8. FLOOD DISCHARGES AND SEDIMENT VOLUMES

8.1 Introduction

Estimates of flood discharge are required for the rehabilitation of the Tuk Thla and Kompong Tuol regulators and associated embankments that enable the diversion of water to Kandal Stung and Tonle Bati. The embankment south of Tuk Thla including the Kompong Tuol regulator, was constructed in the Pol Pot era. It was breached by the flood of August 1991 with a peak level approximately 0.1 m above the embankment level. Following repair work, the embankment was breached again in October 1992, although it was not overtopped at that time. Failure then, and again in March 1994, was due to piping through the embankment material due to large head differences across the embankment. The flood of August 1994 again breached the structure.

The discharge capacity of the regulators depends on tailwater conditions. Euroconsult[1] quote estimates in the range 300 - 400 m^3/s, and a capacity of 400 m^3/s is generally accepted as the maximum. The precise capacity depends on the gate settings and downstream conditions that are controlled by the annual flood in the Tonle Bassac. From photographs taken at the time of the 1991 flood, and reproduced in the Euroconsult report, evidently the full capacity was not used. One gate at Tuk Thla remained closed while seven others had not been fully opened. In August 1994, the gates could not be fully opened, and the effective capacity was estimated at only about 250 m^3/s.

Flood estimation is extremely difficult due to the poor records. There was no severe flood during the periods when flows in Prek Thnot were recorded, primarily in the 1960s, and there is no systematic surveying of flood levels or general flow conditions. Most information refers to the upper river between the proposed dam site and Kompong Speu. There are no data for the lower reaches down to Tuk Thla.

High floods exceed the conveyance capacity of the main river channel and cause widespread inundation. The total width of flow on the flood plain can reach several kilometres. Little is known of the flow conditions on the flood plain; there are many obstructions to flow such as dikes carrying roads and a railway. Some of these dikes cross the flood plain; others run parallel to the general direction of flow.

Extreme floods can be estimated for the dam site where there are some records of annual maximum floods, although it is necessary to use regional information from elsewhere to define the shape of probability distribution of annual floods. Estimates for floods on the lower river depend on the balance between attenuation and distribution of the floods from upstream and the additional flood flows generated by rainfall on the lower basin. There are few data that can be used to define this balance, and the estimation of flood flows at Tuk Thla remains uncertain.

8.2 Previous flood estimates

The first estimates of the probable maximum flood for the design of Prek Thnot dam and spillway are well summarised in a paper prepared by SMHEA[2] in 1965. Storm maximisation was carried out by the Commonwealth Bureau of Meteorology, Australia using techniques developed by USWB. SMHEA transformed the maximum storm into a reservoir inflow flood by the unit hydrograph method based on five historical floods in the range 300 -

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1 Euroconsult, Prek Thnot Multipurpose Project, Reappraisal Report Vol 5 - Irrigation, Jan 1992.

2 Snowy Mountains Hydro-electric Authority, Papers prepared for an Engineering Seminar, Phnom Penh, Nov 1965

500 m^3/s. They concluded that the shape of unit hydrograph had less impact on the spillway flood than the sequence of rainfall and loss rate. The final estimate was an inflow peak of 12000 m^3/s with a 5-day volume of 1480 mcm giving a peak spillway flow of 4870 m^3/s.

The frequency curve presented by SMHEA in 1965 showed a 100-year flood peak of about 1000 m^3/s and a 5-day flood volume of about 450 mcm. These estimates are based on extrapolation of log-normal frequency curves. The March 1922 flood is shown at 8500 m^3/s with a 5-day volume of about 2000 mcm. This flood was considered an outlier to the flood frequency curve. A contemporary review of the 1922 flood by Berthelot[3] suggested a peak flow of 4000 m^3/s and a return period of 1000 years.

More recently, SMEC[4] (1992) and the Australian Bureau of Meteorology have revised their flood estimates using the latest available rainfall data and techniques. Current values for the probable maximum reservoir inflow and spillway design floods have been increased by more than a factor of three. The peak inflow is now estimated as 41280 m^3/s with a 3-day flood volume of 4410 mcm. The revised estimate for the 100-year flood of 1800 m^3/s is quoted as resulting from interpolation between the PMF, the 1922 flood and the 12 years of recorded data. There is no detail of the procedure followed.

Further study of the flood regime of Prek Thnot is presented by SMEC[5] (1993) in a report concerned with the rehabilitation of Tuk Thla and Kompong Tuol regulators. Their conclusion, that the 100-year flood should be increased to 8000 m^3/s, is based largely on a review of the August 1991 flood. They present estimates of the combined channel and flood plain flow near Kompong Speu using Manning's equation of 3100 m^3/s, and of the flow over the Highway 3 embankment based on survey and weir formula of 4050 m^3/s. Evidently, SMEC now believes that the 1922 flood should no longer be regarded as an outlier in flood frequency analysis.

The necessary simplifications made in the SMEC(1993) analyses can result in exaggerated estimates of peak flow. The Manning analysis assumes uniform flow and particularly a uniform energy slope. In practice it is very unlikely that such conditions exist. There are physical changes in slope, and many man-made obstructions to water movement. Both imply that energy loss might be localised with shallower energy gradients between zones of higher loss associated with road embankments and other natural and man-made obstructions in the flood plain. Flow over embankments such as Highway 3 requires more detailed analysis. Downstream water levels are likely to influence flow over the embankment, especially in conditions of widespread inundation.

Euroconsult estimated the floods in the tributaries and small rivers for return periods up to 100 years by deriving empirical equations relating flood flow to basin area using data from eastern Thailand.

All these estimates for intermediate floods[6] are summarised in Table I-21.

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3 Berthelot R, A Note on the 1000-year Flood for Prek Thnot, ECAFE, Mar 1965.

4 Snowy Mountains Engineering Corporation, Prek Thnot Multipurpose Project, Reappraisal Report, Volume 1-Summary, Jan 1992.

5 Snowy Mountains Engineering Corporation, Report on the Rehabilitation of the Kompong Tuol Road Dike, Feb 1993.

6 The term intermediate flood is used here to refer to floods of up to 1000 years return period in comparison with extreme or probable maximum floods associated with spillway design for the proposed Prek Thnot dam.

8.3 Regional flood frequency analysis

A powerful form of regional flood frequency analysis, developed by the Institute of Hydrology[7], enables records from many rivers in a hydrologically similar region to be combined (averaged) to give a composite flood frequency curve. This approach is particularly effective when only short records exist on a river. It allows information from other rivers to be included in the frequency analysis.

The series of annual maximum floods on each river is made dimensionless by dividing by the mean annual flood. Thus, the records from separate rivers are combined on a dimensionless scale. A three-parameter general extreme value distribution[8] is fitted to the regional data. When this regional curve is applied to a particular river, only the shape of the frequency curve that is transferred. The curve is scaled by an estimate of the mean annual flood derived from data for that river.

Farquharson et al (1987)[9] present a large number of frequency curves derived from records in many countries and climates. They show that typical regional curves can be derived that are applicable to the rivers in each region. For some regions, separate curves describe differences in flood response on large and small basins or on basins in different altitude ranges.

Three of these curves are relevant to Cambodia. They are shown in Figure I-38. Curve A is derived from rivers in Thailand and Malaysia (Malay Peninsula); B refers to basins in Thailand (area < 5000 km^2, altitude > 100 m), and C to basins in Thailand (area < 5000 km^2, altitude < 100 m). There is a clear distinction between the lowland curve for Thailand and the other two, possibly showing the large flood attenuation capability of lowland rice areas.

Curve A, the steepest and most upwardly curving, is used here to estimate intermediate floods at the proposed dam site. The curve is based on a total of 119 years of record from five rivers. Data from Anlong Touk and Thnuos Luong are used to estimate the mean annual flood. Some allowance is made for the fact that no high floods were experienced during the period of the data, and because the observed floods are daily average flows rather than true peaks. Factors of 1.07 and 1.15 respectively are applied. The observed floods are assigned a relative frequency and plotted for comparison with the frequency curves.

These results are also summarised in Table I-21. The 100-year flood is estimated to be 1900 m^3/s, the 1000-year flood, 3900 m^3/s. These figures compare well with those presented by SMEC in 1992; the underlying shape of the frequency curve is the same. They bear no comparison to the more recent and much higher estimates by SMEC in 1993.

A 100-year flood of 8000 m^3/s implies a mean annual flood of about 2000 m^3/s. The recorded flood flows at Thnuos Luong and Anlong Touk in the 1960s suggest a mean annual flood of about 500 m^3/s. A mean of 2000 m^3/s implies out-of-river floods in many, if not most, years. Also it is difficult to reconcile with the survival of the Kompong Tuol embankment from 1976 to 1991 given that the combined flood discharge of the regulators is about 400 m^3/s.

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7 Institute of Hydrology, Flood Studies Report, NERC, London 1975.

8 The cumulative probability of non-exceedence $F(q) = \exp\{-[1-k(q-u)/a]^{1/k}$, where k, u and a are parameters of the distribution. In the special case when $k = 0$, the distribution reduces to the 2-parameter double exponential Gumbel distribution.

The Gumbel reduced variate y, used in plotting the probability distribution, is defined by $q = u + a(1-\exp\{-ky\})/k$.

9 Farquharson F A K, Green C S, Meigh J R and Sutcliffe J V, Comparison of Flood Frequency Curves For Many Different Regions of the World, Proc. Int. Symp. on Flood Frequency and Risk Analysis, Louisiana, USA, 1985.

8.4 Flood transfer to Stung Toch

There is no single channel forming a distributary to Prek Thnot at Kompong Tram except for the canal which was intended to distribute water on the right bank of the river via Stung Toch when the control structure was completed. In the event, the embankment forming part of the structure was destroyed by a flood in 1978 or 1979 and the canal is now closed by an embankment that is at the same height as the natural river bank. However, flood waters are transferred in the direction of Stung Toch by over-bank flow, and, although not in a single channel, the general pattern of flood flow is that described by SMEC.

Because the transfer probably takes place over a substantial length of the right bank of Prek Thnot, it is difficult to estimate. Typically, the river has a bank-full capacity in the range 500 to 700 m^3/s. It is clear that some flood water will be diverted when floods exceed bank-full discharge, but the extent of flood diversion at different water levels cannot be defined with the limited data available. Taking a central estimate of 600 m^3/s as the bank-full capacity of the river, flood diversion to Stung Toch might be expected to occur about every four years on average.

8.5 Floods at the railway embankment

The railway from Phnom Penh to Takeo was constructed between 1960 and 1965, and later extended to Kampot and Kompong Som. The railway runs on a high embankment across the Prek Thnot/Stung Toch flood plain and there are three main bridges - one over Prek Thnot, one over a by-pass channel of Prek Thnot, and one over Stung Toch. In addition, there are two small bridges between the by-pass channel and Stung Toch. There are also a limited number of culverts, usually 1 m diameter concrete pipes, either singly or in groups.

No damage occurred during the high flood of 1966, but the bridge over Stung Toch was severely damaged by bombing during the war in the early 1970s. The bridge was repaired in 1986. The extreme flood of 1991 did not damage any of the three main bridges. In 1993, SMEC reported that there is no evidence that the embankment was over-topped in 1991 and that there was no indication of other damage. Field reconnaissance suggests that their description substantially understates the extent of the flood damage that occurred and its possible consequences for flood flows at Kompong Tuol.

Field reconnaissance along a 9 km section of the railway embankment from Phnom Phleung Chheh Roteh to Phnom Prey Totoeng revealed that extensive damage had occurred to the embankment itself during the 1991 flood. The damaged section lies entirely between the two rivers where the embankment elevation is about 1 m lower than the sections on either side of the flood plain. Enquiries at the office of the railway engineer confirmed that the embankment had been severely damaged and that major rebuilding had been needed over a length of 240 m. All the main river bridges (over the main channels of Prek Thnot and Stung Toch and over the by-pass channel of Prek Thnot) had survived undamaged.

Figure I-39 shows the elevations of the railway embankment (track level) and the approximate elevation of the ground at the foot of the embankment between the two major river crossings. Over much of this length the embankment is about 1 m lower than it is near the bridges. Also, the surrounding land is much lower over the first 2.5 km from Prek Thnot than the small ridge (possibly an old levee bank) near the left bank of Stung Toch. It is this stretch of lower embankment combined with lower land where most of the damage occurred. There is visual evidence of flow along the upstream face of the embankment from Prek Thnot towards the south. This may have occurred after the embankment was breached, but it caused significant erosion of the upstream face.

Local people confirm that the flood did not overtop the embankment, and this was the view of the railway authorities engineer who consider that differential water levels and piping were the cause of the collapse of part of the embankment. In total, a damaged length of about 1 km was seen, but it is not possible (after reconstruction) to assess the extent of the damage and the figure of 240 m is assumed to refer to the most severely damaged section. Information from villagers confirms the understanding of the railway engineers that failure was initiated by piping caused by a large difference in water level between the upstream and downstream sides of the embankment. It is not possible to estimate the flow through this damaged section; water levels are not known, nor is the profile of the damaged section.

Figure I-40 shows the river sections at the three main bridges, which have been juxtaposed for comparison. The relative elevations are correct, but the distance scale is arbitrary in that the true distance between the sections is much greater than shown on this illustration. The by-pass channel is an old channel of Prek Thnot which has been partially silted up so that the bed level is about 3 m higher than the present main channel. Also, it clear that the Stung Toch channel is about 1.5 m higher still. This is consistent with the idea that Stung Toch was once a major channel and that siltation has, over time, filled a previously larger channel. At a given general flood level, it is expected that the greater part of the flood discharge will be passed by the main bridge over the present Prek Thnot channel.

It is possible to estimate roughly the relative flow through the three main bridges under free-flowing conditions when downstream water levels do not influence the conveyance of the bridges. These are shown for a range of upstream water levels (to national datum) in Table I-22. However, free flowing conditions are unlikely to exist at high discharges when the limited conveyance of Tuk Thla and Kompong Tuol structures means that water levels are raised in the reach between the railway and Highway 3 embankments.

The proportion of the total flow that is passed by the bridge over Stung Toch increases from zero for total flows up to about 600 m^3/s to about 11% when the total flow reaches 2200 m^3/s. This accords with the supposition that transfers at Kompong Tram only take place above a bank-full discharge of about 700 m^3/s. While the higher flows indicated in Table I-22 are not reliable for the reasons stated above, it is possible that they give a reasonable indication of the relative flows through each of the three main bridges.

8.6 The flood of August 1994

A major flood occurred during the period 2 - 4 August 1994. It was unusual that there was very little rainfall in the lowland areas, including Phnom Penh and Kompong Speu, but heavy rainfall in the mountains. The flood hydrograph was of short duration. The flood started to rise at Thnuos Luong at 08:00 on 31 July, peaked during the night of 2 August, and was receding rapidly by 4 August. The peak discharge at Kompong Tuol occurred about noon on 3 August.

The peak water level at Thnuos Luong was 7.87 m above the datum of the old gauge. Extrapolation of the new rating curve gives a within-bank discharge of 850 m^3/s; the old cuve gives 720 m^3/s. There was some overbank flow. Flows on the right bank were blocked by the highway embankment and returned to the river at the Highway 4 bridge. Flows on the left bank moved parallel with the highway in the direction of Kompong Speu. These flows were relatively slow moving and probably did not exceed 20% of the within-bank flow, which would suggest a total peak discharge of about 1020 m^3/s (860 m^3/s from the old rating curve). From the flood frequency curve for the dam site, the return period of the August 1994 flood is about 10-20 years.

The peak water level on 2 August at Thnuos Luong was about 0.30 m below the level reached at the peak of the 1991 flood, based on flood marks at the DoAHH Provincial Office at Kompong Speu. The main difference between the two floods seems to be in volume terms. The 1991 flood lasted for much longer and caused much more widespread inundation. In

August 1994, the area flooded was much smaller all along the river except in the area of the Highway 3 embankment, where the impact was very similar to that in 1991.

At Kompong Tuol, the water level rose steadily to within a few centimetres of the top of the embankment. Discharges through the two control structures were significantly less than their potential capacity due to problems in opening the gates fully, and the head difference across the embankment exceeded 2 m. Failure of the embankment was initially by piping, followed by collapse of the material above the pipes. At the same time small flows started across Highway 3 causing some damage and closure of the highway. In all respects except the widespread inundation, the August 1994 flood had similar effects to that of 1991.

8.7 Flood discharge at Tuk Thla

Floods at Tuk Thla derive primarily from the headwaters basin above the proposed dam near Anlong Touk. They are attenuated by flood plain storage, and augmented by smaller floods from the intervening tributaries. Also, some of the flood water is transferred into Stung Toch mainly by overbank flow in the region of Kompong Tram. Flow in Prek Thnot and Stung Toch are separated by a low ridge of higher land near the railway embankment, but at very high flows, this land will become inundated and the water surface will be continuous along the upstream side of the railway and Highway 3 embankments.

Euroconsult estimated the tributary floods using empirical equations derived from flood data from eastern Thailand. These equations are accepted as reasonable; they imply growth for increasing return period that is consistent with the regional flood frequency curve discussed above. They are also consistent with other unpublished regional equations.

When translating the dam site floods to Tuk Thla, Euroconsult discuss the balance between attenuation in the flood plain and the additional flood flows from the tributaries downstream of the dam site. They conclude that use of flood estimates applicable at the dam site would be conservative as it is likely that the attenuation of flood flows down the river due to flood plain storage would exceed the contribution from the tributary areas.

Euroconsult quote figures for the areas inundated and the depth of inundation during the 1991 flood. About 46000 ha were flooded to depths ranging from 1 m to 2.5 m, and the duration of flooding ranged from 2 to 10 days. This represents a considerable volume of flood storage, possibly 250 to 500 mcm between the dam site and Tuk Thla. SMEC do not estimate the attenuation of floods by flood plain storage downstream of the dam site.

The scale of the attenuation effect of the flood plain storage might be estimated by looking at the attenuation effect of the flood storage at the proposed dam. Table I-21 shows that the flood attenuation for moderate floods of about 50% can be expected. This corresponds with the Euroconsult estimates. The precise attenuation depends on the shape of the flood hydrograph used and the baseflow assumed. The flood storage needed varies with the severity of the flood, but between 150 and 200 mcm would be needed to attenuate the 100-year flood. While an estimate of the attenuation of flood peaks by channel and flood plain storage must take account of the passage of the flood wave, it is reasonable to infer that attenuation exceeds the possible flood contribution from the tributaries. Thus the use of flood estimates from the dam site for design at Tuk Thla should be conservative, even if floods on the tributaries are coincident with those on the main river. The moderate diversion of flood flows into Stung Toch - perhaps as much as 10% of the discharge - supports this conclusion and may provide a margin of error, given the general uncertainty associated with all the flood estimates.

Recommended design floods for Tuk Thla are summarised below. Floods in Stung Toch are those deriving from its own catchment area. For design of structures in Stung Toch, it is reasonable to add as much as 15% of the equivalent flood at Tuk Thla, bearing in mind the considerable uncertainty in the estimate of flood transfer.

Estimates of flood discharge (m^3/s)

	Return Period (years)						
	10	20	25	50	100	500	1000
Prek Thnot at Tuk Thla	860	1100		1500	1900	3200	3900
Stung Toch			54		121		
Stung Tonle Bati			103		231		

Estimates for Stung Toch and Stung Tonle Bati are those derived by Euroconsult (1992)
Estimates for Stung Toch refer only to floods deriving from its own basin area

8.8 General flood design issues

The natural flood regime of Prek Thnot allows for flood flows exceeding the channel capacity (bank-full discharge) to be carried by the wide flood plain. The extreme floods inundate large areas and sometimes cause serious loss of crops and livestock as well as some rural infrastructure. The precise distribution of flow on the flood plain is governed by the detailed topography and especially the natural remnant levee bank features (usually the site of villages), and the man-made features such as road and railway embankments and flood protection works. Field bunds and most secondary canal banks are usually too small to influence the flow distribution of major floods.

The natural land-forms, primarily the old levee banks, are not continuous features and usually do not cause a major barrier to flood plain flows. It is the major, man-made, structures on the river and the flood plain that have changed this essentially natural situation. Attempts to control in-bank river levels for irrigation diversion, such as Tuk Thla/Kompong Tuol, and historically at Kompong Tram, together with embankments across the flood plain carrying roads or railways, substantially change the natural regime. The Roleng Chrey regulator is arguably an exception to this general observation.

For a control structure to be effective and transparent during floods, its gate capacity should match the bank-full discharge of the river under flood conditions, and it must be operated (and capable of being operated) so that this discharge capacity is available when a major flood comes. SMEC estimates that flood plain flows can be several time the within-river flow for extreme floods. There is no reason to doubt this; bank-full capacity of the river is generally of the order of 700 m^3/s. The larger part of an extreme floods has to be carried on the flood plain.

The embankments crossing the flood plain should be seen as the main problem. They are badly designed to pass floods, with very little capacity for passing flood waters on the flood plain sections. They should be 'transparent' to floods by having adequate culverts or small bridges distributed along their full length on the flood plain. Flood waters could then pass without substantial diversion away from the natural direction of flow. In their present form, they concentrate the flood plain flow back at the river sections, which puts great pressure on the bridges or control structures to pass the full weight of the flood. When the flood exceeds the capacity of these structures, some form of damage or collapse occurs. Any idea that the flood might be held back and attenuated by these embankments is not consistent with the historical events.

The experience of August 1994 illustrates this point. A relatively moderate flood with a return period of about 10 years destroyed the Kompong Tuol embankment. It is well known that the control structures in their present condition could not pass such a flood. But, the main reason for the damage to the embankment is that the highway and railway embankments have a totally inadequate number of culverts to pass the flood plain flows. Water levels upstream of the embankment would not have risen to a critical level if such facilities had been in place.

The only structure on the river to withstand the major floods is the control structure at Roleng Chrey. It is instructive to consider why this is so. In the 1991 flood the structure became an island with perhaps the major part of the flood flow passing round it on the adjacent flood plain. The structure itself did not need to pass the total flood flow, and the effective gate capacity is probably of the same magnitude as the bank-full flow[10]. There are no significant embankments across the flood plain; the embankment for Highway 4, and that partially constructed for a railway line, run along the flood plain and not directly across it.

The railway embankment poses an additional hazard to structures downstream. The damage to the embankment is described above, although the timing and speed of the collapse is not known. However, it is very likely that the railway embankment was holding back some flow which was then released, increasing the flood flow seen downstream. If, as SMEC describe, the area between the railway and road embankments resembled a large lake, the additional flood wave caused by the collapse of part of the railway embankment would have travelled rapidly to Kompong Tuol and its associated road embankment. However, the time sequence of events in 1991 is not clear. If the railway embankment partially collapsed before the road embankment was breached, the incremental flood wave caused would have put greater pressure on the road embankment. If the road embankment was breached first, the hydraulic gradient could have been increased across the railway, hastening the damage there.

Reconstruction of the railway embankment has not provided significantly more flood capacity, although there are a few open areas spanned by temporary bridges. It seems likely that the structure would respond in the same way as before to a flood of the magnitude of that in 1991.

Inevitably, this casts doubt on the use of a 'natural' design flood for the design of engineering works at Kompong Tuol. If the railway embankment collapses, the flood peak downstream is unpredictable. This uncertainty is added to that inherent in the estimate of the natural flood in the design. In these circumstances, it is prudent to consider the safety of a redesigned structure by considering ways in which any additional discharge can be passed elsewhere. Ideally, the railway and road embankments should be provided with considerably greater culvert capacity distributed along the full width of the flood plain. This would reduce the likelihood of future collapse and of an enhanced flood wave downstream.

8.9 Sediment load

In the lower Prek Thnot - defined for this purpose as downstream of Kompong Speu - the river channel meanders across the flood plain, the low flow channel itself meandering within the wide sand bed of the river. Typically, the river section is 80 - 100 m wide and bank-full depth is about 8 m. The river channel is incised into the flood plain and the banks are near vertical cliffs of 2 - 4 m height. There are shallow levees on both sides of the river.

The main channel bed is predominantly coarse sand, which is exploited for construction work, primarily in river reaches from Kompong Tram down to Kompong Tuol. Substantial volumes of sand are taken from the river channel. The banks comprise unstable and friable material of a wide distribution of grain size. Floods deposit layers of much finer silt on the lower parts of the banks and on shoals in the river bed.

It is noticeable that recent aerial photography shows little river channel movement over the period of several decades since the 1:50000 mapping was produced. However, there are many instances of localised change where parts of the banks have collapsed, sometimes due to drainage or access works.

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10 A precise estimate of the gate capacity under drowned conditions, such as will occur during a major flood, is impossible without substantially more detailed topographical information.

Sediment samples were analysed to provide particle size distribution for samples typical of the coarse sand that forms the river bed in the lower reaches of the river, below Kompong Speu, and the finer material that is found deposited on the banks. It is reasonable to assume that the former is carried as bed load during periods of flood discharge; the latter is carried in suspension over a wider range of discharge. Both particle size distributions are illustrated in Figure I-41.

In the absence of any direct measurements of sediment load, it is necessary to estimate sediment rating curves by empirical methods using a range of widely used estimating equations. The equations used are given in Appendix B. The ratings can be integrated with the flow duration curve (derived in Chapter 3) to provide estimates of the total sediment transport. The process of sediment transport is very complicated and the equations developed contain many simplifications. They do not give other than a rough guide to the sediment load that can be expected.

The Shields and Einstein-Brown bed load equations give estimates of average annual sediment load of 0.37 and 0.31 mcm/year respectively for a typical median grain size of 1.4 mm. The Ackers and White total load equation did not give meaningful results.

8.10 Discussion

(1) Limitations of the data

With existing data, it is not possible to reach firm figures for intermediate or extreme floods in Prek Thnot basin. The accuracy of all the estimates must be regarded as very poor. That the latest estimates by SMEC are over four times higher than previous estimates, and those made in this study, is a measure of the uncertainty about the flood regime of the river. The estimates of floods of even 100 years return period owe as much to reasoned judgement as they do to hydrological and hydraulic analysis of the data.

A more coherent body of data including flood levels, topography, and the dimensions and capacity of man-made structures throughout the basin is essential to the interpretation of historical floods. Routine data collection procedures must be strengthened in Cambodia and special efforts made urgently to survey the evidence of recent major floods. Until this information is available, the analysis cannot be improved further.

This is also true for the prediction of the effects of river training works. The protection of rice lands, particularly in the development areas, by reducing inundation is an attractive prospect. But the consequence of diversion of water elsewhere, or the concentration of flow between higher flood banks, is difficult to predict without good information. Any extensive development involving significant interference with the natural flow regime should be examined by hydraulic modelling of the river and its flood plain.

(2) Flood risk

The statistical idea of risk[11] influences the selection of a design flood for engineering structures. The risk of a 100-year flood being exceeded in a 50 year economic life of a structure is 0.39, whereas the risk falls to 0.05 for the 1000 year flood over the same period.

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11 The risk that an event that is exceeded every T years on average will occur at least once in a given period of years D (such as the during the design or economic life of a structure) is given by the expression:

$$r = 1 - (1-1/T)^D$$

For example, the risk that the 100 year flood will be exceeded at least once in a period of 50 years is 0.39, which means that the flood will be exceeded at least once in 39 out of every 100 periods each of 50 years duration.

It is generally agreed that for Prek Thnot the 1000-year flood is about twice the magnitude of the 100-year flood. The flood attenuation potential of Prek Thnot dam is such as to reduce the 1000-year flood to about the magnitude of the present 100-year flood. Thus a structure designed to pass the 100-year flood without the dam should pass the attenuated 1000-year flood after the dam is built.

These considerations suggest that, if there is some likelihood that Prek Thnot dam will be built in the next 10 or 20 years, it might be reasonable to accept a higher risk in the short term if the longer term risk is acceptable. In this tentative scenario, the risk of the 100-year flood being exceeded in 10 years is 0.10 and the risk of the 1000-year flood in the succeeding 40 years is 0.04.

(3) Flood warning

Improvement in flood warning capability is essential to ensure that the maximum capacity of the control structures at Tuk Thla and Kompong Tuol is available in time of severe flood. A flood forecasting system is desirable, but present poor communications and inter-departmental coordination limit the length of warning that can be achieved. Advice of water level rise at Roleng Chrey or Kompong Speu would give a some hours advance warning at Tuk Thla; information from locations further upstream would be better. Longer warning times can be obtained only by rainfall monitoring in the headwaters using telemetered data. These developments are not possible with present security conditions in the upper basin.

What is ultimately feasible depends on improvements in the communications between operators of the different control structures on the river. This requires both technical and institutional improvement. It needs to be considered within a general development programme for the Prek Thnot basin, and whether the dam is a component of that development. This should be considered at the same time as the institutional arrangements that are needed to ensure water sharing during the run-of -river phase of development.

Tables

Table I-1 Location of rainfall stations

Map code	File code	Name	Latitude		Longitude		UTM coordinates E	N	Altitude m
103	110510	Set Bo	11	26	105	01	5030	2650	10
104	110406	Prek Leap	11	35	104	55	4920	2820	10
105	110408	Petit Takeo	11	32	104	55	4908	2749	10
106	110411	Phnom Penh (Town)	11	36	104	50	4915	2822	11
108	110403	Phnom Penh (Met)	11	33	104	51	4845	2780	10
109	110409	Takhmau	11	26	104	58	4940	2690	10
110	110410	Bat Rocar	11	08	104	47	4763	2200	8
113	110418	Chhak Chhoeu Neang	11	30	104	46	4714	2740	10
114	110412	Tram Khuan	11	16	104	42	4685	2475	11
115	110423	Thnal Tetung	11	29	104	40	4640	2704	10
117	110404	Kompong Speu	11	26	104	31	4474	2660	17
118	110422	Chocung Roas	11	39	104	33	4550	2875	37
119	110413	Phnom Sruoch	11	22	104	22	4320	2580	55
120	110420	Amleang	11	47	104	21	4288	3042	70
121	110416	Sre Khlong	11	18	104	18	4240	2520	58
123	110407	Slakou	11	05	104	43	4660	2264	12
123	100408	Slakou	11	05	104	43	4660	2264	12
124	110419	Sangker Satub	11	38	104	08	4120	2895	76
125	110424	Stung Chral	11	11	104	04	3946	2365	30
126	110421	Kirirom	11	19	104	02	4000	2530	680
		Takeo (Town)	10	59	104	47	4763	2140	10
		Prey Phdau	11	28	104	37	4582	2675	26
127		Sre Ambel	11	07	103	47	3677	2287	1
133		Veal Rinh	10	42	103	48	3695	1826	
134		Tuk Laak	10	40	103	55	3822	1789	
136		Boker	10	37	104	04	3985	1734	950
137		Kampot (Met)	10	37	104	13	4148	1734	1
138		Chakrey Ting	10	41	104	15	4184	1808	

Notes: Not all these stations have useful periods of data.
The map code is used on the maps in the Lower Mekong Hydrologic Yearbooks.
The file codes are used in the computer files generated from the Yearbooks.

Table I-2 Mean monthly rainfall and raindays for Prek Thnot basin and some western stations

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean monthly rainfall (mm)														
103	Set Bo	8	12	2	76	134	144	110	145	190	248	116	41	1225
104	Prek Leap	3	14	4	47	98	178	148	157	154	253	126	31	1213
105	Petit Takeo	3	5	5	57	104	129	135	128	171	271	178	11	1197
106	Phnom Penh (Town)	2	13	11	69	120	136	161	200	234	211	125	21	1305
108	Phnom Penh (Met)	4	7	13	66	135	142	151	163	252	257	126	21	1337
109	Takhmau	5	9	1	61	137	187	123	188	193	267	80	49	1300
110	Bat Rocar	7	2	9	119	131	130	228	151	290	332	85	46	1531
113	Chhak Chhoeu Neang	2	7	16	84	157	100	118	75	206	180	65	20	1029
114	Tram Khuan	18	10	3	115	155	144	147	112	210	293	117	52	1377
115	Thnal Tetung	9	8	20	66	124	173	117	122	217	277	96	44	1273
117	Kompong Speu	16	17	22	66	137	132	129	119	223	226	115	19	1221
118	Chocung Roas	3	15	20	83	124	169	157	134	282	210	66	16	1279
119	Phnom Sruoch	12	13	17	74	188	155	137	178	246	259	96	70	1444
123	Slakou	8	2	19	70	151	128	169	148	230	240	102	39	1305
126	Kirirom	13	20	25	148	239	175	253	304	265	359	81	34	1915
0	Takeo (Town)	1	1	6	40	85	81	124	84	137	208	75	6	849
0	Prey Phdau	1	2	12	81	156	112	118	102	251	202	130	14	1181
127	Sre Ambel	21	42	42	256	415	580	864	805	541	363	47	34	4009
133	Veal Rinh	36	32	52	225	416	584	940	887	779	426	85	35	4496
134	Tuk Laak	16	38	81	141	473	563	958	890	609	421	64	27	4282
136	Boker	61	40	51	146	582	469	1089	1247	693	559	126	35	5097
137	Kampot (Met)	23	27	55	179	151	176	343	297	245	281	91	62	1928
138	Chakrey Ting	34	20	25	145	193	135	185	216	233	231	60	32	1508
Mean monthly number of raindays														
103	Set Bo	1	1	1	5	8	12	11	12	12	15	7	3	85
104	Prek Leap	1	0	1	4	7	12	10	14	13	12	6	3	82
105	Petit Takeo	1	0	1	5	13	15	14	14	17	15	8	1	105
106	Phnom Penh (Town)													
108	Phnom Penh (Met)	2	1	1	4	14	18	17	18	20	21	10	4	129
109	Takhmau	1	1	0	4	8	12	8	11	13	13	4	2	76
110	Bat Rocar	2	1	0	5	8	10	12	14	16	17	7	2	93
113	Chhak Chhoeu Neang	1	0	0	6	9	8	8	7	10	13	2	0	62
114	Tram Khuan	2	1	1	5	7	12	14	11	14	15	4	2	86
115	Thnal Tetung	1	0	1	4	7	11	8	10	13	15	6	2	75
117	Kompong Speu	1	1	1	5	9	13	11	9	15	15	6	1	87
118	Chocung Roas	1	1	1	4	10	12	12	12	15	13	2	1	83
119	Phnom Sruoch	2	1	1	6	12	13	14	17	17	16	5	4	108
123	Slakou	2	1	2	7	15	16	18	16	19	16	10	4	125
126	Kirirom	5	3	1	10	21	21	23	24	22	21	7	1	158
127	Sre Ambel	4	3	3	10	19	24	26	27	23	19	3	2	161
133	Veal Rinh	3	2	4	9	17	20	24	22	20	12	4	2	138
134	Tuk Laak	2	2	4	9	18	24	25	26	20	20	4	3	156
136	Boker	9	10	12	14	25	26	25	31	29	24	10	6	221
137	Kampot (Met)	5	6	7	13	17	21	26	23	20	23	11	7	179
138	Chakrey Ting	3	2	0	11	14	19	23	19	18	22	6	2	138

Table I-3 Review of rating curves for Prek Thnot at Anlong Touk

Gauge height (m)	Discharge (m3/s) 1963		1964-65		1966-70	
0.1			1.2	(27)	0.9	(-5)
0.2	2.5	(42)	2.4	(36)	1.9	(8)
0.5	7.5	(37)	6.6	(21)	5.6	(2)
1.0	20	(30)	18	(17)	16	(4)
1.5	33	(12)	33	(12)	30	(2)
2.0	51	(8)	48	(1)	49	(3)
2.5	71	(3)	70	(1)	72	(4)
3.0	96	(2)	95	(1)	95	(1)
3.5	130	(6)	125	(2)	125	(2)
4.0	167	(8)	155	(0)	156	(1)
4.5			188	(-1)	194	(2)
5.0			226	(-1)	235	(3)
5.5			266	(-1)	280	(4)
6.0			306	(-2)	326	(4)
6.5			350	(-3)	380	(6)
7.0			400	(-2)	440	(7)
7.5			458	(-1)		

Notes: The rating curves are summaries of those published in the Lower Mekong Hydrologic Yearbooks for the years shown.

The figures in parenthesis indicate the percentage difference between these curves and the single curve derived in this study. Positive values indicate possible overestimation of flows in the Yearbooks.

Table I-4 Flow duration statistics for Prek Thnot at Anlong Touk

Percentage of time discharge is exceeded	Discharge (m3/s) Jan-Dec	Jun-Aug	Dec-Mar
5	166	138	11.9
10	109	93	7.6
20	59	63	4.2
30	34	47	3.2
40	19	34	2.3
50	11	28	1.8
60	4.9	22	1.3
70	2.7	16	1.1
80	1.4	12	0.7
90	0.7	5.9	0.5
95	0.4	3.4	0.1
99	0.1	1.0	0.1

Note: Statistics are derived from daily flows at Anlong Touk from Sept 1963 - February 1970

Table I-5 Catchment areas of rivers relevant to the Project area

	Incremental area (km2)									
	left bank			right bank			combined			Cumulative area (km2)
	total	low land	high land	total	low land	high land	total	low land	high land	
Prek Thnot										
Dam site							3638			3638
Anlong Touk	9	0	9	3	0	3	12	0	12	3650
Rolang Chrey	78	32	46	152	125	27	230	157	73	3880
Kompong Speu	90	52	38	52	46	6	142	98	44	4022
O Krang Ambal	456	112	344	146	95	51	602	207	395	4624
Tuk Thla / K. Tuol	80	80	0	56	41	15	136	121	15	4760
Stung ?							33	33	0	
Stung Toch							190	170	20	
Tonle Bati							262	232	30	

Note: These areas with the exception of that to the dam site have been derived from the 1:50,000 maps.
The area to the dam site is not consistent between different reports and a figure of 3638 km2 has been used so that the drainage area to Anlong Touk corresponds to that in the Lower Mekong Hydrologic Yearbooks.

Table I-6 Basin parameters used with the runoff model

		Bank	Area	Rainfall	Lowland	Additional storage
			km2	mm	%	mm
Prek Thnot to Anlong Touk			3650	1800	0	0
tributaries	to Roleng Chrey	both	230	1500	68	30
tributaries	to O K A confluence	both	288	1400	67	30
O Krang Ambel		left	456	1400	25	15
tributaries	to Tuk Thla	both	136	1200	89	40
Stung Toch			190	1300	89	40
Stung Tonle Bati			262	1300	89	40

Table I-7 Summary of model-predicted runoff

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Runoff (mm)													
Prek Thnot at Anlong Touk													
- observed	1.8	0.8	0.6	2.3	12	18	26	50	81	113	31	6.1	342
- predicted	2.6	1.2	0.5	3.5	13	17	30	33	65	120	36	13	335
Tributaries to Tuk Thla	0.7	0.1	0.0	0.0	0.0	2.0	9.4	11	26	52	16	5.1	123
Stung Toch	0.4	0.0	0.0	0.0	0.0	0.0	0.0	4.3	14	40	12	3.7	75
Stung Tonle Bati	0.4	0.0	0.0	0.0	0.0	0.0	0.0	4.3	14	40	12	3.7	75
Runoff volume (mcm)													
Prek Thnot at Anlong Touk													
- observed	6.7	2.8	2.1	8.5	42	67	93	181	296	413	114	22	1249
- predicted	9.4	4.4	2.0	13	46	63	109	121	239	438	132	46	1222
Tributaries to Tuk Thla	0.8	0.1	0.0	0.0	0.0	2.2	10	12	29	58	18	5.7	136
Stung Toch	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.6	7.7	2.3	0.7	14
Stung Tonle Bati	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.1	3.6	11	3.2	1.0	20

Note: These data refer to the model fitting and testing period 1964-1969

Table I-8 Estimated dates of occurrence of selected water levels in Tonle Bassac 30 km downstream of Phnom Penh

Water level	Date when the water level falls below the given level on the recession		
(m)	average	latest	earliest
5.5	12-Nov	01-Dec	28-Oct
5.0	20-Nov	06-Dec	04-Nov
4.5	29-Nov	15-Dec	15-Nov
4.0	08-Dec	20-Dec	22-Nov
3.5	17-Dec	28-Dec	29-Nov
3.0	28-Dec	09-Jan	10-Dec
2.5	11-Jan	25-Jan	22-Dec
2.0	27-Jan	28-Feb	06-Jan

Table I-9 Reference crop transpiration (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1963								130	140	140	133	149	
1964	159	170	213	205	138	161	160	151	132	138	128	129	1884
1965	147					139	165	155	131	144	144	144	
1966	148	158	207	190	154	154	141	146	129	137	132	126	1822
1967	131	154	194		160	154	141	145	141	139	149	154	
1968	155	164	223	170	156	153	154	145	126	134	137	132	1849
1969	140	155	195	200	175	154	136	146	118	139	131	143	1832
1970	140	146	195	179	162	129	152	143	138	124	131	130	1769
1981	145	154	207	183	160	173	156	147	137	144	121	150	1877
1982	147	158	211	163	165	133	157	148	136	148	131	158	1855
1983	140	177	240	215	199	177	158	143	141	124	145	147	2006
1984	145	170	229	201	167	142	157	145	129	146	157	149	1937
1985	154	185	206	194	165	148	160	162	133	137	128	160	1932
1986	145	152	215	184	153	150	152	162	123	142	121	133	1832
1987	138	154	203	195	189	146	153	156	129	125	117	139	1844
1988	140	158	218	164	148	143	158	164	152	130	164	159	1898
1989			178										
1990			164										
1991					182	137	130	130	125				
1992				188	174	141	126	120	114	125	125	119	
1963-70	146	158	205	189	158	149	150	145	132	137	136	138	1841
1981-92	144	164	207	187	170	149	151	148	132	136	134	146	1868
1963-92	145	161	206	188	165	149	150	147	132	136	135	142	1857
cv	0.05	0.07	0.09	0.08	0.09	0.09	0.08	0.08	0.07	0.06	0.10	0.09	
max	159	185	240	215	199	177	165	164	152	148	164	160	
min	131	146	164	163	138	129	126	120	114	124	117	119	

Note: These estimates are based on data from Phnom Penh meteorological station at Pochentong.

Table I-10 Comparison of mean values of the meteorological variables

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature	(deg C)												
Tmax	JS	30.7	32.6	34.5	35.2	34.1	33.2	32.6	32.1	31.7	30.6	30.1	30.2
Tmin	JS	21.2	22.7	24.2	25.4	25.3	25.0	24.7	24.7	24.4	24.2	23.6	21.7
Tav	JS	26.0	27.6	29.3	30.3	29.7	29.1	28.6	28.4	28.0	27.4	26.9	25.9
Tav	EC	26.0	27.1	28.4	29.5	28.9	28.5	27.9	28.2	27.8	27.4	26.7	25.9
Sunshine	(hours/day)												
	JS	8.6	9.0	9.0	8.0	7.3	6.3	6.3	5.6	5.8	6.8	7.6	8.5
	EC	8.4	8.0	8.6	8.0	6.5	6.4	4.6	5.6	4.3	6.5	7.1	7.8
Humidity	(%)												
	JS	67.4	65.3	62.5	67.0	75.4	77.0	78.7	79.3	82.4	81.9	76.6	71.2
	EC	71.1	71.5	70.1	72.5	81.5	81.0	83.2	83.3	84.9	83.3	78.5	74.2
Wind speed	(m/s)												
at 10 m	JS	2.4	2.2	2.7	2.2	2.1	2.4	2.7	2.6	2.2	1.8	2.3	2.4
at 0.5 m	EC	0.58	0.50	0.59	0.57	0.55	0.63	0.63	0.50	0.52	0.43	0.64	0.57
at 2m	JS	1.8	1.7	2.1	1.7	1.6	1.9	2.0	2.0	1.6	1.4	1.7	1.8
at 2m	EC	0.8	0.7	0.8	0.8	0.7	0.9	0.9	0.7	0.7	0.6	0.9	0.8

Notes: JS refers to the JICA Study, EC refers to Euroconsult. All data are from Phnom Penh meteorological station.
JICA Study averages refer to the years 1963-70 1981-92, Euroconsult averages refer to the following years:
Temperature 1907-09 1919-21 1923-38 Humididty 1931-38 Wind 1934-38 Sunshine 1934-38.

Table I-11 Comparison of the reported irrigation areas with Prek Thnot dam and comparative estimates based on the JICA study inflow series

Firm power	Energy	Irrigation area			JICA comparison based on 10 year simulation	
		SMEC / Euroconsult		Tahal		
		double cropping	triple cropping	composite plan	irrigation area	energy
MW	Gwh		ha		ha	Gwh
Full supply level 58.5 m (1120 mcm)						
0	45	34000			34000	40
0	45		20000		20500	40
1.5	29			50000	53000	39
2		33000			32500	35
2			18600		18000	38
4	38			35000	32600	37
5	45 (40)	27000			**	**
5	45 (40)		15000		**	**
Full supply level increased 2.5 m or 3 m						
1				66000	55000	41
5	48 (47)	25500			26100	42
5	48 (47)		14300		14800	42
5				40000	28900	42

Notes: Figures in parenthesis indicate firm energy.

The JICA comparison uses the average irrigation demands defined in the relevant reports, the performance targets defined by SMEC, and a common 10-year inflow series described in the text.
** the firm power target of 5 MW could not be met 95% reliability in this simulation.

Tahal considered raising the full supply level by 2.5 m.
SMEC / Euroconsult considered raising the full supply level by 3 m, while also raising the minimum operating level

Table I-12 Comparison of gross irrigation demand (mcm/10000 ha)

		Euroconsult				Tahal
		power priority		irrigation priority		
		double cropping	triple cropping	double cropping	triple cropping	Composite cropping average year
		55% efficiency		55% efficiency		70% efficiency
Jan	1	14.9	29.4	15.0	29.7	7.7
	2	16.4	29.4	15.0	29.7	16.4
Feb	1	17.1	29.4	15.5	29.7	12.8
	2	16.4	29.4	15.5	29.7	15.1
Mar	1	17.1	30.7	16.9	32.0	13.9
	2	14.9	30.7	17.3	32.0	12.5
Apr	1	15.6	30.7	15.9	29.7	8.5
	2	17.1	30.7	15.0	29.7	3.1
May	1	8.2	17.4	8.0	16.4	0.0
	2	11.2	17.4	11.2	16.4	19.4
Jun	1	18.6	24.1	18.3	25.0	8.1
	2	17.1	24.1	19.2	24.2	17.2
Jul	1	10.4	17.4	15.5	17.9	8.8
	2	11.2	14.7	13.1	17.9	12.3
Aug	1	18.6	22.7	15.0	22.6	8.7
	2	17.1	22.7	15.0	22.6	8.7
Sep	1	7.5	12.0	5.2	10.9	10.5
	2	6.7	13.4	5.2	10.9	6.3
Oct	1	8.9	17.4	7.5	16.4	0.0
	2	8.2	17.4	7.5	16.4	0.0
Nov	1	15.6	21.4	14.5	23.4	0.0
	2	14.9	21.4	13.6	22.6	0.0
Dec	1	17.9	29.4	18.3	28.1	0.3
	2	14.2	29.4	16.9	28.1	7.8
Total		336	563	330	562	198

Table I-13 Estimates of average river slope

River distance (km)

	Peam Khley	Roleng Chrey	Thnuos Luong	Prey Phdau	Kompong Tram	Railway line	Kompong Tuol
Roleng Chrey	14.4						
Thnuos Luong	22.0	7.6					
Prey Phdau	39.2	24.8	17.2				
Kompong Tram	49.7	35.3	27.7	10.5			
Railway line	73.2	58.8	51.2	34.0	23.5		
Kompong Tuol	78.4	64.0	56.4	39.2	28.7	5.2	
Bassac confluence	104.4	90.0	82.4	65.2	54.7	31.2	26.0

Straight-line (flood plain) distance (km)

	Peam Khley	Roleng Chrey	Thnuos Luong	Prey Phdau	Kompong Tram	Railway line	Kompong Tuol
Roleng Chrey	10.5	0.0					
Thnuos Luong	15.8	5.6	0.0				
Prey Phdau	28.7	18.5	13.0	0.0			
Kompong Tram	33.5	23.1	17.7	5.3	0.0		
Railway line	47.0	36.8	31.4	18.5	13.8	0.0	
Kompong Tuol	49.3	38.8	33.6	20.9	15.9	3.2	0.0
Bassac confluence	63.2	53.0	47.6	34.8	29.9	16.2	14.4

Elevation of river bed (m)

Peam Khley	Roleng Chrey	Thnuos Luong	Prey Phdau	Kompong Tram	Railway line	Kompong Tuol	Bassac confluence
34.0	29.3	26.2	16.0	12.5	8.2	8.0	3.0

Difference in elevation (m)

	Peam Khley	Roleng Chrey	Thnuos Luong	Prey Phdau	Kompong Tram	Railway line	Kompong Tuol
Roleng Chrey	4.8						
Thnuos Luong	7.8	3.1					
Prey Phdau	18.0	13.3	10.2				
Kompong Tram	21.5	16.8	13.7	3.5			
Railway line	25.8	21.1	18.0	7.8	4.3		
Kompong Tuol	26.0	21.3	18.2	8.0	4.5	0.2	
Bassac confluence	31.0	26.3	23.2	13.0	9.5	5.2	5.0

River slope (mm/km)

	Peam Khley	Roleng Chrey	Thnuos Luong	Prey Phdau	Kompong Tram	Railway line	Kompong Tuol
Roleng Chrey	330						
Thnuos Luong	355	401					
Prey Phdau	459	534	593				
Kompong Tram	433	475	495	333			
Railway line	352	358	352	229	183		
Kompong Tuol	332	332	323	204	157	38	
Bassac confluence	297	292	282	199	174	167	192

Note: These elevations are approximate pending verification of local benchmark elevations.

Table I-14 Monthly mean values of the meteorological data for Tonle Bati.

			Feb	Mar	April	May	June	July
Temperature		degrees C						
	7 am		24.2	25.1	26.9	27.4	26.4	26.0
	7 pm		29.4	29.5	30.0	28.5	27.3	27.0
	mean		26.8	27.3	28.5	27.9	26.8	26.5
	max		34.1	34.1	35.5	34.2	32.6	31.2
	min		22.7	23.5	24.8	25.4	25.0	24.6
	mean		28.4	28.8	30.1	29.7	28.8	27.9
Relative humidity		%						
	max		86	86	86	86	86	86
	min		40	43	43	51	56	61
Sunshine hours			10.3	10.1	11.1	9.9	9.1	8.3
Pan evaporation		mm/day	5.7	4.8	5.4	5.2	4.3	3.8
Rainfall		mm	0.2	11.4	8	43.2	13.5	34.4

Table I-15 Record of gate operation at Roleng Chrey

June 1993 - July 1994

	number of gates open	height raised (m)	additional information
20-Jun-93	1	0.7	
25-Jun-93	1	1.0	
29-Jun-93	1	0.3	
02-Jul-93	1	2.0	
11-Jul-93	1	1.0	
13-Jul-93	1	0.6	
16-Jul-93	1	1.0	
20-Jul-93	1	1.0	
31-Jul-93	1	1.0	
01-Aug-93	1	1.0	
05-Aug-93	1	0.7	
12-Aug-93	1	1.2	
24-Aug-93	1	1.6	
27-Aug-93	1	1.2	
02-Sep-93	1	0.7	
05-Sep-93	1	0.7	
08-Sep-93	1	0.7	
11-Sep-93	1	0.7	
16-Sep-93	1	1.7	
20-Sep-93	1	0.8	
06-Oct-93	1	0.8	
09-Oct-93	1	0.8	
11-Oct-93	5	6.0	}
14-Oct-93	3	5.0	}
17-Oct-93	2	2.0	} One or more gates were open continuously in this period,
19-Oct-93	3	5.0	} but there is no detailed information
23-Oct-93	5	1.0	} on the precise times of gate adjustment.
27-Oct-93	3	5.0	}
05-Nov-93	1	0.5	}
11-Nov-93	1	0.5	
26-Mar-94	3	1.2	
27-Mar-94	1	1.2	
01-Apr-94	1	1.0	
09-Apr-94	1	0.8	
27-May-94	1	2.0	
10-Jun-94	1	1.2	
01-Jul-94	1	0.8	
09-Jul-94	1	0.8	
12-Jul-94	2	1.3	first gate opened at 09:30, second gate at 17:00
13-Jul-94	2	1.3	second gate closed at 09:15
14-Jul-94	1	0.6	first gate lowered to 60 cm at 09:15, closed at 13:00
14-Jul-94	1	1.2	gate opened at 22:00
15-Jul-94	2	1.2, 1.8	second gate opened 06:00
16-Jul-94			closed all gates 08:00 depth 1.0m
18-Jul-94	1	0.7	}
19-Jul-94	1	0.7	} continuous operation
20-Jul-94	1	0.7	}
21-Jul-94	1	0.7	}
22-Jul-94			gate closed 09:00 depth 1.2 m
23-Jul-94	1	0.8	} gate opened 21:15
24-Jul-94	1	0.8	}
25-Jul-94			gate closed 09:00 depth 1.2 m

Notes: Except where shown above, gates are opened for periods of less than 24 hours, and usually for less than 12 hours.
When more than one gate is open, the opening height is not necessarily the same for each open gate.

Table I-16 Dates of opening of the left bank main canal gate at Roleng Chrey

December 1993 - July 1994

16-Dec-93	24-Jan-94	10-Feb-94	03-Mar-94	03-Apr-94	02-May-94	01-Jun-94
17-Dec-93		12-Feb-94	05-Mar-94	09-Apr-94	04-May-94	05-Jun-94
19-Dec-93		19-Feb-94	06-Mar-94	17-Apr-94	15-May-94	06-Jun-94
23-Dec-93		24-Feb-94	07-Mar-94	18-Apr-94		16-Jun-94
			10-Mar-94	21-Apr-94		17-Jun-94
			11-Mar-94	22-Apr-94		21-Jun-94
			12-Mar-94	24-Apr-94		
			13-Mar-94	26-Apr-94		
			15-Mar-94	30-Apr-94		
			21-Mar-94			
			25-Mar-94			
			26-Mar-94			
			31-Mar-94			

Notes: This record includes only occasions when the operator opened the gate, it does not include occasions when the farmers themselves opened the gate.

On each occasion, one gate is opened by 30-40 cm for 8-10 hours.

Table I-17 Maximum discharge through Roleng Chrey gates (m3/s)

Gate opening (m)	Number of gates open: 1	2	3	4	5
0.00	0	0	0	0	0
0.10	9	17	26	35	44
0.25	22	43	65	86	108
0.50	43	85	128	171	214
0.75	63	127	190	254	317
1.00	84	167	251	335	418
1.25	104	207	311	414	518
1.50	123	246	369	492	615
2.00	161	322	482	643	804
2.50	197	395	592	789	986
3.00	232	465	697	930	1162
3.50	266	533	799	1066	1332
4.00	299	599	898	1198	1497
4.50	331	663	994	1325	1657
5.00	362	725	1087	1449	1812
5.50	392	785	1177	1570	1962
6.00	422	844	1265	1687	2109
6.50	450	901	1351	1802	2252

Note: These discharges are calculated assuming free flowing conditions.
For discharges above 600 m3/s, it is likely that drowned flow conditions will apply, and that discharge will be less than that shown above.

Table I-18 Comparison of the time of events following gate operations at Roleng Chrey

July 1994

	Gate operations							Thnuos Luong		Prey Phdau	
	gate number	open/adjust time		height (m)	close time		water level (m)	start of flood	start of recession	start of flood	start of recession
09-Jul-94	1	10:00	est	0.8				09:45		13:30	
10-Jul-94	1	open all day	?	0.8							
11-Jul-94	1		?	0.8	08:00	est	?		***		21:00
12-Jul-94	1	09:30		1.3				11:00		15:30	
	2	17:00		1.3				17:00		***	
13-Jul-94	1	open all day		1.3							
	2			1.3	09:15		?		***		***
14-Jul-94	1	09:15		0.6	13:00				09:30		19:30
	1	22:00		1.2				22:45		03:30 F	
15-Jul-94	1	open all day		1.2							
	2	06:00	**	1.8				06:30		13:30	
16-Jul-94	1			1.2	06:00		1.0		10:00		17:00
	2			1.8	06:00						
18-Jul-94	1	10:00	est	0.7				11:30		***	
19-Jul-94	1	open all day		0.7							
20-Jul-94	1	open all day		0.7							
21-Jul-94	1	open all day		0.7							
22-Jul-94	1			0.7	09:00		1.2		19:00		05:00 F
23-Jul-94	1	21:15		0.8				22:15		03:30 F	
24-Jul-94	1	open all day		0.8							
25-Jul-94	1			0.8	09:00		0.8		***		19:30

Notes
Times of events at Thnuos Luong and Prey Phdau are accurate.
Times of gate operations are approximate except for the opening on 12 July which was observed.
When times of gate operations are not known, assumed times are indicated by "est"
*** indicates that the events could not be defined precisely from the charts.
** indicates gate opening at the request of the gauging team.
F indicates the following day

Table I-19 Summary of daily volumes - Prek Thnot - July 8-20 1994 (mcm)

		8 July	9 July	10 July	11 July	12 July	13 July	14 July	15 July	16 July	17 July	18 July	19 July	20 July	Total
Peam Khley	observed	1.6	3.2	2.7	3.5	5.9	7.2	6.8	5.3	3.4	2.6	2.2	2.1	3.5	50.0
Roleng Chrey	gate release	0.0	4.1	4.6	1.1	7.9	6.8	4.1	9.2	1.1	1.1	3.9	3.8	2.9	50.7
Thnuos Luong	observed	0.7	2.1	3.7	1.8	4.1	8.0	4.5	8.5	2.5	1.1	1.1	3.9	2.9	44.8
	routed release	0.0	3.2	4.8	1.8	5.8	7.9	4.0	9.5	1.9	0.7	3.6	4.1	3.0	50.3
Prey Phdau	observed	0.5	1.0	3.2	3.4	1.4	5.2	6.2	5.1	5.6	1.0	0.7	2.1	3.7	39.1
	routed release	0.0	1.0	4.2	3.5	2.4	7.9	5.8	7.1	5.4	1.4	2.2	3.9	3.5	48.3

Table I-20 Comparison of expected and actual estimated diversions above Roleng Chrey (mcm)

		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Estimated upstream diversions									
Number of days canal gate open (1993-94)		4	1	4	13	9	3	6	0
Volume diverted	LB main canal	1.0	0.2	1.0	3.1	2.2	0.7	1.4	0.0
	RB canals	2.2	2.2	2.0	2.2	2.1	2.2	2.1	2.2
	Total	3.1	2.4	2.9	5.3	4.3	2.9	3.5	2.2
Expected upstream irrigation demand									
Monthly average (10 year design period)		3.7	1.9	0.0	0.0	2.7	4.0	2.3	2.7
Excess diversion		0.0	0.5	2.9	5.3	1.5	0.0	1.2	0.0
Flow above Roleng Chrey Monthly average (10 year design period)		64	9.3	5.2	4.5	9.5	38	79	130
Proportion diverted (%)		5	26	56	100	45	8	4	2

Note: The calculation of actual diversions is subject to a wide margin of error. The figures are only indicative of possible diversions.
The main canal gate is assumed to pass 0.24 mcm per day of opening. The right bank canals are assumed to flow for 90 % of the time.
The expected diversions refer to 1400 ha of irrigation following the Euroconsult plan as described in Chapter 5.

Table I-21 Comparison of flood estimates

Consultant	Year	Mean annual flood (m3/s)	Flood estimates for given return period (m3/s) T=10	T=20	T=25	T=50	T=100	T=500	T=1000
Floods at the dam site									
SMHEA	1965			840		960	1060	1300	
SMEC	1992			930		1350	1800	3600	
JICA Study	1994	490	860	1100		1500	1900	3200	3900
Floods attenuated by the proposed dam									
Euroconsult	1992			330		500	610	1540	2200
JICA Study	1994			600		820	1100	1800	2200
Floods at Tuk Thla/Kompong Tuol									
SMEC	1993			4000		6000	8000		
Floods on the tributaries									
Euroconsult	1992	O Krang Ambel	153		230		345		
		Stung Toch	54		81		121		
		Stung Tonle Bati	103		154		231		

Notes: The mean annual flood is derived from the series of annual maximum floods recorded at Anlong Touk and Thnuos Luong between 1960 and 1970, adjusted to allow for the data being in terms of mean daily flow and to allow for there being no severe floods in the period.
In the case without dam, both Euroconsult and the JICA study recommend that floods estimated for the dam site should be used for design at Tuk Thla / Kompong Tuol.
The estimates for Stung Toch refer only to floods from its own catchmment area, not transfers from Prek Thnot.

Table I-22 Discharges through the main railway bridges

Upstream water level (m)	Prek Thnot main bridge (m3/s)	Prek Thnot by-pass bridge (m3/s)	Stung Toch (m3/s)	Total (m3/s)	Percentage through Stung Toch
10.0	14	0	0	14	0
10.5	87	12	0	98	0
11.0	192	42	0	234	0
11.5	321	84	0	405	0
12.0	472	134	0	606	0
12.5	640	192	7	838	1
13.0	825	256	43	1124	4
13.5	1024	326	97	1447	7
14.0	1238	401	164	1803	9
14.5	1465	481	242	2188	11

Note: These figures are subject to considerable uncertainty and should be regarded only as indicating the relative flows through the different bridges.
The calculation assumes 'free-flowing' conditions.

Figures

Figure I-1 Water balance components - Prek Thnot at Anlong Touk

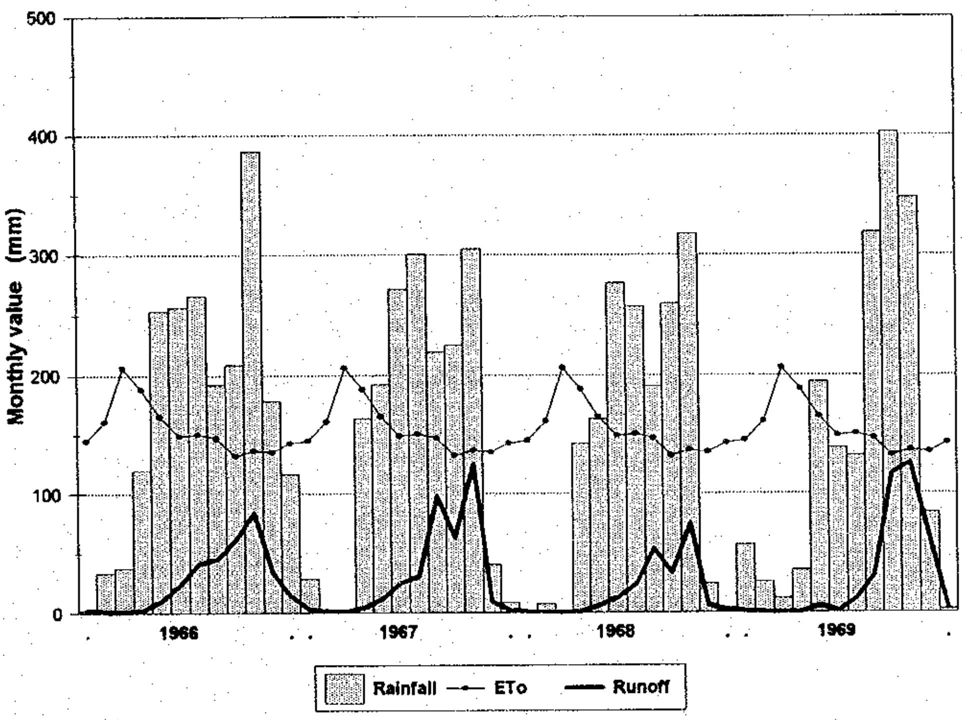


Figure I-2 Regional comparison of mean monthly rainfall

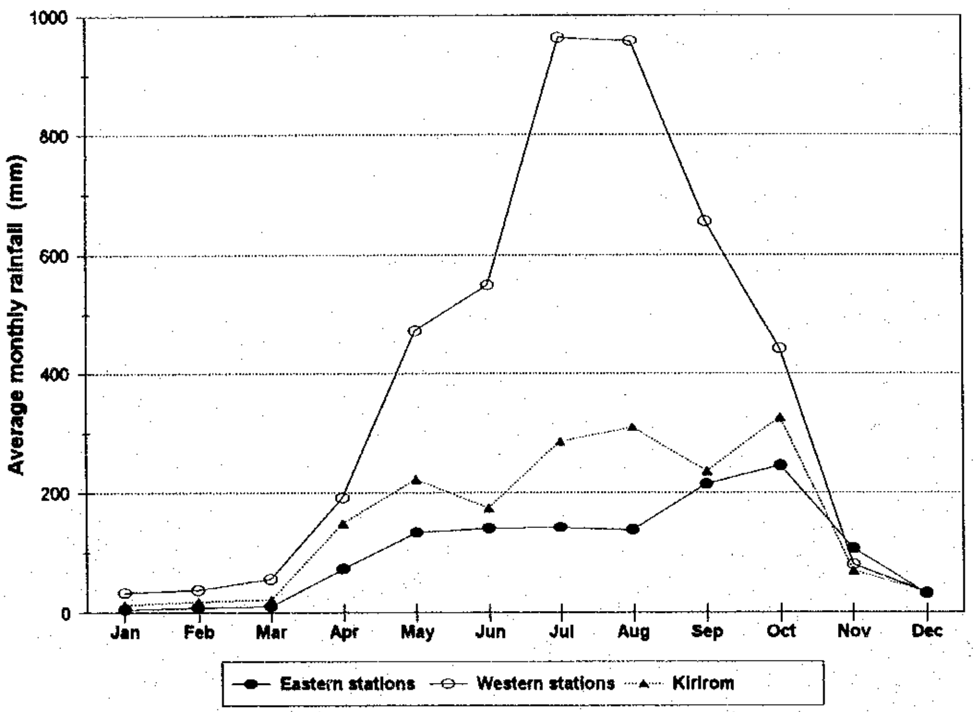


Figure I-3 Regional comparison of the number of raindays

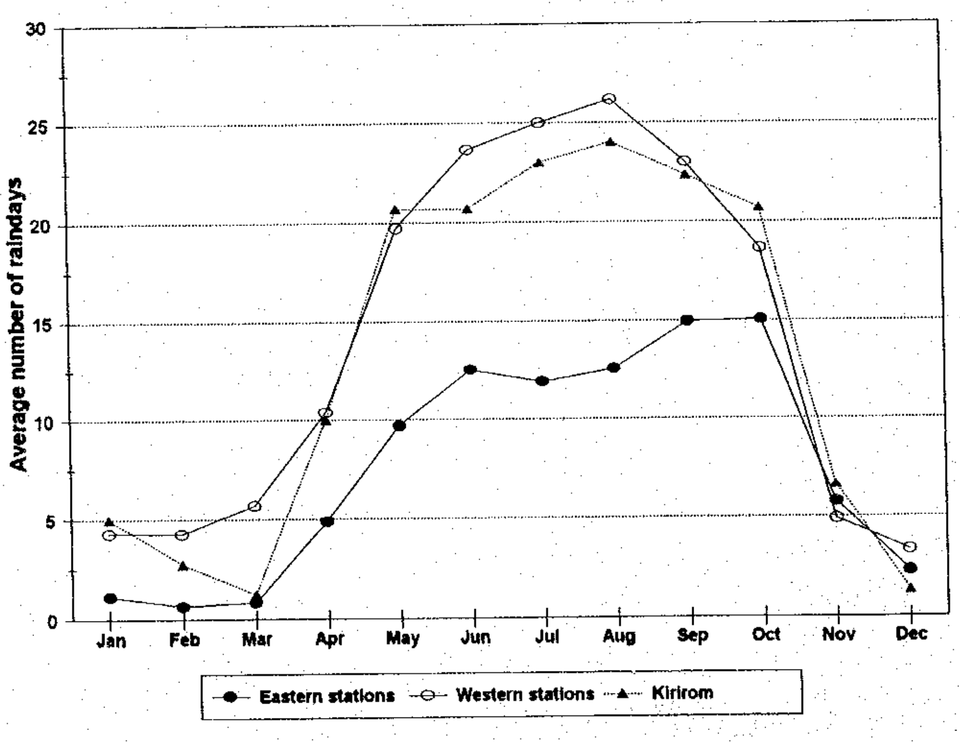


Figure I-4 Regional comparison of average rainfall intensity

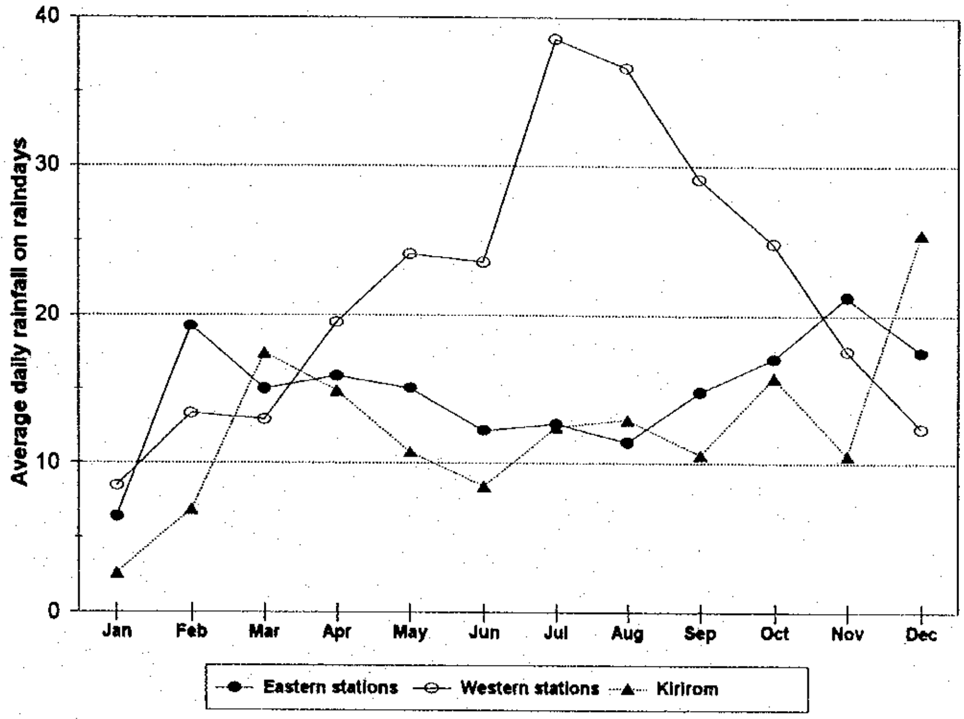


Figure I-5 Variation of mean annual rainfall with longitude

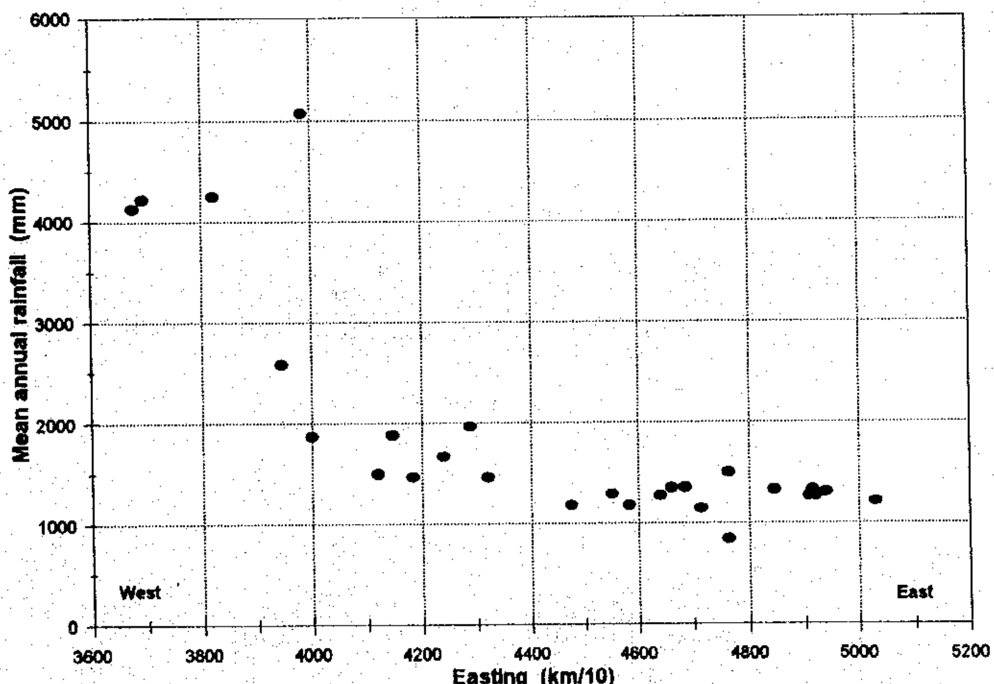


Figure I-6 Spatial correlation of annual rainfall

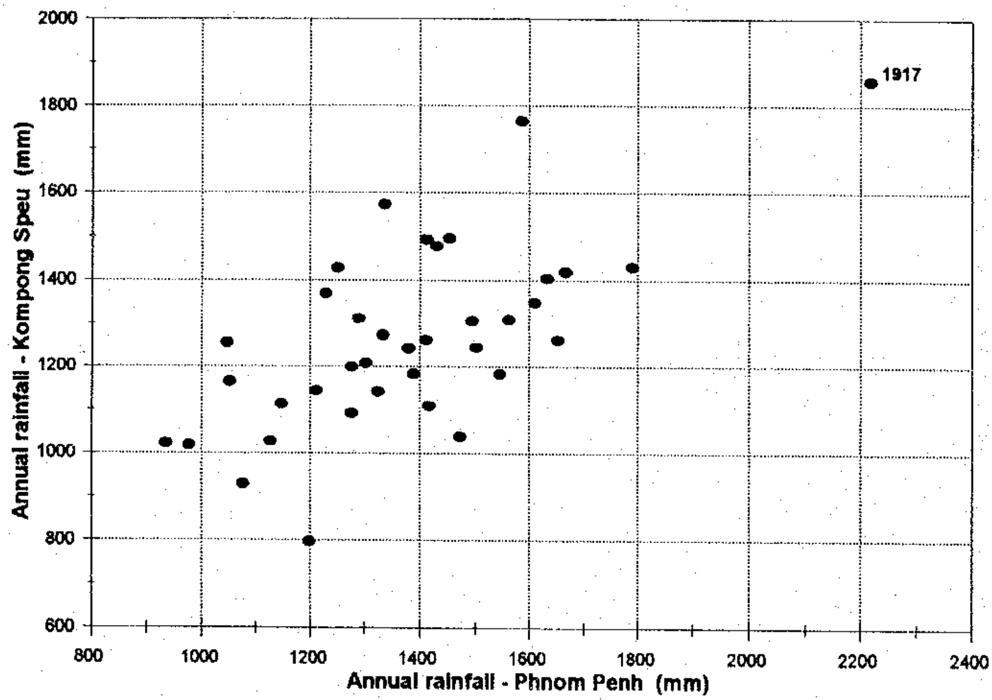


Figure I-7 Time series of May-November rainfall

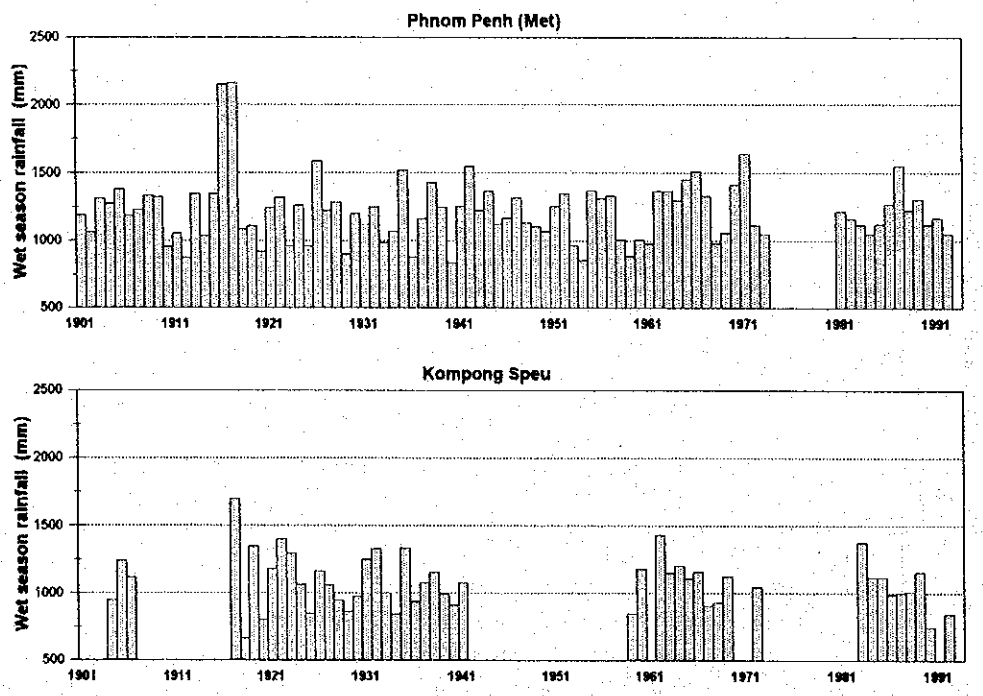


Figure I-8 Proportion of annual rainfall occurring in May to November

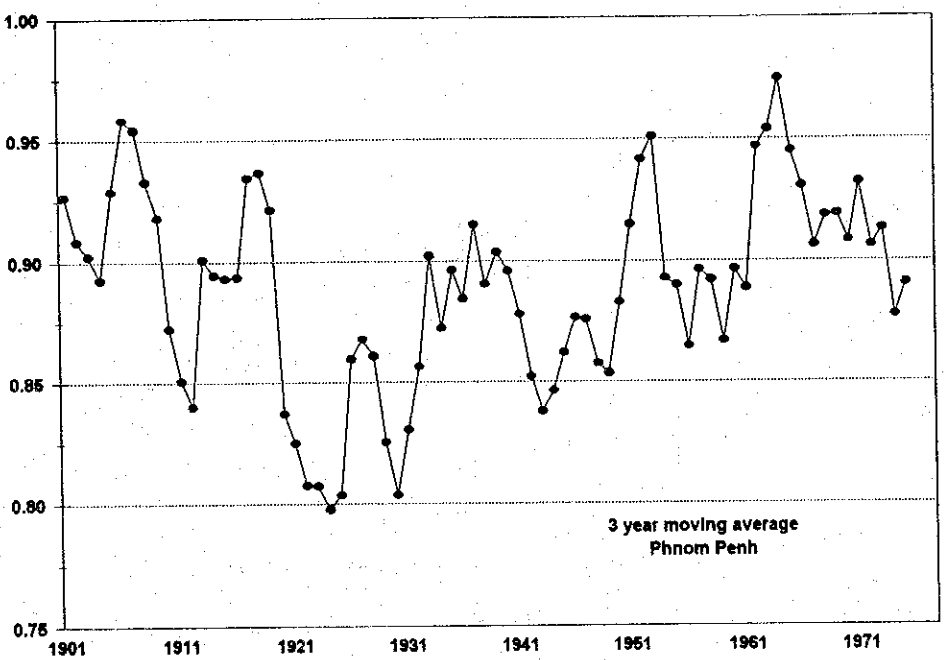


Figure I-9 Number of raindays related to monthly rainfall

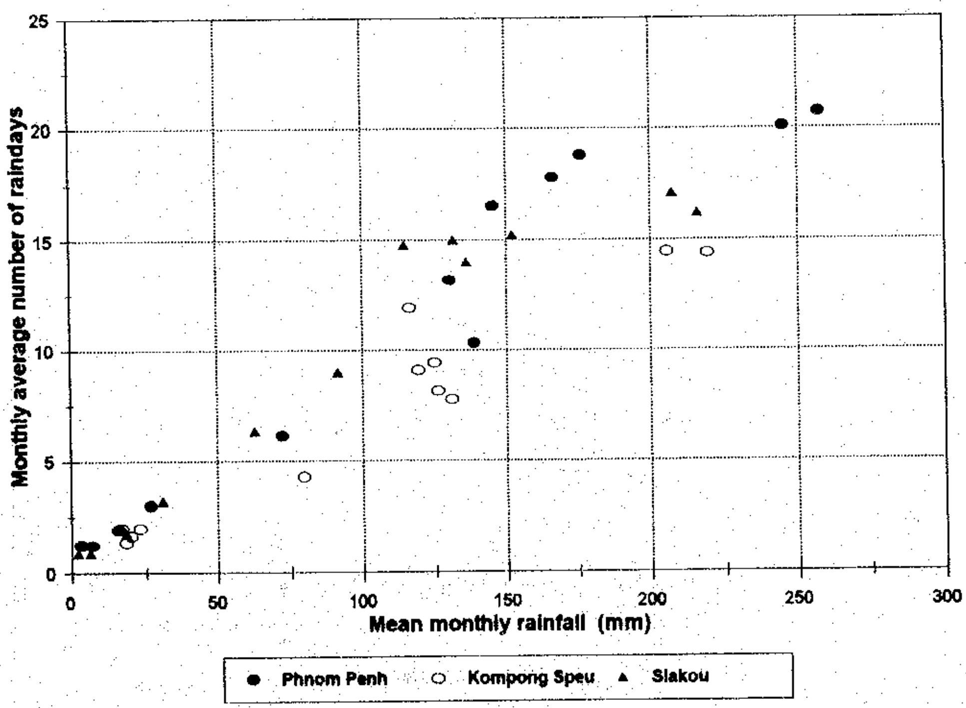


Figure I-10 Frequency analysis of daily rainfall

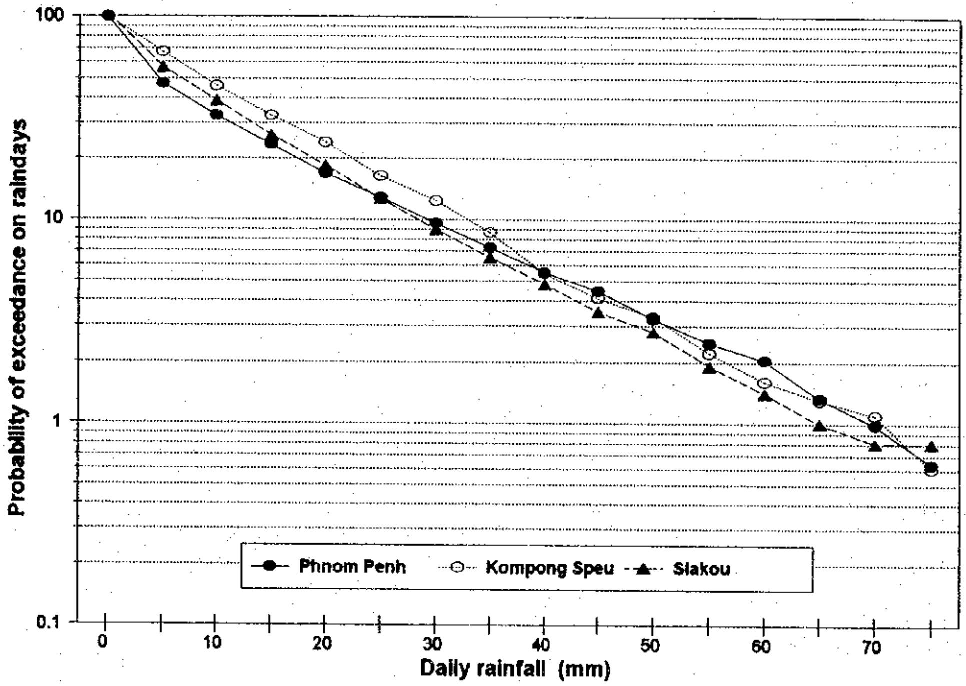


Figure I-11 Frequency curves for annual maximum n-day rainfalls

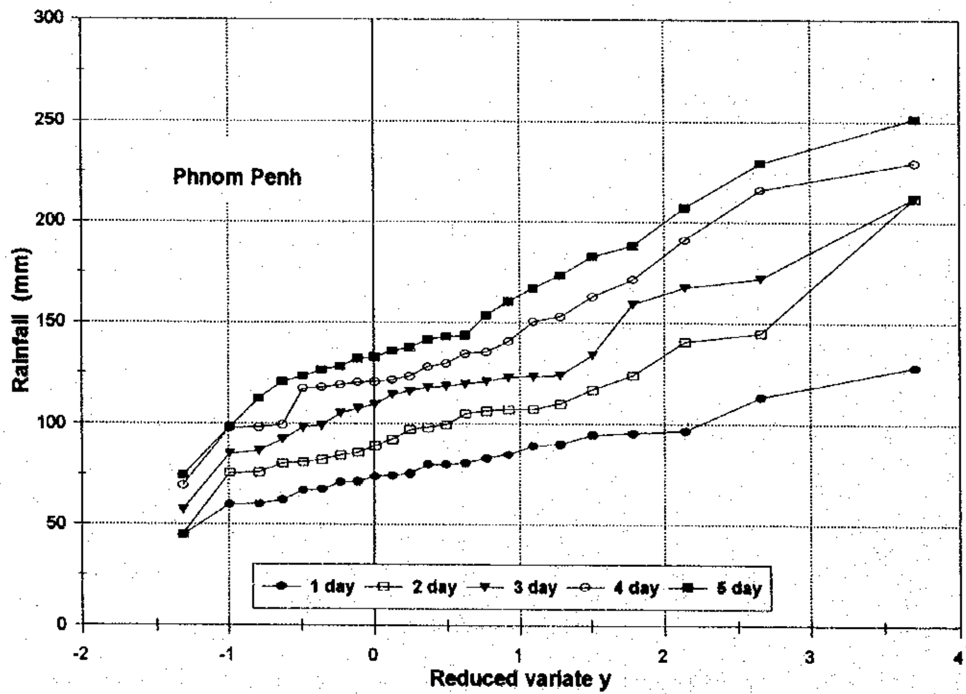


Figure I-12 Review of rating curve for Prek Thnot at Anlong Touk

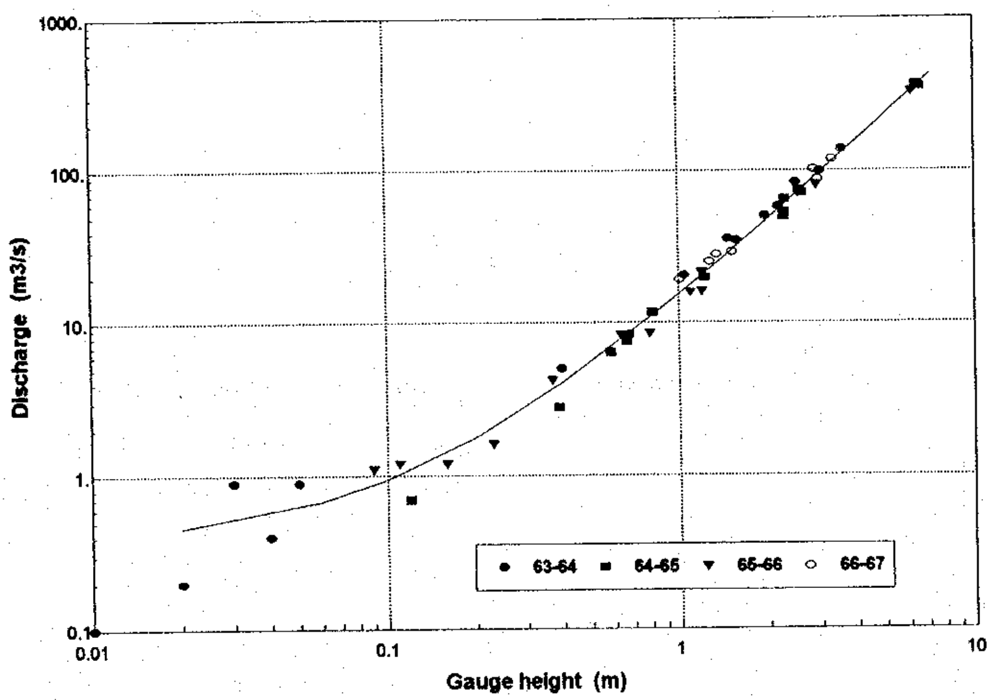


Figure I-13 Review of rating curve for Prek Thnot at Thnuos Luong

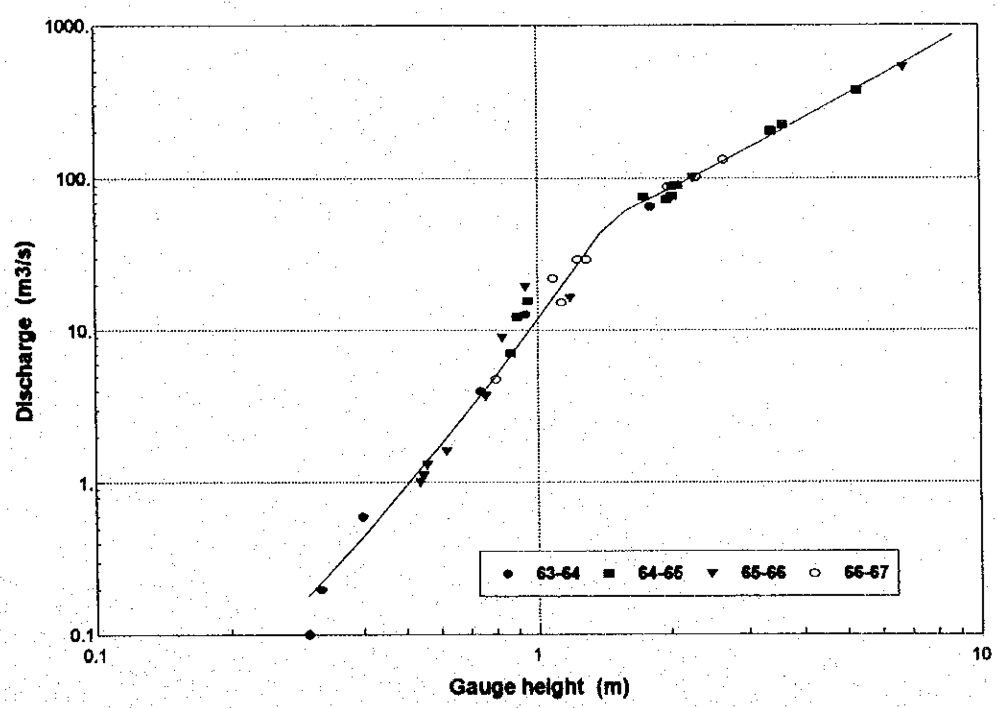


Figure I-14 Implied increase in flow between Anlong Touk and Thnuos Luong

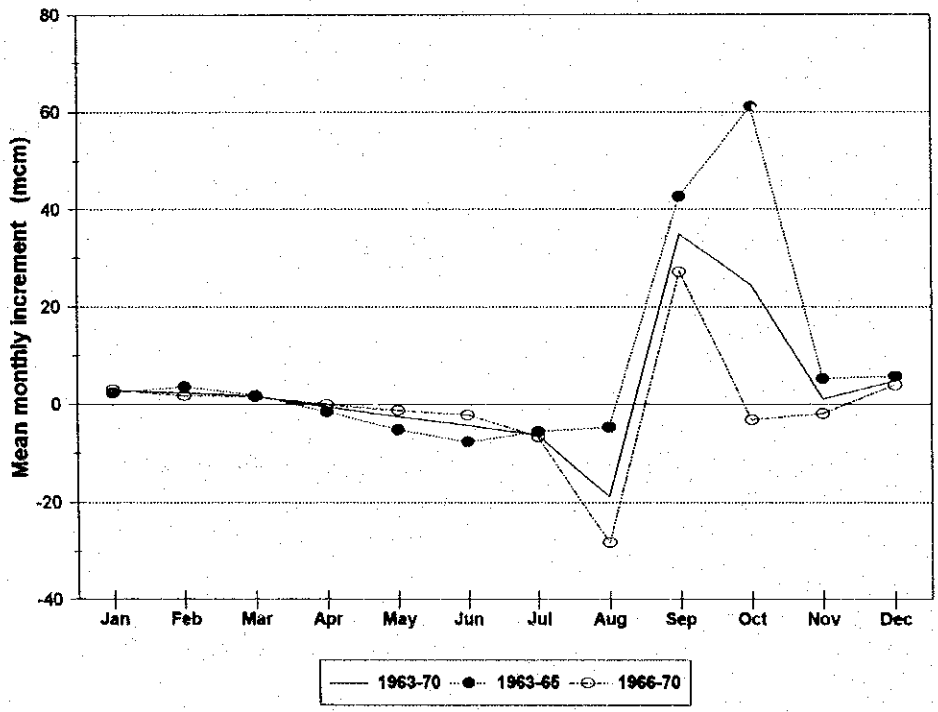


Figure I-15 Annual hydrographs for Prek Thnot at Anlong Touk (m3/s)

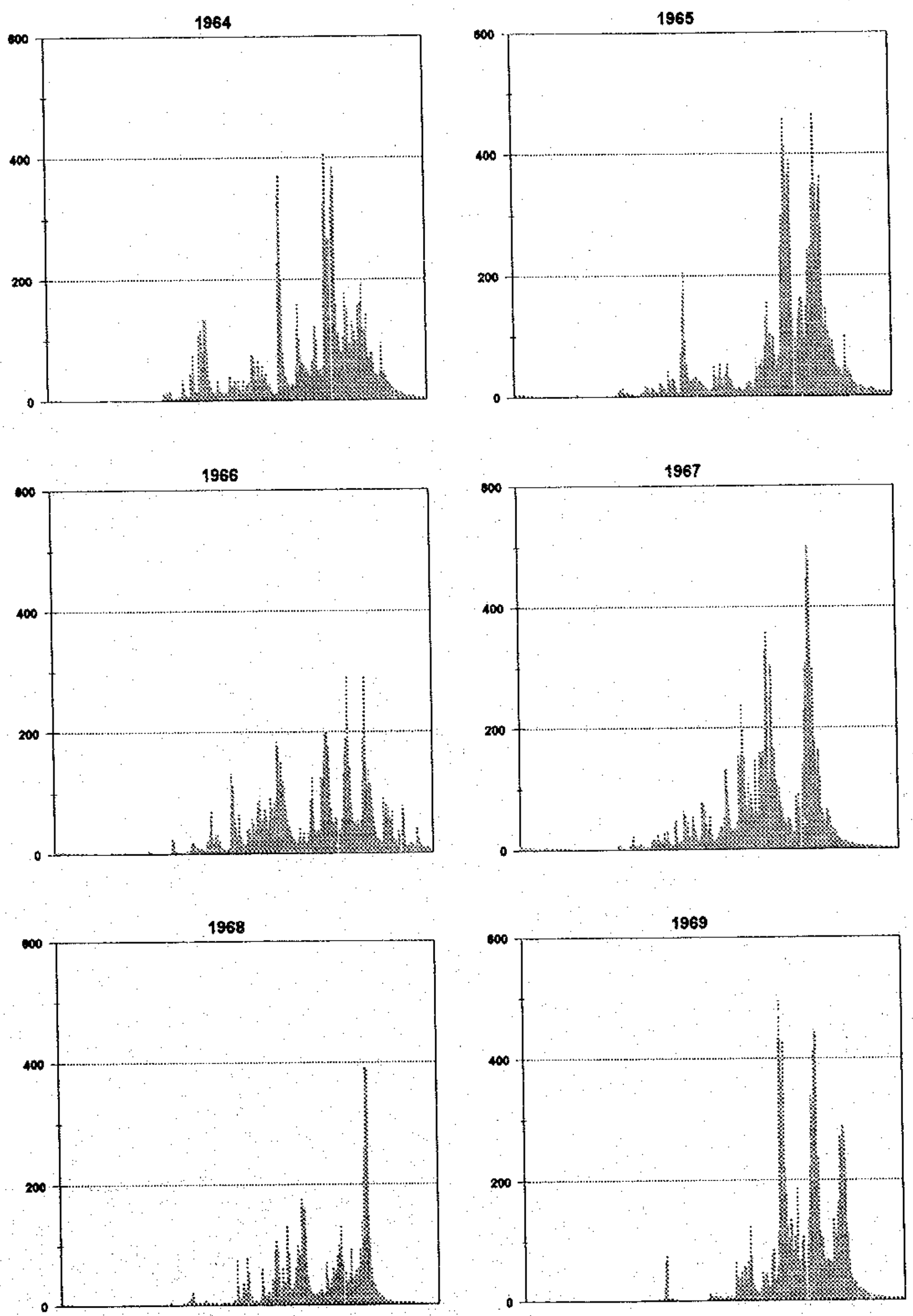


Figure I-16 Log-scaled annual hydrograph for Prek Thnot at Anlong Touk

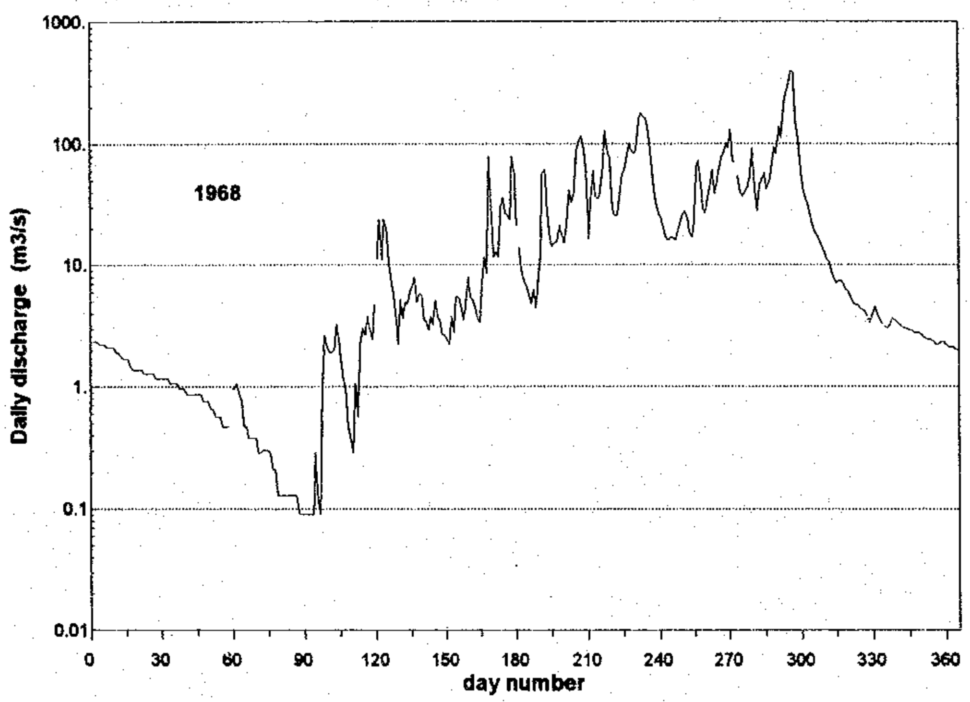


Figure I-17 Typical flow duration curves for Prek Thnot at Anlong Touk

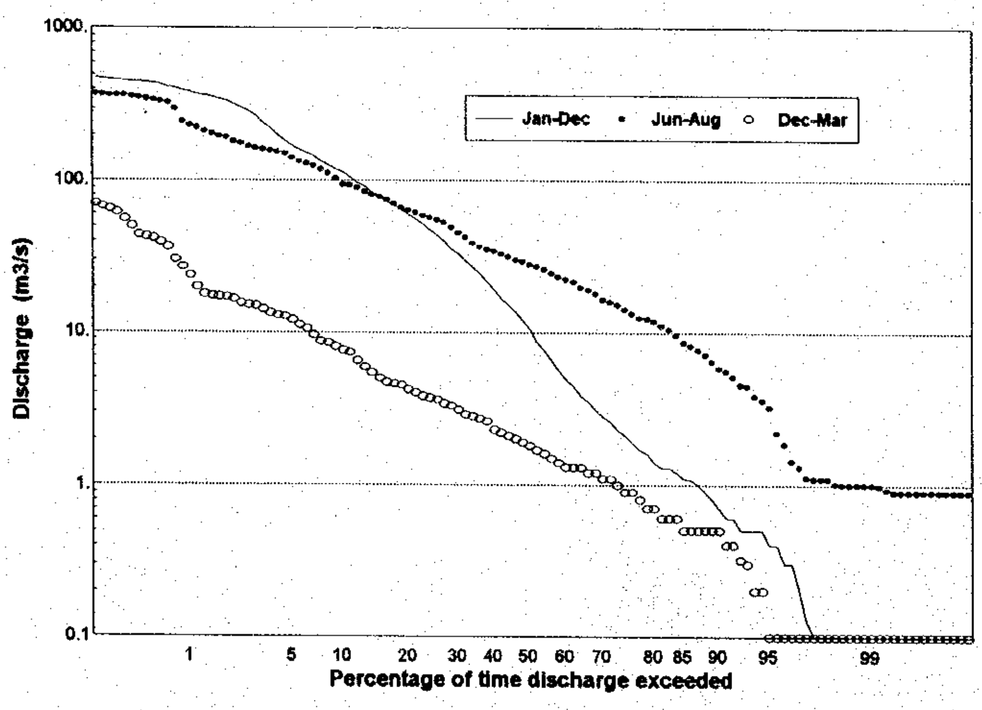


Figure I-18 Runoff model fitted to Prek Thnot at Anlong Touk

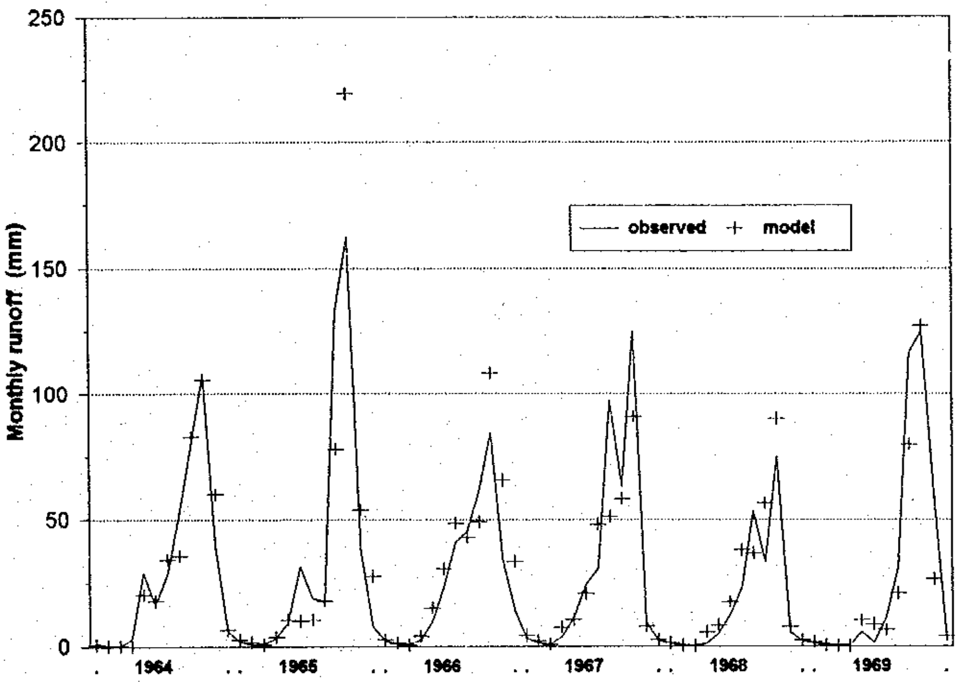


Figure I-19 Runoff model fitted to Prek Thnot at Anlong Touk

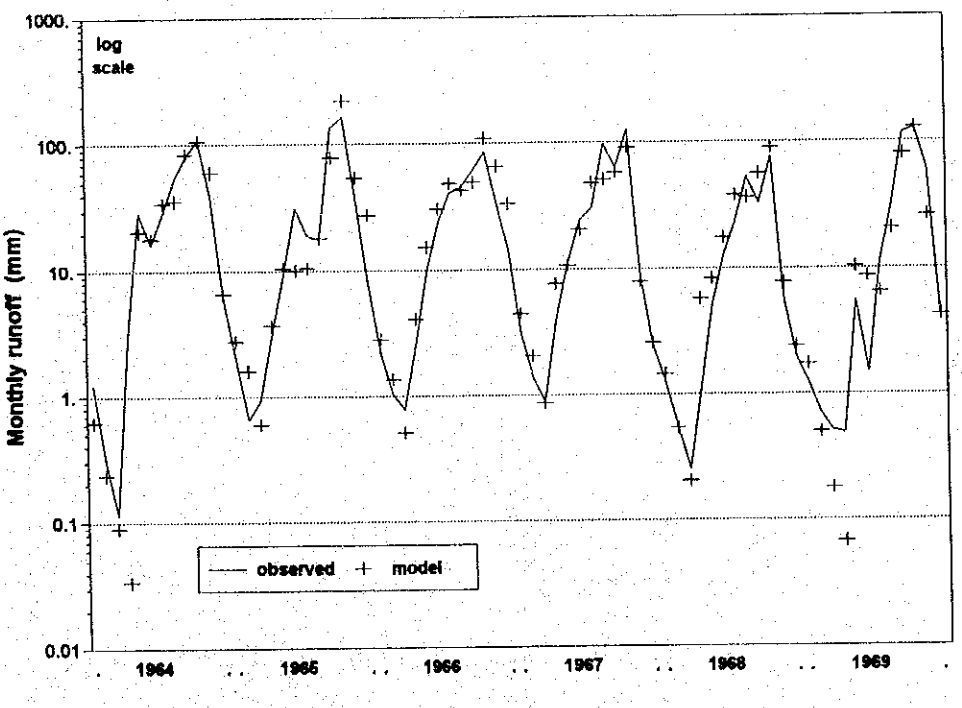


Figure I-20 Model-predicted average monthly runoff distribution

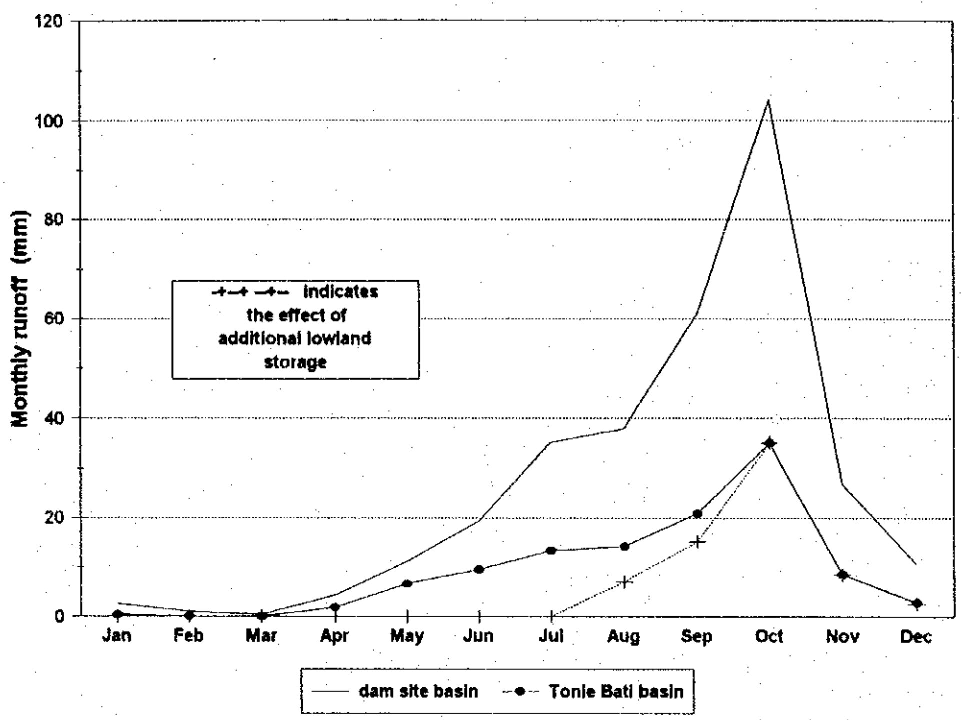


Figure I-21 Water level in Tonle Bassac below Phnom Penh

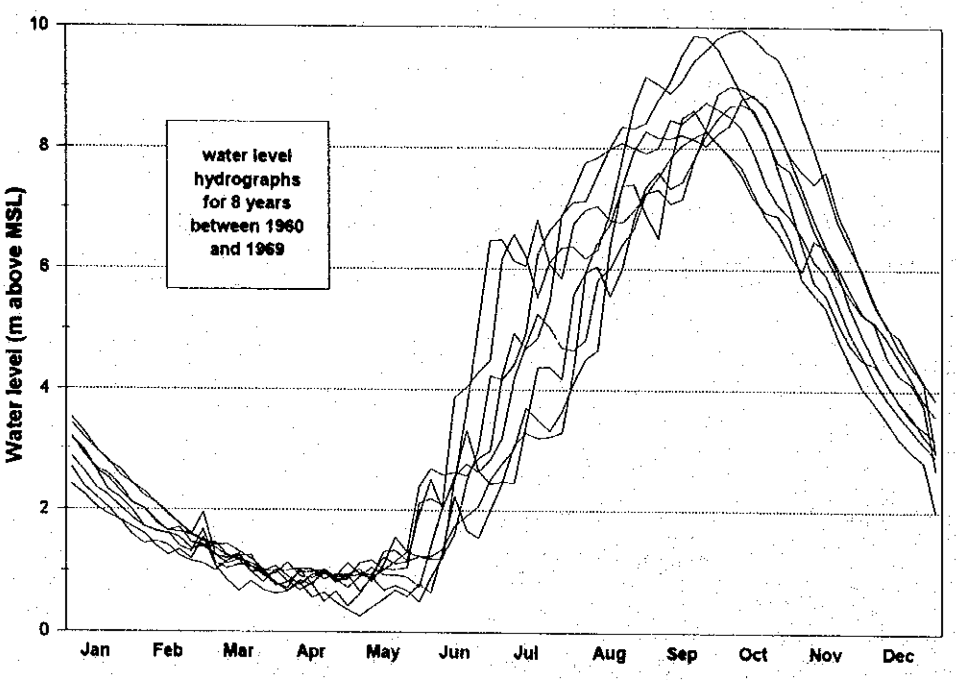


Figure I-22 Monthly variation of reference crop transpiration

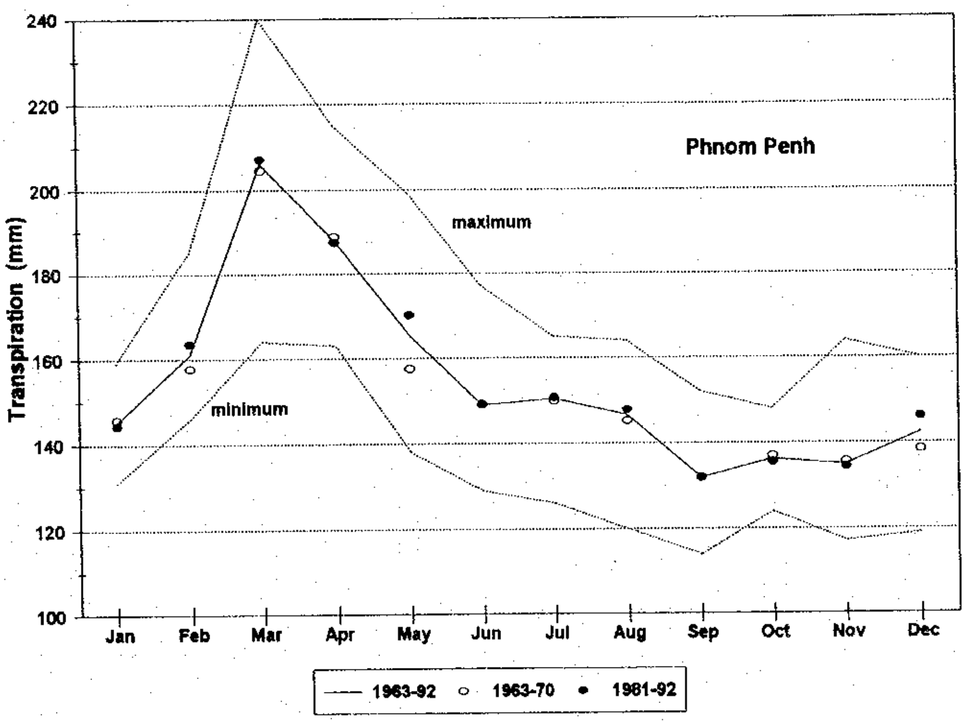


Figure I-23 Comparison of reference crop transpiration estimates

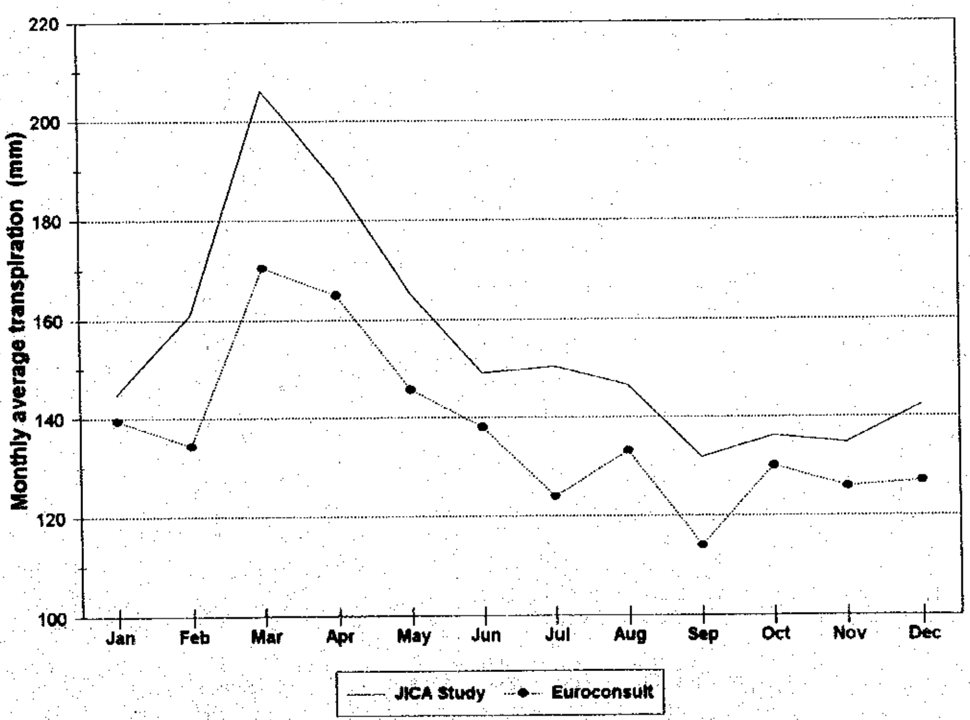


Figure I-24 Comparison of pan evaporation and potential transpiration

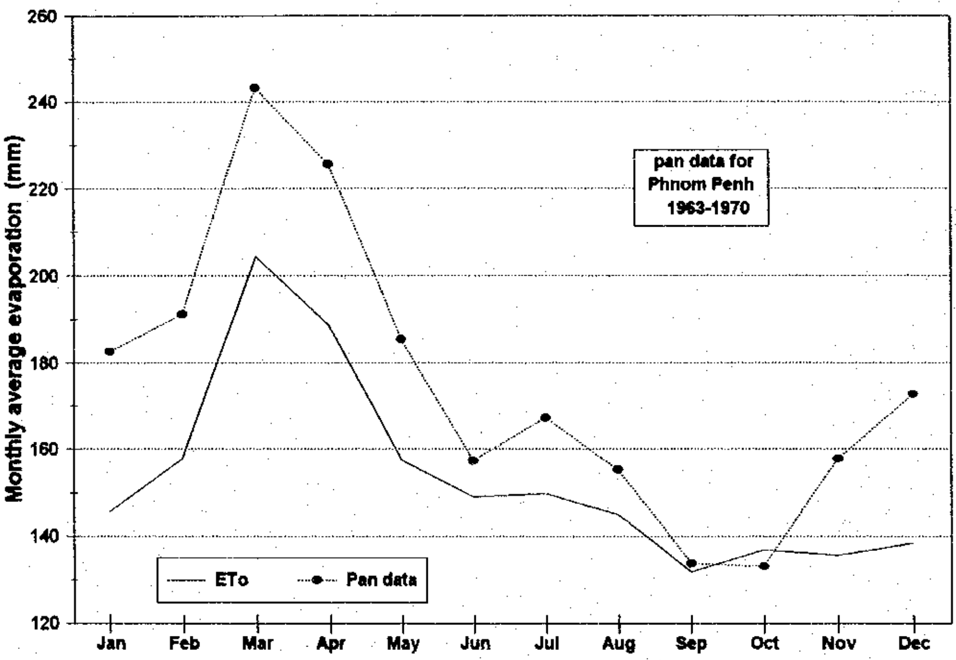


Figure I-25 Comparison of pan evaporation between stations

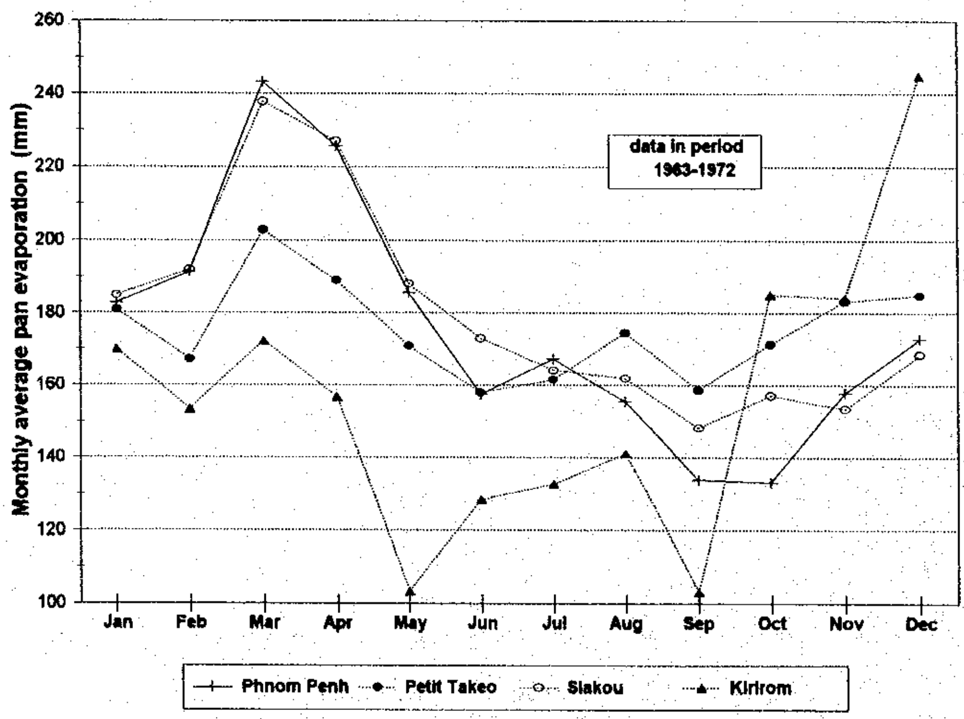


Figure I-26 Model-derived 15-day effective rainfall

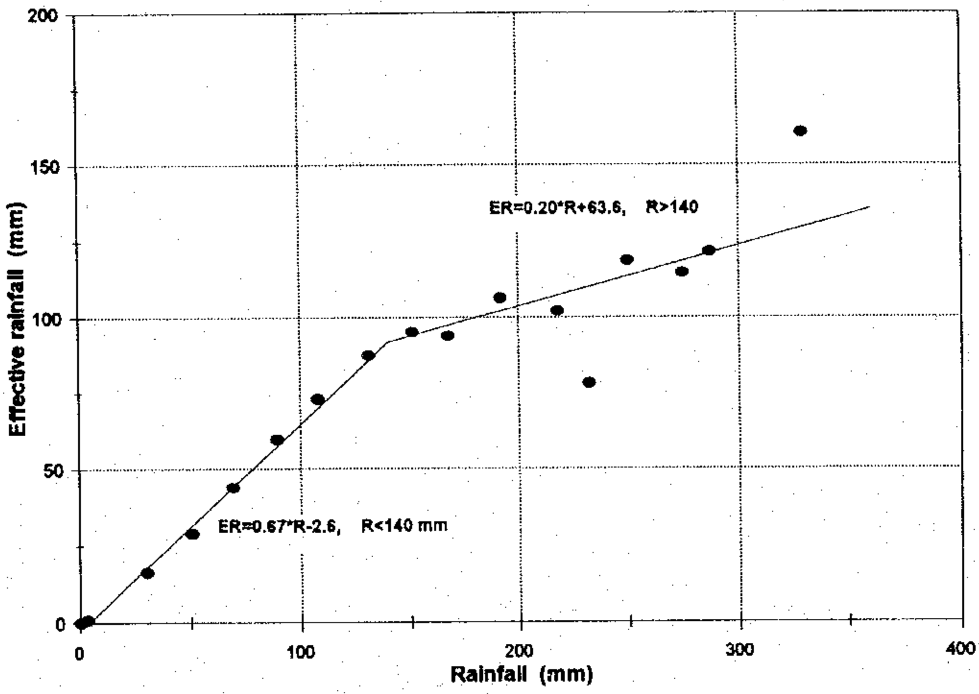


Figure I-27 Comparison of probability distribution of annual runoff series

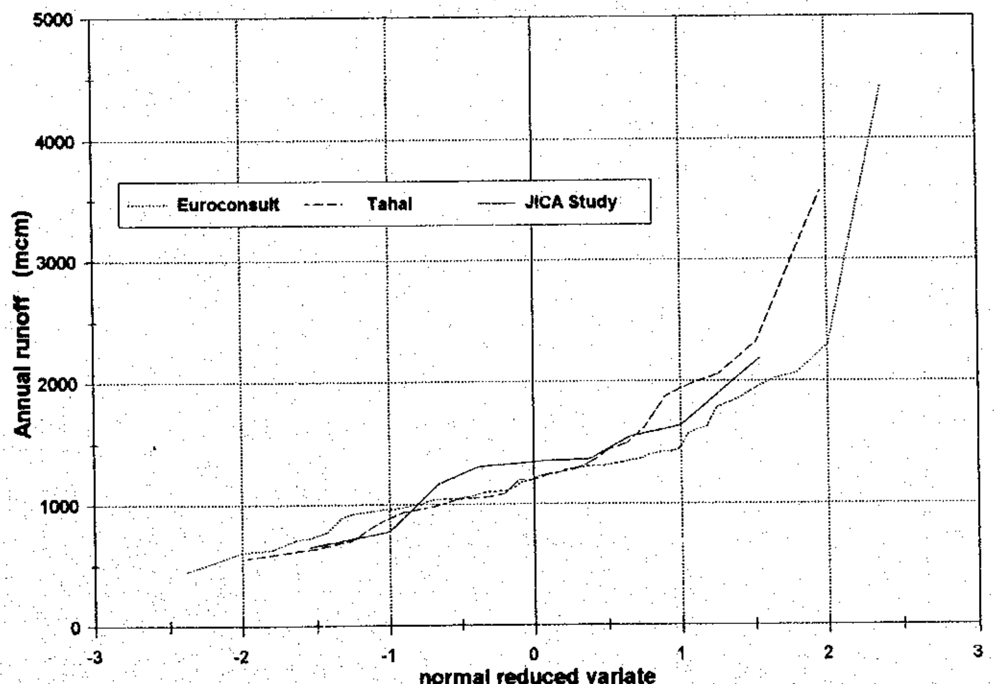


Figure I-28 Provisional rating curve for Prek Thnot at Peam Khley

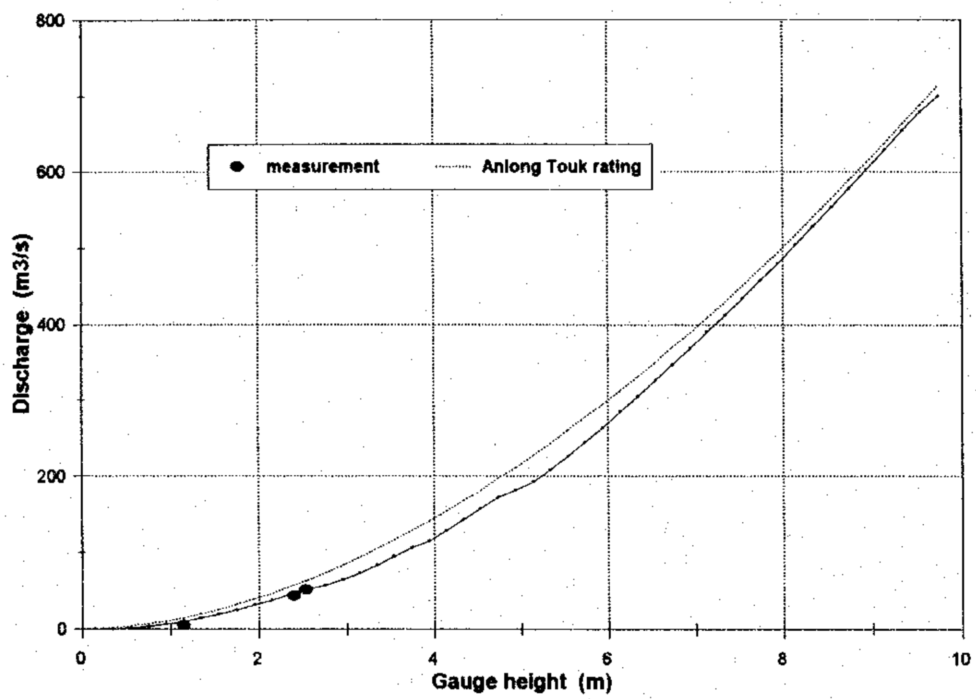


Figure I-29 Provisional rating curve for Prek Thnot at Prey Phdau

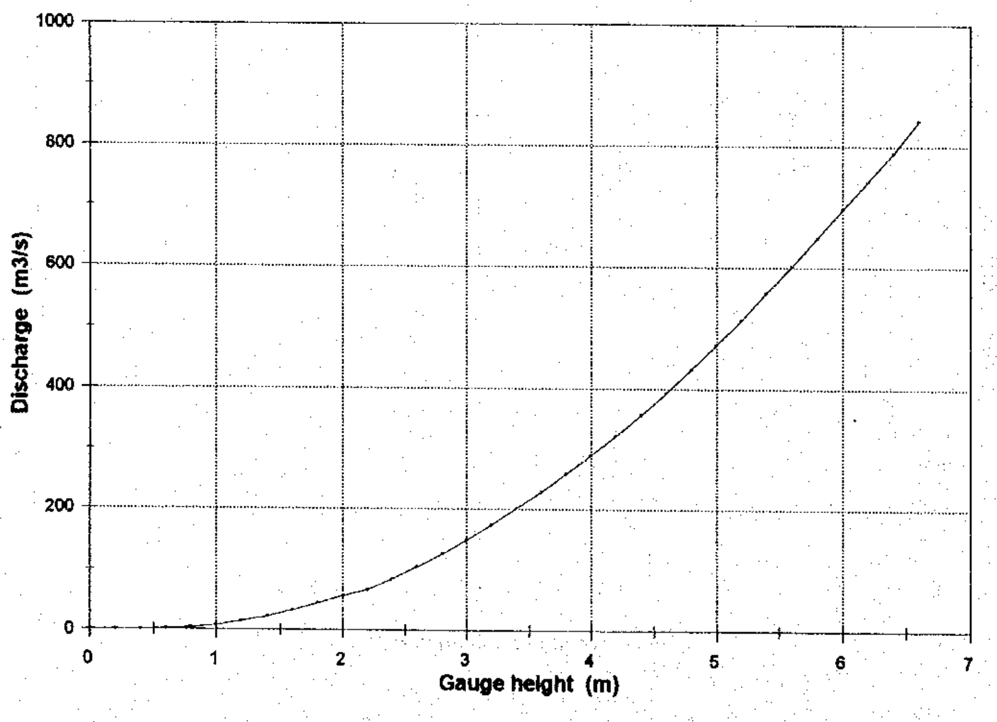


Figure I-30 Description of observed discharges - Prek Thnot at Thnuos Luong

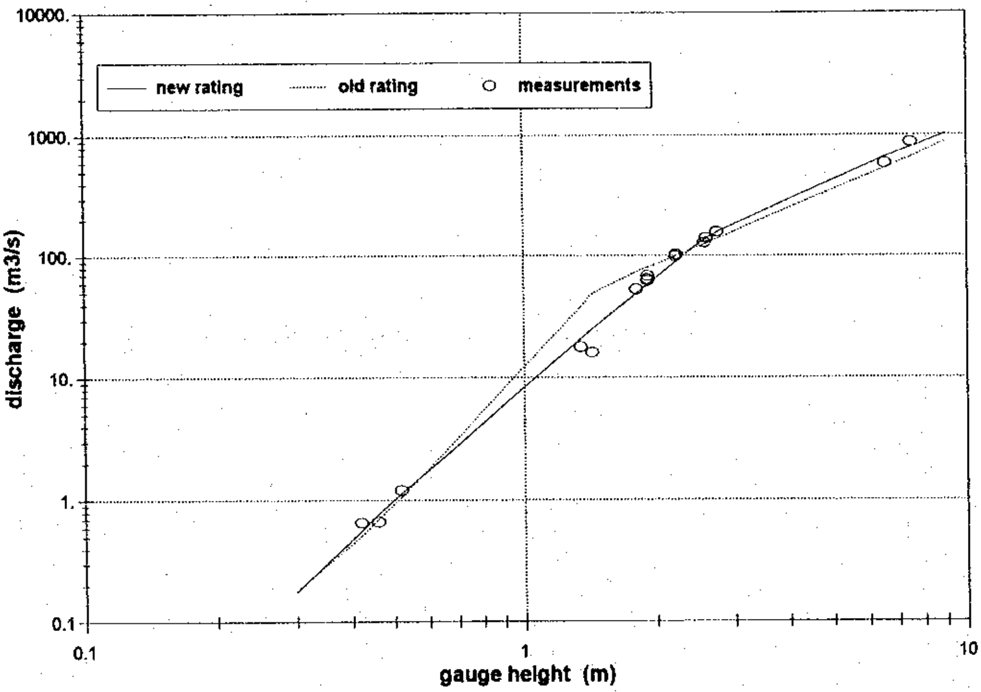


Figure I-31 Provisional rating curve for Prek Thnot at Thnuos Luong

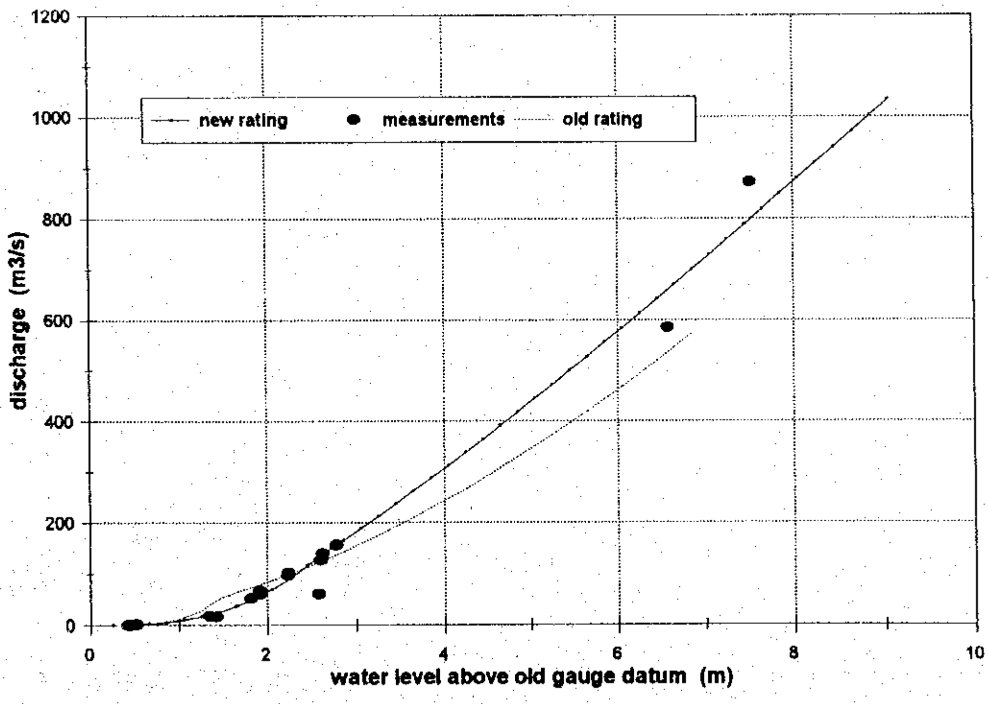


Figure I-32 Reconciliation of levels at Thnuos Luong

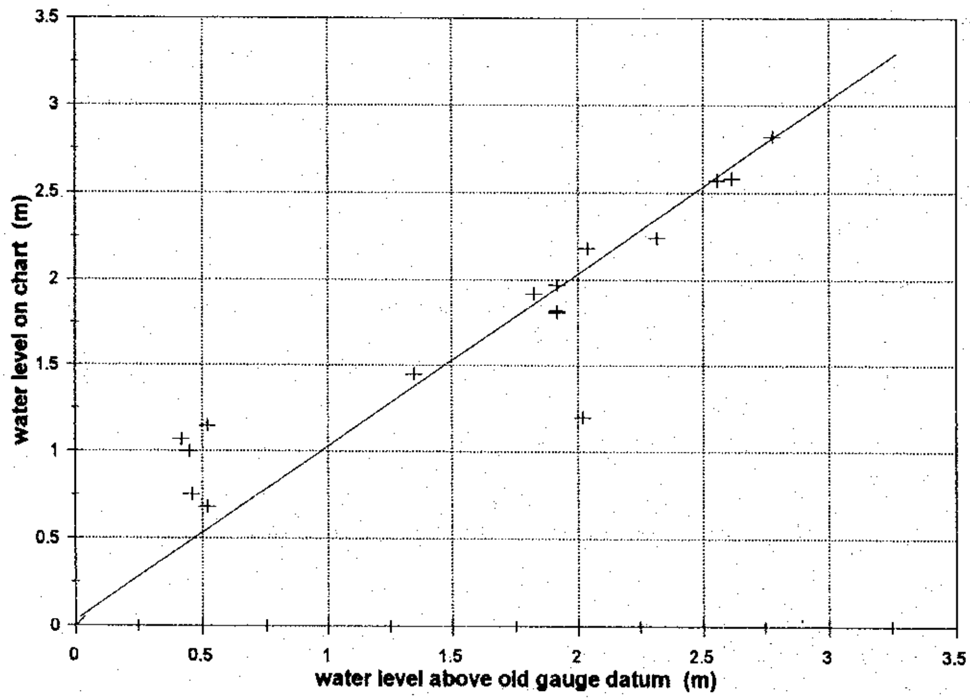
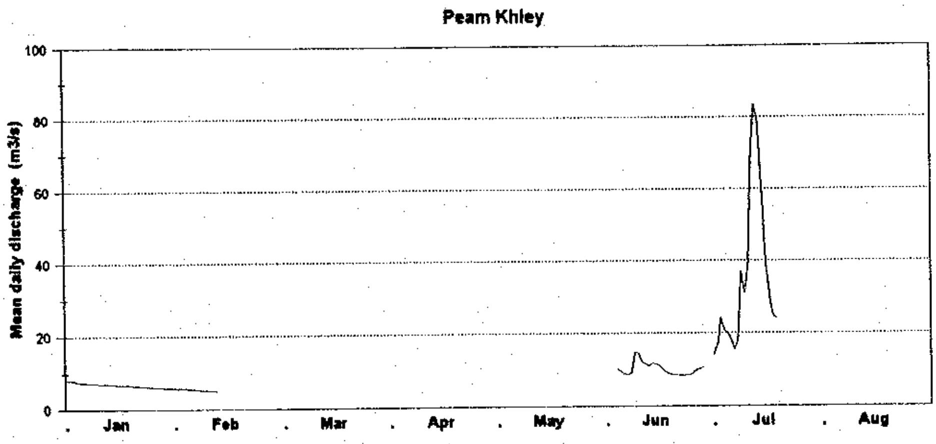
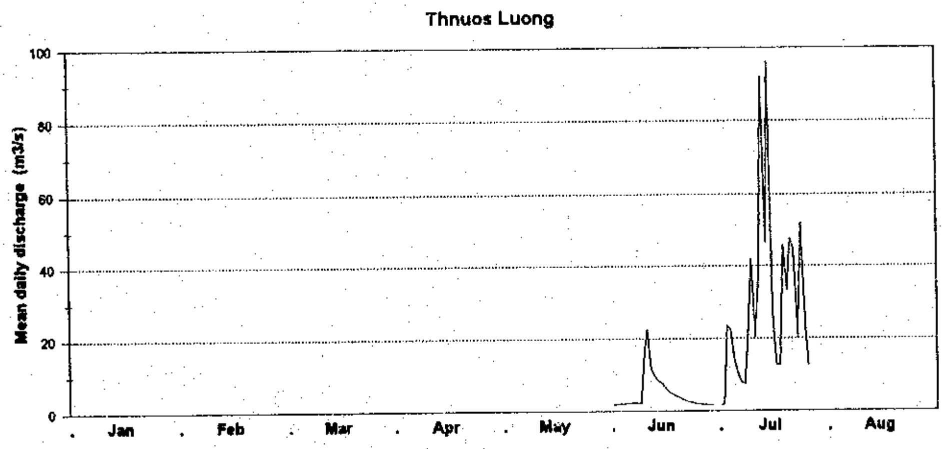


Figure I-33 Daily mean discharge in Prek Thnot - January to August 1994





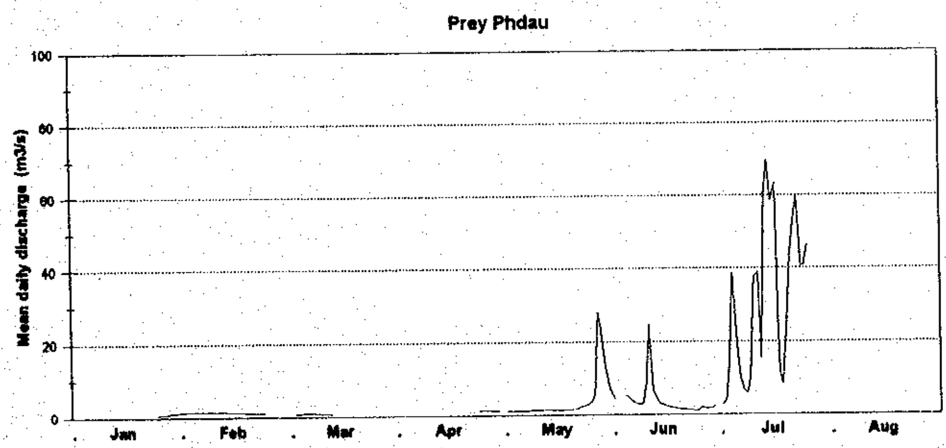


Figure I-34 Water level hydrographs - O Andong and Tonle Bassac

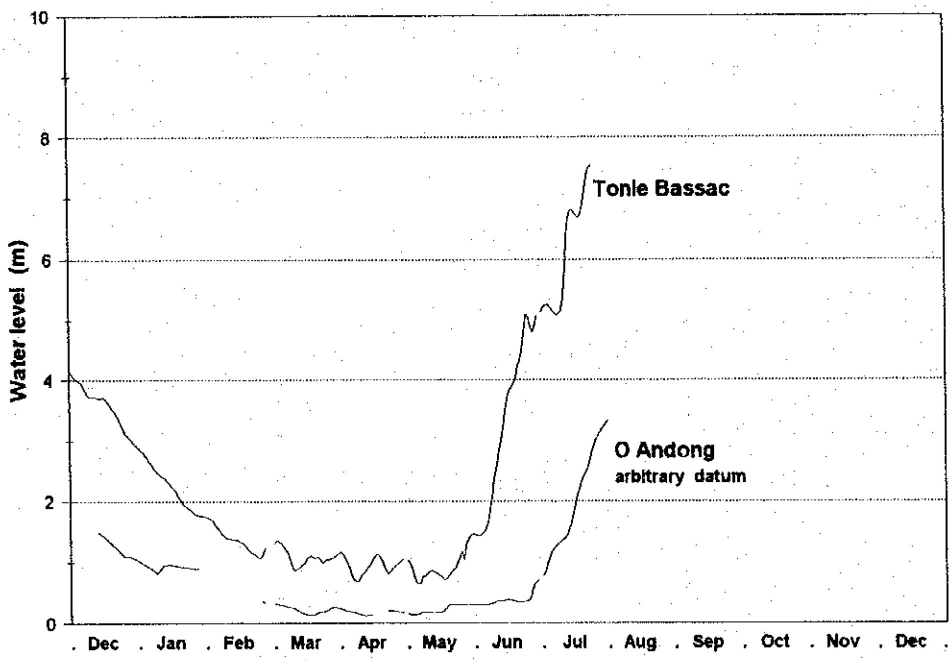
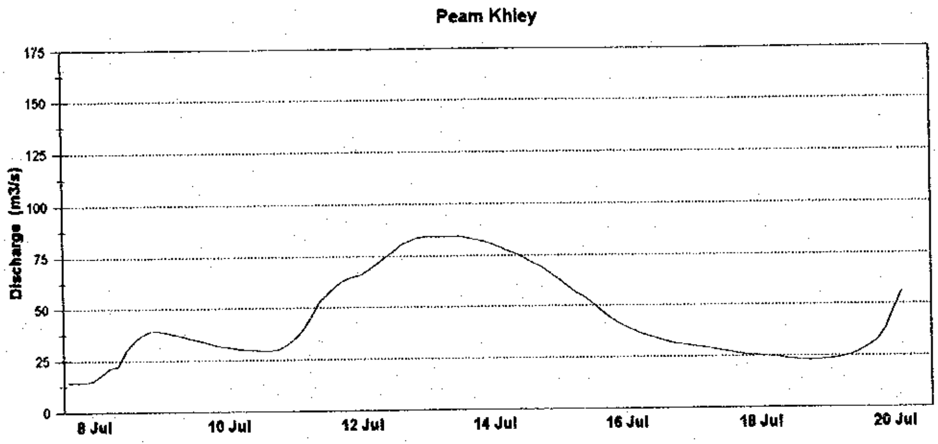
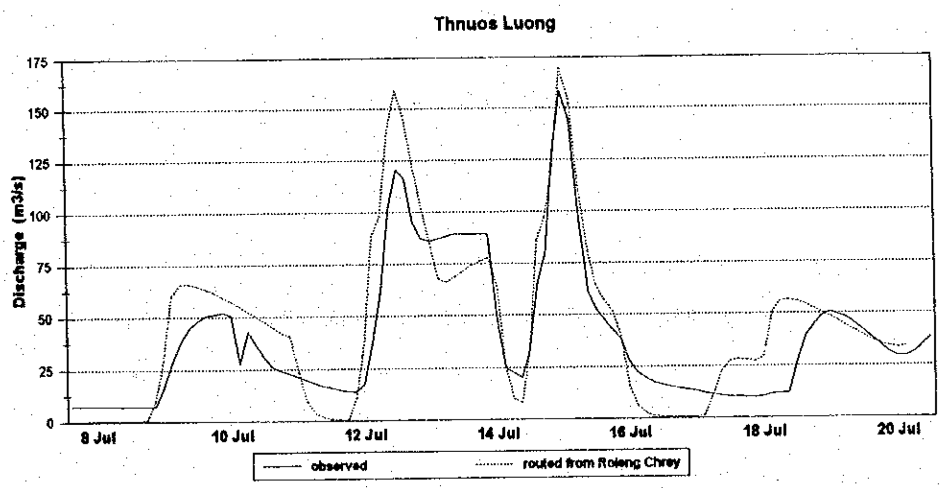


Figure I-35 Comparison of observed hydrographs and routed releases from Roleng Chrey





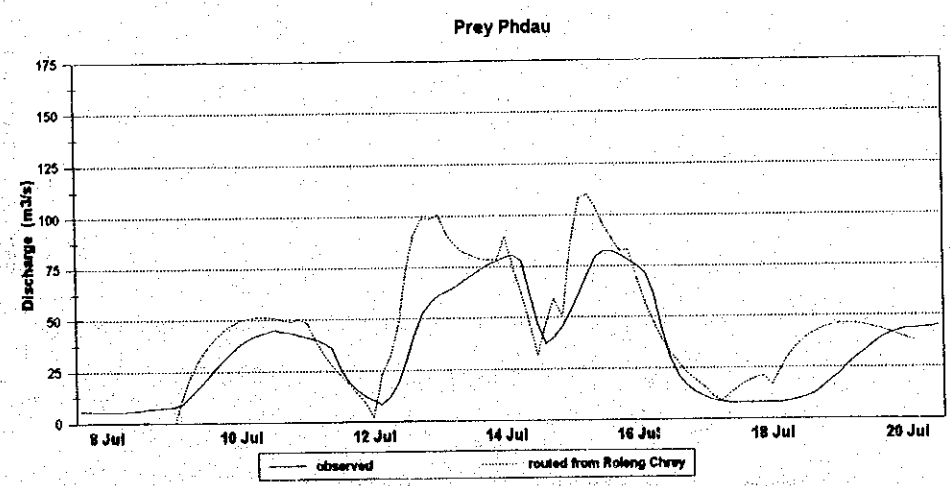


Figure I-36 Comparison of observed and routed daily volumes from Roleng Chrey

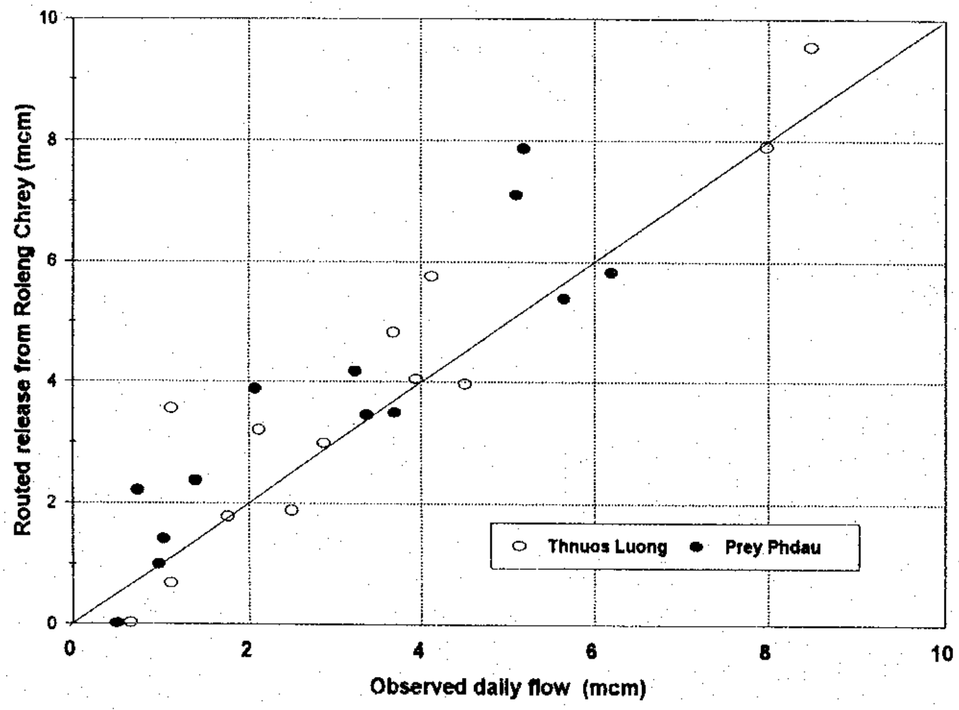


Figure I-37 Illustration of revised operating strategy for Roleng Chrey

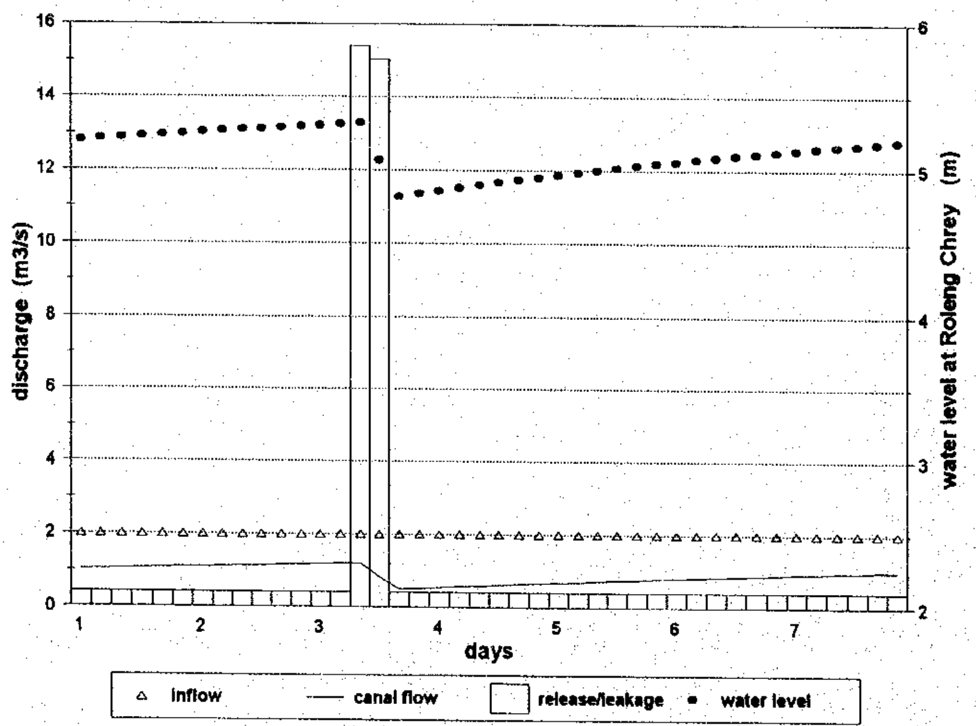


Figure I-38 Frequency curves for annual maximum floods on Prek Thnot

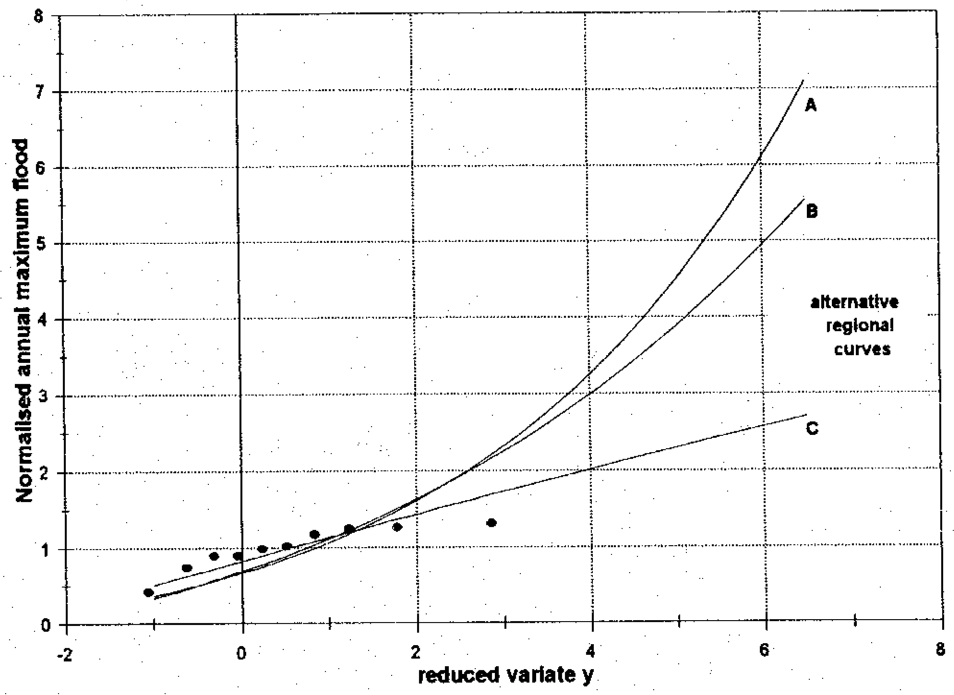


Figure I-39 Elevations along the railway embankment

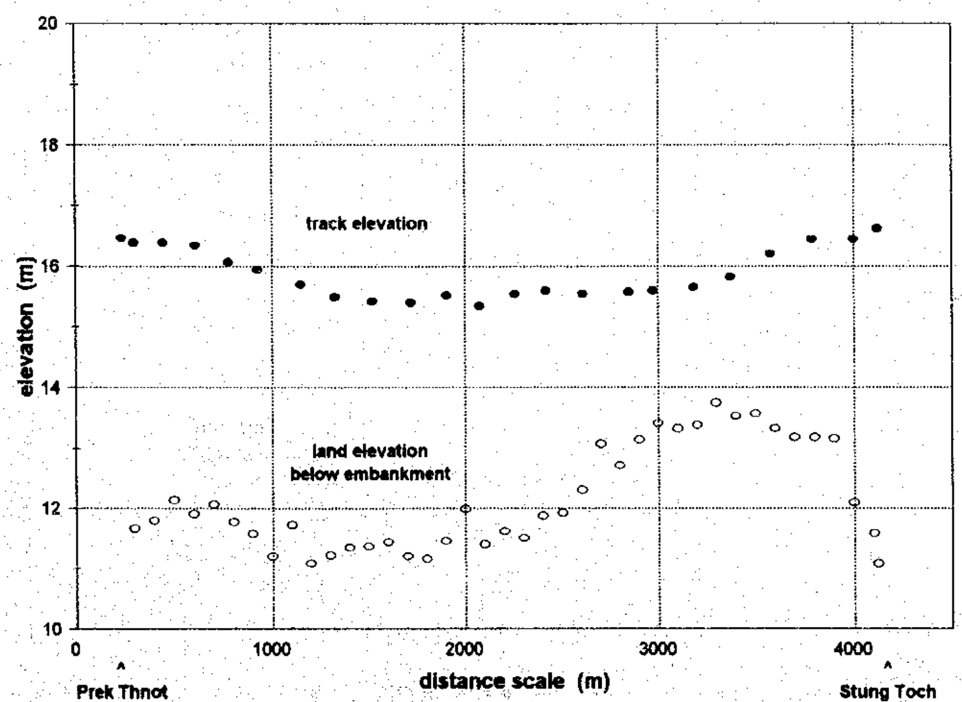


Figure I-40 Relative cross-sections of bridges under the railway

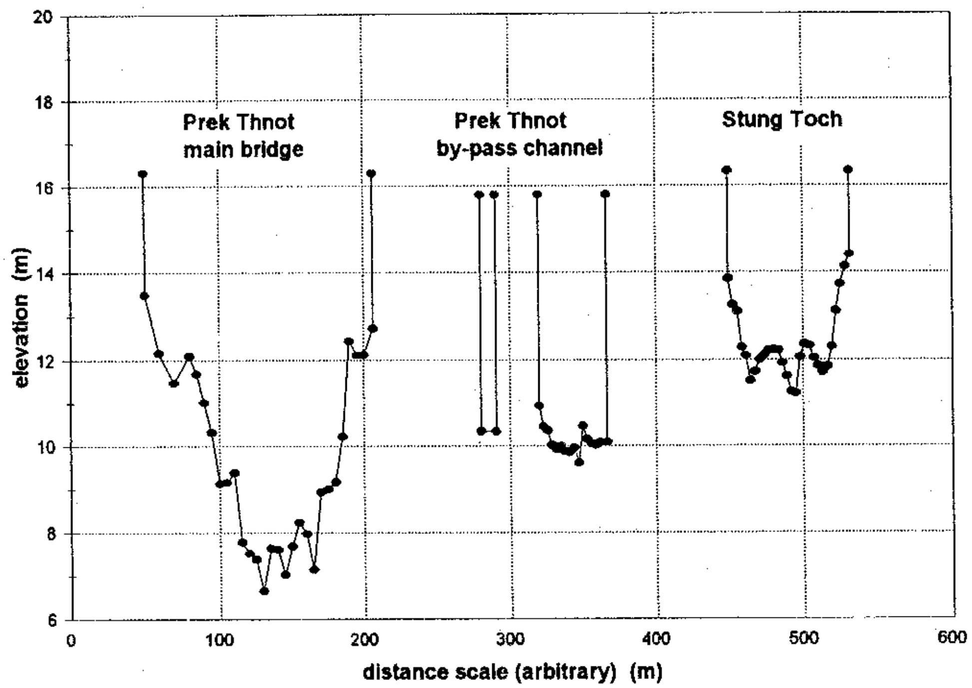
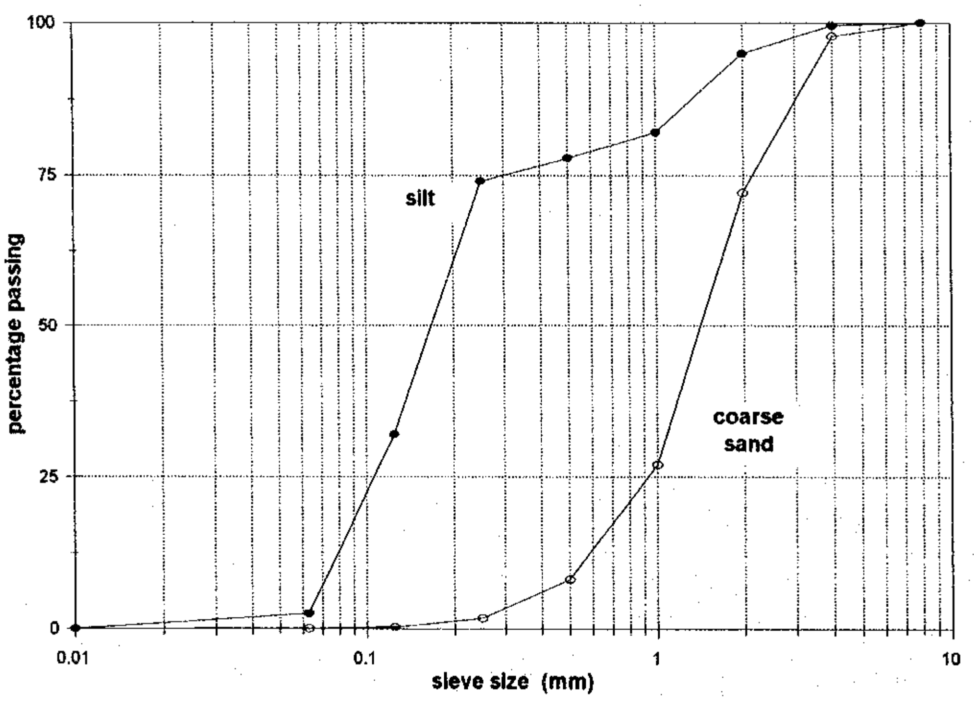


Figure I-41 Typical sediment analyses for Prek Thnot below Kompong Speu



APPENDIX A

EQUATIONS USED IN THE ANALYSIS OF ROLENG CHREY RELEASES

EQUATIONS USED IN THE ANALYSIS OF ROLENG CHREY RELEASES

Roleng Chrey gates

For free flowing conditions, the discharge from the gate openings is given by:

$$Q = b \cdot C_d \cdot y_G \cdot \sqrt{2 \cdot g \cdot y_1}$$

where: Q ; the discharge (m^3/s),
b ; the width of the gates (m),
y_1 ; the upstream depth of water above the cill of the gate opening (m),
y_G ; the height of the gate opening(m),
C_d ; the discharge coefficient.

The discharge coefficient Cd is estimated from:

$$C_d = C_c / \sqrt{1 + C_c \cdot y_G / y_1}$$

where: C_c ; the contraction coefficient (usually 0.61 for vertical sluice gates).

Spill over the closed gates is approximated by the weir formula:

$$Q = 2/3 \cdot b \cdot C_{cd} \cdot \sqrt{2 \cdot g} \cdot h_1^{3/2}$$

where : Q; the discharge (m^3/s),
b ; the width of the gates (m),
h_1 ; the upstream depth of water above gate level (m),
C_d ; the discharge coefficient (0.7 is appropriate), and the approach velocity can be neglected.

In a time sequence calculation, the water balance of the upstream storage is also modelled. For moderate inflows, backwater effects can be ignored and the storage is estimated from:

$$S = 1/2 \cdot b_{ch} \cdot \frac{l_{max}}{y_{max}} \cdot (y_1)^2$$

where: S ; the upstream channel storage (m^3),

b_{ch} ; the width of the upstream channel (m)

l_{max} ; the maximum length of channel storage (m),

y_{max} ; the maximum depth of water at the gate (m),

y_1 ; the actual depth of water at the gate (m).

In the reported analysis, it is assumed that the average river channel width is 80 m and the maximum length of channel storage is 13.5 km.

Main canal gates

Discharge from the radial gate is estimated from the equations above for Roleng Chrey gates except that the contraction coefficient varies with gate opening for a radial gate and is given by:

$$Cc = 1 - 0.75\ (8 / 90) + 0.36\ (\theta / 90)^2$$

where : θ ; the angle to the horizontal of the lower edge of the radial gate.

Routing of flood waves down river

The total outflow is routed down river using the Muskingham procedure, which relates outflow from a river reach to inflow and outflow in the previous time step according to the following equation:

$$O_{t+\Delta t} = C_0 \cdot I_{t+\Delta t} + C_1 \cdot I_t + C_2 \cdot O_t$$

where : O ; the outflow from the reach,

I ; the inflow to the reach,

C_n ; functions of two parameters K and x.

This procedure effectively allows for the change of channel storage in the reach. The parameters **K** and **x** are found empirically, although **K** is considered to be proportional to reach length, and **x** is roughly inversely proportional to reach length amongst other factors.

APPENDIX B

SEDIMENT TRANSPORT EQUATIONS

SEDIMENT TRANSPORT EQUATIONS

Shields' bed load equation

The sediment discharge per unit width of river is given by:

$$q_s = \frac{10 \cdot q \cdot S_0 \cdot \rho^2}{\rho_s} \cdot \frac{(\tau_0 - \tau_{cr})}{(\rho_s - \rho)^2 \cdot g \cdot D}$$

where : q_s ; the sediment discharge Dm³/s),

q ; he river discharge (m³/s),

S_0 ; he slope of the channel bed,

ρ ; the density of water, r_s the density of sediment (kg/m³),

τ_0 ; the sheer stress at the bed,

τ_{cr} ; the critical value for movement (N/m²),

D ; the characteristic grain diameter (m).

The Einstein- Brown bed load equation

The sediment discharge per unit width of river is given by:

$$q_s = \Phi \cdot \sqrt{\frac{(\rho_s - \rho) \cdot g \cdot D^3}{\rho}}$$

Φ is a dimensionless bed-load function which can be approximated by:

$$\Phi = 40 \cdot [\frac{\rho \cdot R^1 \cdot S_0}{(\rho_s - \rho) \cdot D}]^3$$

where : R^1 ; the proportion of the hydraulic radius relevant to sediment transport (m).

ANNEX II

SOILS AND LAND USE

ANNEX II

SOIL AND LAND USE

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1. METHODS AND APPROACH ADOPTED

1.1 Phase I Study

All available information on soils, land capability and land use for the Study area was collected as a first step. This information was then reviewed as in Section 2 below.

Good quality 1:25,000 scale aerial photographs of the Study area flown in November 1992 were available for three days in Phnom Penh. During that time a rapid interpretation was undertaken and a map of the 'land units' so delineated was drafted at photo-scale onto a topographic basemap. Despite the short period of access to the photographs it is considered that this map is more accurate and reliable than any of the pre-existing maps. A 'land unit' is defined as an area of land having a relatively uniform assemblage of landform, soils and native vegetation. Some variation in these parameters occurs within many land units; others are almost homogenous in their characteristics.

In the field, information on soils, land use and vegetation was collected as well as some data on landforms and hydrology. Soil profiles were exposed using a 75 mm soil auger and in some cases by digging pits. The soils were classified according to the FAO system (FAO-UNESCO, 1974). Only 105 inspection sites were able to be described in the field which is less than generally accepted intensities for a 1:50,000 scale map. However other soils information had been collected previously by Tahal and others and this was used to alleviate the deficiency.

During the field work, the lack of aerial photographs made it difficult to identify, delineate and distinguish between the land units of the 'plains'. The plains, which are the main rice growing areas, have significant variation in their soils, but these are represented by only very subtle differences in aerial photo-pattern. These differences are very important in mapping alluvial plains but are impossible to detect using only topographic maps.

1.2 Phase II Study

Aerial photographs interpretation was carried out. The objective was to map the soils identified and described during Phase I (but which had not then been mapped) within the mapping units for this Feasibility Study. Initially, almost uniform photo-patterns thought to represent the different soils were identified and delineated. A variety of fluvial land forms were represented. Secondly, existing land use (as at November 1993 - January 1994) was delineated. The lines drawn on the photographs were then traced onto transparent film, assembled into maps. Preliminary Legends were devised for the maps.

In the field, a total of 47 pre-selected soil profiles were located, exposed using a soil auger and described in morphological terms. A further 55 soil profiles exposed and described during Phase I were also used in the analysis. An example of the soil profile description forms used is given in Appendix 1. Fifty five samples were collected from the augered profiles and delivered to the Department of Agronomy Soils Laboratory for analysis. Following the field work, the aerial photograph interpretation was revised and amended as necessary and the soils and land use maps were finalized. Legends for the maps were also finalized.

Soil chemical and physical analyses were conducted in the Department of Agriculture and Department of Water Resources laboratories in Phnom Penh. Some of the results have proven to be difficult to interpret, probably partly due to the long history of agricultural use including terracing and domestic activity that has taken place in the area. As a result, in classifying the soils some categories have had to be deduced based upon both the analyses and soil pH tests carried out in the field, plus morphological characteristics.

A land use plan for the priority area and soil improvement plan were then formulated based on the above result.

2. REVIEW OF THE EXISTING INFORMATION

2.1 Existing Information

Technical information including maps and reports is in short supply in Cambodia. Of fundamental importance was the Prek Thnot Multipurpose Project Reappraisal Report (Euroconsult, 1992), particularly Volume 5, Irrigation. This volume is in four separately bound subvolumes: Volume 5.1 is the main report, and Volume 5.2 contains (amongst other things) Annex 2; Soils, Land Use and Land Capability.

Annex 2 is based upon studies undertaken by Tahal (1972 and 1973) along the left bank of the Prek Thnot River, and soil studies carried out by the Cambodian Ministry of Agriculture in cooperation with Vietnamese experts in Kandal and Takeo Provinces (1986 and 1988). It also takes into account a soils map and report prepared by Crocker (1963) for the whole of Cambodia. Topographic maps and patterns of existing land use were also used as a guide to soil distribution and capability.

For this Master Plan Study, the maps made in cooperation with the Vietnamese for Kandal and Takeo Provinces were also consulted directly.

Two other maps at 1: 500,000 scale and made using satellite imagery were also consulted. These were a 'Rice Ecosystems of Cambodia' map produced by the Cambodia - IRRI Rice Project (1992) with field checking and funded by AIDAB; and a 'Reconnaissance Land Use Map of Cambodia' (1991) made without field checking and prepared by the Mekong Secretariat with French assistance.

The Inception Report for Project Implementation in The Transport And Agriculture Sector, Irrigation Rehabilitation Component (BCEOM, 1993) provided useful information on the problem of erosion on dispersible clay soils in the region.

The summary volume of the Prek Thnot Reappraisal Report (SMEC, 1992) was also helpful. Good quality but old topographic maps at 1:50,000 and other scales were also available (Joint Operations Graphic-Ground, 1967). Other sources are cited in the text.

2.2 The Euroconsult Reappraisal Report

The Euroconsult Report is itself partly a review report in that it lists the data that were available at that time and assesses their usefulness for the Reappraisal of the Prek Thnot project. Euroconsult note that no systematic soil survey undertaken by conventional aerial photograph interpretation and field checking had in the past been carried out over the area.

The work of Crocker (1963) is reviewed. His soils map of Cambodia was accompanied by a report containing information on geology and physiography as well as soils. According to this, the Study area lies almost entirely in the 'central plains' of Cambodia, merging in the far east with the alluvial plain of the Mekong River. The materials of the central plain are mainly transported deposits of Tertiary to Pleistocene age, but some are young river and lake deposits and colluvium. These old sedimentary plains are almost flat and only 5 m to 15 m above mean sea level, or about 4 m above high tide at the lowest point. It is possible that some of these materials have an estuarine or a marine origin.

Crocker identified a number of great soil groups, several of which probably occur in the Study area, however, his mapping scale was very broad. He described the soils on the very old sedimentary materials as having a sharp texture contrast between sandy topsoils and compact, heavier-textured subsoils with an accumulation of clay and sesquioxides (iron and aluminium oxides). In less well drained areas increased sesquioxide accumulation forms plinthite or laterite in the soils, sometimes at shallow depth, and in poorly drained areas grey hydromorphic soils occur. The recent river and lake deposits have uniform textured, fertile clay soils.

Euroconsult also review other information on the soils, for example, the soils maps made by Tahal (1972 and 1973) and those for Kandal and Takeo Provinces prepared in cooperation with the Vietnamese. The soils have not been correlated between these latter maps and similar soils have been given different names. However, the main soil categories described conform broadly with those of Crocker (1963).

As a preamble to their assessment of land capability for the area Euroconsult outlined and discussed the soil conditions they considered to be most important for irrigated agriculture. These included conditions of soil texture, permeability, soil water storage capacity, soil fertility, soil toxicities and internal soil drainage. Their discussion of these factors is particularly relevant and helpful.

Existing land capability information was then reviewed by Euroconsult. Their purpose was to establish the capability of the soils for irrigated rice. The only land capability study at a level of detail appropriate for an irrigation development had been carried out by Tahal in 1973. This covered the 'Pioneer' study, in the west of the Prek Thnot area along the left bank of the river. Tahal placed most of the area (about 75%) in class 3 and nearly all the rest in class 4. Euroconsult found some discrepancies in the terminology and criteria used by Tahal, but based on his work and taking into account yields presently obtained on these soils they concluded that the Prek Thnot area as a whole was 'not really suitable for irrigation development'.

Because the information on soils of the Prek Thnot area as a whole was so variable in precision and authority and often too contradictory for systematic correlation, a novel approach was adopted by Euroconsult to circumvent the problem. It involved grouping the various soils data directly in terms of their suitability for rice, without first devising a common soil classification system. The mapping units are described in arbitrary terms which do not conform to any recognized system. This approach was seen as necessary by Euroconsult but it is unconventional, and has led to a land suitability map only able to provide a rough guide for future planning purposes.

For consistency, Euroconsult adopted the system used by Tahal (which appears to have been based on the USDA 1951 system) for their reappraisal of the Prek Thnot project. This led to the establishment of five land suitability classes (Euroconsult called them 'capability' classes):

Class 1	soils (highly suitable for rice) are young, fertile, unleached soils formed on recent alluvium which receives an annual increment of silt from flooding.
Class 2	soils (moderately suitable for rice) are older and lie outside of and around the class 1 soils, and receive silt deposits only in very high floods.
Class 3	soils (poorly suitable for rice) are very variable in their pedological characteristics but are mainly old, strongly leached, infertile soils with coarse to loamy topsoils and loamy to clayey subsoils. Most areas (on Euroconsult's map) are in this category.
Class 4	soils (very poorly suitable for rice) may be very sandy and infertile, or high in sodium or carbonates, or have a toxic subsoil. Laterite (plinthite) may occur at shallow depth.
Class 5	soils (not suitable for rice) may be steep, very sandy, etc.

Because very little field data were available Euroconsult had to compile their land capability maps mainly from relative elevation obtained from topographic maps and correlated with the recorded position of various soils in the landscape, plus information on the parent materials of the soils. The land capability maps so produced are therefore very broad and general.

Maps of existing land use were also compiled by Euroconsult, but these too are very broad and generalized because they were produced using topographic maps and satellite imagery, with some field checking. Some information on land use (the location of villages) was also included in the soil maps made with Vietnamese cooperation.

2.3 Other Sources

The only soils and land use data located other than those already reviewed within the Euroconsult report included the two maps at 1:500,000 scale entitled 'Rice Ecosystems of Cambodia' (1992) and 'Reconnaissance Land Use Map of Cambodia' (1991). These maps were of little use as the whole Study area fell into only one or two of the mapped categories. The topographic maps were very helpful for location of sites in the field, and the Transport and Agriculture Sector Inception Report (BCEOM, 1993) was useful as a reference on dispersible soils.

2.4 Adequacy of the Existing Data

In summary, the pre-existing soils, land capability and land use data for the entire Study area are imprecise, based upon inadequate and often questionable sources, some of which in tuan have relied heavily on older, small scale maps. These data are only able to provide a rough guide for future planning purposes.

3. MASTER PLAN AREA

3.1 Existing Land Use

3.1.1 Present Condition of the Study Area

In parts of this Section references are made to the land units, which are described in Section 5.4 below. Designations such as 'Hc' or 'Hs' are the symbols used in the land unit map to identify those land units.

Most of the plains areas are used for wet season rice. Only one crop can be grown per year in most areas because of a shortage of irrigation water in the dry season. Most farmers grow a variety that takes five months to maturity but is of good quality and commands a high price in the markets. However a small proportion of land is planted with two successive crops of a lesser quality variety that matures in only three months. Dry season (but non-irrigated) crops are planted in swampy areas as the water levels recede, from about late November.

Most people live where the better soils occur, and because of population pressure and the slightly uneven topography in these areas the fields are smaller. Because the better soils are formed on young, often still-active alluvium, there is also abundant water for wet season rice in these areas.

The higher land is flood free and generally less suitable for rice because of higher soil permeabilities. For example, land unit Hs consists of ancient deposits of alluvial sand which are too high to be commandable. Consequently it is used for villages, and as most of these areas are linear in shape, they form good transport corridors. The village areas may be densely packed with houses or have only scattered buildings. Plantations of sugar palm are common, also some coconuts, mangoes, cassava, sweet potatoes and other crops. Some rice is grown when sufficient wet season rainwater can be impounded but the crops are poor. Land unit Hc is similar.

Many villages are also located on land unit Hy, which is also higher than surrounding terrain, but here the elevation difference is small and many areas are flooded and probably commandable for irrigation. The soils are good, and wherever possible land not needed for domestic purposes is used for paddy rice. Even non-commandable land may be used for rice, if sufficient rain water can be impounded for the crop.

Farm and domestic animals are important to the village people. Domestic chickens and pigs roam freely, and there are some small commercial flocks of ducks. Crabs, frogs and small fish are caught or trapped in the paddy fields and form an important part of the diet of the village people.

Cattle are important as draught animals and are often kept under shelter, or tethered along roadsides and on higher ground in village areas. Many are allowed to graze under supervision along the paddy field bunds during the cooler parts of the day. Most cattle are partly hand fed by cut-and-carry means, often with weeds removed from the rice crops or with harvested rice straw. All animal manure is collected and used as fertilizer for the rice crops.

The last rain usually falls in October. In November the streams and canals cease flowing (except the larger rivers) and the paddy fields progressively dry out. Rice is harvested from the highest fields first, after their water has been drained onto lower fields. After the harvest the men may seek employment in Phnom Penh to earn money for additional food, or perhaps a motorcycle, or building materials for a house. The sugar palms, which may provide about 20 % of a family's food or some cash income, are tapped during the dry season.