GOVERNMENT OF MALAYSIA
LEMBAGA LETRIK SABAH
(SABAH ELECTRICITY BOARD)

FEASIBILITY STUDY REPORT
ON
TENOM PANGI HYDROELECTRIC POWER DEVELOPMENT PROJECT, PHASE III
(SOOK RESERVOIR)

VOLUME II

APPENDIX-A : HYDROMETEOROLOGY

SEPTEMBER 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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ABBREVIATIONS

(1) Domestic Organization

DID (JPT)	:	Drainage and Irrigation Department
DOA (JP)	:	Department of Agriculture
EPU	:	Economic Planning Unit
MMS	:	Malaysian Meteorological Service
SEB (LLS)	:	SABAH ELECTRICITY BOARD
SEDC	:	State Economic Development Corporation
SEPU	:	State Economic Planning Unit

(2) International or Foreign Organization

JICA	:	Japan International Cooperation Agency

(3) Measurement

Length

mm = millimeter
cm = centimeter
m = meter
km = kilometer

Area

ha = hectare
km^2 = square kilometer

Volume

l = liter
m^3 = cubic meter
cft = cubic feet

Weight

kg = kilogram
ton = metric ton

Time

sec, s = second
min = minute
hr = hour
yr = year
SST = Sabah Standard Time

Electrical Measures

V = Volt
kW = Kilowatt
MW = Megawatt
kWh = Kilowatt hour
MWh = Megawatt hour
GWh = Gigawatt hour

Money

M$ = Malaysian dollar
M¢ = Malaysian cent
US$ = US dollar
US¢ = US cent
¥ = Japanese Yen

Other Measures

% = per cent
o = degree
' = minute
" = second
m^3/sec, m^3/s = cubic meter per second
cusec = cubic feet per second

(4) Economy and Finance

EIRR	:	Economic Internal Rate of Return
FIRR	:	Financial Internal Rate of Return
FC	:	Foreign Currency
LC	:	Local Currency
GDP	:	Gross Domestic Product
GRDP	:	Gross Regional Domestic Product
OMR	:	Operation, Maintenance and Replacement
L.S.	:	Lump Sum

(5) Other Abbreviations

El.	:	Elevation above mean sea level
NHWL	:	Normal high water level
HWL	:	High water level
LWL	:	Low water level

1. GENERAL

This appendix describes in detail the hydrometeorological survey and study results for the Tenom Pangi Hydroelectric Power Development Project -Phase III (Sook Reservoir). The survey and study are carried out by a joint team of JICA and SEB in 1985. Detailed data such as hourly and daily rainfall records, hourly and daily runoff records, hydrographs, etc. were collected through the field survey.

1.1 Scope of Work

The "Scope of Work", agreed upon between the Government of Malaysia and JICA, stipulates detailed scope of the hydrometeorological study as summarized below :

The hydrometeorological study consists of the 2 stages ; preliminary investigation stage and detailed field investigation stage. The scope of work for the preliminary investigation stage is as follows.

(1) Site reconnaissance

Siting of hydrological observation stations (siting of rainfall gauging stations, water stage gauging stations and discharge observation stations)

(2) Preliminary field investigation works

Installation of hydrological observation stations: Installation of observation instruments and establishment of system for continuous observation

Based on the study results at the preliminary investigation stage, the following works will be carried out at the detailed field investigation stage.

(1) Discharge observations

Actual measurement of discharge, sediments at the installed discharge observation stations

(2) Hydrometeorological investigation on flood/drought runoff and sediments

1.2 Padas Basin

Sabah is a mountainous country of dense tropical rain forests as well as alluvial and swampy coastal plains. It is intersected by numerous rivers and fertile valley plains. There lie central mountain ranges having occasional peaks of 1,000 to 2,000 m high. Above all, the highest range is the Crocker Range. It culminates at Mount Kinabalu having a peak of 4,101 m or 13,455 ft, the highest mountain in Southeast Asia.

Rivers are numerous throughout the country and are of importance for the area, being often used as the means of transportation and communication. Swift streams flow down the slopes of the Crocker Range into the South China Sea. The Padas River is the longest river in the west coast area. The longest river in the east coast area is the Kinabatangan River.

The Padas basin is the second largest basin in Sabah after the Kinabatangan basin. It is situated at the southwestern corner of Sabah. Drainage area of the Padas River is 9,180 km^2, occupying 10.6 per cent of the whole area of the State of Sabah. Total river length is about 195 km along the Padas River and about 175 km along a tributary, the Pegalan River. It consists of 3 major sub-basins and 2 divisions as shown below :

(1) Upper Padas sub-basin
(2) Pegalan sub-basin
(3) Sook sub-basin
(4) Tenom gorge section
(5) Coastal flood plain

Their principal features are shown below.

Padas Basin

Sub-basin/division	River Length (km)	Basin Width (km)	Drainage area (km^2)	Percentage of area (%)
1. Upper Padas	120	55	3, 670	40
2. Pegalan	100	40	2, 295	25
3. Sook	100	40	1, 835	20
4. Tenom gorge	40	20	645	7
5. Coastal flood plain	35	35	735	8
Total	(195)/1	-	9, 180	100

/1: Upper Padas + Tenom gorge + Coastal flood plain

The Sook River is one of the largest tributaries of the Pegalan River. It joins with the main stream Pegalan at about 3 km downstream of the town of Keningau. The Sook River drains 1,835km^2 of the drainage area with its 100km long river course. River gradient is relatively gentle as shown below.

River Gradient

No.	Location	Elevation (m AMSL)	River Length (km)	Gradient
1.	Confluence near Kg. Ansip	235		
			5	1/260
2.	Biah G.S.	254		
			48	1/590
3.	Contour Line 1,100 ft (335 m AMSL)	335		
			30	1/490
4.	Kg. Tulid	396		
			17	1/25
5.	Farthest basin divide	1, 082		
	Total/Mean	dH = 847 m	100	1/450 /1

/1: Weighted mean

The proposed Sook damsite is located on the Sook River at about 3.5 km upstream from the confluence with the Pegalan River, where the Sook River breakthroughs the tertiary rocky hill and forms a narrow gorge. The drainage area at the proposed Sook damsite is 1,732 km^2. Width of the river floor at the damsite is about 30m. A dam of 60 to 70m high will effectively create a reservoir having gross storage capacity of 730 - 1,140 x 10^6 m^3.

The existing Tenom Pangi project is located on the mainstream Padas at the upper reach of the Tenom Gorge, about 100 air km south of Kota Kinabalu. It consists of an intake weir, about 5 km long headrace tunnel and a 66 MW power station. The drainage area at the weir site is 7,815 km^2. The Tenom Gorge forms a series of rapids with an average gradient of about 1/100. In its upstream 16 km reaches, about 170 m of water head is available. The Tenom Pangi power station harnesses the head of about 75 m in the uppermost section of the Tenom Gorge.

Location of the State of Sabah and the Padas River basin is as depicted in Fig. A 1.

1.3 Previous Studies

A feasibility study on the Padas River Hydroelectric Power Development Project was conducted in 1974 (Ref.1). The feasibility study formulated a stage development plan as follows.

Stage 1: Construction of Tenom diversion weir and Pangi power station with 2 units of generating equipment (2 x 22 MW = 44 MW) as run-of-river type

Stage 2: Installation of 3rd unit at Pangi power station (in total 3 x 22 MW = 66 MW)

Stage 3: Construction of Sook dam and extension of Tenom Pangi power station

Detailed studies of feasibility level were worked out for Stages 1 and 2, which have been implemented by 1984. The study for stage 3 was also made on a pre-feasibility level. The present feasibility study is made in succession to this pre-feasibility study.

Preceding the present feasibility study, the following two studies have been made.

(1) Hydrologic Study on Flood Occurred in January 1981 (Ref.9)

(2) Review of Firm Power Availability (Ref.10)

Ref.9 reviews a flood occurred in January 1981. This flood having an estimated peak flow of 2,100m^3/s is identified to be the observed maximum flood of the Padas River exceeding the one that flooded some part of Tenom town in 1934. This study recommended to revise the then design flood of the Pangi power station (1,400m^3/s) to be 2,100m^3/s in accordance with design criteria; the larger flood should be adopted to the design flood between recorded maximum and 100-year floods.

Ref.10 reviews dependability on power output of the Pangi power station with 10 years' additional runoff data (May 1973 to February 1983) obtained after the feasibility study (Ref.1). It proved that there is little change in the power dependability of the Pangi power station as a run-of-river type.

1.4 Hydrometeorological Stations and Available Data in Project Area

(1) Rainfall Gauging Stations

There are 21 rainfall gauging stations in the Padas basin including ones that have been closed by 1985. These station are listed in Table A 1. Out of them, the following 5 stations are of so-called recording type that is equipped with one set of automatic rain gauge and manual rain gauge.

(a) Kemabong (4959001)
(b) Kg. Sook (5163002)
(c) Keningau Meteorological Station (5361002)
(d) Apin Apin (5462001)
(e) Tambunan Agricultural Station (5663001)

The remaining 14 stations excluding Pangi Damsite and Mini Secretiat Tenom are of non-recording type having a manual rain gauge with daily reading at 08:00 SST (00:00 GMT). The following 4 stations of non-recording type have been closed by 1985.

(a) Ulu Tomani (4358001)

(b) Tenom (5159001)

(c) Biah Scheme (5261001)

(d) Sunsuron Agricultural Station (5763001)

Available periods of rainfall records are as shown in Fig. A 4. In addition to these periods, monthly rainfall records are available at 4 stations for years before 1950 as shown below.

Station Name	Station No.	Available Periods
Sapong Estate	5059002	1924-1927, 1930-1939
Tenom	5159001	1921, 1924-1927, 1930-1939
Keningau	5361001	1918-1944
Tambunan	-	1918-1927, 1930-1940

As shown in Fig. A 4, rainfall observation in the Padas basin was started in 1918 at Keningau and Tambunan, followed by Tenom in 1921 and Sapong Estate in 1924. After the World War II, 2 more stations started rainfall observation, one at Melalap Estate in 1952 and the other at Tulid in 1953. The Tulid station is the oldest one in the Sook basin. Eight more stations were established from 1961 to 1970. All the above rainfall stations are of non-recording type equipped with manual rain gauge of daily reading at 08:00 SST.

In addition to the above, DID established the 5 recording type rainfall stations in the Padas basin in 1965 to 1966.

(2) Stream Gauging Stations

There are 4 stream gauging stations on the Padas River system; Kemabong on Upper Padas, Tenom Lama on mainstream Padas, Ansip on Pegalan and Biah on Sook. Their location, drainage area, etc. are as listed in Table A 2. These stations are established in 1968, and have been operated with periodical flow measurement. Available periods of runoff data at these stations are as shown in Fig. A 4.

Preceding establishment of the above stations, river water level was observed at the 4 stations as also listed in Table A 2. No flow measurement was made at these stations.

(3) Other Data

The following data are also observed at Keningau Meteorological Station of DID in the Padas basin.

(a) Evaporation by US Class-A Pan
(b) Daily mean wind speed
(c) Temperature
(d) Relative humidity
(e) Sunshine hour

1.5 Check Measurement of Drainage Area

Preceding the present hydrological study, drainage area of the Padas basin is measured for confirmation on topographic maps in a scale of 1/50,000. First, boundary line of the Padas basin was drawn on the maps. Then the Padas basin is divided into sub-basins, and area of each sub-basin was measured using a planimeter 3 times at least. If there are large differences among the 3 planimeter readings, then another measurement was made.

The drainage areas thus obtained are summarized below together with ones presented in the DID data book (Ref.2) and the feasibility report (Ref.1).

Drainage Area of Padas Basin

Basin	Place	Drainage Area (km^2)			
		DID Ref. 2	FS-1974 Ref.1	Present Measurement	Used in Present Study
Upper Pegalan	Ansip	2,175	-	2,188	2,175
Sook	Biah	1,683	1,683	1,701	1,683
Sook	Damsite	-	1,732	1,705	1,732
		-	(1,770) /1		
Pegalan	Confluence at Tenom	-	4,275	4,412	4,275
Upper Padas	Kemabong	3,184	-	3,204	3,184
Upper Padas	Confluence at Tenom	-	3,440	3,620	3,440
Padas	Tenom Lama	7,715	7,715	8,032	7,715
Padas	Tenom Diversion Weir	-	7,815	8,046	7,815

/1: Figure in the main report of Ref. 1.

As shown in the above table, there is little difference among the 3 estimates for the drainage areas at Biah, Ansip and Kemabong. The new value of drainage area at Tenom Lama (8,032 km^2) is larger than the previous one (7,715 km^2) by 317 km^2, which corresponds to 4.1 per cent of the area.

To avoid duplicity in drainage area neglecting the above differences, the previous value of each drainage area is adopted in the present feasibility study as presented in the rightmost column of the above table.

2. FIELD SURVEY

Hydrometeorological survey conducted for the Project during the detailed field investigation stage consists of the 3 parts; field survey, data collection and compilation, and hydrometeorological study as listed below.

(1) Field survey

- Field reconnaissance in the Sook basin

- Site selection for new rain gauges in the Sook basin

- Inspection of discharge measurements that are being made by DID

- Check of backwater effect of the existing Tenom Pangi diversion weir on the upstream water level and flow rating curve at the Tenom Lama stream gauging station

- Connection of the datum elevation of staff gauges at the Biah stream gauging station on the Sook River to a bench mark system that is established by the topographic survey team

- Installation of a temporary water level gauge at the proposed Sook damsite

- Sampling and laboratory test of suspended sediment by a contractor

(2) Data collection and compilation

- Data collection from DID in Kota Kinabalu, Weather Services in Kota Kinabalu, Agricultural Department in Keningau, Tenom Pangi power station, DID in Kuala Lumpur, etc.

- Data compilation such as tabulation of raw data, preparation of summary table, gauge height - runoff conversion, unit conversion, measurement of drainage area on maps, etc.

(3) Hydrometeorological study

- Meteorological study on temperature, relative humidity, dew point, wind speed, evaporation, etc.

- Rainfall study

- Runoff study

- Flood study

- Derivation of probable maximum precipitation (PMP) and probable maximum flood (PMF) for the Sook basin

The above hydrological survey was commenced on June 17, 1985 and is completed by October 18, 1985 except sampling and laboratory test of suspended sediment that will be continued by a contractor until mid 1986. The new rain gauges will be installed by DID in the Sook basin in near future. The hydrometeorological study was continued in Japan to prepare this final feasibility report.

2.1 Field Reconnaissance

Field reconnaissance was conducted in and around the Sook basin in mid-August 1985. Through the reconnaissance, the following are identified.

(1) There are many logging roads in the Sook basin branching from a trunk road connecting Keningau with Pensiangan, though they are

not gravel-surfaced. Some of them are extending beyond the southern boundary of the Sook basin.

(2) Major logging areas in and around the Sook basin are shifting from the southern part of the Sook basin to the areas beyond the southern boundary, including the upper Padas basin on its right bank. Logging in the Sook basin has almost been finished. The Sook basin is presently covered by secondary forest and grass land except ranch, farmland, etc. Some areas are under shifting cultivation.

(3) The Sook basin consists of a continuation of low hills having the Sook plain in its centre. Mean elevation of the Sook plain is about 350 m. Elevation along the Sook basin boundary generally varies between 600 m and 900 m with the highest peak at 1,204 m. However, most of the basin lies below 600 m in elevation.

(4) Water of the Sook River always presents muddy colour even at low flow contrasting with a clear colour of the Pegalan River water at the confluence. However, the upper Sook River at Kg. Tulid shows a clear colour of water at low flow stage similar to the one of the Pegalan River. It gets coloured when reaches at the downstream end of the Sook plain.

(5) River water of Sg. Karamatoi is muddiest among tributaries of the Sook River, and the next is Sg. Puntih. According to people of Kg. Malaing, water of the Sg. Karamatoi was clear before 1982 when there was no logging roads in its upstream basin, but has been always muddy since then.

(6) Though water of the Sook River at the confluence with the Pegalan River appears muddy even at low flow stage, there is little sediments in the flowing water that will settle even one month after the sampling. While river water of Sg. Karamatoi and Sg. Puntih includes much sediments that will settle in a day.

(7) Flow of the Pegalan River sharply increases responding to rainfall, and presents muddy colour. However, it will recede and become clear after flooding.

2.2 Site Selection for New Rain Gauges in Sook Basin

As shown in Fig. A 3, all of the 4 rainfall stations in and around the Sook basin are situated in its eastern part and there is none in the southwestern part. In order to clarify areal distribution of rainfall in the Sook basin, it is proposed to install new rain gauges in this southwestern part of the Sook basin. They are at Kg. Kalampun and Kg. Bonor as shown in Fig. A 5. At these 2 stations, both automatic and manual rain gauges will be installed. It is also proposed to install an automatic rain gauge at Tulid, where a manual rain gauge has been operated since 1953.

Locations of the new rain gauges are arranged to cover the Sook basin as equally as possible taking into consideration accessibility to the sites and availability of a gauge keeper for observation and maintenance.

The site conditions of the new rainfall stations are as described below:

(1) Kg. Kalampun

The site is beside a school building of Kg. Kalampun, Keningau. The site is accessible by a 4-wheel-driven car except in heavy rain. It is at about 1.5 hours driving distance from Keningau town.

(2) Kg. Bonor station

The site is beside a school building of Kg. Bonor, Dalit, Keningau. The site is accessible by a 4-wheel-driven car except in heavy rain. It is at about 2 hours driving distance from Keningau town.

(3) Kg. Tulid station

The newly selected site is about 15 m apart from an office building of Agricultural Department at Kg. Tulid. The existing 5" manual rain gauge should be shifted to this site since it is located too close to the office building and thus affected by local disturbance of wind. The site is accessible by a 4-wheel-driven car except in heavy rain. It is at about 1.5 hours driving distance from Keningau town.

At the meeting among SEB, DID and the JICA survey team held on June 25, 1985, it was agreed that DID will install the new rain gauges for SEB and will undertake observation so far as the respective sites are accessible by a car.

2.3 Discharge Measurement

There are 4 stream gauging stations on the Padas River System upstream from the Tenom Pangi diversion weir as shown in Table A 2. A field survey team of DID stationed in Keningau is undertaking discharge measurement at these stream gauging stations since their establishment in 1968. Discharge measurements of as many as about 700 times have been carried out at each station by 1984.

Equipment used for the measurement is well maintained. Flow velocity is measured by 2-points method. Results of the measurements are sent to DID in Inanam, Kota Kinabalu and compiled for periodical checking of the respective rating curves. The equipment, field operation and data compilation system are adequate, and it is judged that the rating curves thus established are highly reliable for the ranges from low flow to such high flows as discharge measurements are made.

2.4 Backwater Effect of Tenom Pangi Diversion Weir on Water Level at Tenom Lama

The Tenom Pangi diversion weir started its operation since end of 1983 to cause water level rise in the upstream river reaches. However, no appreciable backwater effect on the water level was observed at Tenom Lama until end of 1984 as the discharge measurements made in 1984 proves little change in the rating curve as shown in Fig. A 32. While from early 1985, the discharge measurements show an upward shift of rating curve. An upward shift of about 1m was recorded on September 2, 1985.

As shown in Fig. A 33, water level at the Tenom Pangi diversion weir was kept about 2.5m below its HWL before commissioning of the No. 3 generating unit in the end of 1984. This water level is raised after the commissioning. On September 2, 1985, water level at the weir site was about 173.20m being about 1.8m higher than ones in 1984. A discharge measurement made on this day shows an upward shift of about 1m in Tenom Lama water level, while no shift was observed when the weir site water level was kept at 171.4m on March 28, 1984. It suggests that raise of water level at the weir site up to about 171.4m does not affect upstream water level at Tenom Lama.

Test operation of the spillway gates of the Tenom Pangi diversion weir was made in January 1984 to check its backwater effect to Tenom Lama. All the spillway gates were fully opened when the weir site water level was at its HWL 173.9m. The gates were closed after 20 to 30minutes. This opening and closing operations were repeated for 16 times. Water level chart at Tenom Lama during this test operation is shown in Fig. A 30. As show in the figure, the operation interval was too short to attain stable water level at Tenom Lama that would be realized when all the gates are kept fully opened. The maximum water level drop recorded on the chart was 2.8 ft (0.85m), which is slightly smaller than the above-mentioned shift of 1m observed on September 2, 1985.

It is therefore concluded that the Tenom Pangi diversion weir will not cause appreciable backwater effect to Tenom Lama so far as its water level is kept at or below 171.4m. If the water level is raised to higher levels, there will be considerable backwater effect to Tenom Lama. When the weir site water level is kept at HWL 173.9m, water level rise at Tenom Lama will be more than 1m.

It is then judged that the backwater effect to Tenom Lama was practically negligible until the end of 1984, but the rating curve of Tenom Lama is not applicable thereafter.

2.5 Datum Elevation of Staff Gauge at Biah on Sook River

Datum elevation of the staff gauges at Biah on the Sook River was surveyed on October 22, 1985 based on a bench mark TBM 27, that was established by the topographic survey team. The elevation of gauge height zero is obtained to be 253.316 m above mean sea level (AMSL). Gauge height at the survey was 1.10 m corresponding to a water level of 254.416 m AMSL and to a flow of 9 m^3/s. A temporary bench mark was also established at this site by painting on the concrete step in front of the shelter for water level recorder. Elevation of this bench mark is 257.256 m AMSL.

2.6 Water Level Gauging at Proposed Sook Damsite

In order to check water level at the proposed Sook damsite, a temporary water level gauge was established at an alternative dam axis on the downstream side. The gauge was painted on rock surfaces in the left bank for water level range from 247.30 to 248.50 m AMSL. A temporary bench mark was also established by painting on an outcrop of bedrock beside the gauge. Elevation of this bench mark is 248.868 m AMSL.

2.7 Suspended Sediment Sampling and Laboratory Test

Sampling of river water and its laboratory test for sediment and water quality were awarded to a contractor, Ground Engineering Sdn. Bhd. (Sabah) as a part of the laboratory tests for construction materials.

Water sampling for sediment analysis is being continued by the contractor at Biah stream gauging station located at about 1.5 km upstream from the proposed main damsite. Sampling of 10 times out of

30 times, that are contracted for 12 months' period, has been made by the end of November 1985.

The results are as shown below.

Sampling Data

Date	Time (hr)	Gauge Height (m)	Concentration of Total Solid (ppm)	Water Temperature (°C)
Sept.11, 1985	14:00	0.87	135	29.0
Sept.27, 1985	11:30	1.20	344	28.5
Oct. 3, 1985	16:35	1.92	797	27.0
Oct. 5, 1985	17:00	1.85	405	26.5
Oct. 8, 1985	10:00	1.95	740	26.5
Nov. 18, 1985	08:55	1.90	416	27.0
Nov. 20, 1985	08:30	1.88	250	26.5
Nov. 22, 1985	09:15	1.78	1, 158	26.5
Nov. 25, 1985	15:00	1.73	101	27.0
Nov. 27, 1985	08:30	1.64	591	26.0

3. METEOROLOGICAL STUDY

3.1 General Climate

Climate of Sabah is the tropical rain forest climate characterized by constantly moist days throughout the year. The northeast winds generally begin in mid-October and last until mid-April, and the southwest winds prevail from mid-April to mid-October. The southwest wind is generally weaker than the northeast wind. However, the southwest wind becomes stronger from afternoon to night (Ref.8). The rainy season of the west coast of Sabah generally coincides with the time of the southwest wind, and rainfall in the east coast is abundant during the northeast wind. However, due to region's insularity this climate is somewhat modified from place to place.

Heavy rainfall occurs in the coastal belt area where it records from 2,000 to 3,000 mm a year. A large inland plain, where the Padas River drains, is sheltered from the southwest winds by the Crocker Range on its western boundary and from the northeast winds by the mountainous hinterlands between the plain and the east coast, creating one of the driest area in Sabah. Average annual rainfall in this area, however, amounts to 1,500 mm to 2,000 mm. The monthly rainfall is between 100 mm to 200mm. Seasonal pattern of rainfall distribution is not clearly defined. The areal distribution of mean annual rainfall is as depicted in Fig. A 8.

Sabah is outside the typhoon threaten zone, but torrential rainstorms accompanied by high winds are frequent. Maximum wind speeds recorded during the past 31 years from 1954 to 1984 are 27.7 m/s at Kota Kinabalu, and 21.0 m/s at Sandakan. A maximum wind speed of 26.4 m/s was recorded at Labuan Aerodrome in August 1953. While mean wind speed at Keningau is as low as 0.56 m/s.

Temperatures in Sabah are generally constant throughout the year, ranging from about 29.5°C in the day time to about 22°C during night. Temperature decreases with the altitude, and it falls to about 10°C at night in the higher mountainous area.

The Padas basin is characterized by the marine-equatorial climate subject to northeast and southwest winds. Mean daily temperatures are in the range of 30°C on the coastal flood plain falling to 26°C in the other inland areas and less than 20°C in the mountainous areas. Relative humidity is uniformly high throughout the year at around 70 per cent.

3.2 Temperature, Relative Humidity and Dew Point

Temperature at 08:00 SST is observed at Keningau Meteorological Station in the Padas basin. Mean, minimum and maximum temperature at Keningau are as presented in Tables A 3 to A 5. Their mean monthly patterns are as depicted in Fig. A 6. As shown in the figure, mean temperature is 21.9°C varying in a narrow range from 19.4 °C in January to 23.9°C in April.

Mean relative humidity at 08:00 SST at Keningau is as presented in Table A6. Its mean monthly pattern is almost constant at around 70 per cent as depicted in Fig. A 7.

Maximum dew points at Keningau are obtained based on the dry-bulb temperature and relative humidity records using the following formula of J.F. Bosen (Ref.11).

$$T - T_d = (14.55 + 0.114 \times T) \times X + [(2.5 + 0.007 \times T) \times X]^3$$

$$+ (15.9 + 0.117 \times T) \times X^{14}$$

where T = Dew point in degree Celsius

T_d = dry-bulb temperature in degree Celsius

$X = 1 - f / 100$

f = relative humidity in per cent

The maximum dew points thus obtained are as presented in Table A 7. An envelopment of the maximum dew points is shown in Fig. A 56. As shown in the figure, the maximum dew point observed at Keningau is 24.4^{o}C at the station level of 290 m.

Mean sunshine hour at Keningau is 6.4 hr/day as presented in Table A 10. It corresponds to annual sunshine hour of 2,336 hr. Mean monthly pattern of sunshine hour is as shown in Fig. A 7. Minimum monthly mean sunshine hour recorded during the past 10 years from 1976 to 1985 is as high as 3.6 hr/day (108 hr/month). This sunshine could be a power source for such equipment as telemetering rain and water level gauges, etc.

3.3 Wind Speed

Wind speed is observed at Keningau Meteorological Station on the daily mean basis. Mean surface wind speed at this station is listed in Table A 11 for 14 years from 1972 to 1985. Mean surface wind speed at this station is 0.56 m/s. There is no other station in the Padas basin that observes wind speed.

In order to estimate maximum wind speed that is expected around the Project area, mean and maximum wind speed records at 3 principal meteorological observatories in Sabah are also collected. They are Kota Kinabalu International Airport, Labuan Aerodrome and Sandakan Airport. The wind records are listed in Tables A 12 to A 17.

Mean and maximum wind velocity at these stations are as summarized below.

Wind Speed in Sabah

Station Name	Height of Anemometer Above Ground (m)	Wind Speed (m/s) Mean	Maximum
Keningau Meteorological Station	3.5	0.56 (13)	-
Kota Kinabalu International Airport	14.5	1.9 (16)	27.7 (31)
Sandakan Airport	12.2	1.7 (16)	21.0 (31)
Labuan Aerodrome	14.1	1.6 (7)	26.4 (18)

Note: Figures in parentheses show number of years of records.

As shown in the above table, mean wind speed at Keningau Meteorological Station is about one third of ones at the other stations. Keningau is located in the inland plain while Kota Kinabalu and Sandakan are at coast and Labuan is on an island. The low wind speed at Keningau is due to its insularity from coast.

The maximum wind speed recorded at the 3 coastal stations is 27.7 m/s (100 km/hr). It is estimated that the maximum wind speed at Keningau is less than that at Sandakan of 21.0 m/s (76 km/hr). If it is assumed that the maximum wind speed is proportional to square root of the mean wind speed, then the maximum wind speed at Keningau is estimated to be around 15 m/s (54 km/hr).

3.4 Evaporation

Evaporation is observed using a US Class-A pan at Keningau Meteorological Station since 1972. Its monthly evaporation records are listed in Table A 9. Mean monthly pattern of the pan evaporation is as depicted in Fig. A 6 showing similar pattern to ones of mean temperature and mean sunshine hour. Monthly fluctuation of mean pan evaporation is, however, small between 127 mm in February and 160 mm in March as shown below.

Mean Pan Evaporation at Keningau

(Unit: mm)

Month	Evaporation	Month	Evaporation
Jan.	129	July	141
Feb.	127	Aug.	149
Mar.	160	Sep.	145
Apr.	149	Oct.	139
May	149	Nov.	133
June	138	Dec	132
	Annual		1, 691

4. RAINFALL STUDY

In order to see rainfall characteristics in Sabah, mean monthly rainfall at Keningau is first compared with those at Kota Kinabalu on the west coast, Sandakan on the east coast and Pensiangan in an inland in the south of the Padas basin. Monthly rainfall records at these stations are listed in Tables A 20 to A 22 and Table A 34.

Mean Rainfall at Typical Stations in Sabah

(Unit : mm)

Month	Keningau (1918-1983)	Kota Kinabalu (1924-1980)	Sandakan (1879-1980)	Pensiangan (1922-1980)
January	154	129	455	195
February	110	58	274	168
March	140	86	198	262
April	137	139	121	298
May	188	216	151	304
June	131	318	194	278
July	115	264	187	221
August	110	254	213	236
September	135	321	243	261
October	157	367	262	266
November	134	319	355	275
December	149	262	468	224
Annual	1, 660	2, 733	3, 121	2, 988

As shown in the above table, mean annual rainfalls at Kota Kinabalu, Sandakan and Pensiangan are as high as around 3,000 mm contrasting with the relatively low value of 1,660 mm at Keningau. Kota Kinabalu is located at the west coast and Sandakan at the east coast of Sabah. Keningau is located at an inland being surrounded by mountain ranges. Pensiangan is also located at an inland but the topography is rather open to southeast toward Celebes Sea and to northeast toward Sulu Sea.

The above mean monthly rainfall pattern is shown in Fig. A 9 to see difference in seasonal pattern of rainfall in Sabah. As shown in the figure, the seasonal pattern may be classified into the following 3 types

Type 1: <u>Sandakan</u>

This type has single peak in December to January being affected by the northeast trade wind that usually prevails from mid-October to mid-April. This is a typical pattern in the east coast of Sabah. During the southwest wind season from mid-April to mid-October rainfall of this type is lower than the average. The southwest wind hardly affect rainfall in the east coast areas around Sandakan.

Type 2: <u>Kota Kinabalu</u>

This type has double peaks; one in June and the other in October. The month of June is in the middle of the southwest wind season, while October is the transition month from southwest wind to northeast wind. Dry months continue from January to April. Rainy season starts in June and lasts until November. May and December are the transition period. This type is a typical pattern in the west coast areas around Kota Kinabalu.

Type 3: <u>Keningau and Pensiangan</u>

This type has no distinct season. Every month has almost uniform rain on a long-term mean basis. It is considered that this type is affected by both the southwest wind and the northeast wind due to its location in an inland. The Padas basin belongs to this type.

It is noticeable that the patterns at Keningau and Pensiangan are similar to each other in spite of large difference in their annual rainfall. This fact may be understood as follows.

(1) Both the places are located in inland areas and are, therefore, affected by both the southwest and northwest winds to have almost uniform rain throughout the year.

(2) Since Keningau is located in an inland plain being surrounded by mountain ranges that block humid air mass inflow, rainfall amount is less compared to ones observed in the coastal areas locating upwind.

(3) Open topography around Pensiangan permits humid air mass inflow to intrude into the inland from Celebes Sea in the southwest wind season and from Sulu Sea in the northeast wind season resulting in high rainfall amount throughout the year.

4.1 Available Rainfall Data

There are 21 raingauges in the Padas basin including ones that have been closed by 1985. These raingauges are as listed in Table A 1. The raingauges are classified, by DID, into 2 types; recording type and non-recording type. The recording type is equipped with a tipping bucket type raingauge with an automatic recorder for 3 months continuous operation and a manual raingauge. While the non-recording type has only a manual raingauge. Diameter of old manual raingauge is 5 inches and new one is 8 inches or 200 mm.

There are 4 rainfall stations being presently operated in and around the Sook basin as listed below.

(1) Keningau Meteorological Station (automatic and manual rain gauges)

(2) Kg. Sook (automatic and manual rain gauges)

(3) Tulid (manual rain gauge)

(4) Nabawan (manual rain gauge)

Available periods of rainfall records observed in the Padas basin are as shown in Fig. A 4. Monthly rainfall records at these stations are listed in Tables A-23 to A 43.

4.2 Mean Annual Rainfall

Annual rainfalls at selected 11 gauges in the Padas basin are as shown in Table A 18. Mean annual rainfall of the Padas basin is 1,856 mm (1960 - 1984) as an arithmetic mean of the 11 stations. Due to lack of rain gauges in the Upper Padas basin and western part of the Sook basin, the correct basin rainfall is not presently known.

4.3 Mean Monthly Rainfall Pattern

Mean monthly rainfall at Kg. Sook, Tulid, Biah Scheme, Keningau and Apin Apin are as presented in Table A 19. Their mean monthly patterns are as shown in Fig. A 10. As shown in the figure, there is little seasonal fluctuation in rainfall.

Monthly Rainfall (1960 - 1984/Padas Basin)

(Unit: mm)

Month	Rainfall	Month	Rainfall
Jan	150	July	136
Feb	123	Aug	140
Mar	136	Sept	170
Apr	143	Oct	172
May	190	Nov	179
June	151	Dec	166
		Total	1, 856

4.4 Frequency Analysis on Annual Maximum Daily Rainfall

Frequency analyses are made on the annual maximum daily rainfall records at all the 5 recording type stations and at 10 non-recording type stations. The rainfall data are presented in Table A 45. Probable daily rainfalls of each station are obtained by Log-Pearson Type III method. Results are presented in Table A 46.

Probable daily rainfalls at Keningau, Kg. Sook, Tulid, Apin Apin and Nabawan that are located in and around the Sook basin are as shown below.

Probable Daily Rainfall In And Around Sook Basin

(Unit :mm)

Station Name	Keningau	Kg. Sook	Tulid	Apin Apin	Nabawan	Mean
Station No.	5361001	5163002	5364001	5462003	5164001	
Years	1960-1983	1965-1983	1960-1983	1961-1983	1970-1984	
Sample Size	23	19	24	21	15	
Return Period (yr)						
2	66	83	91	80	82	80
5	89	101	111	104	115	104
10	107	113	124	120	138	120
30	134	132	146	143	171	145
50	147	141	156	153	188	157
100	166	153	171	166	201	171

As shown in the table, there are no distinct differences in the probable daily rainfall among the 5 stations.

4.5 Depth - Duration Analysis

Mean depth-duration pattern in and around the Sook basin is as shown in Table A 49 and Fig. A 13 for durations shorter than 24 hours. As shown in the figure, rainfall in the Sook basin has such a characteristic as about 85 per cent of 24-hour rainfall concentrates in 6 hours. This short duration suggests that rainfall in and around the Sook basin is mainly brought by thunderstorms but not by general storms that cover wide area and continues for longer duration. These torrential showers are usually observed in afternoon to midnight.

Maximum depth - duration ever recorded in and around the Sook basin is as presented in Tables A 47 and A 48 and shown in Fig. A 12. The maximum 1-day rainfall is 162 mm. An envelopment of the maximum point depth - duration records is also shown in Fig. A 12.

4.6 Depth - Area Analysis

Depth - area relation of rainfalls during the typical storms including the one that caused the recorded maximum flood on January 14, 1981 is as shown in Tables A 50 to A 52 and in Fig. A 25. As shown in the figure, rainfall in and around the Sook basin is characterized by its limited rain area. Basin mean rainfall for a duration of 1 day is as small as 0.43 times of point rainfall even during the recorded maximum storm in January 1981.

5. RUNOFF STUDY

5.1 Available Runoff Data

Runoff records at Tenom Lama on the Padas River, Biah on the Sook River, Ansip on the Pegalan River and Kemabong on the Upper Padas River are presented in Tables A 56 to A 59. The runoff records from the beginning to 1980 are collected from DID in Kota Kinabalu, while the ones thereafter are tentatively obtained for the present study by converting daily gauge height records, made available by DID, with respective runoff rating curves that were established by DID for the period until 1980. Daily mean gauge height at Tenom Lama for 1984 and ones at Biah for 1984 and 1985 are read on the respective recording charts provided by DID.

The gauge height data at Tenom Lama for the period from February 25, 1981 to July 20, 1981 are added by 0.87 m before converting to runoff because of the following reasons.

(1) The Tenom stream gauging station was damaged by the recorded maximum flood occurred on January 14 to 15, 1981. The station resumed water level recording from February 25, 1981 at the same place. The station was shifted to the left bank beside the access road to the Tenom diversion weir site on July 21, 1981. Results of discharge measurement made at the station during this period and preceding and succeeding periods are shown in Fig. A 31. As clearly shown in the figure, the 5 times measurements made during this period shows downward shift of the rating curve by 0.87 m on an average.

(2) Flow at this 5 measurements are varying from about 80 m^3/s to 220 m^3/s, and shows an almost uniform shift for the range

proving that this downward shift is not due to incidental error during discharge measurements but that there must be certain change in hydraulic condition or certain error. Though one measurement made in 1980 is also apart from the rating curve by 0.80 m being similar to the shift of the 5 measurements, it is judged that this difference is due to incidental error since all the other measurements in 1980 shows no shift of the rating curve.

(3) There are two conceivable cases that can cause the above uniform downward shift. One is the actual shift of rating curve due to scouring of riverbed and/or river bank by flood flow. Second is such error in gauge height reading as would cause the above constant shift in rating curve but not incidental one.

(4) The scouring of riverbed is not realistic in this case since the shift is only limited to this period and almost constant through the period. And the measurement after July 21, 1981 shows sudden complete recovery of the previous rating curve since the establishment in 1968, that is, previous river section or hydraulic condition. Moreover, Tenom Lama gauging station is located on the Tenom Gorge and, therefore, considered not to have such serious erosion of river bank as of the upper reaches meandering on the alluvial plain.

(5) There are two conceivable cases that can cause error in gauge height as follows.

(a) Mis-reading of gauge height on the staff gauge during discharge measurement

(b) Upward shift of staff gauge during the flood in January 1981 or mis-installation of staff gauge after the flood

(6) Mis-reading during discharge measurements is not realistic since the 5 measurements including one made by Tobishima shows almost the same shift of rating curve.

(7) Possibility of upward shift of staff gauge during the flood in January 1981 or its mis-installation after the flood is possible and most probable.

(8) It is thus concluded that the gauge height records read on the staff gauge at Tenom Lama from February 25, 1981 to July 20, 1981 is not correct but should be added by about 0.87 m.

5.2 Reliability of Flow Rating Curve

As described in Chapter 2.3 hereof, it is judged that the flow rating curves of the 4 stream gauging stations on the Padas River System are highly reliable for the flow ranges where actual flow measurements are frequently made. These flow ranges of measurements are as shown below.

Flow Range of Discharge Measurement

(Unit: m3/s)

Station Name	Flow Range	
	From	To
Tenom Lama	10	600
Biah	1	175
Ansip	2	175
Kemabong	10	560

5.3 Mean Annual Runoff

Annual mean runoffs at the 4 stream gauging stations on the Padas River System are presented in Table A 55 and summarized below.

Mean Annual Runoff of Padas River System

(Unit: m^3/s)

Station Name	River	Drainage Area (km^2)	Mean Annual Runoff (m^3/s yr)	(mm)	(10^6 m^3)
Biah	Sook	1,683	29	543	915
Ansip	Pegalan	2,175	50	725	1, 577
Kemabong	Upper Padas	3,184	119	1, 179	3, 753
Tenom Lama	Padas	7,715	210	858	6, 623

Yearly fluctuation of the annual mean runoff is as shown in Fig. A 34.

5.4 Mean Monthly Runoff Pattern

Monthly mean runoff records at the 4 stream gauging stations are listed in Tables A 56 to A 59 and shown in Fig. A 35. As shown in the figure, monthly pattern of runoff is generally the same with one of the mean rainfall. Mean runoff is relatively high in the early part of northeast wind months of November to January, and in the early month of southwest wind months of May. While in the later part of the northeast wind months of March and of the southwest wind months of August, the mean runoff and its standard deviation are lowest.

In the month of January, mean runoff of the Padas River at Tenom Lama fluctuates in a wide range from 28 m^3/s in 1973 to 895 m^3/s in 1981 as also shown by its largest standard deviation of 216 m^3/s. It means that the month of January will be a drought month in some year like 1973, and will also be a flooding month in another year like

1981. The similar feature but with smaller range is seen also in the other months except October to December that are always rich water months. It is, however, difficult to classify months by season.

5.5 Water Balance of Padas River System

Long-term mean runoffs at the 4 stream gauging stations on the Padas River System are summarized below to see the water balance in the Padas basin.

Water Balance of Padas Basin

Station Name	River	Drainage Area		Mean Runoff		
		(Km^2)	(%)	(m^3/s)	(%)	(mm)
Biah	Sook	1, 683	21.8	29.4	14.0	551
Ansip	Pegalan	2, 175	28.2	50	23.8	725
Kemabong upper	Padas	3, 184	41.3	119	56.7	1, 179
Residual basin	Upper Padas/ Pegalan	673	8.7	11.6	5.5	562
Total at Tenom Lama		7, 715	100	210	100	858

The following conclusions are derived from the above table.

(1) More than half (56.7 per cent) of the runoff of the Padas basin at Tenom Lama comes from the Upper Padas basin upstream from Kemabong, that share 41.3per cent in drainage area.

(2) The Sook basin shares only 14.0 per cent in the runoff though it covers 21.8 per cent in drainage area.

(3) Mean annual runoff height varies from 551 mm of Sook sub-basin to 1,179 mm of Upper Padas sub-basin. One of the Upper Pegalan is 725 mm being medium.

(4) Runoff of the residual basin is obtained as a balance of ones at the 4 stream gauging stations. It is judged based on the following 2 hydrological aspects of this sub-basin that its mean annual runoff height of 562 mm is slightly underestimated.

(a) The topography of this sub-basin is mountainous except alluvial plain along the Upper Padas and Pegalan Rivers being similar to one of the Upper Pegalan but unlike the Sook sub-basin. While the mean annual runoff height of this sub-basin computed to be 562 mm is only 78 per cent of the one of the Upper Pegalan sub-basin of 725 mm.

(b) This sub-basin is adjacent to both the Upper Padas and Upper Pegalan sub-basins. It is therefore expected that basin rainfall of this sub-basin is not so small compared to them but rather similar to.

It is estimated that an overestimation of such flood flow at Kemabong as much exceeding the measured range of flow rating curve resulted in this underestimation of runoff of the residual basin.

(5) As a whole, it is concluded based on the above water balance that the runoff of the Padas River System is well measured by DID and is highly reliable except high flood flow of the Upper Pegalan River at Kemabong.

5.6 Runoff Coefficient

Mean runoff coefficients of the Padas basin at the 4 stream gauging station sites are checked below one by one for confirmation of rainfall and runoff data as well as to clarify basin characteristics.

5.6.1 Sook Sub-basin at Biah

Mean annual basin rainfall of this sub-basin is estimated as an average of ones at Keningau, Biah Scheme, Kg. Sook, Tulid and at Nabawan as shown below.

Station Name	Years of Records	Mean Annual Rainfall (mm)
Keningau	1918 - 1983	1,633
Biah Scheme	1967 - 1981	1,799
Kg. Sook	1966 - 1983	1,892
Tulid	1960 - 1983	2,047
Nabawan	1970 - 1984	2,246
Mean		1,923

Assuming that mean annual basin rainfall during the period from 1969 to 1984 is equal to the above, mean runoff coefficient of the Sook sub-basin is computed by:

$$C = Qm / Rm$$
$$= 551 / 1923$$
$$= 0.29$$

Where, Qm = mean annual runoff height in mm

Rm = mean annual basin rainfall in mm

It is considered that this low runoff coefficient of the Sook basin of 0.29 is mainly due to its basin topography characterized by the

Sook plain locating in its centre and the continuation of low hills covering the remaining areas except mountain slopes along the basin boundary.

5.6.2 Upper Pegalan Sub-basin at Ansip

Mean annual basin rainfall of this sub-basin is estimated as an average of ones at Keningau, Apin Apin, Sunsuron Agricultural Station, Tambunan, Tambunan Agricultural Station and at Tulid as shown below.

Station Name	Years of Records	Mean Annual Rainfall (mm)
Keningau	1918 - 1983	1,633
Apin Apin	1961 - 1983	2,005
Sunsuron Agr. At.	1965 - 1984	1,836
Tambunan	1918 - 1967	1,819
Tambunan Agr. St	1966 - 1980	1,924
Tulid	1960 - 1983	2,047
Mean		1,877

Mean runoff coefficient is then estimated as:

$$C = 725/1877$$
$$= 0.39$$

5.6.3 Upper Padas Sub-basin at Kemabong

Mean annual basin rainfall of this sub-basin is assumed to be given as an average of ones at Ulu Tomani and Kemabong as shown below.

Station Name	Years of Records	Mean Annual Rainfall (mm)
Ulu Tomani	1965 - 1980	1,785
Kemabong	1966 - 1983	1,695
Mean		1,740

Mean runoff coefficient of the Upper Padas sub-basin is then estimated as:

C = 1,179/1740
= 0.68

5.6.4 Residual Sub-basin

Mean annual basin rainfall of the residual sub-basin is estimated as an average of ones at Tenom, Melalap Estate, Keningau, Sapong Estate, Batu Bajau and Kemabong as shown below.

Station Name	Years of Records	Mean Annual Rainfall (mm)
Tenom	1921 - 1967	1,766
Melalap Estate	1952 - 1983	1,520
Keningau	1918 - 1983	1,633
Sapong Estate	1960 - 1983	1,658
Batu Bajau	1966 - 1984	1,719
Kemabong	1966 - 1983	1,695
Mean		1,665

Mean runoff coefficient of the residual basin is then estimated as:

C = 562/1,665
  = 0.34

5.6.5 Padas Basin at Tenom Lama

Mean annual basin rainfall of the Padas basin at Tenom Lama is estimated as an average of the ones of Sook, Upper Pegalan, Upper Padas and the residual sub-basins with weight of drainage area as shown below.

Sub-basin (1)	Drainage Area (km^2) (2)	Weight (3)	Mean Annual Basin Rain (mm) (4)	Weighted (mm) (4) x (3)
Sook	1, 683	0.22	1,923	423
Upper Pegalan	2, 175	0.28	1,877	526
Upper Padas	3, 184	0.41	1,740	713
Residual	673	0.09	1,665	150
Total/Mean	7, 715	1.00		1, 812

Mean runoff coefficient of the Padas basin at Tenom Lama is then estimated as:

C = 858 / 1812
  = 0.47

The above runoff coefficients are summarized below for comparison.

Runoff Coefficient of Padas Basin

Sub-basin	Drainage Area (Km^2)	Basin Rain (mm/yr)	Mean Runoff Coefficient
Sook at Biah	1, 683	1, 923	0.29
Upper Pegalan at Ansip	2, 175	1, 877	0.39
Upper Padas at Kemabong	3, 184	1, 740	0.68
Residual	673	1, 665	0.34
Total at Tenom Lama	7, 715	1, 812	0.47

As shown in the above table, the mean runoff coefficient of the Padas basin at Tenom Lama is 0.47. Ones of the 4 sub-basins vary in a wide range from 0.29 of the Sook sub-basin to 0.68 of the Upper Padas sub-basin. Since the mean annual rainfalls of the 4 sub-basins are similar to each other, it is judged that the above differences in runoff coefficient are mainly due to different basin topography.

5.7 Frequency Analysis on Drought

Upon implementation of the Sook reservoir project, the existing Tenom Pangi power station will not suffer from water shortage of such short duration as less than about 1 month since the Sook reservoir has an enough storage capacity to augment its discharge for Tenom in such a short period. The Sook reservoir, however, could not meet the water requirement when serious drought continues for more than a few months. It is, therefore, important to check the frequency and duration of these droughts.

According to the past runoff records from 1969 to 1984 presented in Table A 57, the long-term mean runoff of the Padas River at Tenom Lama is 210 m^3/s. The maximum duration of such low runoff as less than 100 m^3/s is 6 months but limited in a range from January to September excluding the 3 rich water months from October to December.

Then frequency of the drought is checked for the 6 duration of 1 month to 6 months based on the 16 years' monthly mean runoff records at Tenom Lama. The annual minimum runoff of each duration is presented in Tables A 62 and A 63. They are plotted on a log-normal probability paper as shown in Fig. A 36. A curve is fitted by eye to each group of points.

Frequency of drought of the Padas River at Tenom Lama and its duration are as summarized below.

Frequency and Duration of Drought of Padas River at Tenom Lama

(Unit: m^3/s)

Return Period	Duration (month) 1	2	3	4	5
2 yr	65	90	110	120	130
5	35	45	60	75	100
10	12	20	28	40	65
20	5	12	18	25	30
Drought in 1983	6	9	12	19	27

As shown in the above table, the drought recorded in 1983 corresponds to a return period of about 20 years, and one in 1973 about 10 years respectively.

6. GENERATION OF LONG-TERM RUNOFF SERIES

6.1 General

As described in Chapter 5.1, runoff records of 16 years from 1969 to 1984 are available at the 4 stream gauging stations on the Padas River System. They can be the basis for a combined operation study of the Sook reservoir project and the Tenom Pangi power station.

In order to check dependability on power output of the Sook - Tenom Pangi project for longer periods of hydrological conditions, additional 17 years' monthly runoff series from 1952 to 1968 is generated based on the monthly rainfall records using a runoff model. Accordingly, a 33 years' runoff series in total from 1952 to 1984 will be available for the operation study.

6.2 Methodology

As a runoff model for estimating runoff based on rainfall records, Tank Model method is adopted for its simplicity of idea and validity proved in Japan and Southeast Asian countries. The Tank Model method was developed by Dr. M. Sugawara in 1963 and has been widely applied for runoff analysis in Japan.

A simple tank model is illustrated in Fig. A 37. This model consists of 4 tanks aligning in a vertical. Right side holes of each tank represent runoff from the basin while a bottom hole of each tank represents infiltration. Rainfall is first stored in the uppermost tank. The rain water caught in the uppermost tank will go out of the tank through right side holes and/or through bottom hole depending on the water level in the tank. The second tank receives the water that is infiltrated from the uppermost tank through its bottom hole. The same process is repeated for the third and last tanks. Sum of the water come out from right side holes of the 4 tanks will be the runoff of the basin. The uppermost tank represents surface runoff, the second tank represents interflow, while the bottom 2 tanks represents stable base flow.

Outflow from each hole is computed by the following equation.

Qij = (Si - Hij) x Aij

Where, Qij = Outflow from j-th hole of i-th tank in mm

Si = Depth of stored rain water in i-th tank in mm

Hij = Height of j-th hole of i-th tank from its bottom in

mm (Hi = 0 for bottom hole)

Aij = Multiplier of j-th hole of i-th tank

Evapotranspiration loss of the basin is subtracted from the stored water in the uppermost tank. If there is no water, it is subtracted from the second tank, and so on.

Using the above tank model method, runoff of the Padas River at Tenom Lama and one of the Sook River at Biah are estimated in accordance with the following procedure.

(1) Estimation of basin rainfall
(2) Estimation of evapotranspiration loss
(3) Calibration of tank model for runoff records from 1969 to 1984
(4) Computation of runoff for 1952 to 1968 from rainfall

In the derivation of long-term runoff series, special attention is paid to the following two points.

(1) Consistency in annual runoff height
(2) Consistency in low runoff during droughts

6.3 Estimation of Basin Rainfall

6.3.1 Mean Rainfall over Padas Basin

Monthly basin rainfall is estimated for the 32 years between January 1952 and December 1983, dividing the Padas basin into the Pegalan basin and the Upper Padas basin whose drainage areas upstream from Tenom Lama are $4,275km^2$ and $3,440km^2$ respectively.

Monthly basin rainfall of the Pegalan basin upstream from Tenom Lama is calculated using monthly rainfall records of the 5 stations within the basin; Tenom, Melalap, Keningau, Tulid and Tambunan of which rainfall records are available over 20 years. Absent data of the 5 stations are made up for by the single regression analysis or the multiple regression analysis.

Monthly basin rainfall of the Upper Padas basin is estimated as follows. Within this basin, there are 3 rainfall stations; Sapong Estate, Kemabong and Ulu Tomani. Though these 3 stations are located apart to each other, their rainfall patterns are comparable. Hence, monthly basin rainfall of the Upper Padas basin is represented by rainfall records of Sapong Estate of which rainfall records are available over a longer period than the other stations. Absent data are estimated in the same way as for the Pegalan basin, using rainfall records at Kemabong and Ulu Tomani.

Based on the basin rainfalls thus obtained for the 2 sub-basins, monthly basin rainfall of the entire Padas basin is estimated by the following equation.

$$R = (4,275 \times Rpe + 3,440 \times Rpa)/7,715$$

where,

R (mm): Basin rainfall of the Padas basin
Rpe (mm): Basin rainfall of the Pegalan basin
Rpa (mm): Basin rainfall of the Upper Padas basin

6.3.2 Mean Rainfall over Sook Basin

Monthly basin rainfall of the Sook basin upstream from Biah, 1,683km^2 in area, is estimated as arithmetic means of rainfall records of the 4 stations in and around the basin; Biah Scheme, Kg. Sook, Nabawan and Tulid for the 31 years between January 1952 and December 1982.

6.4 Estimation of Evapotranspiration Loss

6.4.1 Evapotranspiration Loss in Padas Basin

A relationship between annual basin rainfall and annual basin evapotranspiration loss is derived from the table below for the period of which observed runoff data are available.

	(1)	(2)	(1)-(2)	(2)/(1)
Year	Annual Basin Rainfall (mm)	Observed Runoff Height (mm)	Evapo-transpiration Loss (mm)	Runoff Coefficient
1969	1,543.5	600.7	942.8	0.39
1970	2,020.1	961.5	1, 058.6	0.48
1971	2,012.7	913.0	1, 099.7	0.45
1972	1,337.7	771.9	565.8	0.58
1973	2,165.5	837.1	1, 328.4	0.39
1974	2,031.4	931.6	1, 099.8	0.46
1975	1,962.3	886.6	1, 075.7	0.45
1976	1,458.3	754.9	703.4	0.52
1977	1,788.8	1, 171.4	617.4	0.65
1978	1,246.0	577.4	668.6	0.46
1979	1,825.9	967.3	858.6	0.53
1980	1,607.0	833.9	773.1	0.52
1981	1,737.6	934.8	802.8	0.54
1982	1,157.7	600.6	557.1	0.52
1983	1,379.7	680.8	698.9	0.49
Average	1,684.9	828.2	856.7	0.50

From this table, the following relation between the annual evapotranspiration and annual basin rainfall is derived.

$$EV = 0.631 \times R - 206$$

where, EV : Annual basin evapotranspiration (mm)

R : Annual basin rainfall (mm)

For converting annual basin evapotranspiration into monthly basin evapotranspiration, conversion rates are obtained from the mean monthly pan evaporation at Keningau shown in Chapter 3.4.

6.4.2 Evapotranspiration Loss in Sook Basin

In the same way, a relation between annual basin rainfall and annual evapotranspiration loss is obtained from the table below.

	(1)	(2)	(1)-(2)	(2)/(1)
Year	Annual Basin Rainfall (mm)	Observed Runoff Height (mm)	Evapo-transpiration Loss (mm)	Runoff Coefficient
1968	1,909.6	370.7	1,538.9	0.19
1969	1,648.7	307.3	1,341.4	0.19
1970	2,257.0	566.0	1,691.0	0.25
1971	2,345.7	534.2	1,811.5	0.23
1972	2,077.0	479.8	1,597.2	0.23
1973	1,937.1	563.8	1,373.3	0.29
1974	2,201.1	638.0	1,563.1	0.29
1975	2,142.6	616.1	1,526.5	0.29
1976	1,753.4	389.6	1,363.8	0.22
1977	2,366.3	630.4	1,735.9	0.27
1978	1,826.1	257.2	1,568.0	0.14
1979	2,085.1	530.7	1,554.4	0.25
1980	2,172.2	522.2	1,650.0	0.24
1981	2,260.2	650.2	1,610.0	0.29
1982	1,550.5	335.0	1,215.5	0.22
Average	2,035.5	492.7	1,542.8	0.24

From this table, the following equation is derived.

EV = 0.570 x R + 383

where, EV : Annual basin evapotranspiration (mm)
R : Annual basin rainfall (mm)

For the computation of monthly basin evapotranspiration, the same conversion rates as described hereinbefore for the Padas basin are used.

6.5 Calibration of Tank Model

6.5.1 Tank Model for Padas Basin at Tenom Lama

Multiplier and height of each hole of the tank model is determined by trial and error in the comparison of gauged runoff and simulated runoff for the period between January 1969 and December 1983 of which gauged runoff records are available. Since the available rainfall data are limited, the tank model is obtained with priority given to consistency in low runoff during such droughts as observed in 1973 and 1983. The adequacy of simulated runoff is examined with regard to:

(a) Runoff hydrographs during droughts (See Fig. A 39)
(b) Annual runoff heights and annual runoff coefficients (See a table below)
(c) Runoff duration curves (See Fig. A 40)

	(1)	(2)	(3)	(4)	(3)/(1)	(4)/(1)
Year	Annual Basin Rainfall (mm)	Evapo-transpiration Loss (mm)	Runoff Height (mm) Observed	Simulated	Runoff Coefficient for Observed Runoff	for Simulated Runoff
1969	1,544	768	601	764	0.39	0.50
1970	2,020	1,068	962	934	0.48	0.46
1971	2,013	1,064	913	924	0.45	0.46
1972	1,338	638	772	773	0.58	0.58
1973	2,166	1,160	837	978	0.39	0.45
1974	2,031	1,075	932	981	0.46	0.48
1975	1,962	1,032	887	900	0.45	0.46
1976	1,458	714	755	751	0.52	0.52
1977	1,789	922	1,171	861	0.65	0.48
1978	1,246	580	577	695	0.46	0.56
1979	1,826	946	967	847	0.53	0.46
1980	1,607	808	834	799	0.52	0.50
1981	1,738	890	935	874	0.54	0.50
1982	1,158	524	601	642	0.52	0.55
1983	1,380	664	681	710	0.49	0.51
Average	1,685	857	828	829	0.50	0.50

As shown in the above table, the observed and simulated annual runoff heights and annual runoff coefficients show a reasonable likeliness. Low runoffs during droughts in 1973 and 1983 show adequate consistency as shown in Fig. A 39. Runoff duration curve of the simulated runoff series shown in Fig. A 40 also shows adequate consistency to the observed one.

It is thus judged that the tank model shown in Fig. A 38 is applicable to estimate monthly runoff series of the Padas basin at Tenom Lama that will be used for monthly reservoir operation study.

6.5.2 Tank Model for Sook Basin at Biah

The tank model is calibrated in the comparison of gauged runoff and simulated runoff for the period between January 1968 and December 1982 of which gauged runoff records are available. The adequacy of generated runoff is examined in the same way as for the Padas basin at Tenom Lama. Estimated basin rainfall and evapotranspiration loss, and simulated annual runoff height and annual runoff coefficient are shown below.

	(1)	(2)	(3)	(4)	(3)/(1)	(4)/(1)
Year	Annual Basin Rainfall (mm)	Evapo-transpiration Loss (mm)	Runoff Height (mm) Observed	Simulated	Runoff Coefficient for Observed Runoff	for Simulated Runoff
1968	1,910	1,471	371	421	0.19	0.22
1969	1,649	1,323	307	301	0.19	0.18
1970	2,257	1,669	566	533	0.25	0.24
1971	2,346	1,720	534	595	0.23	0.25
1972	2,077	1,566	480	538	0.23	0.26
1973	1,937	1,487	564	468	0.29	0.24
1974	2,201	1,637	638	558	0.29	0.25
1975	2,143	1,604	616	492	0.29	0.23
1976	1,753	1,382	390	427	0.22	0.24
1977	2,366	1,731	630	601	0.27	0.25
1978	1,826	1,424	257	449	0.14	0.25
1979	2,085	1,571	531	498	0.25	0.24
1980	2,172	1,621	522	492	0.24	0.23
1981	2,260	1,671	650	647	0.29	0.29
1982	1,551	1,267	335	307	0.22	0.20
Average	2,036	1,543	493	489	0.24	0.24

As shown in the above table, the observed and simulated annual runoff heights and annual runoff coefficients show a reasonable likeliness. Low runoffs during droughts in 1973 and 1983 show adequate consistency as shown in Fig. A 44. Runoff duration curve of the simulated runoff series shown in Fig. A 45 also shows adequate consistency to the observed one.

It is thus judged that the tank model shown in Fig. A 43 is applicable to estimate monthly runoff series of the Sook basin at Biah that will be used for monthly reservoir operation study.

6.6 Generation and Evaluation of Generated Long-term Runoff Series

6.6.1 Long-term Runoff Series of Padas Basin at Tenom Lama

Using the tank model thus established, runoff is generated for the period between January 1952 and December 1968. They are shown in Fig. A 41 and in Table A 57 together with the observed ones for the period from January 1969 to December 1984. A duration curve of this runoff series from 1952 to 1984 is shown in Fig. A 42 together with one for the period from 1969 to 1984. As shown in the figure, the runoff records of the period from 1969 to 1984 is severer in view of reservoir operation than one of the period from 1952 to 1984.

6.6.2 Long-term Runoff Series of Sook Basin at Biah

Using the tank model thus established, runoff is generated for the period between January 1952 and December 1967. They are shown in Fig. A 46 and in Table A 59 together with the observed ones for the period from January 1968 to December 1984. A duration curve of this runoff series from 1952 to 1984 is shown in Fig. A 47 together with one for the period from 1968 to 1984. As shown in the figure, the runoff records of the period from 1968 to 1984 is also severer in view of reservoir operation than one of the period from 1952 to 1984.

7. FLOOD STUDY

In order to provide basic data for determination of design flood of the proposed Sook dam and power station, a flood study is conducted. It consists of frequency analyses on flood peak flow and flood volume, study on flood hydrograph shape, and development of dimensionless graph, unitgraph, probable maximum precipitation and probable maximum flood. Unitgraph, probable maximum precipitation and probable maximum flood are separately described in Chapter 8.

7.1 Available Flood Data

Flood data of the Sook River are available at Biah stream gauging station for 17 years from 1968 to 1984. Annual maximum floods at this station are as listed in Table A 65. The maximum flood of 410 m^3/s is recorded on January 14, 1981. Specific flow of this flood is as low as 0.24 $m^3/s/km^2$. It is judged that the main reason of this low flood flow is the topography of the Sook basin characterized by the Sook plain and continuation of low hills covering the whole basin except mountain slopes along the basin boundary.

It is also noticeable that the 3 largest floods among the 17 years were recorded in the latest 4 years; 1981, 1983 and 1984.

In order to check reliability of the above flood records of the Sook River, ones of the Pegalan River at Ansip, Upper Padas River at Kemabong and Padas River at Tenom Lama are also collected as listed in Table A65. These data suggests that the flood in January 1981 is a very large flood not only on the Sook River but also on the Upper Padas and Padas mainstream as summarized below.

Flood Recorded in January 1981

River	Station	Drainage Area (km^2)	Peak Flow (m^3/s)	Peak Flow ($m^3/s/km^2$)
Sook	Biah	1,683	410	0.24
Pegalan	Ansip	2,175	-	-
Upper Padas	Kemabong	3,184	(4,250)/1	1.33
Padas	Tenom Lama	7,715	2,100/2	0.27

/1: Estimated only for reference by converting the gauge height record of 9.96m with simply extrapolated rating curve on a semi-log-paper.

/2: After Ref.9.

The above peak flow of the Padas River at Tenom Lama is not recorded one but after the estimate made in March 1983 as presented in a study report (Ref.9). Peak flow of the Upper Padas River at Kemabong is obtained for reference although the high flood flow at Kemabong is somewhat overestimated as described in Chapter 5.2.

The drop in peak flow at Tenom Lama compared to ones at upstream gauging station is due to storage effect of the river channel. The Padas River forms a natural reservoir during high floods due to its gentle slope upstream from Tenom Lama and bottleneck at Tenom Gorge. It is, therefore, possible that the inflow into this natural reservoir is considerably higher than the flow that is observed at Tenom Lama locating in the Tenom Gorge.

7.2 Frequency Analysis on Annual Maximum Flood

Frequency analyses are made on the annual maximum floods recorded at the 3 stream gauging stations on the Padas River System except Kemabong on the Upper Padas River. The flood records are listed in Table A 65. The analyses are made by the Log-Pearson Type

III method. In the case of Tenom Lama on the Padas River, the maximum flood experienced in 1981 is excluded from the sample for the analysis taking into consideration the following.

(1) As described in a study report prepared on this flood (Ref.9), an assumption that this flood was sampled from the same population with the other floods is to be rejected from the statistical viewpoint.

(2) As a reason of the above statistical difference of the flood in January 1981 from the others, the following hydrological condition is conceived.

(a) The Padas River consists of 2 major tributaries; the Upper Padas and the Pegalan. The Tenom Lama stream gauging station is located in the Tenom Gorge immediate downstream from the confluence of the 2 tributaries. The drainage area of the Padas River at Tenom Lama is as large as 7,715 km^2.

(b) The typical rainstorm in the Padas basin is characterized by its short duration usually less than 6 hours (see Fig. A 14) and locality (see Fig. A 25) compared to ones brought by such general storms as monsoon or tropical cyclone.

(c) Due to the above-mentioned hydrological features of the Padas basin, floods of the 2 tributaries seldom occur at the same time. Therefore, main portion of the flood flow at Tenom Lama is sometimes coming from the Upper Padas River and sometimes from the Pegalan River. The same situation is probable even within the Pagalan basin or in the upper Padas basin.

(d) While in the case of the flood in January 1981, high rainfall was recorded at all the rain gauges in the Padas basin over the 4 continuous days from January 11 to 14, 1981. Daily rainfalls in this flood and in the second largest flood in December 1975 are tabulated in Table A 53 for comparison. As shown in the table, the mean 4 days' rainfall of the flood in January 1981 is 93.5 mm being 3.2 times of the one of 29.6 mm in December 1975. It is noticeable that all the stations recorded rainfalls for all the 4 days in the case of flood in January 1981.

(e) It is thus judged that the flood in January 1981 is different from the others in such hydrological aspect as the rain area spread all over the Padas basin and continued for 4 days after the one month antecedent rainfall, although the rainfall was not continuous on a hourly time basis within a day. Accordingly flood flow of the 2 tributaries arrived at Tenom Lama on the same day to cause the unprecedented high flood flow at Tenom Lama. Rareness of this coincidence of floods on the 2 tributaries is considered to be the reason of the above-mentioned statistical difference.

In fact, point rainfalls observed during this storm on January 13, 1981 at typical stations in the Padas basin are less than respective 2-years probable daily rainfalls as shown below. While the flood at Tenom Lama corresponds to as large return period as 2,000 years if the frequency curve shown in Fig. A 48 is applied. It suggests that the mean daily rainfall of 29.4 mm on January 13, 1981, that approximates the basin rain, has also a high return period though it is small if compared with the point probable rain.

Probability of Storm and Flood in January 1981

Station Name	Station No.	Rainfall on Jan. 13'81	2-years Probable Rainfall (mm)
Kemabong	4959001	-	66
Kg. Sook	5163002	21.0	83
Keningau Met. St.	5361002	-	65
Apin Apin	5462001	42.6	77
Tambunan Agr. St.	5663001	-	62
Batu Bajau	5059001	6.6	56
Sapong Estate	5059002	12.2	72
Nabawan	5164001	38.9	82
Melalap Estate	5260001	52.6	71
Biah Scheme	5261001	7.6	69
Keningau	5361001	29.6	76
Tulid	5364001	32.5	91
Apin Apin	5462003	55.0	80
Sunsuron Agr. St.	5763001	24.4	50
Mean	-	29.4	-

Annual maximum flood records at Kemabong on the Upper Padas River are also presented in Table A 65 for reference. All of the floods at this station are obtained using the extrapolated rating curve that is judged to give overestimate as discussed in Chapter 5.2. Therefore, no frequency analysis is made on these flood records at Kemabong.

Results of the frequency analyses on the annual maximum floods are presented in Table A 66. Flood frequency curve at the respective stations is shown in Figs. A 48 to A 50.

7.3 Frequency Analysis on Annual Maximum Flood Volume

In order to know flood inflow volume of the proposed Sook dam, frequency analyses are also made for 6 flood durations; 1 day, 2 days, 3 days, 7 days, 14 days and 30 days. Maximum flood volume for the respective flood durations is first picked up for every year of records based on the daily runoff records of the Sook River at Biah. These flood volume records are listed in Table A 67. Probable flood volume for each flood duration is computed in accordance with Log-Pearson Type III method. Results are presented in Table A 68. The frequency curve is shown in Fig. A 51.

The recorded maximum flood volume and 100-year probable flood volume are shown below for comparison.

Flood Volume of Sook River

(Unit : 10^6 m^3)

Duration	Recorded Maximum	100-year Probable
1 day	31	44
2 days	59	79
3 days	89	116
7 days	161	232
14 days	250	390
30 days	926	605

The recorded maximum flood volume corresponds to a return period of about 30 years being similar to the one of maximum flood peak flow. The 100-year probable flood volume is about 1.5 times of the recorded maximum.

7.4 Shape of Typical Flood Hydrographs

Typical shapes of the floods recorded at Biah on the Sook River are as shown in Fig. A 52 with their peak at time zero on abscissa and dimensionless ordinate. As shown in the figure, these floods may be classified into the following 4 major types by their shape.

(1) Basic Type

Type I : Single peak
Type II : Plateau peak

(2) Combined Type

Type III : Multi-peak
Type IV : Step-up

The hydrograph type consists of basic type and combined type. The basic type is a single flood having sharp peak (Type I) and relatively flat but long-lasting peak (Type II). A series of several basic type floods forms the combined type flood. The combined type floods may be classified into two. One has multi-peaks each of that has a similar magnitude of peak flow (Type III). The other is characterized by its step-up rising curve (Type IV). Rising period of the step-up type is often as long as 4 to 5 days from the beginning.

These 4 major types are further classified into 1 to 3 sub-types resulting in 8 sub-types in total as follows.

Type I: Single peak

Type Ia: Sharp rising single peak
Type Ib: Gradual rising single peak

Type II: Plateau peak

Type IIa: Plateau peak
Type IIb: Sphinx

Type III: Multi-peak

Type IV: Step-up

Type IVa: Step-up single peak
Type IVb: Step-up plateau peak
Type IVc: Step-up multi-peak

Each sub-type has characteristics as described below.

(1) Basic Type Ia: Sharp rising single peak

This type has the simplest shape consisting of sharp rising curve, single peak and simple recession curve. The rising period is around 10 hours. This type of flood usually recedes in about one and a half day. A peak flow of 184 m^3/s is observed during flood Nos. 73-2 and 75-2.

(2) Basic Type Ib: Gradual rising single peak

This type is similar to Type I except its longer rising period and recession period. It reaches peak in about one day and recedes in about 2.5 days. A peak flow of 115 m^3/s is recorded during flood No. 71-2.

(3) Basic Type IIa: Plateau peak

This type is characterized by its flat peak flows continuing for 1 day to 3 days. An average peak flow of about 130 m^3/s is recorded in flood No. 79-5.

(4) Basic Type IIb: Sphinx

This type is similar to Type IIb but is different therefrom in its sharp peak preceding the plateau type peak. Floods of this type usually have peak flows of 100 to 190 m^3/s.

(5) Combined Type III: Multi-peak

This type consists of 2 or more floods occurring one after another before recession of preceding flood. Interval of peaks is usually 1 or 2 days resulting from such daily shower as often observed in the afternoon to night. A peak flow of 205 m^3/s is recorded in flood No. 75-1.

(6) Combined Type IVa: Step-up single peak

This type is similar to Type Ib in peak and recession period. In the rising period however, runoff is increased day by day and finally reaches its peak. The rising period ever observed is from 1.5 days to 4 days. A peak flow of 280 m^3/s is recorded during flood No. 83-1.

(7) Combined Type IVb: Step-up plateau peak

This type has a step-up rising curve and Type II peak and recession curve. A rising period of about 5 days is observed in flood No. 75-2. The 3rd largest flood of the Sook River (320 m^3/s) occurred on January 26, 1984 is of this type. It continued for about 12 days.

(8) Combined Type IVc: Step-up multi-peak

This type has a step-up rising curve and Type III multi-peak. The recorded maximum flood in January 1981 (410 m^3/s) is of this type. By the step-up rising curve, the river flow increased up to about 200 m^3/s when the largest peak started. This flood continued for about 9 days.

7.5 Hydrograph of Probable Floods

Hydrographs of 10-years, 50-years and 100-years probable flood are derived by enlarging or reducing the one of the recorded maximum flood in January 1981 by a ratio of the respective probable flows to 410 m^3/s. As described in Chapter 7.4, this flood is of step-up multi-peak type and is, therefore, considered to be most probable for such high peak flows and to be severest in view of flood regulation. The hydrographs thus obtained are shown in Fig. A 53, and listed in Tables A 70 to A 72.

7.6 Dimensionless Graph

In order to establish unitgraph of the Sook River, dimensionless graphs are first derived for the following 5 floods in accordance with the procedure recommended by USBR (Ref.13) , in which Tcv is the time from the beginning of an unitgraph to the centre of its volume.

<u>Flood for Hydrograph Analysis</u>

Flood No.	Peak Flow (m^3/s)	Tcv (hr)
70-3	80	11.2
74-4	225	12.8
81-1	410	13.2
82-2	105	19.8
83-4	340	11.7

Since the hydrograph of the flood in January 1981 is most clear in its shape and largest in its peak flow, the dimensionless graph of the Sook River is obtained as the one derived from this flood in 1981 instead of taking average of the 5 floods. The dimensionless graph is shown in Fig. A 54 , in which q denotes discharge in m^3/s, D duration hours of unit rainfall and Lg the lag time between the center of unit rainfall and the time at which the peak discharge takes place.

8. DERIVATION OF PROBABLE MAXIMUM FLOOD

Probable maximum precipitation (PMP) is defined as the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage basin at a particular time of year (Ref.17).

PMP for all durations and sizes of area in a specific basin is usually determined by several types of storms. For example, thunderstorms are very likely to provide PMP over an area smaller than about 1,000 km^2 for durations shorter than 6 hours, but controlling values for longer durations and larger areas will be derived almost invariably from general storms. For short durations, thunderstorms can produce heavier rainfall than can general storms, but they are relatively short-lived, and individual storms cover relatively small areas. General storms, although they often include thunderstorms, produce less intense rainfall on the average, but their longer life and greater areal coverage result in greater rainfall amounts for durations of about 6 hours and longer, and for large areas (Ref.17).

In fact, this longer life and greater areal coverage of storm in January 1981 resulted in the unprecedented flood of the Padas River at Tenom Lama that corresponds to a return period of about 2,000 years if the frequency curve shown in Fig. A 48 is applied for reference. In the Padas basin, occurrence probability of these general storm is low but not nil. Therefore safety of the proposed Sook dam against flood should be checked not only for probable floods but for probable maximum flood (PMF) that would occur under PMP.

Rainfall in the Padas basin is of non-orographic type and, therefore, PMP can be derived in accordance with the procedure using convergence model (Ref.17).

Depth - duration - area relation of storms observed in the Padas basin is discussed in Chapter 4. For maximizing the storm records to obtain PMP, storm maximization factor is first determined in Chpater 8.1. Unitgraph is then derived in Chapter 8.3 based on the dimensionless graph to convert PMP to PMF. After determining base flow, initial rainfall loss and retention loss rate, PMP over the Sook basin is finally converted into the PMF for the proposed Sook dam.

8.1 Storm Maximization Factor

There are the following general procedure for maximizing individual storms to derive PMP.

(1) Moisture maximization
(2) Wind maximization for orographic storm
(3) Transposition adjustments of individual storm that is observed in the other basin and transposed to the project area
(4) Sequential and spatial maximization
(5) Envelopment of depth-area-duration relation of individual maximized storm

Moisture maximization factor is determined for the 4 storms as discussed hereinafter. Wind maximization is not made since the storm in the Padas/Sook basin is of non-orographic type. Transposition adjustments are also not specifically made since the storm records used are observed in and around the Project area and the data are not enough for preparing storm isohyet. In order to take into account this transposition adjustment for relocation within the Sook basin as well as uncertainty of data used in derivation of PMP, an overall adjustment is made to the recorded maximum depth-duration.

Heavier rainfalls are observed in the northwestern slope of the Crocker Range. These rainfalls are intensified by orographic effect of the Crocker Range and, therefore, are not meteorologically possible in the Sook basin. Accordingly they are not transposed to the Sook basin.

Sequential and spatial maximization is also not made due to limited data available, but taken into account in the overall adjustment.

Envelopment is made for the recorded depth - area - duration relation as discussed in Chapters 4.5 and 4.6. Depth-duration curve for durations shorter than 24 hours are fitted to mean pattern as shown in Fig. A 13.

Moisture maximization factor (MMF) is estimated referring to the dew point records as discussed below.

(1) Storm Dew Point

Storm dew points are estimated for the following 4 typical rainstorms.

(a) Storm in September 1973
(b) Storm in November 1973
(c) Storm in January 1981
(d) Storm in January 1984

The storm in January 1981 caused the recorded maximum flood of the Padas River System.

Storm dew points are estimated based on the dry-bulb temperature and relative humidity records using the same formula with the one presented in Chapter 3.2.

Dew point at station level is then reduced to sea level (1,000 mb) dew point with a moist adiabatic lapse rate of 0.40°C / 100 m in elevation (Ref.17).

Each storm dew point is computed as a mean of the ones at Keningau and 3 coastal stations to represent one of the air mass inflow from the South-China Sea as shown in Table 8. The storm dew points varies from 23.0°C to 24.4°C at sea level.

(2) Maximum Dew Point

Maximum dew point probable in the Sook basin is estimated based on the records at Keningau Meteorological Station. Since temperature is read once a day at 08:00 SST, the momentary dew point at 08:00 SST is used in place of persisting 12-hour dew point. The momentary dew point at 08:00 SST is considered not to give overestimate as it is the one in the morning and, therefore, near to the lowest in a day or to the persisting 24-hour dew point.

The maximum dew points at Keningau are collected for every month based on the 14 years records from 1972 to 1985 as presented in Table A 7. These dew points are plotted in Fig. A 56 to draw an envelope curve. The maximum persisting dew point expected at Keningau is 24.4°C equivalent to the sea level dew point of 25.6°C. The sea level dew point in the month of January is about 25.0°C being lower than this value by 0.6°C.

Offshore surface water temperature of the South-China Sea near Sabah is usually above 28°C and drops to 26 to 27°C in the month of January (Ref.8). The maximum sea level dew point estimated for the Sook basin is lower than this sea water temperature by 1 to 3°C. Since the Sook basin is located on the inland plain being apart from the coast by about 80 km and sheltered from the sea by the topographic barrier of Crocker Range having elevation of 1,000 m to 2,000 m, it is judged that this drop of dew point from sea-surface water temperature is minimal.

In the coastal regions of the Gulf of Mexico, maximum persisting 12-hour 1,000 mb dew point ranges from about 1°C to 2°C below upwind-offshore mean monthly sea-surface temperatures (Ref.17). It is then judged that the above estimate of maximum persisting 12-hour 1,000 mb dew point in the Sook basin of 25.6°C is reasonable in relation to the mean offshore sea-surface water temperature.

(3) Moisture Maximization Factor (MMF)

Based on the storm dew point and the maximum dew point expected in the Sook basin, moisture maximization factor (MMF) is determined for the 4 storms using the following formula.

$$MMF = {}_hW_{t_2} / {}_hW_{t_1}$$

where, ${}_hW_{t_2}$ = precipitable water in a saturated pseudo-adiabatic atmosphere from the ground base of moisture column (h) to the height of 300 mb, corresponding to the maximum persisting 12-hour 1,000 mb dew point (wet-bulb potential temperature, t_2)

${}_hW_{t1}$ = precipitable water in a saturated pseudo-adiabatic atmosphere from the ground (h) to the height of 300 mb, corresponding to the storm 1,000 mb dew point (t_1)

The maximum persisting 12-hour ground level dew point t_2 for each storm is read in Fig. A 56 as a maximum around occurrence date of respective storms within 15 days. This dew point is reduced to 1,000mb one by adding 1.2°C (= 0.4°C/100m x 290m). Base elevation of the moisture column is determined at 1,500m as the mean elevation of the mountain barrier between the moisture source in the South China Sea and the Sook basin.

The moisture maximization factor is then obtained as follows.

(a) Storm in September 1973

- Date of peak: September 26
- Storm dew point: $t_1 = 23.7^oC$
- Maximum dew point: $t_2 = 25.3^oC$

- MMF = (82.1 - 30.0)/(71.2 - 26.9)
  = 1.17

(b) Storm in November 1973

- Date of peak: November 3
- Storm dew point: $t_1 = 24.4^oC$
- Maximum dew point: $t_2 = 25.3^oC$

- MMF = (82.1 - 30.0)/(75.8 - 28.3)
  = 1.10

(c) Storm in January 1981

- Date of peak: January 14
- Storm dew point: $t_1 = 23.0^oC$
- Maximum dew point: $t_2 = 25.2^oC$

- MMF = (81.4 - 27.9)/(67.0 - 25.5)
  = 1.29

(d) Storm in January 1984

- Date of peak: January 26
- Storm dew point: $t_1 = 23.3^oC$
- Maximum dew point: $t_2 = 25.3^oC$

- MMF = (82.1 - 30.0)/(69.8 - 26.1)
  = 1.19

The moisture maximization factors thus obtained are in the range from 1.10 to 1.29.

(4) Overall Maximization factor

An overall maximization factor is used to maximize an envelopment of the recorded maximum depth - duration to be conservative, instead of maximizing individual storm by respective maximization factors, due to the limited storm data available. Based on the moisture maximization factor of the 4 storms (1.10 to 1.29), the overall maximization factor is determined to be 1.3 taking into consideration the uncertainty of the data used in derivation of the PMP.

8.2 Probable Maximum Precipitation

The PMP for the Sook basin is then derived in accordance with the procedure as summarized below.

(1) Make an envelopment curve of point depth - duration records of the stations in and around the Sook basin (see Fig. A 12).

(2) Maximize this envelopment with the overall maximization factor of 1.3.

(3) Make areal adjustment to this maximized point depth - duration with the area reduction factor for respective duration (see Fig. A 25).

The PMP over the Sook basin thus obtained is presented in Table A 73, and summarized below.

PMP over Sook Basin

Duration (hr)	Maximized Point Depth (mm)	Sook PMP (mm)
1	100	35
6	177	65
24	211	91
48	329	164
168 (7 days)	564	411

As shown in the above table, mean depth of the PMP over the Sook basin is determined to be 35 mm for duration of 1 hour, and 91 mm for 24 hours. Point depth of the PMP is 100 mm for duration of 1 hour, and 211 mm for 24 hours. This 24-hours point depth is 1.53 times of the maximum 100-year probable point daily rainfall at Kg. Sook that is derived in Chapter 4.4 and shown in Table A 46.

8.3 Unitgraph

A unitgraph is developed for unit rain of 1 mm over the Sook basin and for unit duration of 1 hour based on the dimensionless graph and lag time T_{cv}. Time T_{cv} is defined as a time from the beginning of rise of net hydrograph to center of its volume. T_{cv} is substituted for lag time (Lg+D/2) as the available rainfall data are limited.

Since most of the Sook basin will be connected to the upstream end of the reservoir except Sg. Biah and Sg. Puntih sub-basins; the basin is treated as single basin except the reservoir surface.

Time Tcv of the Sook River is checked for the 7 floods recorded at Biah as summarized below.

<u>Time Tcv of Sook River at Biah</u>

Flood No. /1	Qpeak (m^3/s)	Tcv (hr)
70-2	53	13.4
70-3	82	11.2
74-1	121	14.0
74-4	222	12.8
81-1	410	13.2
82-2	104	19.8
83-4	318	11.7

/1: Refer to Table A64.

Time Tcv of the 6 floods excluding a flood No. 82-2 is in the range from 11.2 hr to 14.0 hr. Their mean is 12.7 hr being similar to the one of the recorded maximum flood No.81-1 in January 1981 (13.2 hr). Thus the Tcv of the Sook River at Biah is estimated to be 13 hr in the present natural condition without the Sook dam.

After construction of the Sook dam, the above time Tcv of the Sook River will be shortened by the reservoir effect extending for about 18.5 km along the natural river course upstream from the damsite. Out of this river length, the downstream portion of 7.5 km is submerged in the wide reservoir while the remaining 11.0 km in the upstream reach is in the relatively narrow valley being similar to the present natural condition.

River flow velocity during the recorded maximum flood in January 1981 is estimated to be around 2.5 m/s from the extrapolated rating curve and area-velocity curves. Time required for the flow having velocity of 2.5 m/s to rush down this downstream wide portion of the reservoir is about 0.8 hr. Then the time Tcv for the case with Sook reservoir is determined to be 12 hr assuming that the lag time to be shortened by the reservoir is 1 hr.

The unitgraphs thus derived for natural condition and with-Sook-dam condition are presented in Tables A 74 and A 75, and depicted in Fig. A 55. Base length of the unitgraph is about 3 days (74 hours).

8.4 Rainfall Loss

Initial rainfall loss is neglected assuming that the whole Sook basin is saturated by antecedent rainfall in such an extreme storm like the PMP. While the retention loss rate after the saturation is assumed to be constant at 1.5 mm/hr

Since there is no data on the retention loss rate of rainfall in Sabah, the above estimate of retention loss is compared to see its adequacy with ones adopted for dam design in Sarawak, Peninsular Malaysia, Philippines and Taiwan as shown below.

Retention Loss Rate of Rainfall

Project	Location	Drainage Area	Retention Loss Rate
Batang Ai	Sarawak		3.0
Bakun	Sarawak	14, 750	4.0
Klang Gates	P. Malaysia	74	5.1
Jor dam	P. Malaysia	123	7.1
Temengor dam	P. Malaysia	3, 400	2.5
Pergau dam	P. Malaysia	1, 290	2.5
Kenyir dam	P. Malaysia	4, 580	2.5
Angat dam	Philippines	568	1.5
Tsengwen dam	Taiwan	481	5.0

Source: Ref.4 for the first 7 projects.

As shown in the above table, the assumed value of 1.5 mm/hr for the Sook dam is smallest.

Total retention loss during the 7 days PMP amounts to 237 mm with the assumed loss rate of 1.5 mm/hr. Effective rainfall will be 174 mm. Therefore runoff coefficient of direct flood flow will be 0.42 that is higher than long-term mean runoff coefficient of the Sook River of 0.29. This higher runoff coefficient during extreme flood is possible and reasonable.

While a higher retention loss rate of 2.0 mm/hr would result in a runoff coefficient of 0.18 that is lower than the said long-term one. It is then judged that this retention loss rate of 1.5 mm/hr is reasonable in view of its runoff coefficient and is, therefore, acceptable in derivation of the PMF for the Sook basin.

8.5 Base Flow

Base flow of the floods recorded at Biah on the Sook River is as shown below.

Base Flow of Recorded Floods

Flood No.	Qpeak (m^3/s)	Base Flow (m^3/s)
74-4	225	40
81-1	410	200
82-2	105	30
83-4	340	130

Based on the above data, the base flow for estimating PMF is assumed to be 300 m^3/s as 1.5 times of the one of the flood No.81-1 that is the recorded maximum flood.

8.6 Probable Maximum Flood of Proposed Sook Dam

The PMP for 7 days' duration is rearranged to hourly rainfalls with its peak at one fourth from the end of the duration maintaining the depth - duration relation. The results are presented in Table A 73.

This hourly hyetograph of the PMP for the Sook basin is converted to PMF using the unitgraph. The PMF is as shown in Fig. A 57. Peak flow of the PMF is 1,940 m^3/s and its 5 days volume is 560 x 10^6 m^3. Its specific flow is 1.12 m^3/s. The PMF is as large as 3.7 times of the 100-year probable flood of 526 m^3/s. If the flood frequency curve is simply extrapolated up to this peak flow for reference, the PMF would correspond to a return period of longer than 10,000 years.

The magnitude of PMF is also evaluated referring to the following Creager's equation for world envelope (Ref.15).

$$q = 46 \times C \times A^b$$

$$b = 0.894 \times A^{-0.048} - 1$$

where, q = specific discharge in $ft^3/s/mile^2$

A = drainage area in $mile^2$

C = a coefficient depending upon the characteristic of the basin

The enveloping curve for C = 100 gives the general trend of all the world maximum flood records with a few exception (Ref.15).

The PMF for the Sook dam corresponds to C = 21. According to a study report (Ref.16), the maximum flood recorded in a region including Malaysia, Indonesia and Thailand corresponds to C = 34 being higher than the one of the Sook PMF. Since the Sook basin is located in an inland plain sheltered from the South-China Sea by Crocker Range and has a gentle hilly topography, it is judged normal that the Sook PMF corresponds to the Creager's C lower than the regional envelope of recorded maximum floods.

Thus the PMF for the proposed Sook dam is determined to have the peak flow of $1,940m^3/S$ as shown in Fig. A 57.

9. SEDIMENT STUDY

Sediments, that are transported into reservoir by flood water and deposited therein through the long-term operation, sometimes drastically reduces effective capacity of the reservoir resulting in short life of the dam. It has been feared that the case may happen on the proposed Sook dam since the water of the Sook River always presents muddy colour even at very low water stage. The colour of the Sook River is apparently different from clear one of the Pegalan River as easily observed at their confluence near Kg. Ansip.

The present study on the reservoir sedimentation, however, revealed that the mean specific sediment transport of the Sook River during the past 17 years from 1968 to 1984 is as low as 84 m^3/km^2/year, being smaller than one of the Pegalan River of 266 m^3/km^2/year. Similar conclusion is derived and presented in a study report prepared by Sabah Campus of University of Malaysia in 1984 (Ref.14).

9.1 Available Sediment Data

DID is carrying out suspended sediment sampling at the 4 stream gauging stations on the Padas River System since 1970. At each station, the sediment sampling has been made for about 40 times by 1982. From the sample, suspended sediment concentration is measured to establish sediment rating curve for each station. These sediment rating curves are shown in Figs. A 58 to A 61. As shown in the figures, each sediment rating curve is well defined for the following flow ranges.

Range of Suspended Sediment Rating Curve

(Unit : m^3/s)

Station Name	River	Recorded Max. Q	Range Defined From	To
Biah	Sook	410	1	80
Ansip	Pegalan	750	10	70
Kemabong	Upper Padas	2, 230 /1	15	300
Tenom Lama	Padas	2, 100	50	500

/1 Second largest

As described in Chapter 2.7, 10 times of sediment samplings have been made at Biah on the Sook River as a part of the field survey. Based on the results, total solid transport and discharge are calculated as presented in Table A 76. Also shown in the table are the suspended solid and total solid transports measured by DID from 1978 to 1982. Mean total solid transport of the 13 times measurements by DID is 134 ton/day which is 2.5 times of the mean suspended solid transport of 53 ton/day. Their balance is the dissolved solid transport.

The total solid transports are shown in Fig. A 62 together with the suspended sediment transports and its rating curve. As shown in the figure, the total solid transports have a similar gradient to the suspended sediment rating curve. Suspended sediment concentration will be measured for about 20 times by the contractor by mid 1986.

9.2 Sediment Rating Curve

Sediment rating curve is generally approximated by a straight line on a full-log-paper as shown in Figs. A 58 to A 61. These lines can be expressed by the following equation.

$Q_s = a \times Q^b$

where, Q_s = suspended sediment transport in ton/day

Q = runoff in m^3/s

a, b = parameter depending on the basin characteristics

The above equation can be transformed as follows.

$\log(Q_s) = \log(a) + b \times \log(Q)$

As shown in the above equation, the parameter "b" is the gradient of the rating curve on a full-log-paper. While the parameter "a" shows a sediment transport at runoff of 1 m^3/s.

The parameter "b" usually varies from 2.3 to 3.0 in accordance with the basin conditions. In Nepal where high land erosion is observed, it is as high as about 2.8 to 3.0. In Japan, Taiwan, Java, etc. it is about 2.5 to 2.7 in general.

The parameters "a" and "b" of the sediment rating curves of the 4 stream gauging stations on the Padas River System are obtained as shown below.

Sediment Rating Curves of Padas River System

Station Name	River	Mean Runoff (m^3/s)	Parameters "a"	Parameters "b"
Biah	Sook	29	0.40	1.84
Ansip	Pegalan	50	0.010	2.73
Kemabong	Upper Padas	119	0.16	1.77
Tenom Lama	Padas	210	0.0014	2.80

As shown in the above table, the parameter "b" of the Padas River at Tenom Lama and Pegalan River at Ansip is as high as about

2.8 being equivalent to the lower value in Nepal. On the contrary, ones of the Sook River at Biah and the Upper Padas River at Kemabong is very low at about 1.8. These distinct difference in values of the parameter "b" suggests that land erosion rate differs much from sub-basin to sub-basin within the Padas basin as described below.

(1) The Sook basin and Upper Padas basin have been less denuded.

(2) Since most of the virgin forest in the Sook basin has been cleared by the past logging operation, this low erosion rate of the Sook basin is considered not to have been maintained only by the forest but mainly by its gentle topography.

(3) While in the case of the Upper Padas basin, the low erosion rate in spite of its steep topography is considered to have been maintained by its thick forest. Logging operation in the Upper Padas basin is started recently. Its effect on the land erosion is, therefore, not included in the above rating curve.

(4) The Upper Pegalan basin has much higher erosion rate than the Sook and Upper Padas basins. There are the following several conceivable reasons of this high erosion rate.

    (a) Erosion of river bank on its downstream reaches meandering on the alluvial plain (Ref. 14).

    (b) Steep topography in its upstream area

    (c) Deforestation in the relatively low elevation areas by the past logging operation

    (d) Construction of Kota Kinabalu - Keningau road

(5) It is estimated from the above values of the parameter "b" that the residual sub-basins downstream from Ansip on the Pegalan River and downstream from Kemabong on the Upper Padas River have also high erosion rate. Topography of these sub-basins is

relatively gentle. It is, therefore, considered that this high erosion rate is due to erosion of river banks meandering on the alluvial plain as pointed out in a study report (Ref.14).

9.3 Sediment Inflow into Sook Reservoir

Suspended sediment transport of the Sook River is computed based on the 17 years' daily runoff records at Biah from 1968 to 1984 using the sediment rating curve shown in Fig. A 61. Its monthly summary is listed in Table A 80 hereof.

Mean daily suspended sediment transport of the Sook River is then obtained to be 352 ton/day. The suspended sediment transport on the recorded maximum flood day on January 14, 1981 is computed to be 20,700 ton which is 64 times of the long-term daily mean. One week transport during this flood is 86,200 ton equivalent to about 9 months' mean transport volume. These concentration to flood periods is a common feature of sediment transport.

The sediment inflow into the proposed Sook reservoir is estimated as described below.

(1) Mean suspended sediment transport of the Sook River at Biah :

352 ton/day

(2) Adjusted for runoff fluctuation within a day (assumed to be 1.2 times of the value obtained by daily mean basis) :

422 ton/day

(3) Adjusted for such probable larger floods expected during the 100 years operation than the ones occurred in the 17 years runoff records used (assumed to be 2 times of (2)) :

844 ton/day

(4) Specific weight of sediments after deposited in the reservoir :

1.3 ton/m^3

(5) Specific annual suspended sediment volume :
(3) x 365 days / (4) / 1,683 km^2 :

$141 \text{ m}^3/\text{km}^2/\text{year}$

(6) Mean specific bed load (assumed to be 20 per cent of (5)) :

$28 \text{ m}^3/\text{km}^2/\text{year}$

(7) Mean specific sediment inflow ((5) + (6)) :

$169 \text{ m}^3/\text{km}^2/\text{year}$

Thus the mean sediment inflow volume is estimated to be 169 m^3/km^2/year. It corresponds to an annual denuded depth of the land of 0.17 mm. Mean sediment volume during the 17 years from 1968 to 1984 is obtained to be 84 m^3/km^2/year excluding the above adjustment (3) for future extreme floods.

Assuming that a trap efficiency of sediment inflow by the Sook reservoir is 100 per cent, the mean annual reservoir sedimentation is computed to be $0.28 \times 10^6 \text{ m}^3$. After the 100 years operation of the Sook reservoir, the total sediment deposit volume would be around $28 \times 10^6 \text{ m}^3$. This total sediment volume corresponds to 310 times of the one week sediment transport of 86,200m^3 estimated for the recorded maximum.

Because of uncertainty of the data and assumption used in estimation of sediment inflow, the above estimate is derived so as to be in conservative side. Actual reservoir sedimentation in a normal flow year will be much less than the above estimate. Most of the above 100-years' sediment volume would be transported during extreme floods like the one in January 1981 or larger ones.

In order to compare the sediment transport of the Sook River with ones of the other sub-basins in the Padas basin, the sediment transports of the Pegalan River at Ansip, the Upper Padas River at Kemabong and the Padas River at Tenom Lama are also computed in accordance with the same procedure. Their monthly summary is presented in Tables A 77 to A 80.

9.4 Evaluation of Estimated Sediment Inflow Volume

Main reason of this low sediment transport of the Sook River (84 m^3/km^2/year for the past 17 years) contrary to its invariable muddy colour may be understood as follows.

(1) Sediment rating curve of the Sook River has the following characteristics.

   (a) Sediment transport at low water stage is higher than that of the Pegalan River. It coincides with a fact that the water of the Sook River is muddy even at low water stage while that of the Pegalan River is clean.

   (b) On the other hand, sediment transport of the Sook River at high flow stage is lower than that of the Pegalan River. It also coincides with another fact that the water of the Pegalan is very muddy when it is flooding but resumes its clean color after flooding.

(2) Most of the annual sediment volume is transported by high flood flow because of such sediment transport characteristic as the higher flow yields higher sediment concentration in unit volume of flowing water resulting in much higher sediment transport.

(3) While the flood of the Sook River is generally lower than that of the Pegalan River. For instance, specific flow of the recorded maximum flood of the Sook River is 0.24 $m^3/s/km^2$ being 0.71 times of 0.34 $m^3/s/km^2$ of the Pegalan. Therefore, it is reasonable that the mean suspended sediment transport of the Sook River of $84m^3/km^2/yr$ is as small as 32 percent of $266m^3/Km^2/year$ of the Pegalan River while the Sook River has always muddy water colour.

It is thus concluded that the sediment transport of the Sook River is relatively low in spite of its visual appearance. The same conclusion has been derived by a study report in 1984 (Ref.14).

The mean daily suspended sediment transports of the Padas River System are summarized below.

Balance of Suspended Sediment Transport on the Padas River System

Station Name	River	Drainage Area		Mean SS Transport /1
		(km^2)	(%)	(ton/day)
Biah	Sook	1,683	21.8	352
Ansip	Pegalan	2,175	28.2	1, 433
Kemabong	Upper Padas	3,184	41.3	1, 241
Residual Basin	Padas	673	8.7	- /2
Total at Tenom Lama		7,715	100.0	9, 426

/1: Mean for the past record period from Jan 1968 to Dec 1984

/2: No record of suspended sediment is available.

10. COMMENTS AND RECOMMENDATIONS

Through the field survey for the present feasibility study, it is revealed that the hydrological observation and measurement in the Padas basin such as rainfall, river water level, runoff measurement and suspended sediment sampling are being well carried out by hand of DID. Some manual raingauges are operated by the other agencies. All the data collected are gathered to DID in Inanam, Kota Kinabalu and compiled there and/or by Federal DID in Kuala Lumpur. These hydrological measurement system is well maintained to obtain useful data for water resources development projects as a whole. It is, however, necessary for the agencies concerned to make an effort so as to reduce number and duration of data gap in rainfall and water level records.

It is to be noted that these observation system of DID aims to cover whole the country for providing basic data necessary for planning of water resources development projects. Once certain project is identified, some reinforcement of the system in the relevant project area will usually be required for the detailed basin study.

In the preliminary investigation stage, it is proposed to install 2 automatic and 3 manual raingauges in the Sook basin as described in Chapter 2.2. These raingauges are installed by SEB and DID.

Through the detailed survey and the succeeding hydrometeorological study for the Project, some more reinforcement of the system in the Padas basin is recommended as described hereinafter.

10.1 Gap in Rainfall and Water Level Data

There are frequent gaps in daily rainfall and water level records of the stations in the Padas basin. Main reason of these gaps are:

(1) Mechanical trouble of automatic rainfall and water level recorders

(2) Lack of reading of manual raingauge

To cope with these troubles, the following countermeasures are conceivable.

(1) Rainfall Recorder

For the machine trouble of automatic raingauges for 3 months operation, the data gaps may be reducible by using an ordinary drum-type recorder for one week operation. Since there is a gauge keeper at each rainfall gauging station site, the recording chart could be weekly replaced by the gauge keeper. At each replacement, the machine condition is easily seen and, therefore, duration of data gap could be limited to one week at the maximum. Replacement of chart on drum type recorder for one week operation needs no special experience but several times of practice may be enough. Furthermore, handling of chart for filing, data check, etc. is also easier than roll chart for long-term operation. It is, therefore, considered to be preferable to adopt this ordinary drum-type recorder for one week operation at such rainfall stations where a gauge keeper is available and frequent machine troubles occurred.

(2) Water Level Gauge

Water level gauge currently installed at the stream gauging stations is of manometer-servo type. Water level recorder is for 3 months operation using a roll chart. In spite of periodical inspection of the gauge and recorder by the experienced staff of DID, however, there are frequent data gap resulting from their machine trouble probably of water level gauge.

In the Padas basin stream gauging stations are located at remote areas from town unlike most of the rainfall stations and, therefore, recorder for long-term operation is required. One week recorder may not be applicable unlike the rain recorders.

While there are several types of water level gauge in addition to the manometer-servo type as follows.

(a) Ordinary float type
(b) Ordinary pressure type
(c) Quartz pressure sensor type
(d) Transistor pressure sensor type
(e) Supersonic type
(f) Sensing pole type

Ordinary float type is most widely used and reliable, but it needs considerable amount of civil works to construct a stilling well rigid enough against flood current. Accuracy of ordinary pressure gauge is low. All the pressure type gauges such as ordinary, quartz, transistor, manometer-servo, etc. are affected by specific density of flowing water, that is, give higher water level than the actual one when flooding with high suspended sediment concentration. Ordinary float type, supersonic type and sensing pole type directly measures water level. Supersonic type usually needs commercial power supply. Sensing pole type needs specialist for its inspection and maintenance.

As briefly explained in the above, each type has advantage and disadvantage. It is, therefore, selected depending upon the site condition, operation and maintenance, construction cost, required accuracy, etc.

It is advisable to check the reason of the frequent machine trouble. If it is of water level gauge, a review of water level gauge type may be required for improving water level recording.

(3) Manual Raingauge

Since a gauge keeper is available at each manual raingauge site, lack of daily reading might be solved by installation of the above-mentioned rainfall recorder for one week operation.

10.2 Rainfall Gauging System in Project Area

Regarding the Sook basin, the following reinforcements of the rainfall observation system are recommended.

(1) Sook Basin

(a) To install one set of automatic raingauge at the proposed Sook damsite upon completion of its construction works. This rain gauge will provide basic data for operation of the proposed Sook reservoir.

(b) To re-install or replace the manual rain gauge at Nabawan with new one, since the present one appears not satisfactory.

(2) Upper Padas Basin

Presently, there is only one rainfall gauging station in the Upper Padas River basin at Kemabong located at its downstream end. A manual raingauge was operated at Kg. Ulu Tomani located at about 24 km by air upstream from Kemabong since 1964 but closed in March 1981.

The Upper Padas basin upstream from Kemabong shares 41 per cent of the total drainage area of the Padas basin at Tenom Lama. Runoff from this Upper Padas basin shares 56 per cent of the total inflow to the existing Tenom Pangi diversion weir. The Upper Padas basin much contributes hydropower generation at the Tenom Pangi power station.

It is recommended to resume rainfall observation at Kg. Ulu Tomani station in order to have rainfall records in the Upper Padas basin.

A motor road is available only to Tomani in the Upper Padas basin, which is located at about 9 km upstream from Kemabong. It is, however, recommended to make reconnaissance survey in the Upper Padas basin to find whether there is any suitable site for additional raingauges from such practical points of view as accessibility to the site and availability of gauge keeper for operation and maintenance.

10.3 Water Level Gauging at Proposed Sook Damsite

Sites for the proposed Sook dam and power station are determined through the layout study near the upstream dam axis between the 2 alternatives studied. The temporary staff gauge established during the field survey is located at the downstream alternative dam axis. Between the 2 alternative dam axes are rapids creating discontinuity in water level.

In order to know the tailwater level of the power station and spillway as well as of the river outlet at this site, it is required to establish a flow rating curve. Since the river flow at this site is easily known by referring to the runoff at Biah stream gauging station located at about 1.5 km upstream, it is enough to observe only water level at the site for various stages.

It is then recommended to install staff gauges and crest-stage gauges or equivalents at the site of the tailrace channel of the proposed Sook power station. Gauge reading on the staff gauge needs to be made at least on every such a day as there is certain rain on the preceding day. Crest-stage gauges are to be checked after every heavy rain.

Date and time of gauge height reading on the staff gauges and check and reset of crest-stage gauges shall be recorded together with gauge height records. Flow at each gauge height reading and each crest-stage will be obtained from recording charts of Biah. By plotting the gauge height and flow thus obtained, a flow rating curve at the power station site will be obtained.

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Table A1 RAINFALL GAUGING STATIONS IN PADAS BASIN

Station No.	Station Index/1	Station Name	Location Lat.(N)	Long.(E)	Alt.(m)	Date of Establishment Manual G.	Automatic G.	Current Equipment/2	Operating Agency/3	Source of Data/4	Remarks
4358001		Ulu Tomani	4°43'	115°53'	396	07/64				DB-1970	Closed 03/81
4959001	SPA	Kemabong	4°54'50"	115°55'20"	183	01/66	01/66	M5, HL	DID	DB-1983	
5059001	SSM	Batu Bajau	5°02'00"	115°57'00"	210	01/71		M5	DOA	DB-1983	
5059002	SSM	Sapong Estate	5°02'00"	115°56'00"	183	01/24		M5	DOA	DB-1983	
5159001		Tenom	5°07'	115°56'	195	01/21				DB-1970	Closed
5159001	SSM	Tenom Cocoa Research St.	5°07'	115°56'	195	01/65		M5	DOA	DB-1983	The same location as Tenom was.
5163001		Sook	5°08'40"	116°18'10"	244		01/65			DB-1970	
5163002	SPA	Sook	5°09'00"	116°18'20"	350	05/77	05/77	M5, HL	DID	DB-1983	
5164001		Nabawan			579	01/70		M5	DOA		
5260001	SSM	Melalap Estate	5°15'00"	116°00'00"	183	01/52		M5	DOA	DB-1983	
5261001	SSM	Biah Scheme	5°15'00"	116°08'00"	259	06/71		M5	DOA	DB-1983	Closed
5361001	SSM	Keningau	5°21'00"	116°10'00"	305	01/18		M5	DOA	DB-1983	
5361002	SPAEWC	Keningau Met. St.	5°21'45"	116°09'40"	290	05/65	05/65	M5, KW	DID	DB-1983	Mentioned as #5361201 in-DB1980
5364001	SSM	Tulid	5°20'00"	116°26'00"	366	01/53		M5	DOA	DB-1983	
5462001	SSA	Apin Apin	5°28'35"	116°16'00"	350	01/67	01/67	M5, HL	DID	DB-1983	
5462003	SSM	Apin Apin	5°28'00"	116°17'00"	457	01/61		M5	DOA	DB-1983	
5663001	SPA	Tambunan Agr. St.	5°37'15"	116°19'35"	680	08/65	08/65	M5, HL	DID	DB-1983	
		Tambunan	5°39'	116°21'	572	01/18				DB-1970	
5763001		Sunsuron Agr. St.	5°44'00"	116°23'00"	549	01/65		M5	DOA	DB-1983	Closed 01/01/85.
		Pangi Damsite				81					
		Mini Secretiat Tenom				83					

/1: SPA = Sabah principal automatic gauge, SSM = Sabah secondary manual gauge, SPAWEC = SPA + evaporation, wind & climatic observation, SSA = Sabah secondary automatic gauge

/2: M5 = Daily reading 5 inch manual rain gauge, HL = Automatic rain gauge Hattori NKA-110, KW = Weekly automatic rain gauge Kent

/3: DID = Department of Irrigation and Drainage (JPT), DOA = Department of Agriculture (JP)

/4: DB-1970 = Hydrologic Records of Sabah to 1968, DID, January 1970

DB-1980 = Hydrological Records for Sabah, 1969-1975, Ministry of Agriculture and Fisheries, Sabah, 1980

DB-1983 = Hydrological Data, Rainfall Records, 1975-1980, Drainage and Irrigation Division, Ministry of Agriculture Malaysia, 1983

Table A2 STREAM GAUGING STATIONS ON PADAS RIVER SYSTEM

River	Station Name	Station No.	Location			Drainage Area (km^2)	Date of Establishment	Gauge Zero (m ABM /2)	Remarks
			Lat.(N)	Longi.(E)	Alt.(m)/1				
Padas	Kemabong	4959401	4°55'00"	115°55'15"	183*	3,184 (1,230)/3	Jan. 29, 1968	18.172	
Padas	Tenom Lama	5159401	5°07'00"	115°55'50"	168*	7,715 (2,980)	Oct. 31, 1968	20.150	Closed in early 1985
Pegalan	Ansip (formerly called Keningau)	5261401	5°17'00"	116°06'40"	229*	2,175 (840)	Nov. 16, 1968	16.285	
Sook	Biah	5261402	5°15'30"	116°08'20"	259*	1,683 (600)	Jan. 27, 1968	24.917	
Water Level Stations (Only water level observation)									
Padas	Gadong		5°21'30"	115°36'40"	5*		Jan. 1963	26.944	
Padas	Tenom Lama		5°06'50"	115°56'00"	183*		Jan. 1963	25.012	
Pegalan	Keningau		5°18'50"	116°09'20"	265*		Jan. 1960	26.274	
Sook	Sook		5°08'30"	116°18'10"	351*		Jan. 1959	25.810	

Source of data: Hydrologic Records of Sabah to 1968, DID, January 1970.

Note: /1; Approximate value

/2; Above BM that has an assumed height

/3; in $mile^2$.

Table A3 MEAN TEMPERATURE AT KENINGAU

(Unit: °C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	16.0	16.0	16.7	17.1	17.1	17.9	15.3	15.2	15.5	-	18.9	15.4	16.5*
1977	15.2	15.1	24.6	25.1	25.6	23.9	22.3	15.2	15.8	16.1	16.2	15.8	19.2
1978	15.2	15.9	17.2	16.9	17.0	16.1	16.1	16.1	15.6	15.9	16.1	15.9	16.2
1979	15.6	16.1	16.1	21.7	22.2	19.4	21.1	22.8	23.3	24.5	21.8	20.9	20.5
1980	16.1	18.6	24.5	29.2	29.1	29.0	28.7	28.4	28.9	21.2	29.2	28.5	26.0
1981	24.5	28.1	28.9	26.8	25.6	-	-	24.6	25.5	25.2	25.3	25.5	26.0*
1982	25.1	24.8	25.7	26.6	26.1	25.3	24.8	25.3	25.9	25.1	25.1	26.0	25.5
1983	25.7	25.9	28.0	29.2	28.8	26.9	25.4	25.8	25.5	24.0	23.5	20.9	25.8
1984	21.1	22.1	21.3	22.4	23.0	22.1	21.8	21.4	22.3	21.3	-	-	21.9*
Mean	19.4	20.3	22.6	23.9	23.8	22.6	21.9	21.6	22.0	21.7	22.0	21.1	21.9

Source: 1976 - 1984 ... DID Kota Kinabalu

Table A4 MINIMUM TEMPRATURE AT KENINGAU

(Unit: °C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1965	16.7	17.8	18.3	18.9	18.9	18.3	17.8	18.9	16.7	18.3	18.3	18.3	16.7
1966	18.3	17.8	18.3	18.9	18.3	18.9	17.8	18.9	18.3	18.9	18.3	18.3	17.8
1967	18.9	18.3	18.3	18.9	18.3	18.3	17.8	17.8	18.3	18.3	18.9	18.3	17.8
1968	17.8	18.3	18.9	18.9	18.9	18.9	18.3	18.3	18.9	18.3	17.8	18.9	17.8
1969													
1970													
1971													
1972													
1973													
1974													
1975													
1976	8.9	8.3	10.6	12.2	10.0	9.4	10.0	10.6	8.9		11.1	13.3	
1977	7.8	11.1	20.0	21.1	20.0	20.0	19.4	10.0	10.6	12.8	11.7	12.2	15.6
1978	10.0	10.0	10.0	11.7	11.1	11.7	11.7	11.1	11.1	11.1	10.0	10.6	
1979	10.6	10.6	10.0	10.0	17.8	12.2	20.6	16.7	19.4	17.8	18.3	16.7	
1980	16.1	12.8	13.9	25.0	24.4	24.4	22.2	23.9	23.9	24.4	24.4	24.4	
1981	18.3	22.8	23.3	20.0	21.1			14.0	20.0	19.0	20.0	19.0	
1982	17.0	18.0	15.5	18.5	19.0	18.0	18.5	14.5	13.0	16.0	17.5	19.0	
1983	17.0	17.6	18.0	21.5	18.5	21.0	19.8	20.1	21.0	16.0	16.0	15.5	
1984	16.9	15.0	15.0	16.9	19.0	16.0	15.9	13.5	16.2	16.0			
1985													
Min.	7.8	8.3	10.0	10.0	10.0	9.4	10.0	10.0	8.9	11.1	10.0	10.6	

Source: 1965 - 1968 ... Hydrologic Records of Sabah to 1968, DID, p.353

Table A5 MAXIMUM TEMPERATURE AT KENINGAU

(Unit: °C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1965	30.6	31.1	31.1	31.1	31.1	31.1	32.2	32.2	31.7	31.1	31.7	31.1	32.2
1966	31.1	31.7	31.1	31.1	31.7	30.0	30.0	31.1	32.2	31.1	31.1	31.1	32.2
1967	31.1	31.1	31.7	31.7	31.7	31.7	31.7	32.2	34.4	31.1	31.1	31.7	34.4
1968	31.7	31.1	32.2	32.2	31.1	30.0	31.1	31.7	32.2	30.0	30.0	31.1	32.2
1969													
1970													
1971													
1972													
1973													
1974													
1975													
1976	25.6	22.2	23.3	23.9	24.4	28.9	23.3	22.2	22.8		27.8	21.1	
1977	21.1	28.9	30.0	30.6	30.0	30.0	30.0	21.1	22.8	22.8	22.2	21.7	26.1
1978	21.1	22.8	17.2	23.3	23.3	22.8	21.7	25.6	22.8	22.2	22.2	21.7	
1979	21.7	22.2	21.1	31.1	28.3	26.7	27.2	28.9	27.8	27.8	26.7	25.6	
1980	24.4	25.6	34.4	34.4	34.4	35.0	36.1	35.0	36.1	35.0	39.4	33.9	
1981	33.3	34.4	35.0	33.3	30.6			36.0	40.0	36.0	38.0	38.9	
1982	35.5	31.8	33.0	34.0	33.0	33.0	34.0	34.5	36.5	34.5	36.5	35.5	
1983	39.0	39.8	38.0	37.7	37.9	36.9	34.8	34.4	37.0	34.0	33.0	28.2	
1984	29.0	31.0	30.0	30.9	31.9	31.1	30.1	29.9	30.0	39.2			
1985													
Max.	39.0	39.8	38.0	37.7	37.9	36.9	36.1	36.0	40.0	36.0	39.4	38.9	

Source: 1965 - 1968 ... Hydrologic Records of Sabah to 1968, DID, p.353

Table A6 RELATIVE HUMIDYT AT KENINGAU

(Unit: °C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	76.7	70.2	73.3	71.6	72.7	67.7	66.1	62.1	57.2		75.3	74.9	69.8*
1977	77.0	78.5	74.0	72.5	74.3	76.3	75.8	73.6	71.0	75.0	74.0	76.1	74.8
1978	72.2	69.2	66.2	72.3	69.6	72.9	72.6	68.0	70.0	70.0	61.0	72.8	69.7
1979	75.0	71.0	76.0	63.0	63.0	64.0	53.0	55.0	59.0	63.7	57.4	58.2	63.2
1980	55.3	55.4	66.4	64.0	57.0	74.5	76.4	73.8	70.7	73.1	75.4	75.7	68.1
1981	76.9	72.3	63.6	76.4	77.1	76.1	75.7	70.0	75.8	75.9	70.7	78.6	74.1
1982	80.6	76.8	72.5	70.9	76.3	74.8	72.5	70.1	66.7	62.3	66.0	75.1	72.1
1983	70.7	65.3	59.7	59.8	62.2	67.2	70.4	70.2	72.3	71.9	72.7	75.9	68.2
1984	76.2	76.4	71.9	72.6	74.4	73.1	70.8	70.1	73.5	69.3			
1985													
Mean	73.4	70.6	69.3	69.2	69.6	71.8	70.4	68.1	68.5	70.2	69.1	73.4	70.3

Source: 1976 - 1954 ... DID Kota Kinabalu

Table A7 MAXIMUM DEW POINT AT KENINRAU (1/6)

January					
Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	21	23.6	23.6	100	23.6
1973	6	24.2	23.6	95	23.3
1974	1	25.0	23.3	86	22.5
1975	28	24.4	23.9	96	23.7
1976	4	23.9	23.1	93	22.7
1977	18	22.8	22.8	100	22.8
1978	24	22.8	22.5	97	22.3
1979	1	23.9	23.6	98	23.6
1980	14	24.4	23.6	93	23.2
1981	2	24.2	23.3	92	22.8
1982	12	24.0	23.0	91	22.4
1983	10	26.0	24.0	84	23.1
1984	2	28.0	24.0	70	22.1
1985	1	24.0	23.0	91	22.4
		Max.			23.7

February					
Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	22	22.5	22.2	97	22.0
1973	14	23.9	23.3	95	23.0
1974	26	23.3	22.2	90	21.6
1975	19	26.7	23.3	74	21.8
1976	29	26.9	23.3	73	21.8
1977	5	22.8	22.8	100	22.8
1978	24	23.3	22.5	93	22.1
1979	3	26.4	23.9	80	22.7
1980	16	24.4	23.1	89	22.5
1981	1	23.9	23.6	98	23.6
1982	20	25.0	24.0	92	23.6
1983	18	25.0	24.0	92	23.6
1984	5	24.5	23.5	92	23.1
1985	11	27.0	25.0	84	24.1
					24.1

Table A7 MAXIMUM DEW POINT AT KENINGAU (2/6)

March					
Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	23	23.9	23.1	93	22.7
1973	21	23.9	23.9	100	23.9
1974	31	22.8	22.8	100	22.8
1975	17	25.0	23.6	88	22.9
1976	1	26.9	23.3	73	21.8
1977	18	23.9	22.5	88	21.8
1978	8	24.4	23.9	96	23.7
1979	10	24.2	23.1	91	22.6
1980	30	25.8	23.6	82	22.5
1981	30	23.3	23.1	98	23.0
1982	7	25.0	23.0	84	22.1
1983	6	23.5	22.5	91	21.9
1984	26	25.0	24.0	92	23.6
1985	25	24.5	24.0	96	23.8
		Max.			23.9

April					
Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	22	25.0	23.9	91	24.0
1973	22	24.4	23.9	90	23.7
1974	2	23.9	23.9	100	23.9
1975	21	23.9	22.8	91	22.3
1976	26	25.3	23.6	86	22.8
1977	28	25.6	]2.9	87	23.3
1978	30	25.6	23.6	84	22.7
1979	6	26.1	24.4	87	23.8
1980	20	26.1	24.2	85	23.4
1981	1	25.6	23.9	87	23.3
1982	25	26.0	24.5	88	23.9
1983	29	27.0	24.0	77	22.7
1984	4	26.5	25.0	88	24.4
1985	7	25.5	24.0	88	23.4
					24.4

Table A7 MAXIMUM DEW POINT AT KENINGAU (3/6)

May

Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	5	25.0	24.4	95	24.1
1973	1	25.0	24.4	95	24.1
1974	20	23.3	23.3	100	23.3
1976	24	23.9	23.1	93	22.7
1976	1	24.7	23.6	91	23.1
1977	9	25.6	23.9	87	23.3
1978	15	27.2	25.0	83	24.1
1979	10	24.7	23.9	93	23.5
1980	9	26.1	25.8	98	25.7
1981	17	27.0	25.0	84	24.1
1982	26	26.0	24.5	88	23.9
1983	21	28.5	25.0	74	23.5
1984	12	25.0	24.0	92	23.6
1985					
		Max.			25.7

June

Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	18	26.9	24.7	83	23.8
1973	11	25.0	24.4	95	24.1
1974	15	23.6	22.2	88	21.5
1975	3	23.3	22.5	89	21.4
1976	27	24.4	22.8	86	21.9
1977	19	24.4	23.3	91	22.8
1978	11	27.8	25.0	79	23.9
1979	9	25.6	24.2	89	23.7
1980	15	25.8	24.2	87	23.5
1981	28	26.0	24.0	84	23.1
1982	17	23.5	23.0	96	22.8
1983	1	29.5	25.5	72	24.0
1984	3	23.5	23.0	96	22.8
1985					
					24.1

Table A7 MAXIMUM DEW POINT AT KENINGAU (4/6)

July						August					
Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)	Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	17	25.6	23.3	82	22.3	1972	13	24.4	23.3	91	22.8
1973	29	23.9	23.3	95	23.0	1973	5	23.3	23.3	100	23.3
1974	21	25.0	22.8	82	21.8	1974	2	22.2	22.2	100	22.2
1975	28	23.3	22.5	93	22.1	1975	19	23.1	22.8	97	22.6
1976	8	23.9	23.1	93	22.7	1976	26	23.3	22.8	96	22.6
1977	7	23.3	22.8	96	22.6	1977	3	24.2	22.5	86	21.7
1978	9	25.0	23.3	86	22.5	1978	4	23.9	22.8	91	22.3
1979	12	24.2	23.1	91	22.6	1979	25	25.8	23.3	80	22.1
1980	24	23.9	22.8	91	22.3	1980	5	26.4	24.4	84	23.5
1981	19	23.0	23.0	100	23.0	1981	30	24.0	23.0	91	22.4
1982	19	24.0	23.0	91	22.4	1982	15	25.0	22.5	80	21.4
1983	31	26.5	24.5	84	23.6	1983	21	26.5	24.5	84	23.6
1984	16	24.0	23.5	96	23.3	1984	20	23.0	22.5	96	22.3
1985						1985					
		Max.			23.6						23.6

Table A7 MAXIMUM DEW POINT AT KENINGAU (5/6)

September						October					
Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)	Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	-					1972	24	25.3	23.3	84	22.4
1973	23	23.9	23.3	95	23.0	1973	21	23.9	23.3	95	23.0
1974	21	23.6	23.3	98	23.3	1974	1	23.9	22.8	91	22.3
1975	27	24.4	23.9	96	23.7	1975	27	23.9	23.3	95	23.0
1976	2	25.0	22.8	82	21.8	1976	6	25.8	23.6	82	22.5
1977	18	23.9	22.8	91	22.3	1977	21	23.9	23.3	95	23.0
1978	5	23.9	22.8	91	22.3	1978	25	27.2	23.9	74	22.3
1979	16	25.6	23.6	84	22.7	1979	15	24.7	23.6	91	23.1
1980	18	26.4	24.2	82	23.1	1980	12	26.7	23.9	78	22.6
1981	27	27.0	25.0	84	24.1	1981	25	27.5	24.5	77	23.2
1982	20	23.5	23.0	96	22.8	1982	16	24.5	23.5	92	23.1
1983	4	24.0	24.0	100	24.0	1983	17	24.0	23.5	96	23.3
1984	9	23.5	23.0	96	22.8	1984	4	23.0	22.5	96	22.3
1985						1985					
		Max.			24.1						23.3

Table A7 MAXIMUM DEW POINT AT KENINGAU (6/6)

November						December					
Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)	Year	Day	Dry (°C)	Wet (°C)	R.H. (%)	D.P. (°C)
1972	18	23.9	23.3	95	23.0	1972	30	25.3	23.9	88	23.2
1973	1	26.1	24.4	87	23.8	1973	8	25.6	23.3	82	22.3
1974	22	22.8	22.8	100	22.8	1974	28	23.3	22.8	96	22.6
1975	3	26.1	23.6	80	22.4	1975	24	26.4	24.4	84	23.5
1976	20	24.4	23.1	89	22.5	1976	22	25.3	23.6	86	22.8
1977	27	25.8	24.2	87	23.5	1977	2	25.0	24.2	93	23.8
1978	18	24.7	23.1	87	22.4	1978	23	25.0	23.9	91	23.4
1979	12	27.2	24.7	81	23.7	1979	9	23.6	23.1	96	22.9
1980	1	25.6	23.9	87	23.3	1980	15	25.8	24.2	87	23.5
1981	15	25.5	24.0	88	23.4	1981	6	27.0	24.0	77	22.7
1982	8	25.0	24.0	92	23.6	1982	10	25.0	23.5	88	22.9
1983	5	25.0	24.0	92	23.6	1983	19	25.0	24.0	92	23.6
1984	28	24.0	23.5	96	23.3	1984	9	24.0	23.5	96	23.3
1985						1985					
		Max.			23.8						23.8