, GSD

23. GROUNDWATER RESOURCE EVALUATION, 1970, Mc Graw Hill

24. NATIONAL WATER RESOURCES STUDY, MALAYSIA, SECTORAL REPORT VOL. 3, 1982, JICA

TABLES

Table 1 INVENTORY OF EXISTING TUBE WELLS

Name of Project	Drilled (No.)	Completed (No.)	Year	Estimated Yield in Total (10^3 m^3/d)
Arau Water Supply Scheme	-	8	1955	5.4
FELDA Water Supply Scheme	-	3	1976	0.9
EPU Water Resources Management Study	85	58	1981	16.4
PWD Groundwater Development Scheme	109	87	1982	21.8
DID Groundwater Exploration Scheme	38	-	1982	-

Table 2 HYDROGEOLOGICAL LAND CLASSIFICATION BY BASIN

Unit: km^2

Basin	Class of Alluvial Aquifer					Class of Rock Aquifer				
Code	I	II	III	IV	IV_b	I	II	III	IV	Total
PL1	0.0	0.0	2.5	13.1	40.6	85.6	0.0	190.4	8.8	341.0
PL2	0.0	0.6	1.9	31.3	19.3	60.0	22.5	181.4	0.0	317.0
PL3	0.0	1.3	0.6	3.8	219.3	0.0	0.0	0.0	0.0	225.0
KD1	0.0	0.0	0.0	0.0	0.0	0.0	8.1	1,212.4	142.5	1,363.0
KD2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	365.0	0.0	365.0
KD3	0.0	0.0	0.0	1.6	343.4	0.0	0.0	0.0	0.0	345.0
KD4	0.0	0.0	1.3	30.6	351.1	0.0	0.0	120.0	0.0	503.0
KD5	0.0	0.0	0.0	75.3	553.1	0.0	0.0	318.1	27.5	974.0
KD6	0.0	0.0	0.0	0.2	4.4	0.0	0.0	13.1	45.3	63.0
MD1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	296.5	687.5	984.0
MD2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	452.3	303.7	756.0
MD3	0.0	0.0	1.1	30.0	0.0	0.0	0.0	480.9	300.0	812.0
MD4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	533.7	361.3	895.0
MD5	0.0	0.0	0.0	11.9	0.0	0.0	0.0	231.5	325.6	569.0
MD6	0.0	7.2	23.8	45.6	289.9	0.0	0.0	192.5	0.0	559.0
MD7	0.0	0.0	0.0	0.0	39.9	0.0	0.0	124.4	98.7	263.0
PR1	0.0	0.0	0.0	62.4	2.2	0.0	0.0	81.9	11.5	258.0
PR2	0.0	0.0	0.0	35.8	228.8	0.0	0.0	0.0	188.4	453.0
PR3	0.0	0.0	0.0	2.8	22.0	0.0	0.0	0.0	275.2	300.0
Total	0.0	9.1	31.2	344.4	2,114.0	145.6	30.6	4,794.1	2,876.0	10,345.0

Table 3 THICKNESS, SPECIFIC YIELD, DEEP PERCOLATION AND PROBABILITY USED FOR POTENTIAL ANALYSIS

Aquifer	Class	Average Thickness of Aquifer (m)	Average Specific Yield (%)	Deep Percolation Rate (%)	Probability of Occurrence of Aquifer (%)
Alluvial	I	30	17	22	90
Alluvial	II	10	15	22	70
Alluvial	III	5	13	22	50
Alluvial	IV_a	1	10	22	20
Rock	I	15	8	15	50
Rock	II	10	5	10	30
Rock	III	10	3	5	10

Table 4 ESTIMATED STORAGE POTENTIAL BY BASIN

Unit: 10^6 m^3

Basin Code	Class of Alluvial Aquifer			Class of Rock Aquifer			Total
	II	III	IV_a	I	II	III	
PR1	0.000	1.626	1.310	102.720	0.000	57.120	162.776
PR2	0.900	1.236	3.130	72.000	11.250	54.420	142.936
PR3	1.950	0.390	0.380	0.000	0.000	0.000	2.720
KD1	0.000	0.000	0.000	0.000	4.050	363.720	367.770
KD2	0.000	0.000	0.000	0.000	0.000	109.500	109.500
KD3	0.000	0.000	0.160	0.000	0.000	0.000	0.160
KD4	0.000	0.844	3.060	0.000	0.000	36.000	39.904
KD5	0.000	0.000	7.530	0.000	0.000	95.430	102.960
KD6	0.000	0.000	0.020	0.000	0.000	3.930	3.950
MD1	0.000	0.000	0.000	0.000	0.000	88.950	88.950
MD2	0.000	0.000	0.000	0.000	0.000	135.690	135.690
MD3	0.000	0.716	3.000	0.000	0.000	144.270	147.986
MD4	0.000	0.000	0.000	0.000	0.000	160.110	160.110
MD5	0.000	0.000	1.190	0.000	0.000	69.450	70.640
MD6	10.800	15.470	4.560	0.000	0.000	57.750	88.580
MD7	0.000	0.000	0.000	0.000	0.000	37.320	37.320
PL1	0.000	0.000	6.240	0.000	0.000	24.570	30.810
PL2	0.000	0.000	3.580	0.000	0.000	0.000	3.580
PL3	0.000	0.000	0.280	0.000	0.000	0.000	0.280
Total	13.650	20.282	34.440	174.720	15.300	1,438.230	1,696.622

Table 5 ANNUAL PRECIPITATION

Unit: mm/y

Basin Code	Precipitation
PL1	1,898
PL2	1,856
PL3	1,996
KD1	1,880
KD2	2,043
KD3	2,280
KD4	2,156
KD5	2,417
KD6	2,973
MD1	2,103
MD2	2,296
MD3	2,400
MD4	2,354
MD5	2,786
MD6	2,354
MD7	2,692
PR1	2,576
PR2	2,337
PR3	2,673

Table 6 ESTIMATED GROUNDWATER RECHARGE BY BASIN

Unit: 10^6 m^3/y

Basin Code	Class of Alluvial Aquifer II	III	IV_a	Class of Rock Aquifer I	II	III	Total
PR1	0.000	1.044	5.470	24.370	0.000	18.070	48.954
PR2	0.244	0.776	12.780	16.704	4.177	16.830	51.511
PR3	0.571	0.264	1.670	0.000	0.000	0.000	2.505
KD1	0.000	0.000	0.000	0.000	1.523	113.970	115.493
KD2	0.000	0.000	0.000	0.000	0.000	37.280	37.280
KD3	0.000	0.000	0.805	0.000	0.000	0.000	0.805
KD4	0.000	0.616	14.515	0.000	0.000	12.940	28.071
KD5	0.000	0.000	40.040	0.000	0.000	38.440	78.480
KD6	0.000	0.000	0.130	0.000	0.000	1.950	2.080
MD1	0.000	0.000	0.000	0.000	0.000	31.180	31.180
MD2	0.000	0.000	0.000	0.000	0.000	51.920	51.920
MD3	0.000	0.580	15.840	0.000	0.000	57.710	74.130
MD4	0.000	0.000	0.000	0.000	0.000	62.820	62.820
MD5	0.000	0.000	7.295	0.000	0.000	32.250	39.545
MD6	3.729	12.326	23.615	0.000	0.000	22.660	62.330
MD7	0.000	0.000	0.000	0.000	0.000	16.740	16.740
PL1	0.000	0.000	35.365	0.000	0.000	10.550	45.915
PL2	0.000	0.000	18.405	0.000	0.000	0.000	18.405
PL3	0.000	0.000	1.645	0.000	0.000	0.000	1.645
Total	4.544	15.606	177.575	41.074	5.700	525.310	769.809

Table 7 PRELIMINARY ESTIMATE OF SAFE YIELD BY BASIN

Unit: 10^6 m^3/y

Basin Code	Class of Alluvial Aquifer II	III	IV_a	Class of Rock Aquifer I	II	III	Total
PL1	0.000	0.522	0.262	12.185	0.000	1.807	14.776
PL2	0.171	0.388	0.626	8.352	1.253	1.683	12.474
PL3	0.400	0.132	0.076	0.000	0.000	0.000	0.607
KD1	0.000	0.000	0.000	0.000	0.457	11.397	11.853
KD2	0.000	0.000	0.000	0.000	0.000	3.728	3.728
KD3	0.000	0.000	0.032	0.000	0.000	0.000	0.032
KD4	0.000	0.308	0.612	0.000	0.000	1.294	2.214
KD5	0.000	0.000	1.506	0.000	0.000	3.844	5.350
KD6	0.000	0.000	0.004	0.000	0.000	0.195	0.199
MD1	0.000	0.000	0.000	0.000	0.000	3.118	3.118
MD2	0.000	0.000	0.000	0.000	0.000	5.192	5.192
MD3	0.000	0.290	0.600	0.000	0.000	5.771	6.661
MD4	0.000	0.000	0.000	0.000	0.000	6.282	6.282
MD5	0.000	0.000	0.238	0.000	0.000	3.225	3.463
MD6	2.610	6.163	0.912	0.000	0.000	2.266	11.951
MD7	0.000	0.000	0.000	0.000	0.000	1.674	1.674
PR1	0.000	0.000	1.248	0.000	0.000	1.055	2.303
PR2	0.000	0.000	0.716	0.000	0.000	0.000	0.716
PR3	0.000	0.000	0.056	0.000	0.000	0.000	0.056
Total	3.181	7.803	6.888	20.537	1.710	52.530	92.649

Table 8 HYDROGEOLOGICAL LAND CLASSIFICATION BY WATER SUPPLY AREA

Unit: km^2

Water Supply Area	Class of Alluvial Aquifer			Class of Rock Aquifer			Total
	II	III	IV_a	I	II	III	
W01	1.3	4.4	23.1	78.4	0.0	118.8	226.0
W02	0.0	0.0	0.0	3.1	10.0	22.5	35.6
W03	0.0	0.0	0.3	1.3	0.0	162.5	164.1
W04	0.0	1.9	65.6	0.3	0.0	283.8	351.6
W05	0.0	0.0	0.0	0.0	0.0	610.0	610.0
W06	0.0	0.0	35.0	0.0	0.0	156.9	191.9
W07	0.0	0.0	0.0	0.0	0.0	200.6	200.6
W08	0.0	0.0	0.0	0.0	0.0	176.3	176.3
W09	0.0	0.0	0.0	0.0	0.0	35.0	35.0
W10	0.0	1.3	50.0	0.0	0.0	439.4	490.7
W11	0.0	0.0	9.4	0.0	0.0	238.1	247.5
W12	0.0	0.0	0.0	0.0	0.0	265.6	265.6
W13	0.0	7.5	48.8	0.0	0.0	104.4	160.7
W14	0.0	0.0	0.0	0.0	0.0	17.5	17.5
Total	1.3	15.1	232.2	83.1	10.0	2,831.4	3,173.1

Table 9 ESTIMATED STORAGE POTENTIAL BY WATER SUPPLY AREA

Unit: 10^6 m^3

Water Supply Area	Class of Alluvial Aquifer			Class of Rock Aquifer			Total
	II	III	IV_a	I	II	III	
W01	1.950	2.860	2.310	94.080	0.000	35.640	136.840
W02	0.000	0.000	0.000	3.720	5.000	6.750	15.470
W03	0.000	0.000	0.030	1.560	0.000	48.750	50.340
W04	0.000	1.236	6.560	0.360	0.000	85.140	93.296
W05	0.000	0.000	0.000	0.000	0.000	183.000	183.000
W06	0.000	0.000	3.500	0.000	0.000	47.070	50.570
W07	0.000	0.000	0.000	0.000	0.000	60.180	60.180
W08	0.000	0.000	0.000	0.000	0.000	52.890	52.890
W09	0.000	0.000	0.000	0.000	0.000	10.500	10.500
W10	0.000	0.844	5.000	0.000	0.000	131.820	137.664
W11	0.000	0.000	0.940	0.000	0.000	71.430	72.370
W12	0.000	0.000	0.000	0.000	0.000	79.680	79.680
W13	0.000	4.876	4.880	0.000	0.000	31.320	41.076
W14	0.000	0.000	0.000	0.000	0.000	5.250	5.250
Total	1.950	9.816	23.220	99.720	5.000	849.420	989.126

Table 10 ESTIMATED GROUNDWATER RECHARGE BY WATER SUPPLY AREA

Unit: 10^6 m^3/y

Water Supply Area	Class of Alluvial Aquifer			Class of Rock Aquifer			Total
	II	III	IV_a	I	II	III	
W01	0.547	1.850	9.715	22.486	0.000	11.360	45.958
W02	0.000	0.000	0.000	0.928	1.997	2.250	5.175
W03	0.000	0.000	0.130	0.384	0.000	16.010	16.524
W04	0.000	0.958	33.095	0.104	0.000	32.540	66.697
W05	0.000	0.000	0.000	0.000	0.000	65.940	65.940
W06	0.000	0.000	18.610	0.000	0.000	18.960	37.570
W07	0.000	0.000	0.000	0.000	0.000	23.430	23.430
W08	0.000	0.000	0.000	0.000	0.000	21.390	21.390
W09	0.000	0.000	0.000	0.000	0.000	4.160	4.160
W10	0.000	0.724	27.850	0.000	0.000	55.630	84.204
W11	0.000	0.000	5.150	0.000	0.000	29.640	34.790
W12	0.000	0.000	0.000	0.000	0.000	31.260	31.260
W13	0.000	4.302	27.990	0.000	0.000	13.610	45.902
W14	0.000	0.000	0.000	0.000	0.000	2.440	2.440
Total	0.547	7.834	122.540	23.902	1.997	328.620	485.440

Table 11 PRELIMINARY ESTIMATE OF SAFE YIELD BY WATER SUPPLY AREA

Unit: 10^6 m^3/y

Water Supply Area	Class of Alluvial Aquifer			Class of Rock Aquifer			Total
	II	III	IV_a	I	II	III	
W01	0.383	0.925	0.462	11.243	0.000	1.136	14.148
W02	0.000	0.000	0.000	0.464	0.599	0.225	1.287
W03	0.000	0.000	0.006	0.192	0.000	1.601	1.799
W04	0.000	0.479	1.312	0.052	0.000	3.254	5.097
W05	0.000	0.000	0.000	0.000	0.000	6.594	6.594
W06	0.000	0.000	0.700	0.000	0.000	1.896	2.596
W07	0.000	0.000	0.000	0.000	0.000	2.343	2.343
W08	0.000	0.000	0.000	0.000	0.000	2.139	2.139
W09	0.000	0.000	0.000	0.000	0.000	0.416	0.416
W10	0.000	0.362	1.000	0.000	0.000	5.563	6.925
W11	0.000	0.000	0.188	0.000	0.000	2.964	3.152
W12	0.000	0.000	0.000	0.000	0.000	3.126	3.126
W13	0.000	2.151	0.976	0.000	0.000	1.361	4.488
W14	0.000	0.000	0.000	0.000	0.000	0.244	0.244
Total	0.383	3.917	4.644	11.950	0.599	32.861	54.354

Table 12 PRINCIPAL FEATURE AND COST ESTIMATE OF ASSUMED GROUNDWATER SOURCE FACILITIES

Case	A1	A2	A3	R1	R2	R3
Aquifer	Alluvial	Alluvial	Alluvial	Rock	Rock	Rock
Class	II	III	IV	I	II	III
Depth of well (m)	50	50	20	50	50	50
Pumping discharge: Q (m^3/d)	330	150	30	660	230	70
Drawdown (m)	5	5	5	5	10	15
Transmissivity: T (m^2/d)	70	30	5	150	25	5
Well type	PWD New	PWD New	PWD New	PWD New	PWD New	PWD New
Pump Capacity (PS)	2	2	0.5	10	4	1.5
Motor Capacity (kW)	2.2	1.5	0.4	7.5	3.0	1.1
Water Source Investment Cost						
1. Well construction (M$$10^3$)	64	64	36	73	73	73
2. Submersible pump (M$$10^3$)	8	6	5	12	10	6
3. Diesel generator set (M$$10^3$)	10	8	8	18	11	8
4. Building (M$$10^3$)	14	14	14	14	14	14
5. Quarter (M$$10^3$)	12	12	12	12	12	12
6. Land acquisition (M$$10^3$)	12	12	12	12	12	12
7. Engineering (M$$10^3$)	5	5	5	5	5	5
8. Physical contingency (M$$10^3$)	13	12	10	10	13	13
Total (M$$10^3$)	138	133	102	160	150	143
O&M Cost						
1. Power generation (M$$10^3$/y)	3.2	2.2	0.7	11.0	4.3	1.5
2. Chlorination (M$$10^3$/y)	2.4	1.0	0.2	4.8	1.6	0.6
3. Well cleaning (M$$10^3$/y)	0.6	0.6	0.6	0.6	0.6	0.6
4. Other cost (M$$10^3$/y)	1.2	1.2	1.2	1.2	1.2	1.2
Total (M$$10^3$)	7.4	5.0	2.7	17.6	7.7	3.9

Table 13 ESTIMATED COST STREAM OF ASSUMED GROUNDWATER SOURCE FACILITIES

Unit: $M\$10^3$

Year in Order	Capital Cost Case A1	A2	A3	R1	R2	R3	O&M Cost Case A1	A2	A3	R1	R2	R3
1	138	133	102	160	143	143	-	-	-	-	-	-
2-7	-	-	-	-	-	-	7.4	5.0	3.7	17.6	7.7	3.9
8	18	14	13	30	21	14	7.4	5.0	2.7	17.6	7.7	3.9
9-15	-	-	-	-	-	-	7.4	5.0	2.7	17.6	7.7	3.9
16	18	14	13	30	21	14	7.4	5.0	2.7	17.6	7.7	3.9
17-23	-	-	-	-	-	-	7.4	5.0	2.7	17.6	7.7	3.9
24	18	14	13	30	21	14	7.4	5.0	2.7	17.6	7.7	3.9
25	58	48	24	50	50	50	7.4	5.0	2.7	17.6	7.7	3.9
26-31	-	-	-	-	-	-	7.4	5.0	2.7	17.6	7.7	3.9
32	18	14	13	30	21	14	7.4	5.0	2.7	17.6	7.7	3.9
33-39	-	-	-	-	-	-	7.4	5.0	2.7	17.6	7.7	3.9
40	18	14	13	30	21	14	7.4	5.0	2.7	17.6	7.7	3.9
41-47	-	-	-	-	-	-	7.4	5.0	2.7	17.6	7.7	3.9
48	18	14	13	30	21	14	7.4	5.0	2.7	17.6	7.7	3.9
49-50	-	-	-	-	-	-	7.4	5.0	2.7	17.6	7.7	3.9

Table 14 ESTIMATED UNIT COST OF WATER SOURCE

Unit: $M\$/m^3$

Discount Rate	Case A1	A2	A3	R1	R2	R3
0.20	0.147	0.266	0.910	0.125	0.219	0.538
0.18	0.166	0.305	1.065	0.136	0.247	0.629
0.16	0.184	0.342	1.210	0.146	0.273	0.714
0.14	0.200	0.378	1.350	0.156	0.298	0.796
0.12	0.217	0.413	1.485	0.165	0.323	0.876
0.10	0.233	0.446	1.616	0.174	0.346	0.954
0.08	0.248	0.479	1.743	0.183	0.369	1.030
0.06	0.263	0.512	1.867	0.192	0.392	1.103

FIGURES

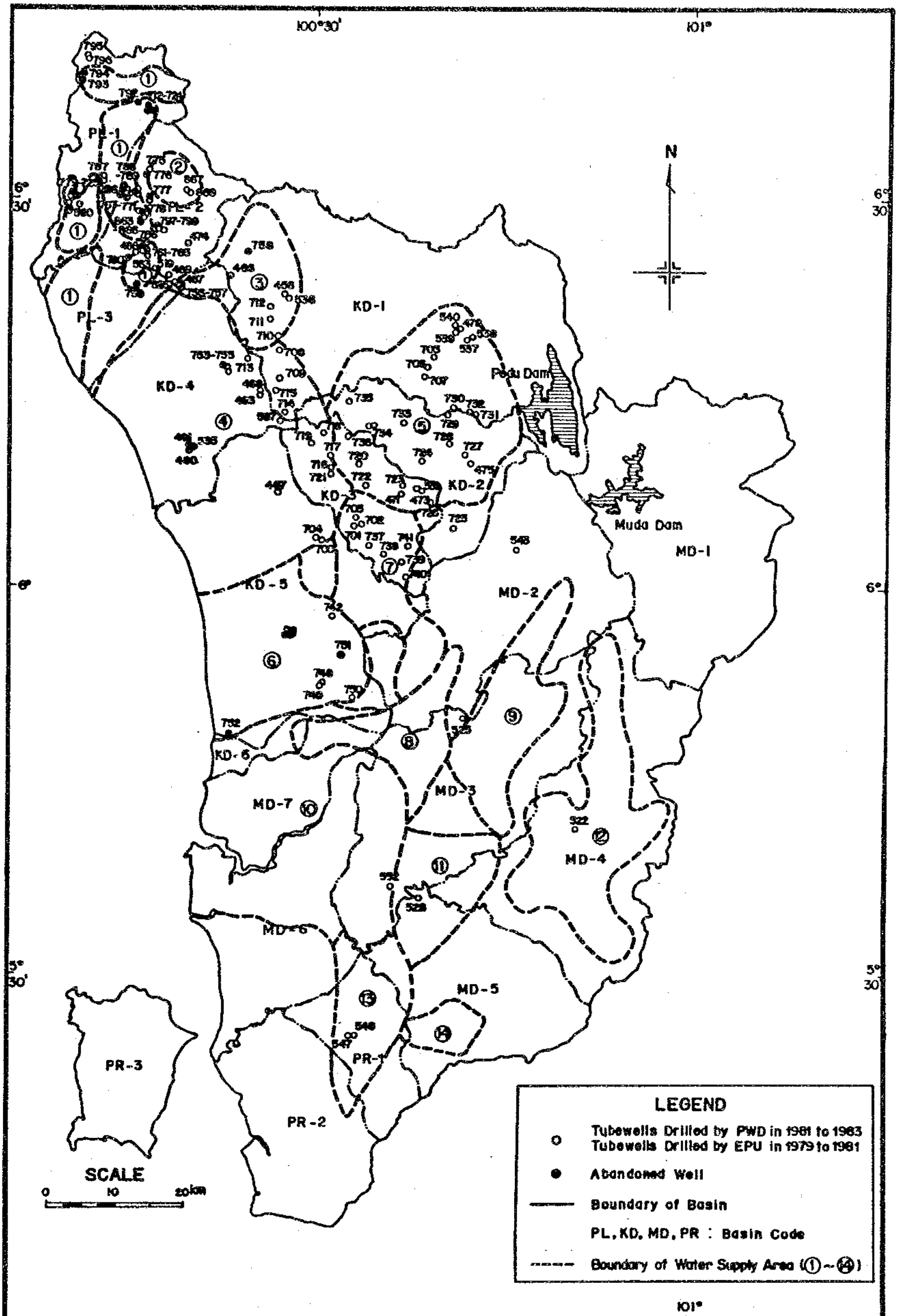

Fig. 1 Location Map of Tubewells

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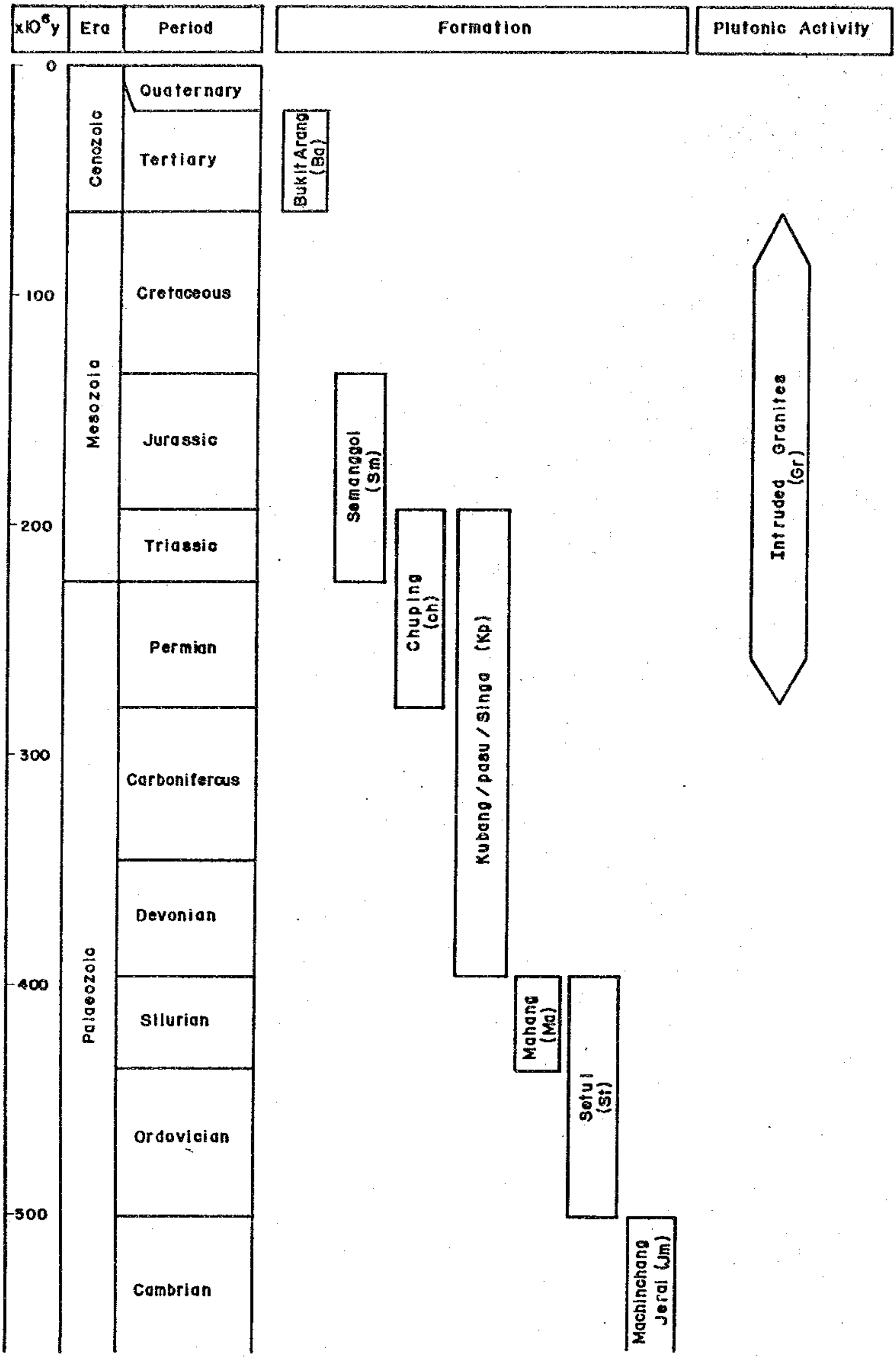

Fig. 2 Geologic Column

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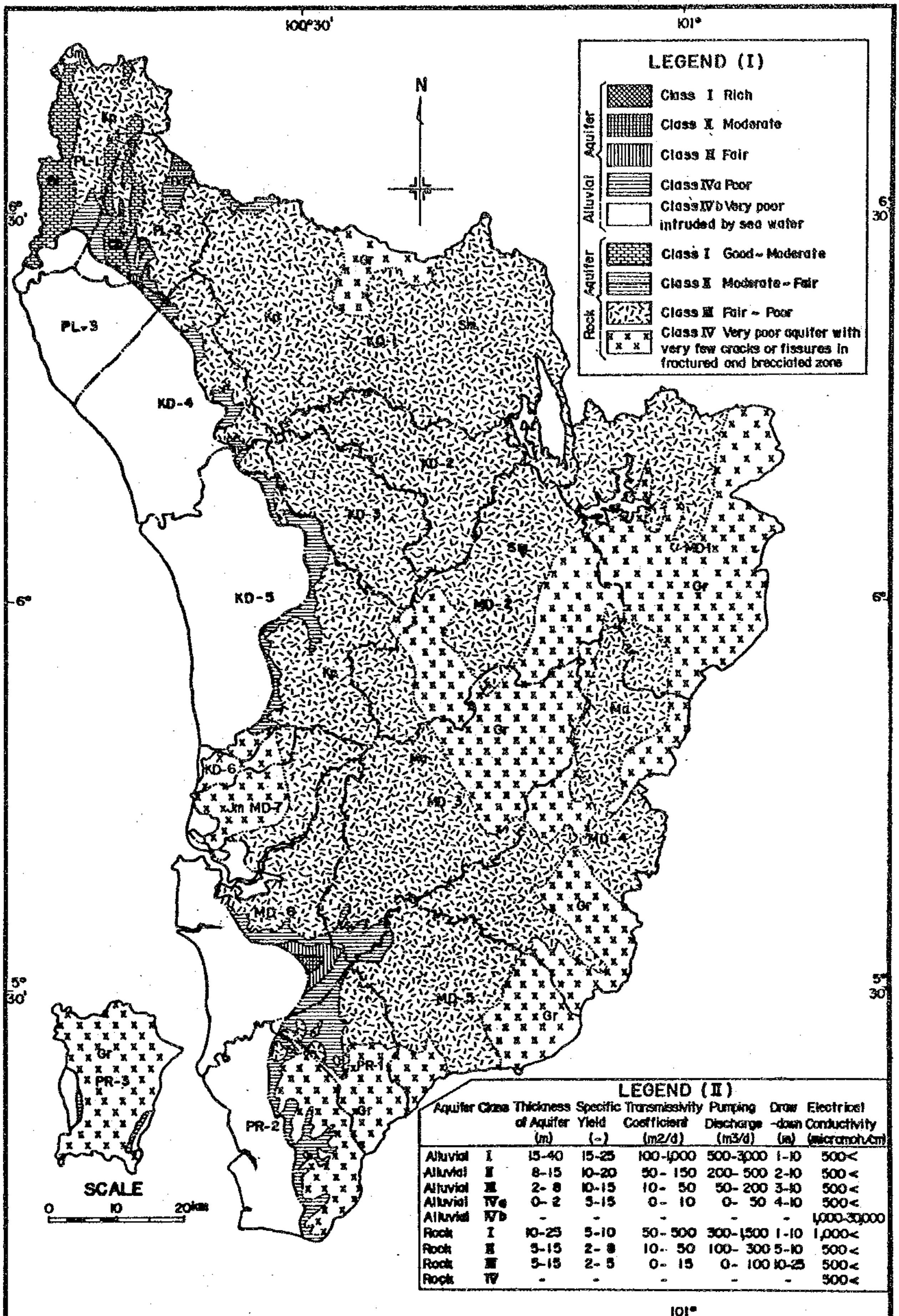

LEGEND (II)

Aquifer	Class	Thickness of Aquifer (m)	Specific Yield (-)	Transmissivity Coefficient (m2/d)	Pumping Discharge (m3/d)	Draw -down (m)	Electrical Conductivity (micromoh/cm)
Alluvial	I	15-40	15-25	100-1,000	500-3,000	1-10	500<
Alluvial	II	8-15	10-20	50- 150	200- 500	2-10	500<
Alluvial	III	2- 8	10-15	10- 50	50- 200	3-10	500<
Alluvial	IVa	0- 2	5-15	0- 10	0- 50	4-10	500<
Alluvial	IVb	-	-	-	-	-	1,000-30,000
Rock	I	10-25	5-10	50- 500	300-1,500	1-10	1,000<
Rock	II	5-15	2- 8	10- 50	100- 300	5-10	500<
Rock	III	5-15	2- 5	0- 15	0- 100	10-25	500<
Rock	IV	-	-	-	-	-	500<

Fig. 3 Hydrogeological Land Classification Map

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100°30'

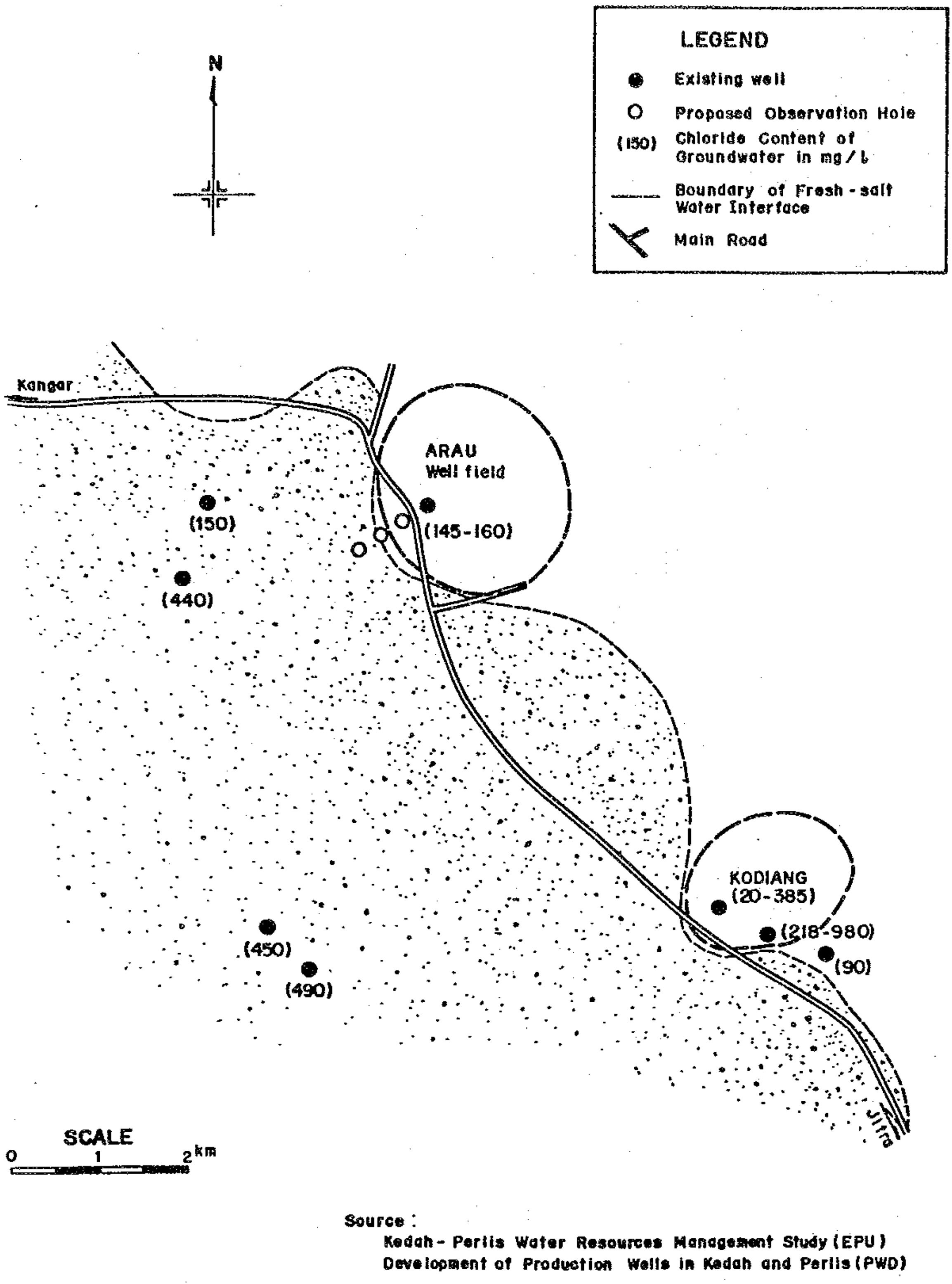

Fig. 4 Proposed Observation Well in Arau Area

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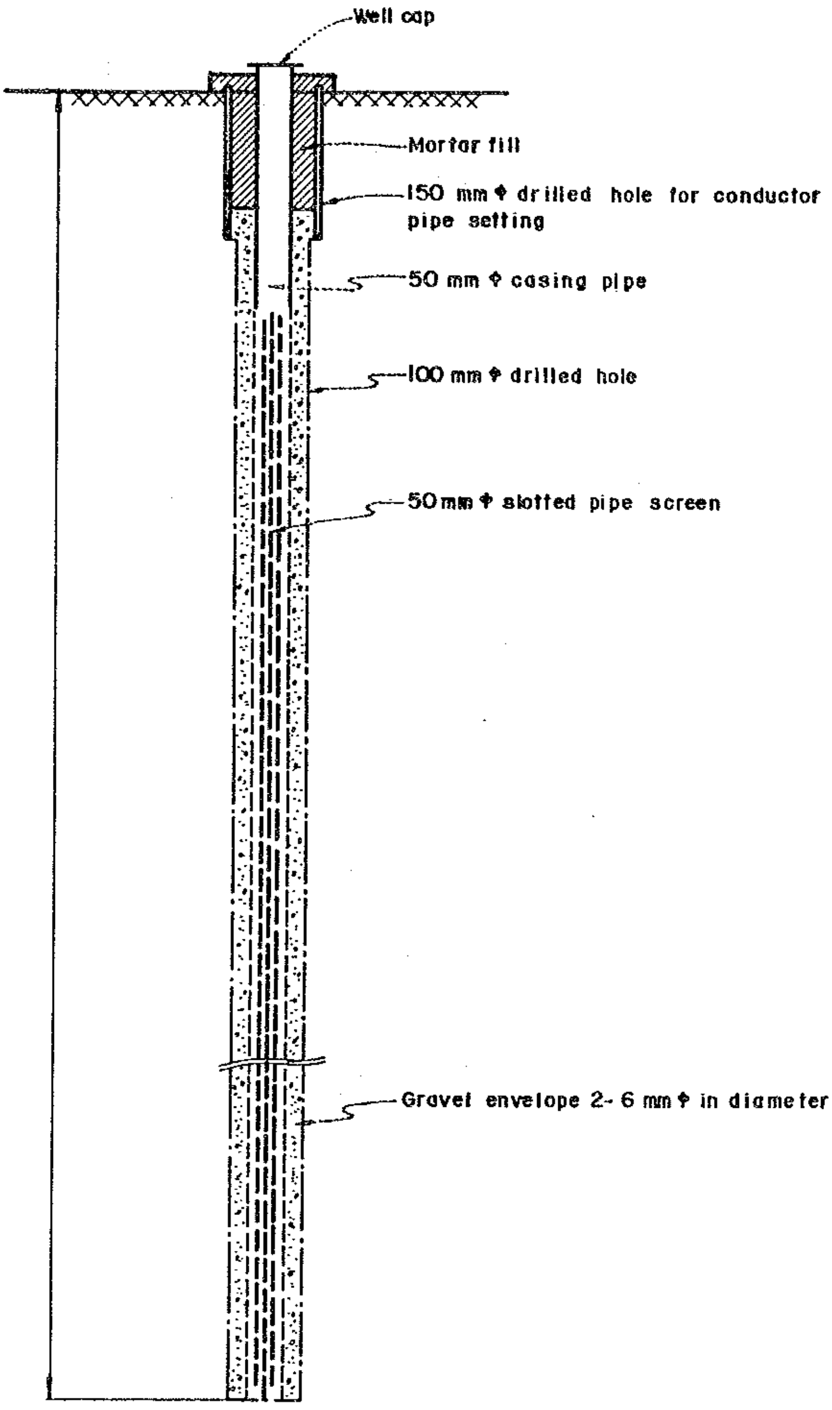

Fig. 5 Typical Observation Well

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