PART III

HYDRO-HYDRAULIC MODELLING

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1. DEVELOPMENT OF HYDRO-HYDRAULIC MODEL FOR THE CAMBODIAN FLOODPLAINS

1.1 Background of Model Development

This Part III of the Main Report outlines all modelling activities carried out during the entire period of the WUP-JICA project/study including the model origin in the Mekong Basin and a similar improvement in the related project. In the initial stage of the study, some hydro-hydraulic simulation models were needed simultaneously with the monitoring activities to verify the observed data and to clarify the hydrological or hydraulic mechanisms in the basin. After a series of discussions with the MRCS due to the apprehension on overlapping of activities with the WUP-A and WUP-FIN projects, the WUP-JICA Team had decided to take over and further develop the model developed by the recently completed project of MRC.

A brief description of the first study on the Mekong where MIKE 11 has been applied applied and the link to the other project where the model was used simultaneously with the WUP-JICA study for detailed flood analysis is herein presented. The part also explains the concepts of the two model systems applied; namely, the rainfall-runoff model and the hydraulic river and floodplain model. The coupling of the two models was studied as well. A detailed description of the topographical and structural data used for model construction is herein given, the hydrological and hydraulic data applied for model calibration or verification is described, and the detailed layout of the models together with the calibration or verification results for the years 1998-2001 is presented.

The model established was used to derive the water balance in the Tonle Sap Lake for the years 1998-2001. The outcome of the water balance study is herein likewise presented.

1.2 Process of Model Development

1.2.1 Chaktomouk Project Model

The Chaktomouk Project was conducted from 1999 to 2000 as one of the MRCS projects funded by the Government of Japan[(1)]. As part of the Chaktomouk Project, a MIKE 11 model was established for the Mekong-Tonle Sap-Bassac river system to provide boundary conditions for a detailed two-dimensional morphological river model (MIKE 21C) that was set up for the Chaktomouk junction. The two-dimensional model was thus the main modelling tool in the project, supported by the one-dimensional river model MIKE 11 with information that could not be obtained from data alone.

The MIKE 11 model, which includes the Tonle Sap and the Great Lake, was set up with its upstream boundary at Kratie on the Mekong and the downstream boundaries at Tan Chau on the Mekong and Chau Doc on the Bassac in Vietnam. The reasons for this wide coverage of the model were: (1) the four river branches close to the Chaktomuk junction had no record of water level and discharge; and (2) the boundaries of the MIKE 11 should be unaffected by changes in the junction caused by the various options studied with the two-dimensional model. Fig. III-1-1 shows the layout of the MIKE 11 model used in the Chaktomouk Project.

Given the above, the focus of the one-dimensional model was to obtain agreement between model results and observations in the four river branches close to the Chaktomuk junction as well as some distance away from the junction. The latter was because it has been recognised that the exchange of water with the floodplains was significant and hence necessary to represent it in the model. However, since the details of flow on the floodplains were not a focus in the project, the floodplains were schematised in a relatively coarse manner. This approach was valid since the model philosophy implies that if the conditions near the junction as well as at some distance from the junction could be simulated by the model, then the overall exchange with the floodplains would implicitly be represented in the model.

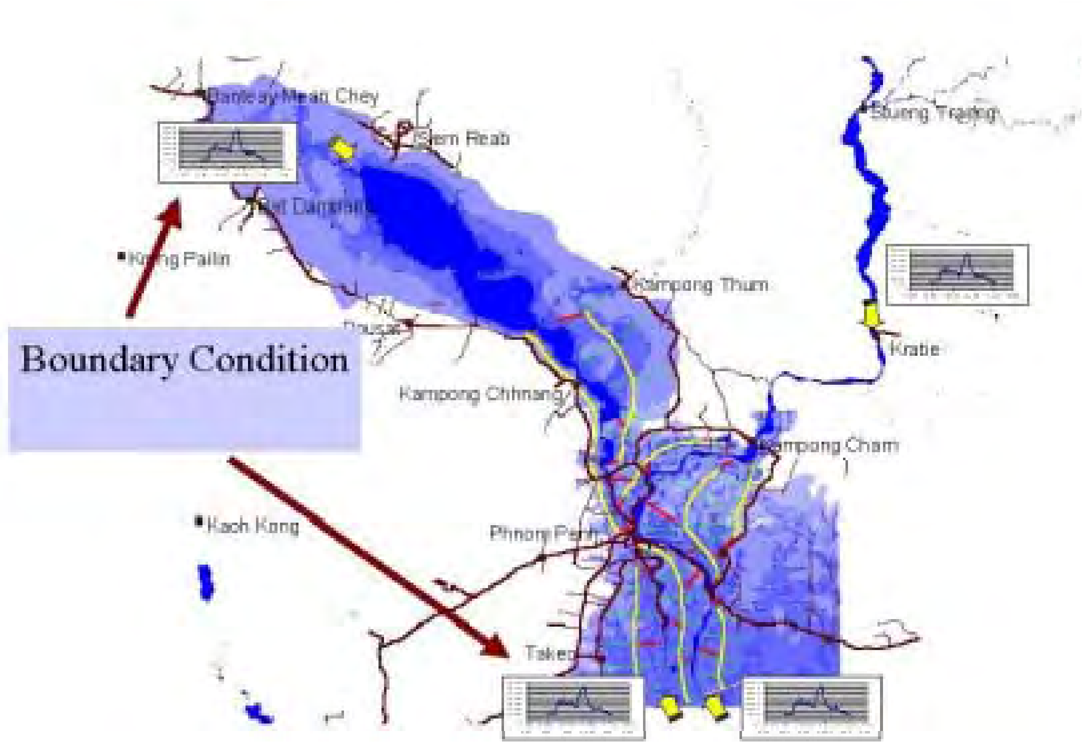


Fig. III-1-1 One-Dimensional Model of the Chaktomouk Project
(Links with floodplains and river courses are shown in red.)

The access to rainfall data has been limited in the study and, besides, there were no discharge measurements available at the tributaries to carry out a direct calibration of the rainfall-runoff model. The calibration of this part of the model was therefore implicitly part of the river model calibration. Altogether five rainfall stations were used for the rainfall-runoff simulation.

During the Chaktomouk Project an extensive measurement campaign was carried out to obtain bathymetry, as well as discharge and sediment data and information. Advanced technology such as ADCP for velocity and discharge measurement was applied. The data was employed in constructing the models and the calibration/verification of the models.

For calibration of the one-dimensional model, the ADCP discharge measurements at the junction and at far distance from the junction taken in the pre-flood, flood, and post-flood periods were used. This was the first time in recent years that discharge data were obtained simultaneously at a number of stations in Cambodia. It was also the first time in recent years that advanced modelling system was used by applying such data. Fig. III-1-2 shows the main output from the ADCP measurement campaign carried out during the Chaktomouk Project in the year 2000.

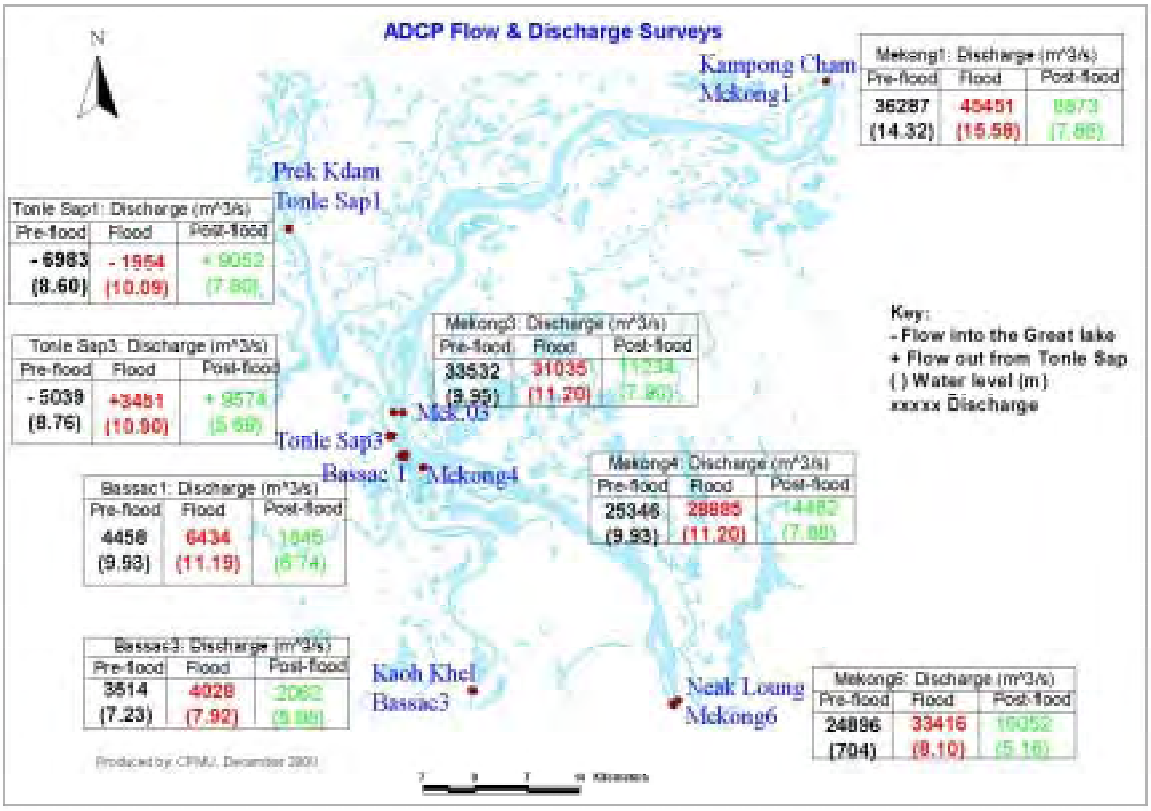


Fig. III-1-2 ADCP Survey Results during the Chaktomouk Project in 2000

1.2.2 WUP-JICA Model

The MIKE 11 model developed in this WUP-JICA Study takes offset in the model constructed for the Chaktomouk Project. This means that some of the model elements such as the schematisation of the main river branches were adopted from the Chaktomouk Model. However, extensive modifications/additions were made to meet the specific purposes of the WUP-JICA study. The improvement works to the model were made in a continuous process as data and information became available during the study. These modifications/additions for model improvement are thoroughly described in Section 1.3 of this Chapter.

The overall purposes of the modelling component of the WUP-JICA study were:

(1) Study on the flow regime in the Mekong river system in Cambodia including:

- Data gap filling;
- Flow regime analysis;
- Water balance study; and
- Downstream flow prediction.

(2) Support to preparation of water utilization rules including:

- Assessment of average monthly flow conditions at key locations; and
- Study on natural reverse flow conditions in the Tonle Sap.

The requirements to fulfil the above purposes are basically that the model can simulate full hydrological years and that the model can give accurate predictions of the hydraulic conditions throughout the Mekong, Bassac, and Tonle Sap river system including the Great Lake in Cambodia. The Chaktomouk Model has therefore undergone revision and improvement with regard to schematisation of rivers, bridges, floodplains and the lake. Besides this, the model has been updated with detailed calibration of rainfall-runoff in the Great Lake tributaries. The model is able to simulate full hydrological years ranging from historical dry to wet years.

The model has been calibrated/verified on events from 1998-2001. Preliminary testing was made for the year 2002 from which data were the most accurate among recent years due to intensive monitoring by the WUP-JICA Study and the TSLV Project as described below.

1.2.3 Relation to Tonle Sap Lake and Vicinities Project

A project was carried out at the MRCS in parallel with the WUP-JICA Study with the title "Consolidation of Hydro-Meteorological Data and Multifunctional Hydrologic Role of Tonle Sap Lake and its Vicinities." In short, the project was called "Tonle Sap Lake & Vicinities Project" or TSLVP [(2)].

The main purpose of the TSLVP was to collect information and analyse the functionality of the various floodplain areas in Cambodia. It was envisaged to describe in quantitative terms the dynamics of filling and release of floodwaters on the floodplains and the exchange of flow between river courses and floodplains and between floodplain compartments inside of floodplains as well. The direct outcome of this was the water balance assessment for the floodplains and the river system.

The project goals were achieved by a combination of basic data collection, data analysis and hydraulic modelling. The data collection comprises continuous measurement of water level at 20 stations located over the floodplains as well as discharge measurement on important tributaries using both conventional methods and the advanced ADP measurement technique. Altogether nine satellite images of the lower Mekong Basin were acquired through the project. The satellite images were taken from July 2002 to January 2003 at 3 to 4-week interval, and show the gradual process of flooding and draining of the floodplains.

A substantial part of the TSLV project was concerned in hydrological/hydraulic modelling. The purpose of the modelling was to provide functional relationships for the floodplain dynamics studied, i.e., volume change, filling/release of floodplain waters, and to support the water balance assessment for the floodplains.

The MIKE 11 Model developed under the WUP-JICA project was used for the purpose of the TSLVP. The model was updated with regard to schematisation of the floodplains, and the links between the main rivers and the floodplains.

The TSLVP and the WUP-JICA project had run parallel in time, so that modelling work was made for the purposes of both projects. Since both projects would benefit from developments made in one of them, the goal was to develop one common model suitable for the purposes of both projects. The model developed represents the combined effort of the two projects and was thus applied for the purposes of both.

1.3 Rainfall-Runoff Model

A major portion of the annual flow volume in the Mekong-Bassac-Tonle Sap river system within Cambodia originates from the upstream. However, local rainfall in Cambodia significantly contributes to the total flow volumes in the initial and the final stages of the monsoon season. During the peak monsoon, although the local contribution tends to be insignificant from the hydrological viewpoints considering the total Mekong runoff, the local runoff is important for the flood protection and management works at major tributaries. Given this it is clear that there was a need to include local rainfall in the model description of the main river and lake systems in Cambodia.

The contribution of local rainfall can be divided into two components. One is the direct rainfall occurring on open water bodies, i.e., the inundated floodplains, river branches and the Great Lake itself and the other is the runoff from tributaries mainly located around the Great Lake, which also stem from local rainfall. Whereas the former can easily be accounted for by converting observed precipitation to a volume contribution over time, the latter is more difficult since it requires long records of observed runoff and/or a calibrated rainfall-runoff model which takes the hydrological catchment characteristics into account and provides the necessary runoff information on the basis of observed rainfall.

Until very recently both rainfall and runoff data in Cambodia were limited. With the improvement of the rainfall network, which has been done since 2000, the amount and quality of rainfall data have been increasing. At the same time the measuring campaign in 2001, under the Technical Support Division of MRCS and involving discharge measurements in all of the tributaries around the Great Lake, has added new and valuable information to the hydrology in the area. For the first time since the 1960s it has been possible to derive rating curves for the tributaries and, further, to perform direct calibration of the rainfall-runoff model.

The rainfall-runoff sub-model of the WUP-JICA model is described in detail below. The model concept behind the rainfall-runoff model is presented prior to the description of the actual model schematisation and calibration. A separate section on derivation of rating curves for the tributaries around the Great Lake is included. Finally the computed runoff to the river model is presented.

1.3.1 Model Concept

MIKE 11 includes several rainfall-runoff models. The most appropriate model for the Cambodian floodplains is the NAM model. The NAM model is a so-called <u>lumped-conceptual</u> type of model for <u>continuous simulation</u>. The term “conceptual” model implies that the hydrological cycle in nature is conceptualised to a number of interconnected reservoirs in the model. “Lumped” means that the physical properties of the area modelled (a catchment or a sub-catchment) are amalgamated into a few characteristic or nominal quantities and parameters. The term “continuous modelling” is used because the model in principle accounts continuously for the water content in the surface (soil moisture) and groundwater reservoirs.

The input to the NAM model consists of a time series of rainfall and evaporation and a number of model parameters. The output is a time series of run-off (distributed on surface run-off, sub-surface flow and groundwater (or base flow) and net-precipitation (i.e., rainfall minus evaporation). The net-precipitation is applied directly to the water covered areas in the MIKE 11 HD (hydrodynamic) model and the simulated run-off to areas not covered by water.

1.3.2 Sub-Catchment Description and Delineation

The Cambodian part of the Mekong river basin from Kratie down to the Vietnamese border was divided into a number of sub-catchments. The sub-catchments reflect physical watersheds with the main tributaries included. The main data source used for the catchment delineation was the MRCS spatial database. However, the JICA Map [(3)] and the French study in the 1963-64 [(4)] were also used as information sources for the sub-catchment delineation and characteristics.

Fig. III-1-3 and Table III-1-1 show the name and location of the delineated sub-catchments and their areas.

TableIII-1-1 Sub-catchments for Rainfall-Runoff Modelling

Sub-catchment name	Catchment Area (km^2)
Stung Chinit	8,236
Stung Sen	16,359
Stung Staung	4,357
Stung Chikreng	2,714
Stung Seam Reap	3,619
Stung Sreng	9,986
Stung Sisophon	4,310
Stung Mongkol Borey	10,656
Stung Sangker	6,052
Stung Dauntri	3,695
Stung Pursat	5,965
Stung Boribo	7,153
Prek Thnoat	6,123
Siem Bok	4,425
Stung Chhlong	5,957
Delta	13,822
Lake (dry season)	2,887

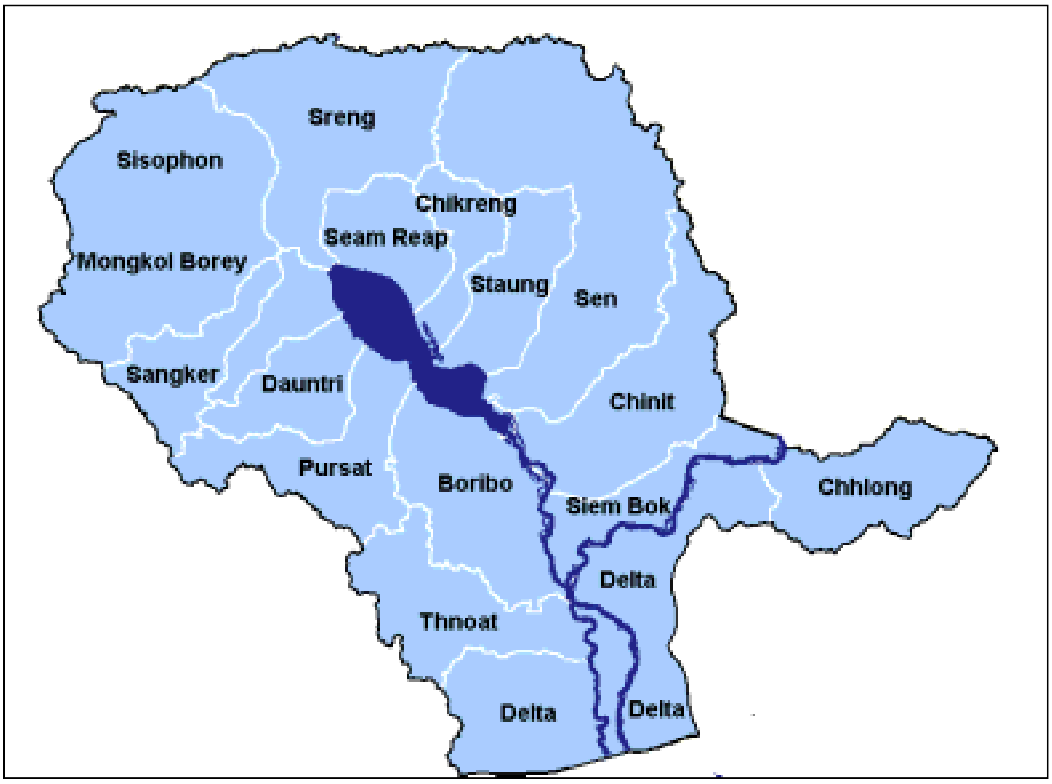


Fig. III-1-3 Sub-catchments for Rainfall-Runoff Modelling

The sub-catchment 'Siem Bok' has a total area of 8,851 km^2 and follows the right bank of the Mekong up to the same altitude as Stung Treng. The Stung Sangker sub-catchment and the small catchment east of it were lumped together to describe the runoff from Stung Sangker (in some accounts called Stung Battambang). The sub-catchment called "Delta" stretches from upstream of Kompong Cham on the left bank of the Mekong down to the Cambodia-Vietnam border. It also includes the floodplains between the Mekong and Bassac rivers and the area west of the Bassac River.

1.3.3 Rainfall and Evaporation Data

(1) Rainfall

Rainfall data were obtained from the HYMOS database at MRCS supplemented with data from the TSD Section of MRCS which requested it from the DHRW under the Ministry of Water Resources and Meteorology. The number of rainfall stations in Cambodia has been increasing since 1998. The number of rainfall stations in Cambodia amounted to 13 in 1998, 22 in 1999, 81 in 2000 and 137 in 2001. Fig. III-1-4 shows the location of stations where data for 2001 was obtained as the most recent.

However, not all stations had a reliable data. The data of each station was scrutinized and the stations with obvious errors or missing data were discarded. For instance, if two neighbouring stations had a difference of 1000 mm or more in their annual total rainfall and one of the stations had an annual total lower than 1000 mm, the latter station showing the lower amount was discarded. Total number of stations used as a result of the examination was 20 for 1998, 27 for 1999, 28 for 2000 and 59 for 2001.The examination process had reduced the total number of stations to 69.

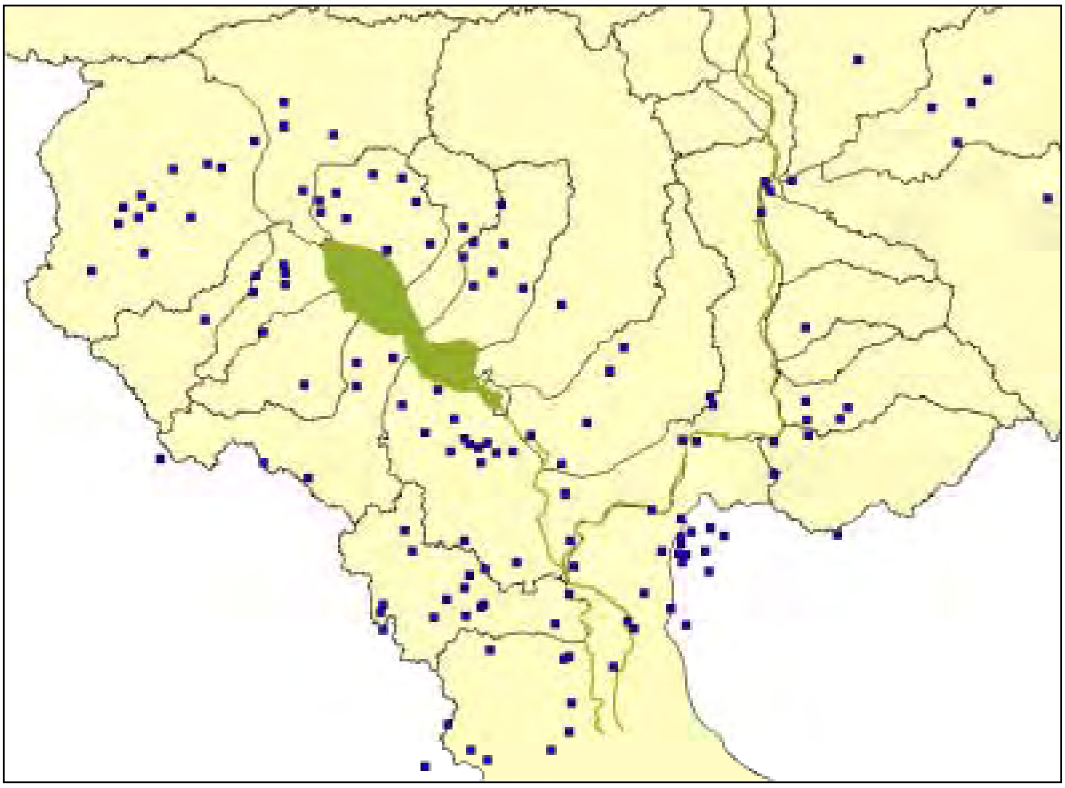


Fig. III-1-4 Available Rainfall Stations in 2001

(2) Evaporation

There were very few recent evaporation measurements in the Tonle Sap basin. Monthly averaged daily evaporation data were never recorded at nine stations in Cambodia. Observation records were only those for 1962 [(4)]. From these nine stations, five are within the model area and were judged relevant to the study. These stations are Phnom Penh, Kompong Cham, Siem Reap, Battambang, and Krakor. Daily evaporation data of the Phnom Penh station of MRCS had existed since the year 2000. The presently available data were converted into monthly averaged daily values and pooled with the data observed in 1962. The mean values of monthly averaged daily evaporation with the observed variations are given in Table III-1-2 below.

Table III-1-2 Monthly Average Daily Evaporation Rates (mm/day)

January	February	March	April	May	June
3.9+/-0.4	4.3+/-0.5	4.6+/-0.8	4.8+/-0.5	4.0+/-0.7	3.7+/-0.6
July	August	September	October	November	December
3.7+/-0.8	2.9+/-0.4	2.9+/-0.5	2.9+/-0.7	3.6+/-0.6	4.1+/-0.5

1.3.4 Runoff Analysis in the Tonle Sap Basin

A recent study had analysed hydrological data for the years 1998 to 2001 collected at stations in the sub-catchments of the Great Lake [(5)]. There had been no runoff data available from the other tributaries in Cambodia. The study had provided a basis for the establishment of discharge rating curves for the tributaries to the Great Lake based on the recent data. It should be mentioned though, that many of the stations have data for only one year, typically year 2001. Further the measurements were mostly carried out from August to December. Thus the rating curves reflect the present characteristics of the rivers, but only in a part of the hydrological year. However, the practical usage of rating curves is that they enable computation of discharges based on past (historical) records of water levels. Hence by using the rating curves to produce discharges for the period 1998-2001, it was inherently assumed that the characteristics of the rivers have not changed. For most stations this was not possible to verify, because their records of water level and discharge were limited.

In the WUP-JICA study, the generation of runoff from the sub-catchments had the following purposes:

- To provide quantification of runoff from sub-catchments in the Great Lake basin needed for the water balance study, because the established mathematical model was the main support tool for the water balance study; and

- To provide an improved basis for calibration of the rainfall-runoff model, a part of the established mathematical model.

The sub-catchment runoff quantification followed the process of: (1) construction of the rating curves based on the above-mentioned recent analysis; (2) data collection from MRCS; and (3) evaluation of the reliability of observed water levels in the years 1998 to 2001. By this process it became clear which sub-catchments and periods have to rely on discharges generated from the rainfall-runoff model.

Detailed information on data availability, construction of rating curves for the tributaries, and the model calibration process can be found in the supporting reports on hydro-hydraulic modelling.

From the examination of runoff data, the best station in terms of data quality and observation period was Stung Chinit. Stung Sreng, Stung Sisophon and Stung Mongkol also had reasonable records, but these were limited by their dependency on the water level at Bac Prea station. The latter data covered only those for 1999 and 2000. Despite some fluctuations, the water level and hence the rated discharges at Stung Boribo were used. The remaining stations had fluctuations or irregularities in theie observed water levels which lead to less reliable rated discharges. The following table summarises the situation of rating curve development in this study.

Table III-1-3 Sub-Catchments and Representative Stations in the Great Lake Basin

Sub-Catchment Name (Stung)	Monitoring Station		Backwater Effects	Reference Station
	Name	Drainage Area (km^2)		
Chinit	Kompong Thmar	4,130	none	-
Sen	Kompong Thom	14,000	prevailing	Panha Chi
Staung	Kompong Chen	1,895	none	-
Chikreng	Kompong Kdey	1,920	none	-
Seam Reap	Untac Bridge	670	none	-
Sreng	Kralanh	8,175	prevailing	Bac Prea
Sisophon	Sisophon	4,310	prevailing	Bac Prea
Mongkol Borey	Mongkol Borey	4,170	prevailing	Bac Prea
Sangker	Battambang	3,230	prevailing	Bac Prea
Dauntri	Maung	835	none	-
Pursat	Bak Trakoun	4,480	none	-
Boribo	Boribo	869	none	-

There were obvious differences between the catchments north of the lake and the catchments south and west of the lake. The catchments on the northern side showed less fluctuation in water levels than those on the southern side. The reason could be the catchment size (larger size means longer response time), catchment topography and the rainfall pattern. The catchments to the south receive runoff from the Cardamom Mountains, and it can be expected that rainfall is more intense and also the annual amount is larger. Also the catchment sizes are smaller to the south, and a shorter response time can be expected, resulting in larger fluctuations in water levels and discharges. In contrast to this, the catchments north of the lake receive less rainfall. They are also generally larger, so that the response time is longer leading to less fluctuating water levels and discharges.

1.3.5 Calibration and Verification of Rainfall-Runoff Model

Although the rating curves were constructed and rated discharges were computed together with the measured discharges as the basis for direct calibration of the rainfall-runoff model, the data were not equally good for all sub-catchments, that is, both the quality and amount of data varied from one catchment to another. Therefore, the calibration parameters from the more successfully calibrated sub-catchments were applied to the neighbouring sub-catchments. This procedure involved of course some uncertainty, but it was considered the only possible alternative.

(1) Calibration of Sub-Catchment

The sub-catchment Stung Chinit was selected as the main calibration catchment on the northern side of the lake. Stung Sen and Stung Sreng were used as secondary calibration catchments since the periods with rated discharge were shorter than those of Stung Chinit. On the southern side the catchment Stung Boribo was the main calibration catchment supported by Stung Pursat and Stung Sangker.

For the setup of a rainfall-runoff model of the present type (lumped, conceptual and physically based), basic data on rainfall and evaporation is needed. Besides, a number of parameters used in the physical process descriptions (e.g., water storage on surface and in the root zone, overland flow, infiltration, interflow and base flow as well as groundwater recharge) are needed. These parameters are usually obtained by trial and error or automatic calibration. However, the very first activity is to evaluate the discharge hydrographs, and clarify features such as peak flow, minimum flow, distribution between direct runoff (overland flow) and base flow, etc. Such an evaluation is very important for the initial selection of model parameters.

The most complete discharge hydrographs were the rated discharges from Stung Chinit and Stung Boribo, as shown in Figs. III-1-5 and III-1-6. In both catchments the relative difference between low and high flows was large. The recession period appeared to be shorter and 'steeper' for Stung Boribo than for Stung Chinit. The peaks (or spikes) during the monsoon were direct runoff from the catchments and they appeared in both catchment types, but were mostly pronounced for Stung Boribo. Stung Chinit had a larger proportion of flow, which was in-between base flow and direct runoff. This flow was interflow and occurred in the upper root zone.

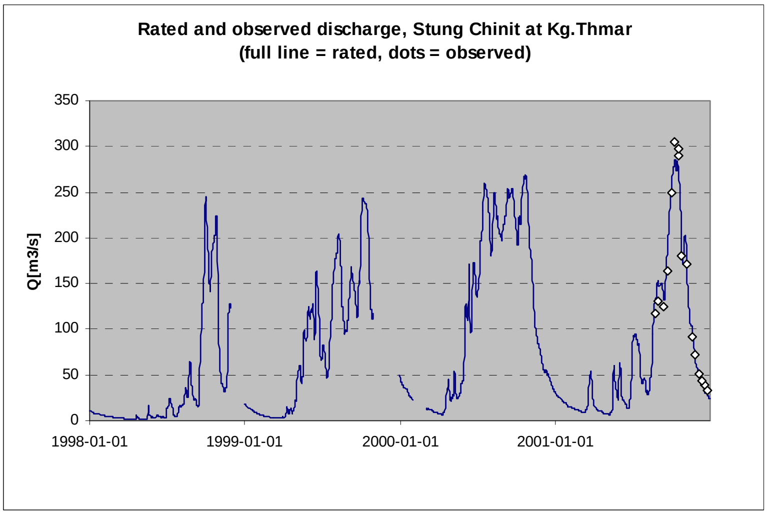


Fig. III-1-5 Rated and Observed Discharge at Kg. Thmar, Stung Chinit

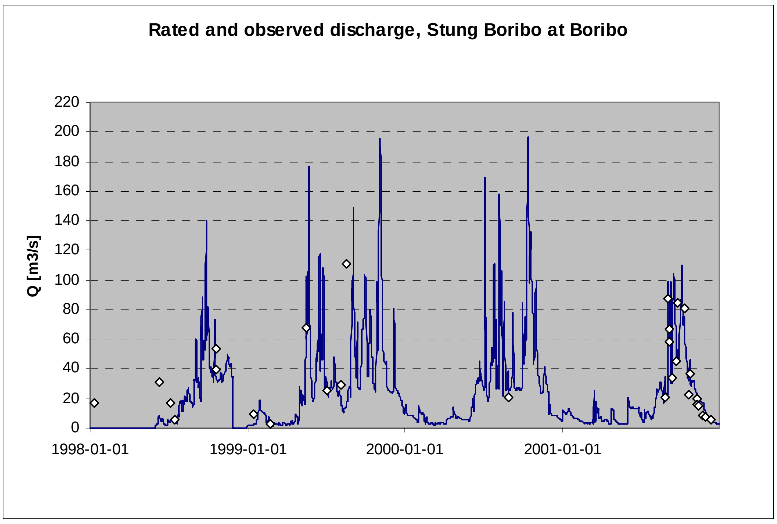


Fig. III-1-6 Rated and Observed Discharge at Boribo, Stung Boribo

The major activities of model calibration and verification are as described below.

<u>Rainfall</u>

After selection of appropriate stations for the catchments, a simple mean area rainfall was calculated with all stations having equal weight. With the relatively large uncertainty in some of the rainfall data as well as the non-uniform distribution of rainfall network, it has not been attempted to apply any sophisticated weighting of the individual stations.

Ideally rainfall stations applied for runoff simulation in each sub-catchment are located within the sub-catchment itself. However, due to shortage or lack of available data, it was necessary to use some of the rainfall data from neighbouring catchments.

Evaporation

The mean value of monthly averaged daily evaporation rates was used for all sub-catchment models.

Model Parameters

Based on the evaluation of discharge hydrographs, the initial values of model parameters were approximated. Then fine-tuning of the parameters was carried out to obtain the best fits of model predictions to the observed data. Model parameters are related to the model concept and description and hence, it requires a thorough description of the rainfall-runoff model in order to interpret the various parameters.

Modelling Results in Stung Chinit Basin

The MIKE 11 NAM model was set up for each individual sub-catchment. The rainfall and evaporation input described above was used in the model, together with the initial choice of model parameters. Through an iterative process with result evaluation and fine-tuning of model parameters, the Stung Chinit sub-catchment was calibrated for the period 1998-2001. The results are presented in Figs. III-1-7 to 8.

Fig. III-1-7 shows the observed, rated and simulated discharge from Stung Chinit for the period 1998-2001. In general there is a good agreement between all three data sets. Peak levels, minimum levels as well as the model simulate the shape of the recession part. Some of the direct runoff peaks during the monsoon were not picked up precisely. This cannot be expected either, since a few rainfall stations can be used. Moreover, the dotted line was a rated discharge, and it was subject to some uncertainty. In general, however, it has been demonstrated that the rated discharge represents the runoff pattern from the catchment, since peak levels, recession pattern in the 2001 measurements and the monsoon duration were simulated quite well.

The accumulated rated as well as the accumulated simulated discharge is shown in Fig. III-1-8. It can be seen that the deviation between observations and simulations is minimal.

The Stung Chinit calibration shows that the lumped conceptual modelling approach is useful for rainfall-runoff modelling in the sub-catchments of the Great Lake Basin. It also shows that the model can be calibrated to a reasonable degree with a relatively few rainfall stations.

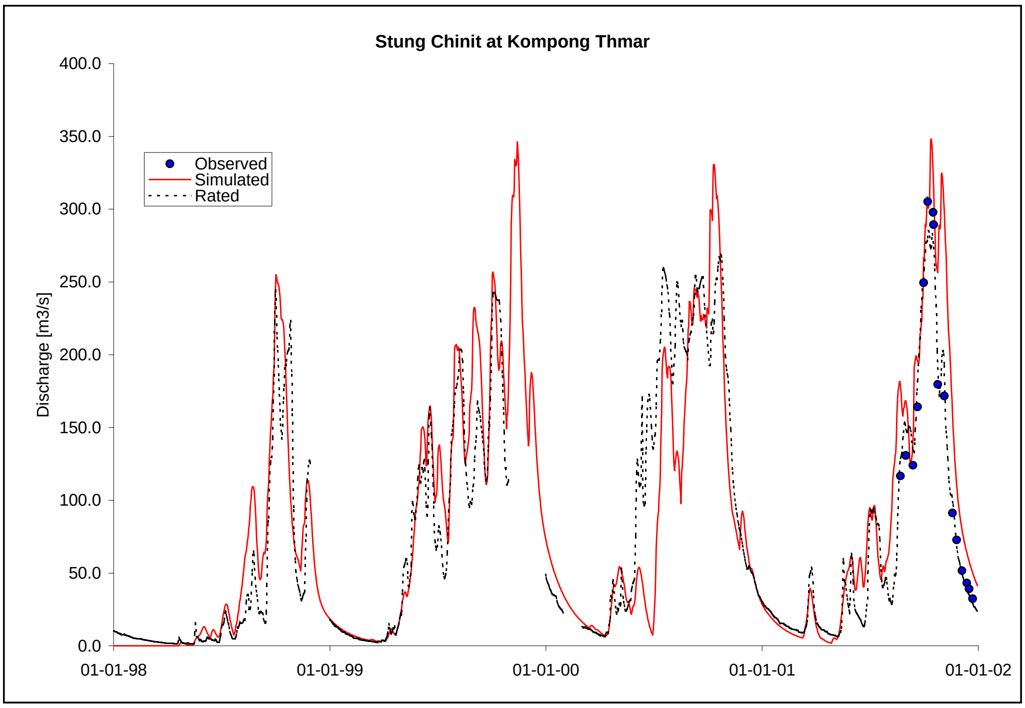


Fig. III-1-7 Comparison among Observed, Rated and Simulated Discharges at Kg. Thmar, Stung Chinit

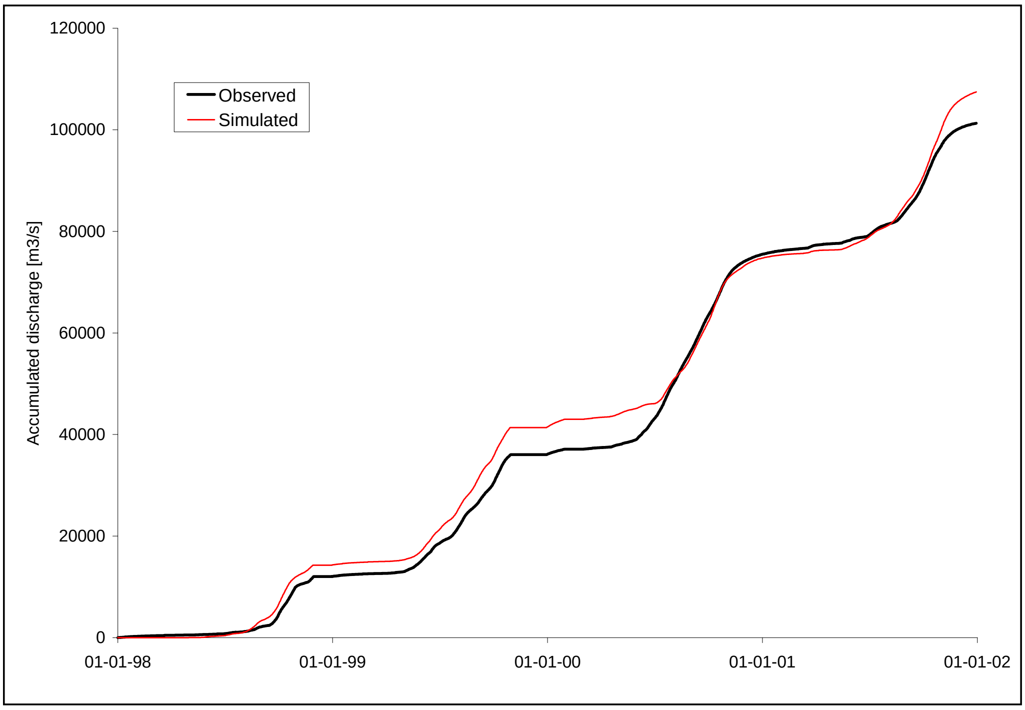


Fig. III-1-8 Comparison among Rated and Simulated Discharges in Accumulative Curves at Kg. Thmar, Stung Chinit

<u>Modelling Results in Stung Boribo</u>

As mentioned previously, the sub-catchments on the southern side of the lake exhibit larger fluctuations in water level and discharges than the northern side sub-catchments. This may be due to the local rainfall pattern in combination with the shape of the terrain.

From the rated discharges it is clear that a substantial proportion of the flow is direct catchment runoff, and also that the catchment has a short response time. This discharge pattern is also seen in the report listed in Reference as No. (4), not only for Stung Boribo, but also for most of the sub-catchments on the south slope of the lake.

The calibration results for Stung Boribo are depicted in Fig. III-1-9. It can be seen that the observed runoff pattern is reasonably well reproduced by the model. Both the peaks and the recession pattern in year 2001 are well reproduced. For the other years, the recession period is less accurately simulated when compared to the rated discharge. A reason for this could be that the rated discharges are not accurate for the recession period. This can be seen in year 2001 where both observation and rated discharges are available. If the dry season flow for the years 1999 and 2000 is increased, it is necessary to have a larger rainfall volume. Otherwise, an increased dry season flow in the model will be on the expense of direct runoff. It is therefore likely that not all rainfall is captured and that some rainfall stations in the hilly area of the catchment would improve this situation.

However, the calibration of the Stung Boribo shows that it is possible to reproduce the runoff pattern, which is a hydrological characteristic of catchments south of the lake.

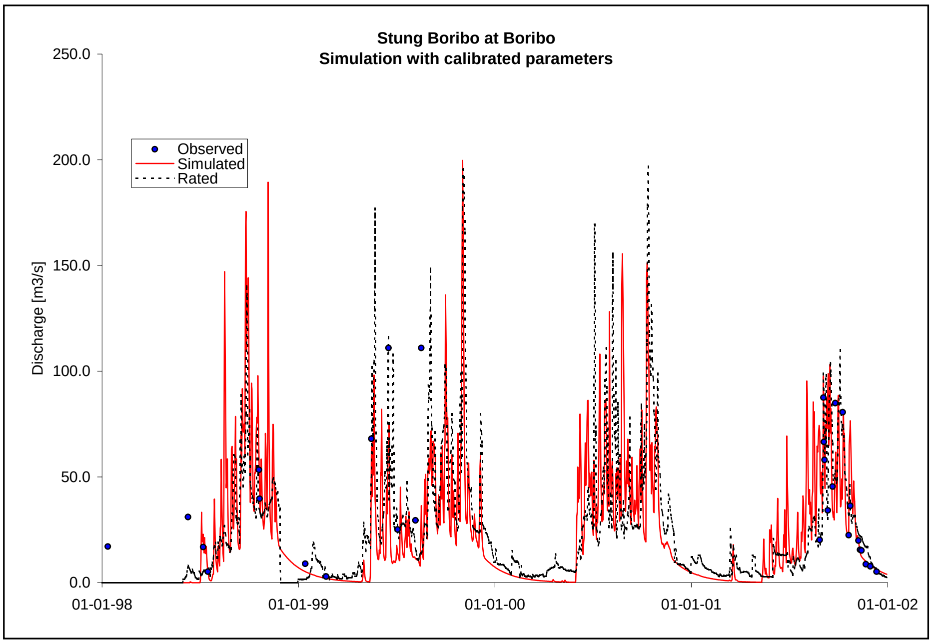


Fig. III-1-9 Comparison among Observed, Rated and Simulated Discharges at Boribo, Stung Boribo

<u>Modelling Results in Other Sub-catchments</u>

Following the above-mentioned two sub-catchments, hydrological modelling was made for the remaining sub-catchments. Generation of simulated hydrographs and model calibration were made, utilizing the results of Stung Chinit and Stung Boribo as the representative sub-catchments in the northern and southern slopes of the lake basin, respectively. Short comments on the modelling are summarized in the following table. Further detailed information is described in the supporting reports on hydro-hydraulic modelling.

Table III-1-4 Modelling Results in the Other Sub-Catchments

Sub-Catchment	Simulated Hydrograph	Reasons and Issues for Further Improvement
Sen	Fairly good	-Shortage of reliable rainfall stations
Staung	Impossible to calibrate	-Low accuracy of water level records -Shortage of reliable rainfall stations
Chikreng	Impossible to calibrate	-Lack of discharge measurements in high-flow
Seam Reap	Impossible to calibrate	-Low accuracy of water level records -Influence of irrigation structures
Sreng	Fairly good	-Not well matching two water level records
Sisophon	Impossible to calibrate	-Not well matching two water level records -Low accuracy and coverage of rainfall data
Mongkol Borey	Impossible to calibrate	-Not well matching two water level records -Shortage of reliable discharge measurements
Sangker	Fairly good	-Not well matching two water level records
Dauntri	Impossible to calibrate	-No water level data available
Pursat	Fairly good	-Low accuracy and coverage of rainfall data

(2) Remarks on Calibration and Application of Rainfall-Runoff Model

The calibration in the Great Lake basin has firstly shown that the applied model concept is suitable for modelling the rainfall-runoff pattern. It has also shown that the runoff characteristics are different between the catchments of the northern and of the southern slopes in the lake basin. Finally, the simulations have shown that model parameters can be transferred with reasonable accuracy to neighbouring catchments as long as simulation is done within the catchments on either the northern or southern side of the lake. For detailed model calibration, the parameters differ slightly among the catchments. It should be mentioned that for full validation of the rainfall runoff model, continued measurements of discharge is required and extended to cover also the rising part of the monsoon. Further, an improvement in the model calibration requires an increased accuracy of the rainfall data and data collected from as many stations as possible.

The catchments in Kandal, Prey Veng and Kompong Cham provinces do not have runoff measurements. Because of mild slopes of their terrain, they are likely to be more similar to the catchments north of the lake than those located south of the lake. Hence, model parameters for these catchments will be similar to those catchments.

In order to use the rainfall-runoff model for generation of input to the river hydraulic model, it is necessary to expand the calibrated sub-catchments around the lake to include the total sub-catchment areas. For example the sub-catchment area of Stung Sen represents the area at Kompong Thom. The catchment is somewhat larger, and the model needs to be re-run with an increased catchment size to provide inflow from the whole catchment.

Further it is necessary to include the sub-catchments that have no measurements of tributaries' discharges. These are the sub-catchments in Kandal, Kompong Cham and Prey Veng provinces. These sub-catchments will either be simulated with the model parameters used for the catchments north of the lake or with those of the southern catchments, dependent on the catchment characteristics.

1.3.6 Computation of Runoff Input for River Hydraulic Model

The sub-catchment areas, which were used for the rainfall-runoff calibration, represent the areas at the gauged stations. Because runoff from the whole area of the catchments is needed, the rainfall-runoff model has been re-run with the total areas of the sub-catchments, but with the calibration parameters unchanged. The total area of the sub-catchments is approximately 37% larger than the sub-areas used for calibration. Therefore, the total volumes of runoff can be correspondingly higher. In addition to the runoff from the sub-catchments, the direct rainfall/evaporation of the lake area is computed and included as input to the river model. This particular contribution is shown in Fig. III-1-10.

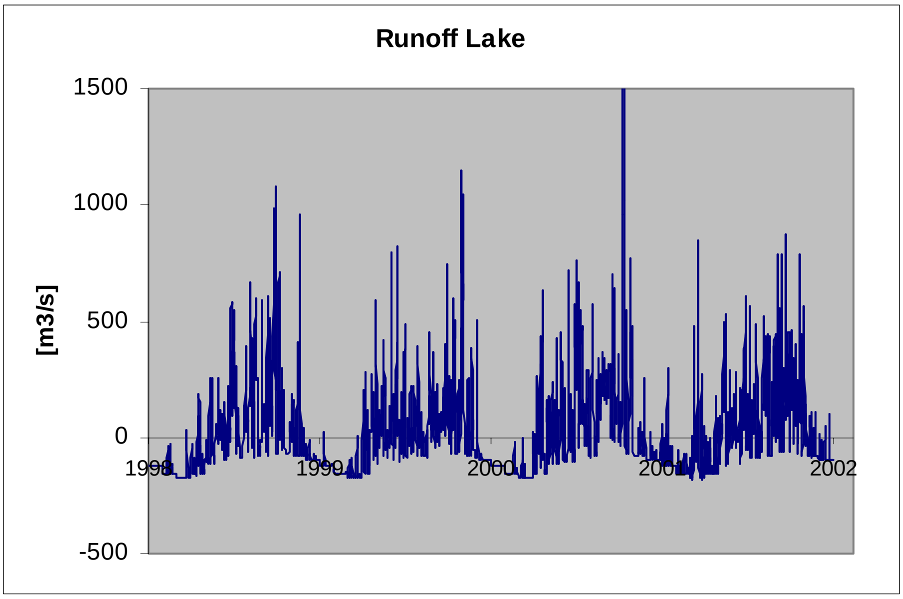


Fig. III-1-10 Simulated Direct Runoff on the Great Lake
(Direct Runoff = Rainfall-Evaporation)

It is important to realise that the total areas of the sub-catchments were used for this computation, thus the area of the lake corresponds to the dry season area. In reality the surface area of the lake increases during the wet season, whereby some of the simulated catchment runoff should be direct rainfall on the lake instead. In the modelling it has not been attempted to model the changing size of sub-catchment areas.

1.4 Hydraulic Model

The main model component of the WUP-JICA model is the hydraulic river and floodplain model. The rainfall-runoff model described in the foregoing section serves only to provide inflow to the river model from local rainfall and tributary runoff.

The construction of the WUP-JICA model takes over the model development from the Chaktomouk Project. However, the Chaktomouk model was too simple for the purposes of the WUP-JICA study, and needed particular improvement on the description of the floodplains as well as the linkages between river and floodplains.

This section describes the data basis for the modelling, the model components as well as the calibration/verification of the model.

1.4.1 Model Concept

This subsection describes briefly the model system applied and describes the model philosophy behind the actual model setup.

(1) Model System

The model system applied was MIKE 11, a one-dimensional mathematical model, which is generalised for modelling of flow in rivers, canals, floodplains, lakes and estuaries. The model has been continuously developed and maintained since the middle of 1980s by DHI, Water & Environment, Denmark. The model package includes modules for rainfall-runoff, flood forecasting, transport of dissolved substances, water quality, and sediment transport. The model system has been developed for Windows and the applied 32-bit compiler technology makes the system fast and efficient. The system has an interface to ArcGIS, which is used for creation of floodmaps.

MIKE 11 is one out of a series of model systems developed by DHI under the shell termed MIKE Zero. Other systems include MIKE 21 for two-dimensional flows, MIKE 3 for three-dimensional flows, MIKE SHE for detailed simulation of the hydrological cycle, MIKE Basin for overall water resource planning simulations, just to mention some. One of the prime assets of the MIKE Zero system is that the models are dynamically interfaced, meaning that models can be constructed with all of their elements. For example a model consisting of a one-dimensional (MIKE 11) and a two-dimensional (MIKE 21) part can be set up for a river-floodplain system in which both one- and two-dimensional flow phenomena are important, and hence run simultaneously.

(2) Actual Model Setup

The river and floodplain system consisting of the Mekong, Bassac, Tonle Sap and the Great Lake including the adjacent floodplains is a complex hydrological and hydraulic water body. The description of the transients in flow over a hydrological year is not possible by means of simple tools and approaches. The process of evaluating and properly understanding the water system starts with a detailed model, which is calibrated/validated against direct observations, and ends eventually with a simpler approach derived from the results of the detailed model.

An example of this is a water balance of the Great Lake. Rainfall data are daily, and the response time of the sub-catchments is within hours or days. If such a system is modelled using monthly averaged data important information may be lost in the description and understanding of how the exchange of flows between rivers and floodplains occurs. The response of the main river system is also within days. Thus in order to properly describe the dynamics of the system, the model should operate on a daily time scale, at minimum. In the present system the tide has effect on far distances upstream in the system. For accurate model description during the dry season, it is therefore important to resolve the tidal variation, which basically means that the model system should operate on a time scale, which is less than one hour.

The spatial scale of a model system of the Mekong is likewise important. Obviously the spacing between the computational points should allow for a correct description of the travel time of a water wave in the system. But certain elements such as bridges, location of interconnecting channels, etc., are also important to include in the model. The floodplains between the main rivers Mekong, Bassac and Tonle Sap must be described in a way that allows for flow exchange with the main river courses. In order to give correct local depths and discharges on the floodplains, and also correct changes in discharge along the main stream the exchange, locations (links) must resemble the real system. It is not necessary to include every bridge and culvert, but links should be established at least between locations on the mainstream where measurements exist, and also at locations where it is known that the major portion of the flow exchange occurs.

The actual model setup includes the Mekong from Kratie in Cambodia to Tan Chau in Vietnam, the Bassac from Phnom Penh to Chau Doc in Vietnam, the Tonle Sap and the Great Lake. The setup includes the river channels as well as the surrounding floodplains.

A significant portion of the available time for modelling in the project has been devoted to collection and evaluation of topographic, infrastructure, and hydrological/hydraulic data/information for proper schematisation. This is necessary for a proper model calibration/verification and hence its applications.

The following describes the data/information for individual model elements of the river and floodplain model.

1.4.2 Topographic and Structural Data

(1) Topographic Data

The model established covers the Mekong-Bassac-Tonle Sap and the Great Lake system from Kratie to Tan Chau and Chau Doc. The model covers the river channels and associated floodplains.

The data sources for topography are different in time and accuracy. The following are the actual data that have been selected for the modelling.

- Mekong river from Kratie to Tan Chau, Tonle Sap and Bassac: Cambodian Hydrographic Office (CHO) survey 1998
- Tonle Sap Lake: CHO survey 1999 for the lake, Philippine Map (1963), for the floodplains
- Flood Plains in Cambodia: Sogreah Map (1963)

<u>Rivers</u>

The source of data for the river cross sections has been the bathymetrical surveys carried out by the Cambodian Hydrographic Office (CHO) in 1998. The outcome of the survey was printed survey maps, which are situated in the Documentation Centre of the MRCS. The accuracy of the survey maps is judged to be good. The resolution in the data along and across the rivers is acceptable. The shortcoming of the data source is that it is solely water survey, and hence the riverbank levels are not included in the cross-sections. On the maps there are spot heights in the vicinity of the river, but they are only given at 1-m intervals and the measurement locations are not very dense. However, the spot levels are the best recent indication of the near bank elevations, and also judged to be more accurate than the maps from the Canadian Colombo Plan data source.

At the initial stage of the project there was some uncertainty regarding the accuracy of the cross-sectional data of the Bassac River. Also it was argued that large differences existed between the general topography levels in Vietnam and Cambodia in the vicinity of the border. In order to come closer to this uncertainty, a levelling campaign from Hatien to Kompong Loung through Chau Doc and Prek Kdam was carried out in 2001. The main conclusion from the survey was that the maximum difference between the levels in Cambodia and Vietnam was 0.25 m, Cambodia being lower than Vietnam. On this ground it was not found worthwhile to change the cross sections in the Bassac River or anywhere else, as there would still remain some questions regarding the adjustment at different locations.

Great Lake

Merging of two data sources has derived the topography for the Tonle Sap Lake (the CHO survey in 1999 and the Philippine Map from 1963). There seems to be no major inconsistency between the two data sources in relation to datum levels, since there is a smooth transition from the plain to the water body of the lake. The merged data set has been used to derive topographical information in parallel cross-sections with spacing of 2 km in the southeast-northwest direction.

Based on the merged data sets a level-volume and a level-area relation have been derived for the lake as a whole. The result is shown in Figure III-1-11, and the numbers are given in Table III-1-5 below. Different attempts have been made in the past for deriving such curves [(6)], but the present is the first one to combine a complete bathymetry survey of the lake with the topography of the floodplains. The southern border of the lake is located at Kompong Chhnang.

Table III-1-5 Elevation, Area and Storage Volume Relation of the Great Lake

Elevation (m)	Cumulative Area (km^2)	Cumulative Volume (MCM)	Elevation (m)	Cumulative Area (km^2)	Cumulative Volume (MCM)
0.5	0	0	4.0	5,828	12,022
0.6	21	1	5.0	7,218	18,545
0.8	666	70	6.0	8,518	26,413
1.0	1,379	274	7.0	9,690	35,517
1.2	1,874	600	8.0	10,935	45,830
1.4	2,125	999	9.0	12,198	57,397
1.6	2,325	1,444	10.0	13,352	70,172
2.0	3,611	2,631	11.0	14,330	84,013
3.0	4,671	6,772	12.0	15,243	98,800

Note: Elevation shown in meters above reflects the mean sea level of Hatien, Vietnam.
MCM means million cubic meters or $10^6 m^3$.

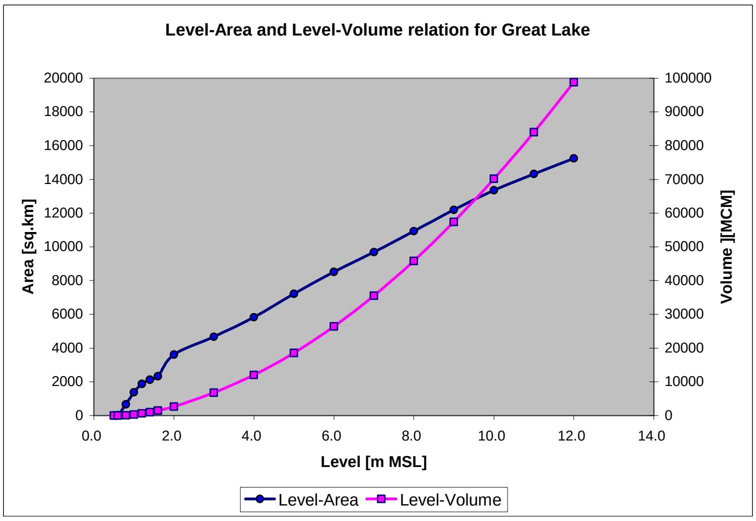


Fig. III-1-11 Elevation, Area and Storage Volume Relation of the Great Lake

Floodplains

Contour lines of the various data sources covering the floodplains are shown in Fig. III-1-12. For the plains along the Mekong, Tonle Sap and Bassac rivers, the Sogreah Data [(7)] are the most reliable. From the Sogreah data of the Cambodian Delta, a Digital Elevation Model (DEM) has been created with a grid cell size of 100 by 100 meters.

Besides the DEM, the JICA map produced for the Ministry of Transportation [(3)] has been used to obtain important information on the floodplains. The information consists, for example, the location of embankments and roads, the location of connected wet and swampy areas, the location and extent of natural embankment subsidence, etc.

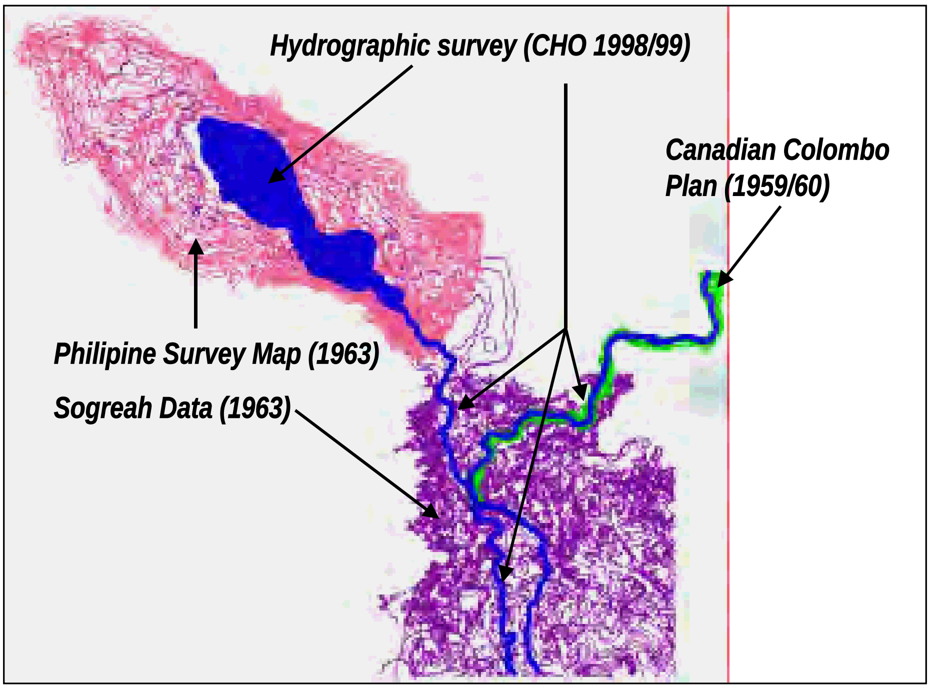


Fig. III-1-12 Topographic Information Sources Available for the Model Construction

(2) Structural Data (Bridges)

The large bridges crossing the main rivers are the Kizuna Bridge in Kompong Cham, the Chrui Changvar Bridge on the Tonle Sap and the Monivong Bridge on the Bassac River. The pillars of these bridges diminish the cross-section area of the river at those locations besides the effect of increasing water levels upstream of the bridges as well as the velocities at the bridge sites. These bridges do not act as control points in the same manner as the bridges on the floodplains, because the flow is confined at the river channels. On the contrary, the bridges on the floodplains act as entry/exit points for floodwater to and from large inundation areas. In view of the above, data on the large bridges were not obtained for the modelling.

The bridges in the model area have been either incorporated individually in the model or lumped together with other bridges. The bridges that are described individually comprise important flow control points, and discharge has been measured at these sites during the 2001/2002 monsoons through the TSLVP [(2)].

The position of the other bridges in the area as well as their widths has been observed through the TSLVP. For the modelling purpose, these bridges have been lumped together at appropriate locations along the main stream. The locations of the lumped bridges correspond largely to the observed entry/exit point of water between the rivers and the floodplains.

The bridges that have been included individually in the model area are: (1) Bridge Nos. 14, 17, 23 and 24 on National Road 6A; (2) Bridge Nos. F1, F2, 2 and F3 on National Road 6, (3) Moat Khmung Bridge on National Road 7 near Kompong Cham; (4) Bridge on the stream Dac on Rural Road 70 near Boeng Thom; and (5) bridges on the tributaries Prek Banam, Stung Sloat, Prek Ampil on the floodplains close to Neak Luong.

The remaining bridges amount to more than 100, and they are scattered around the area along the banks of the Mekong.

The main source of information for the bridges has been the road improvement projects carried out by JICA in recent years [(8)(9)]. From the reports and design drawings of these projects, it has been possible to gather information about the bridges and embankment heights along National Road 6A, 6 and 7. The bridges on National Road 6 are important control points for the floodwater connecting between the Mekong and the Great Lake.

Through the TSLVP, information about the width of the various bridges connecting the Mekong floodwater with the right and left bank floodplains has been obtained. Likewise, information on bridge dimensions at tributaries of the Mekong left bank floodplains south of Neak Luong has been obtained through this project.

1.4.3 Hydraulic Data

The hydraulic data necessary for the modelling are divided into data for boundary conditions and data for internal model calibration. At the model boundaries, either water levels or discharges are needed. For internal model calibration/verification of a system like the Mekong-Bassac-Tonle Sap, both water levels and discharges are needed.

The data that have been examined are from 1998-2002. Water levels have been obtained from the HYMOS database (MRCS) and the DHRW. The discharge measurements available are the ADCP/ADP measurements from campaigns carried out during 2000, 2001 and 2002. The following table shows the stations from which data are available.

Table III-1-6 Stations used for Modelling and Data Availability for 1998 to 2002

Station Name	Station Code	Water Levels	ADCP Discharge	ADP Discharge	Conventional Discharge
Kratie	14901	1998-2002	-	-	-
Kg. Cham	19802	1998-2002	2000, 2002	2001	-
Chrui Changvar	19801	1998-2002	2000, 2002	2001	-
Koh Norea	-	-	2000, 2002	2001	-
Neak Luong	19806	1998-2002	2000, 2002	2001	-
Tan Chau		1998-2002*	-	-	1998-2001*
Kg. Luong	-	1998-2002	-	-	-
Kg. Chhnang	-	1998-2002	-	-	-
Prek Kdam	20102	1998-2002	2000	2001	-
Phnom Penh Port	20101	1998-2002	2000, 2002	2001	-
Chaktomouk	33401	1998-2002	2000, 2002	2001	-
Koh Khel	33402	1998-2002	2000	2001	-
Chau Doc		1998-2002*	-	-	1998-2001*
Bridge No. 2 on Road 6	-	2001, 2002	-	-	2001, 2002

*Note: * means hourly data.*

Fig. III-1-13 shows the location of stations mentioned in the above table.

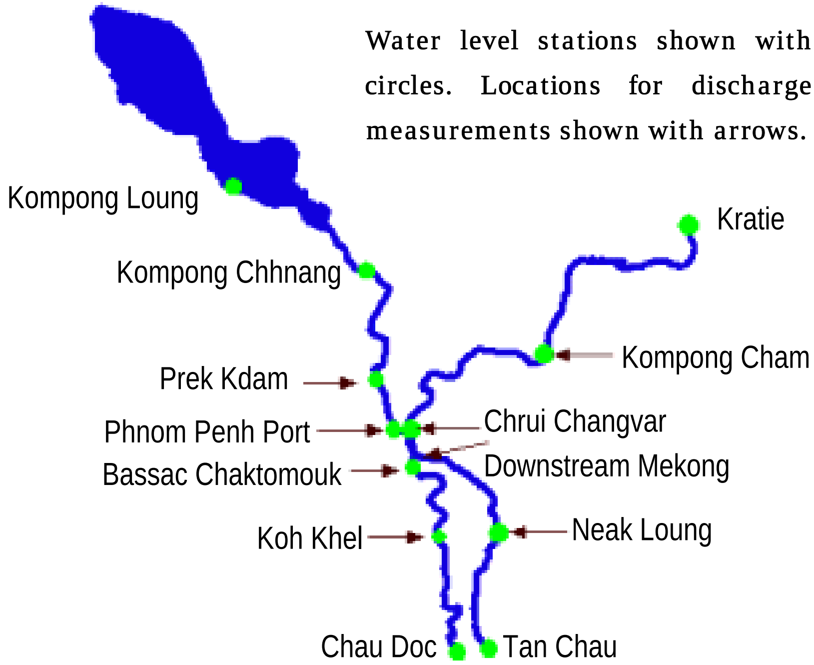


Fig. III-1-13 Hydrological Stations for Hydraulic Modelling

1.4.4 Water Use Data

Water use data is one of the elements of the hydrological cycle, which lacks most in Cambodia. The WUP-JICA Team has not come across any newer data or studies than those produced through the Irrigation Rehabilitation Study in Cambodia (Halcrow, 1994). Based on the 1994 study, a simple estimation of the water usage for irrigation has been made.

The estimation gives for each province in the basin the total required flow rate (in m^3/s) on a monthly basis. The flow rates are the water requirement minus the water returned to the river. The flow abstraction rates have been applied at estimated locations in the various river branches. The abstraction rates are assumed to be applicable for each of the years to be simulated.

1.4.5 Other Data (Satellite Images)

For verification of the hydraulic river and floodplain model, processed satellite images showing flood extent at different periods are useful. Such data exist at MRCS, in the GIS Database of its Technical Support Division. The data within the years studied comprise the following: RADARSAT images consisting of: (1) dry season image of March 16 & 26, 1999; (2) early flood image of September 24, 1999; (3) peak flood image of October 21 & 25, 1999; (4) early flood image of August 25 and September 4, 2000; (5) peak flood image of September 23 and October 5, 2000; (6) post flood image of October 19 & 22, 2000; (7) early flood image of August 30, 2001; (8) peak flood image of September 23, 2001; and (9) post flood image of October 17, 2001.

In the TSLV project, extensive use of eight satellite images taken at approximately one-month intervals from July 2002 to January 2003 has been made. These images served as a basis for verification of the modelling results on the floodplains.

1.4.6 Model Area and Schematisation

This subsection describes the schematisation of the river model based on the data described in the foregoing section.

(1) Topographic Model Elements

Rivers

The hydrographic survey maps described in the previous section were digitised as part of the Chaktomouk Project [(1)], and incorporated in the MIKE 11 model at that time. The cross sections have been used unchanged for the WUP-JICA study. The cross-sections cover the Mekong from Kratie to Tan Chau, the Tonle Sap and the Bassac from Phnom Penh to Chau Doc.

Great Lake

From the lake data described in Subsection 1.4.2, cross-sections covering the entire width of lake and plain have been extracted for every 2 km in parallel lines. These cross-sections have subsequently been incorporated into the cross-sectional database of the MIKE 11 model and used for the modelling. This activity is an improvement of the model compared to the Chaktomouk Project. In the Chaktomouk Project, the lake was modelled with artificial cross-sections in up- and downstream ends. The cross sections were derived with the use of a level-area relation for the lake as a whole made by Nedeco [(10)]. In the WUP-JICA study the lake was still modelled as a single branch, but the number of cross-sections and their accuracy have increased. The improvement of the lake cross-section is necessary for accurate production of maps of flood extent.

Floodplains

The floodplains surrounding the main rivers in Cambodia are inundated every year during the monsoon. The floodplains serve as floodwater storage during the rising and main period of the monsoon, and release the stored water to the river system again during the recession period of the monsoon. Moreover the floodplains in Cambodia serve to convey flow between the main rivers as well as between the floodplain compartments.

The functions of the floodplains are not completely understood, mainly due to lack of data/information on them. It was not the main focus of the WUP-JICA study to understand and analyse the functions of the floodplains. However, the modelling of the floodplains has been made as accurately as possible for the description of flow, exchange and storage mechanisms. By doing so it has been easier to use the model for detailed studies of the floodplains.

It was clear from the available data that there is a significant slope of the surface level on the floodplains. This was concluded from the gradient in water levels on the mainstream during the periods in which floodplains and rivers were connected. Further, the TSLVP, in which water levels were observed at twenty (20) stations on the floodplains, concluded that there is a noteworthy water level slope on the floodplains. With a slope on the plains it follows that there is a flow across the plains. The velocity of this flow will be lower than the velocity in the main stream. Two conclusions can be made on this basis: one is that the rivers and floodplains must be dealt with and described separately with appropriate links to the main river system. The other is that a simple flood-cell approach in which the floodplains are assumed to have horizontal flow slope is not suitable. There will naturally be parts of the floodplains, which can be assumed to have a horizontal water level, and which exchanges flow with the river system at single locations such as bridge openings and smaller channels. Such area can be modelled with a flood cell approach. However, the major part of the floodplains convey flow and it is necessary to construct a system of channels in a quasi-two-dimensional network in order to correctly model the flow on the plains as well as the exchange of flow with the river system.

The floodplains have been schematised as branches, which are linked together and linked with the river channels in a looped network. For the delineation of the various compartments of the floodplains, the map prepared by the MPWT and JICA [(3)] has been extremely useful. From the map it was possible to point out individual floodplain areas, the locations of embankments separating the individual floodplains and also to determine the location of connecting points with the main rivers. The TSLVP has obtained information about dimensions, flow direction and significance of approximately 100 bridges located on the natural levees which link the main rivers with the floodplains. This information has been used in the WUP-JICA study in order to improve the description of the floodplains and the links to the main river system.

From the DEM derived on the basis of contour lines, a number of cross-sections for description of the floodplains have been extracted and distributed on the quasi-two-dimensional network of the floodplains. Fig. III-1-14 shows the network on the floodplains as well as the location and extent of the cross-sections. Fig. III-1-15 shows in detail the schematisation of river and floodplain branches together with cross-sections for the area around Phnom Penh.

Bridges

The bridges mentioned in the previous paragraph have been schematised in the model with the information available on width, slide slopes, invert level, top level from the design drawings in ref./10/ and ref./11/. At the locations in the model where bridges are introduced, the flow equations are substituted with an energy equation thus providing a head loss.

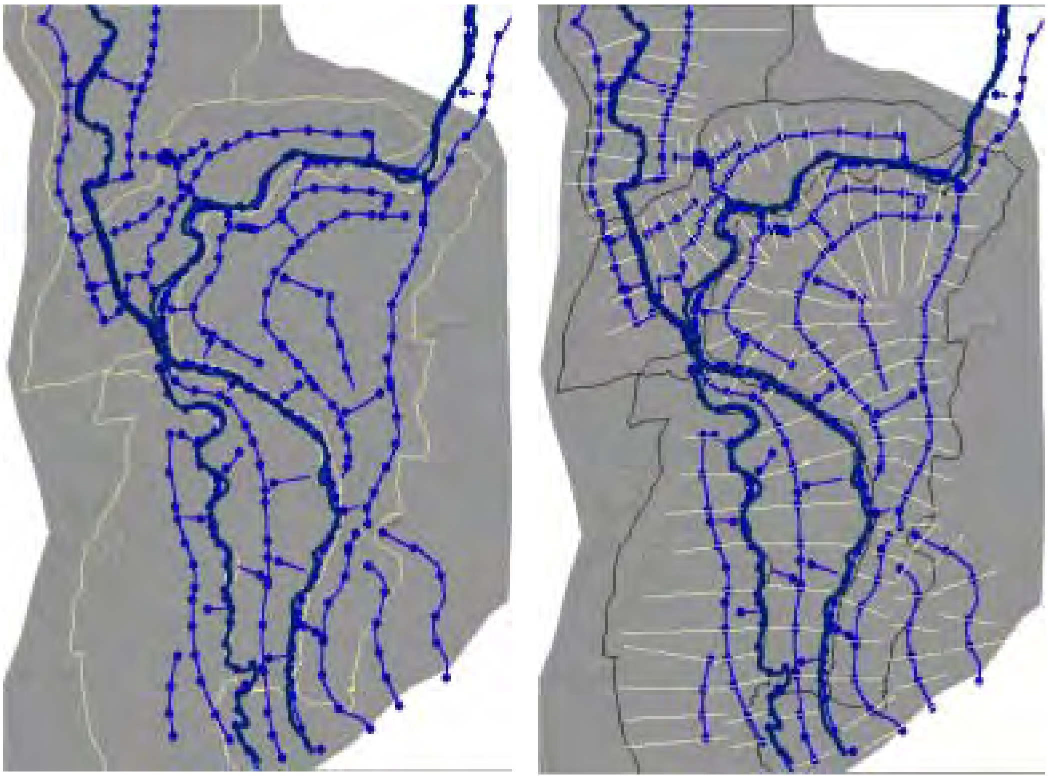


Fig. III-1-14 Detailed View of Quasi-Two-Dimensional Network for the Floodplain Modelling with Cross-Sections Overlaid (Right)

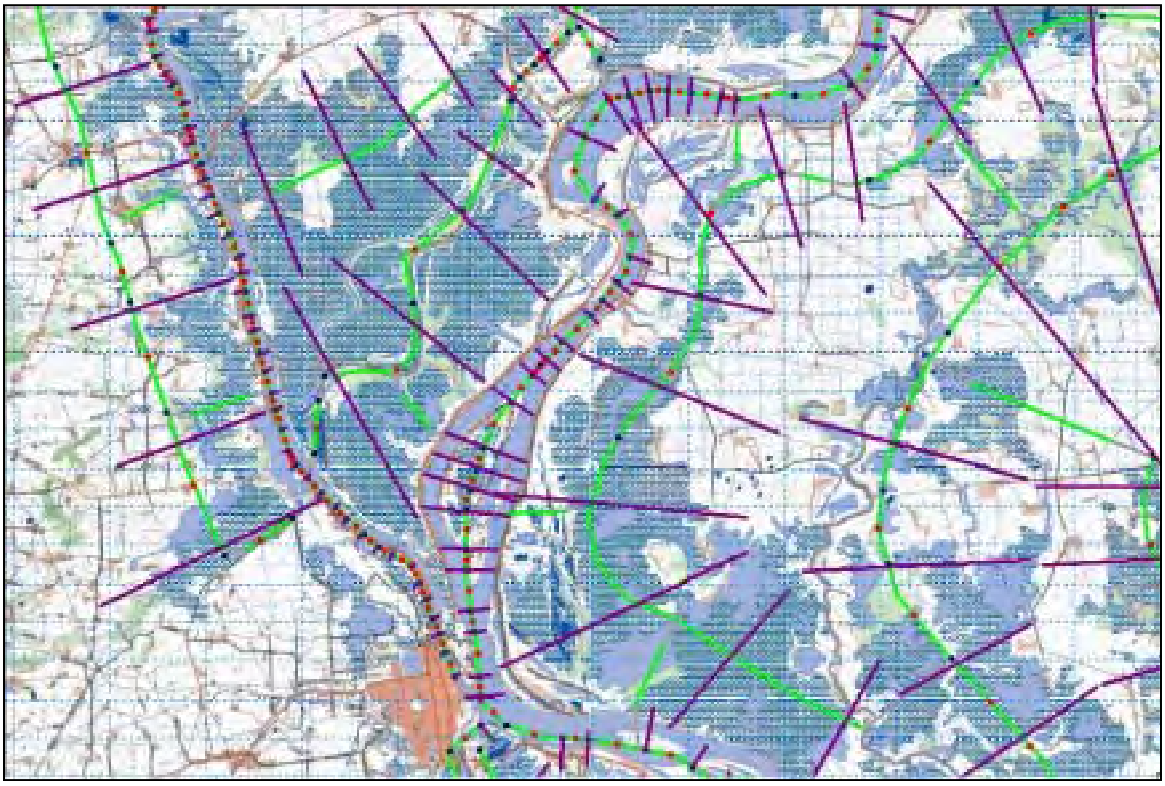


Fig. III-1-15 Detailed View of Branch and Cross-Section Layout around Phnom Penh Area

(2) Model Setup

The model contains altogether 73 branches. Each branch has a number of cross sections depending on the available data and on the need for resolution. Altogether 643 cross sections have been implemented and distributed on the river network.

MIKE 11 uses a staggered grid, meaning that water levels and discharges are computed alternately. Cross-sections are located in computational points for water levels. It is possible to introduce more computational points between two cross-sections. In that case the hydraulic parameters (area, width, hydraulic radius, conveyance, etc.) are computed by linear interpolation of the nearby cross-sections. The total number of computational points in the model amounts to 1,214. At present there has been no attempt to optimise the model set-up, i.e., to reduce the number of cross-sections and computational points while maintaining the accuracy of the model.

Fig. III-1-15 shows the layout of the river and floodplain branches including the locations of cross-sections in the area between the Mekong and Tonle Sap near Phnom Penh. In the figure the location and extent of the cross-sections are seen as orthogonal lines to the branches. Computational points are marked with dots.

A plan view of the model schematisation of the river and flood plain network is presented in Fig. III-1-16. A longitudinal profile covering the Great Lake and Tonle Sap down to Phnom Penh is also presented in this figure. Finally a few selected cross-sections from the river system are also shown in it.

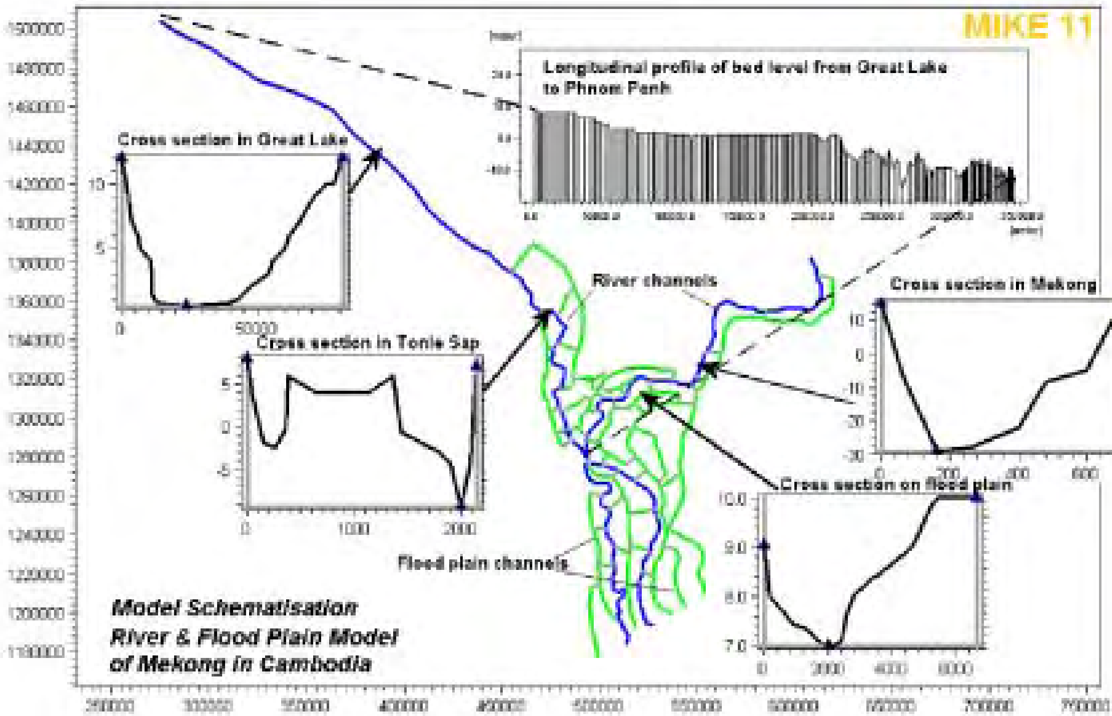


Fig. III-1-16 Model Setup: Alignment of River and Floodplain Channels and their Connections

<u>Catchment Delineation for Rainfall-Runoff Modelling</u>

The computation of rainfall-runoff from the sub-catchments has been described in Section 1.3. The simulated runoff serves as an input to the river and floodplain model. The computed inflow is transferred to the river model in either a single computational point (e.g., the tributaries around the Great Lake) or over a longer reach (which is the case for floodplains).

<u>Boundary Conditions</u>

The river and floodplain model needs boundary conditions at upstream and downstream ends. These boundary conditions are either water level or discharges dependent on availability. Fig. III-1-17 shows the model layout with indication of the boundary location and type. The following boundary conditions were applied:

Kratie	:	Upstream boundary on the Mekong. Due to lack of discharge data, a water level boundary has been applied. Daily values are used.
Great Lake	:	The boundary condition at the upper end of the lake is covered by the runoff from the sub-catchments Sisophon and Mongkol Borey.
Tan Chau	:	Downstream boundary on the Mekong. Hourly water levels are applied.
Chau Doc	:	Downstream boundary on the Bassac river. Hourly water levels are applied.
Floodplain Tributaries	:	The six floodplain branches in the model near the Vietnamese border are all described with a daily water level

boundary.

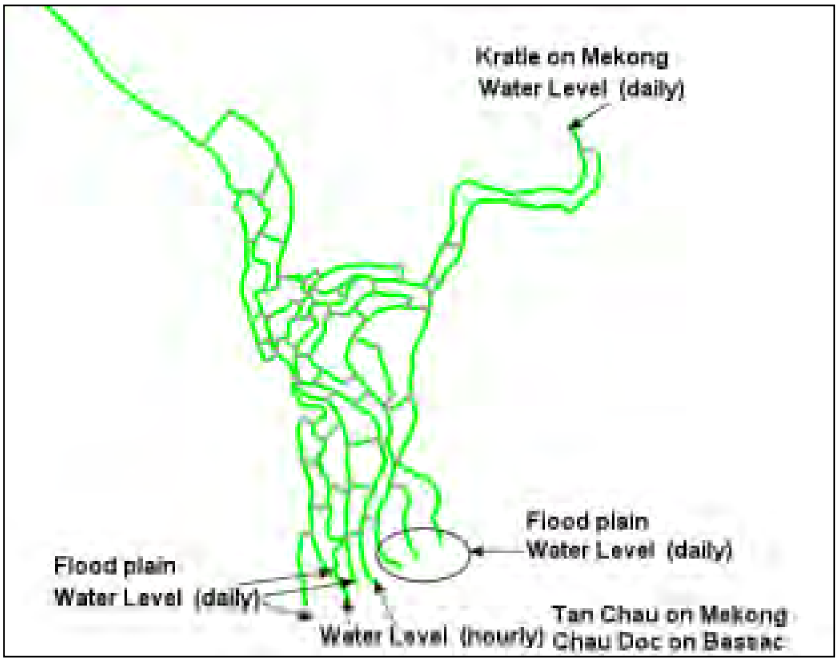


Fig. III-1-17 Locations and Types of Boundary Condition Applied

These branches cover in extent not only the known channels (e.g., Prek Trabaek), but also the surrounding floodplain. It has not been possible to obtain water level data for all of these locations. A time series of daily water level has been obtained only from Xuan To, which is on the right bank floodplain of the Bassac River. A comparison of the water levels here with those of Tan Chau and Chau Doc clearly shows that there is a water level slope between the stations. Through the information from the Vietnamese analysis of the 2000 flood, it has been confirmed that a pronounced water level slope exists on the floodplains from east to west along the border of Cambodia and Vietnam. Using this information together with the observed water levels at Xuan To, Chau Doc and Tan Chau led to the derivation of the water levels at the remaining boundaries by using linear interpolation.

Besides the boundary conditions at the ends of the branches, the model has lateral inflows (internal boundaries) from the tributaries around the Great Lake as well as from Stung Chhlong and Prek Thnoat. Further, direct rainfalls on the Great Lake and on the floodplains are internal boundary conditions for the model.

1.4.7 Calibration and Verification of Hydraulic Model

The river and floodplain model has been calibrated for year 2000, and verified for the years 1998, 1999 and 2001.

In general the roughness coefficient (Manning number) in the system has been the main calibration factor, and was usually adjusted until an acceptable result was achieved on water levels and flow distribution (in case of a bifurcated system). In the present model system the upstream boundary condition is a water level boundary. The discharge at the upper boundary is then computed by using information of the roughness coefficient and flow equations. The inflowing discharge is thus dependent on the choice of roughness coefficient (Manning number). However, it is fortunate that discharge measurements exist downstream on Mekong mainstream at Kompong Cham, since there is no major loss of water from Kratie to Kompong Cham. The approach adopted herein is therefore: to apply the observed water level at Kratie as the upper boundary, then adjust the roughness coefficient until both water level and observed discharge at Kompong Cham are acceptable.

In most calibration situations, the water balance (e.g., in a bifurcated system) is obtained first. Hereafter the water levels are matched. In the present system there are complications in using this approach. The main reason is that the invert levels of many bridges and tributary streams in the model area are not known. The bridges and streams carry water to the floodplains from mainstream, and are therefore important for the water balance. But the magnitude of the water diverted is dependent on the invert level and on the water level in the mainstream, which in turn is dependent on the roughness coefficient. Moreover the diverted volume will adjust the water levels in the mainstream. The calibration task therefore becomes an iterative process where invert levels and roughness coefficients are adjusted until both water balance and water levels are matched. The only guides at hand are the ranges that can be set for invert level variation and variation of roughness coefficient.

The following are the results of model calibration and verification.

(1) Discharge

The simulated and observed discharges at the major stations for the years 1998-2001 are depicted in Fig. III-1-18. Discharge measurements first started in year 2000, but the years 1998-1999 are plotted for comparison and because water levels exist for the entire period 1998-2001. In general the simulated discharges match well the measured discharges. It should be mentioned that there are only few discharge measurements available in year 2000, although they are taken as important points in time, i.e., before, under and after the monsoon.

The discharges match in the mainstream of Mekong as well as in the Tonle Sap and the Bassac. Hence the model is able to reproduce the diversion of flow into the floodplains along the Mekong as well as flow reversal to the Tonle Sap. The diversion of flow into the plains is clearly seen from the time series in comparison with the hydrographs between Kompong Cham and Chrui Changvar. Note that the diverted discharge is almost zero in the dry year 1998. The flow reversal to the Tonle Sap is seen at Phnom Penh Port.

Only in 2001 that discharge measurements started to be made on the tributaries on the floodplains. The most important location for flow exchange between Mekong and Tonle Sap is Bridge No. 2 (Spean Tras) on National Road 6. The figure shows the simulated and observed discharge at this bridge. It can be seen that the flow from Mekong to Tonle Sap (positive values) is accurately reproduced. The flow reversal at this site is not accurately reproduced (negative flow).

(2) Water Levels

The simulated and observed water levels at major stations are shown in Fig. III-1-19. It can be seen that both water levels in the Mekong mainstream as well as the Tonle Sap and the Bassac are accurately reproduced. The water level in the Great Lake (at Kompong Luong) is also reasonably well reproduced. This shows that the topography of the lake is well described in the model and also that the total inflowing volume during the wet season is reproduced.

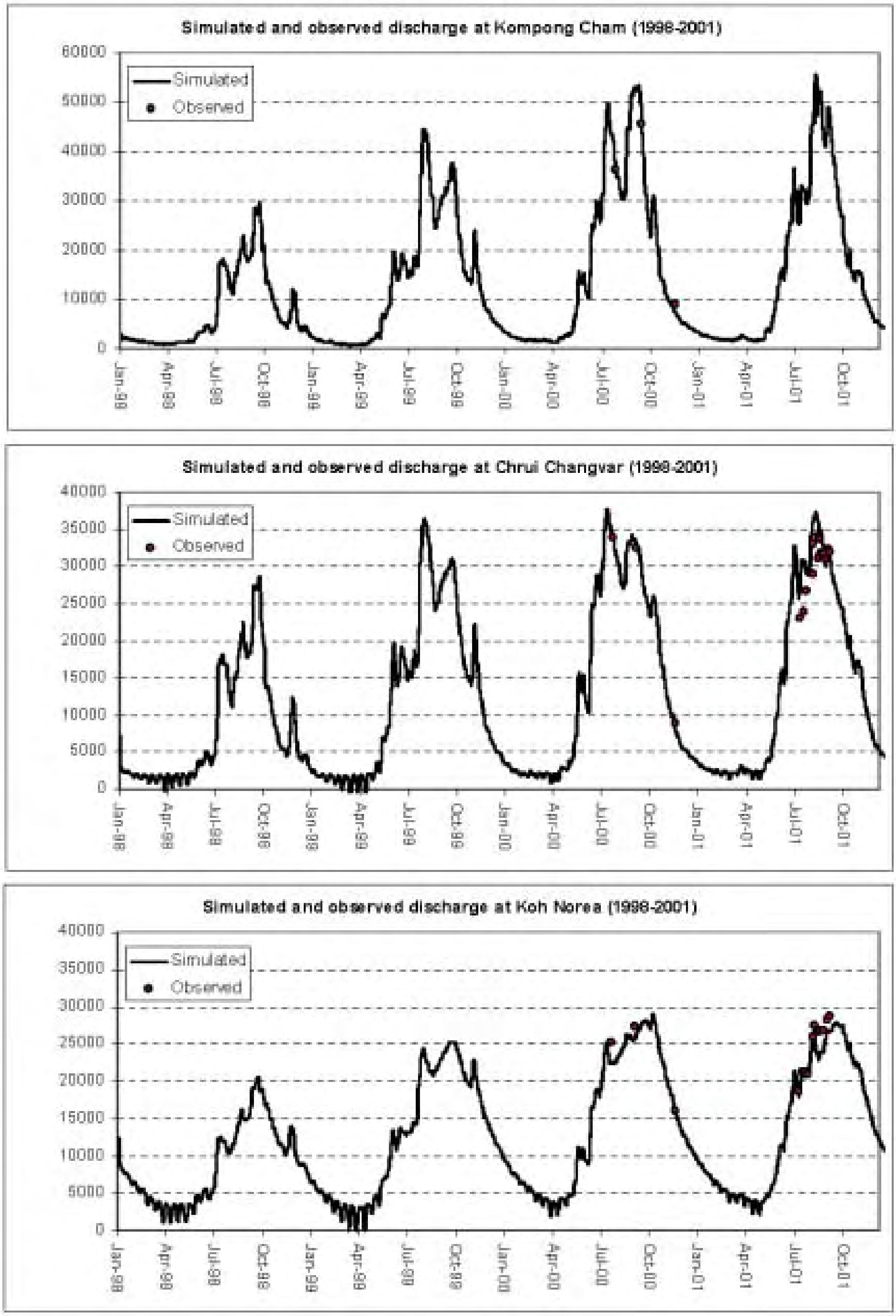
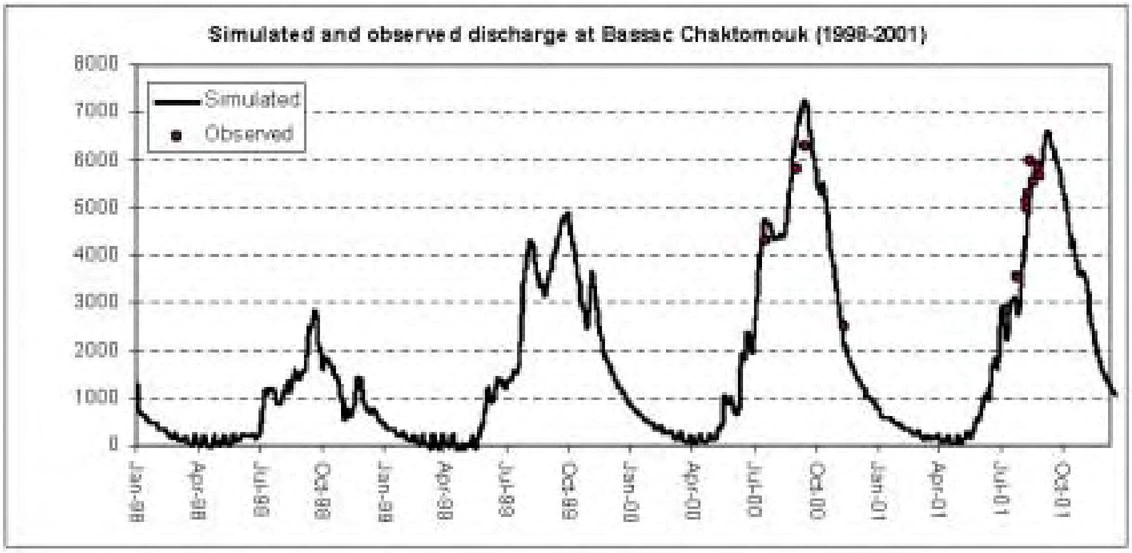
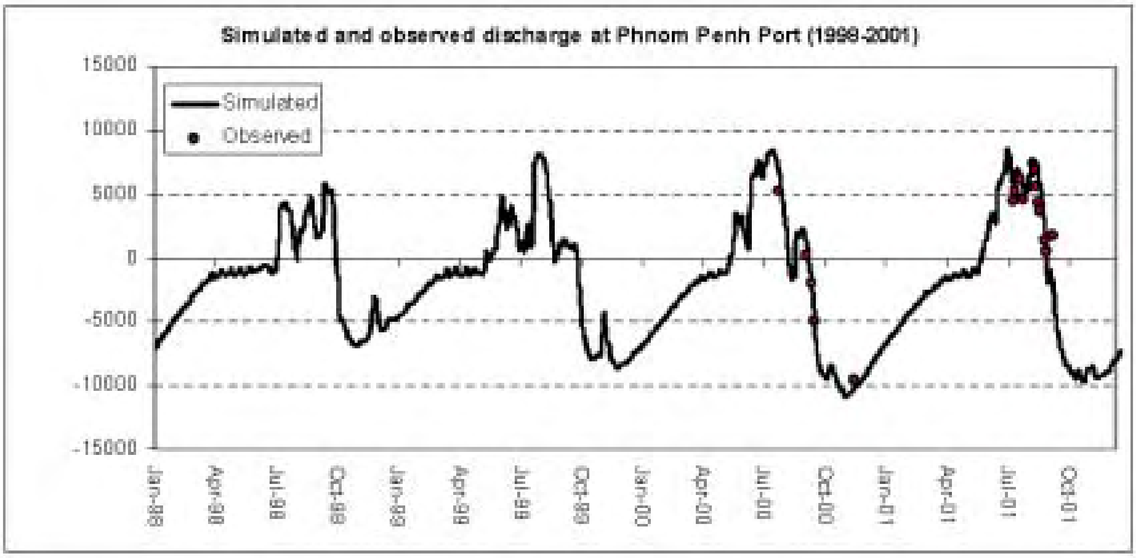


Fig. III-1-18(1/2) Model Calibration Results in Discharge: Mekong Mainstream (Unit: m^3/s)





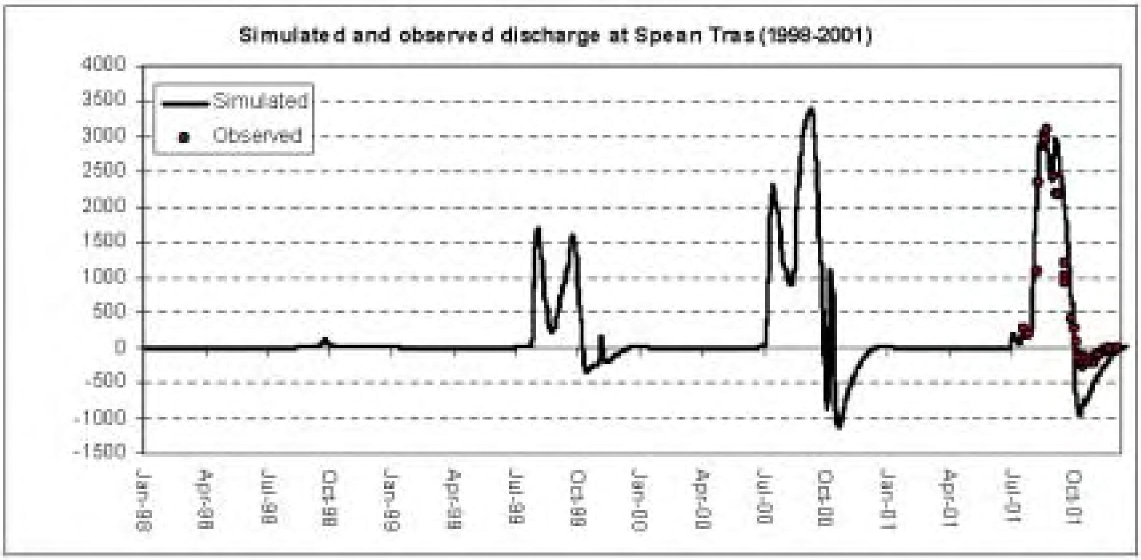
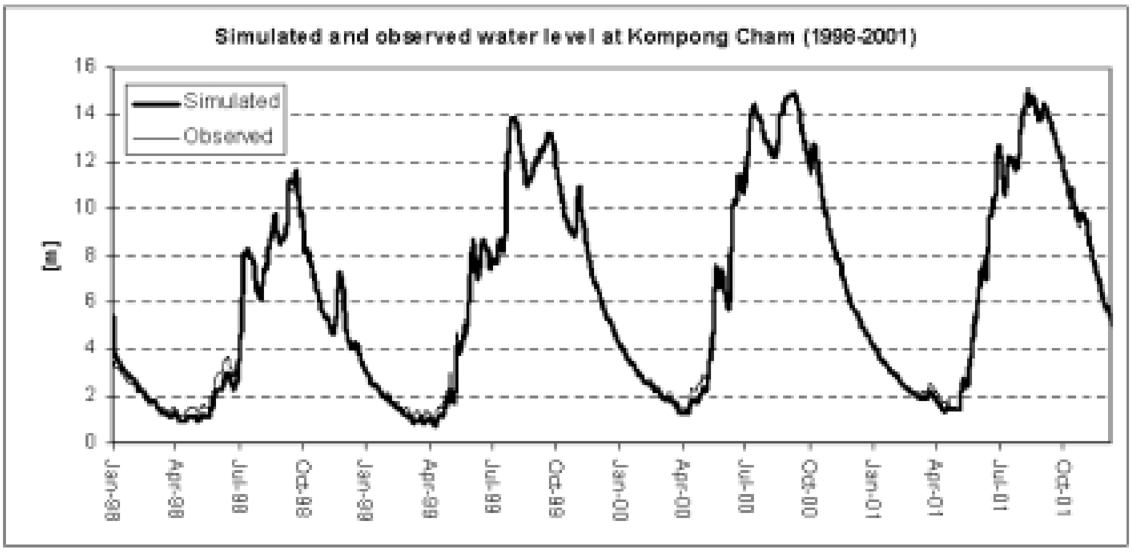
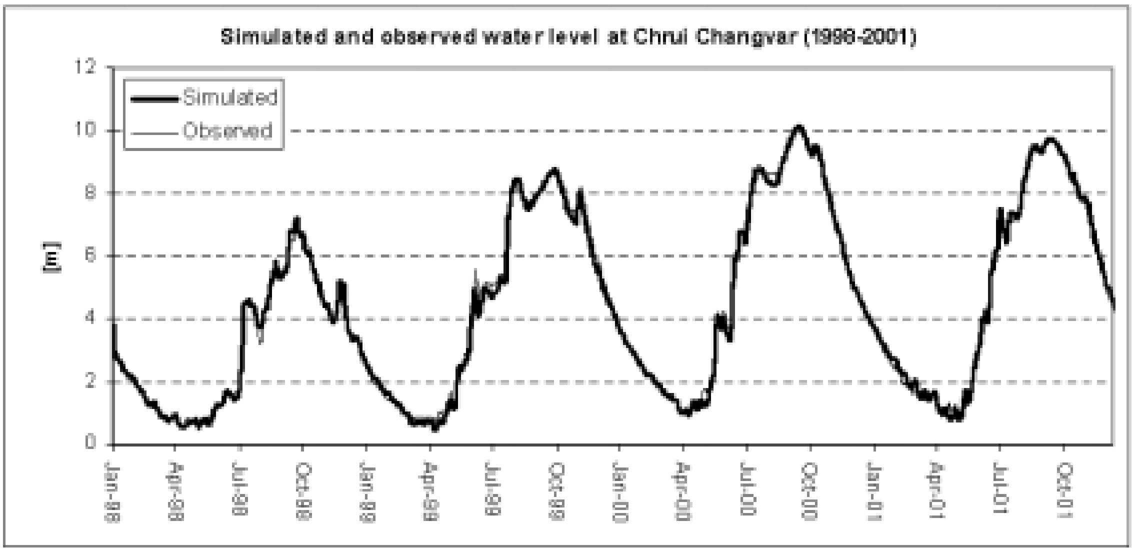


Fig. III-1-18(2/2) Model Calibration Results in Discharge: Bassac, Tonle Sap and Flood Path of Floodplain (Unit: m^3/s)





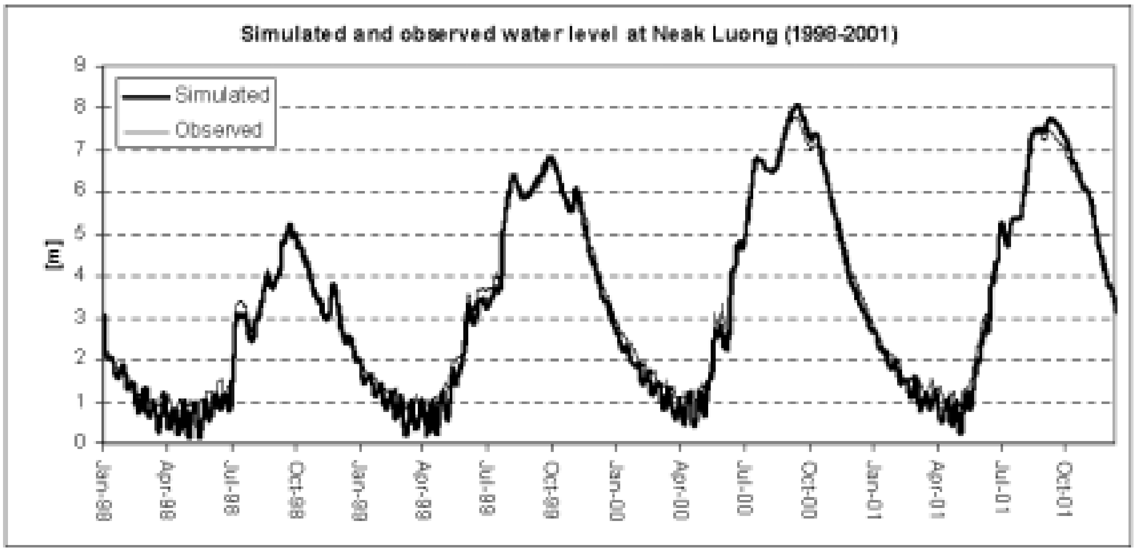


Fig. III-1-19(1/2) Model Calibration Results in Water Level: Mekong Mainstream

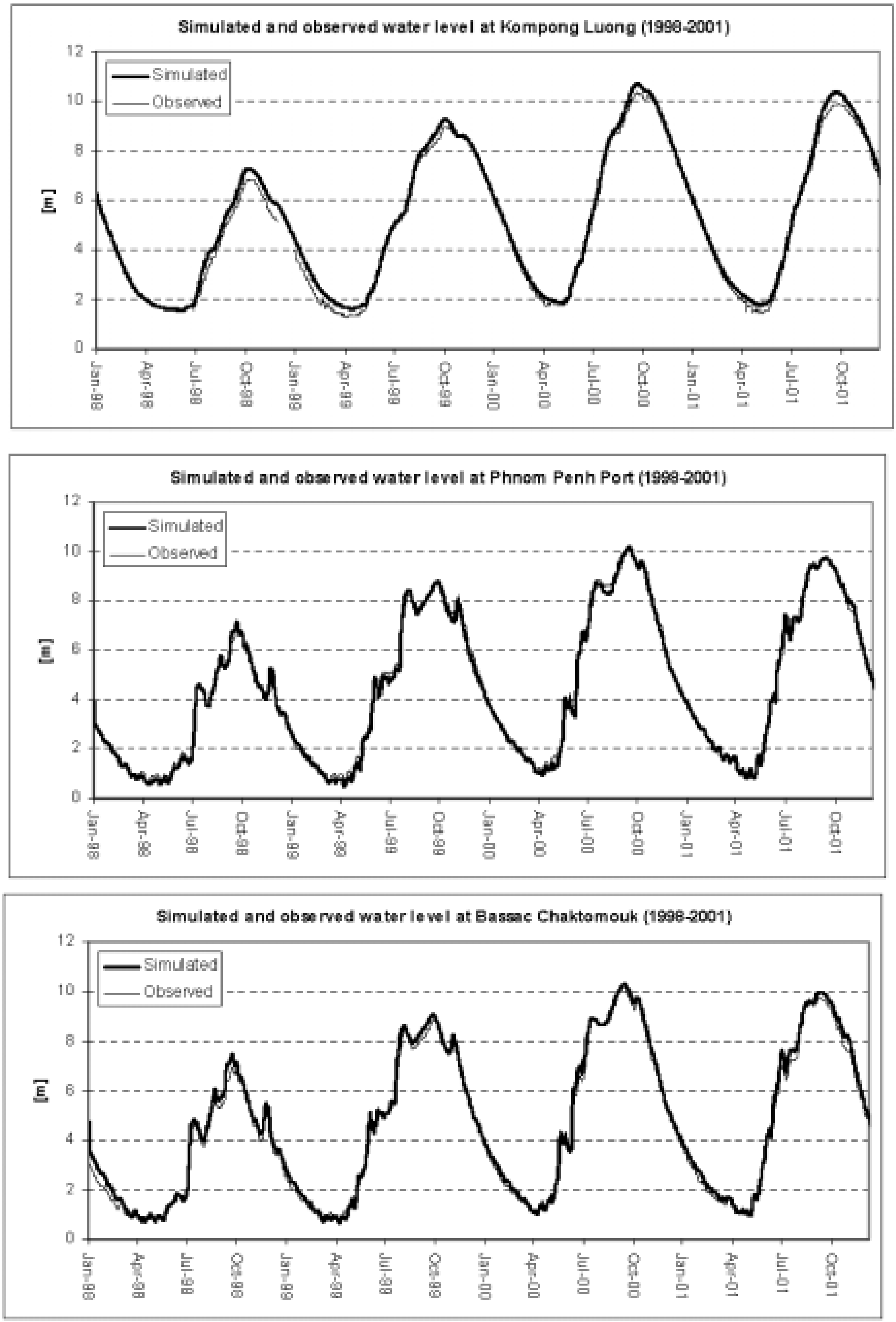


Fig. III-1-19(2/2) Model Calibration Results in Water Level: Great Lake, Tonle Sap and Bassac

(3) Flood Extent

The flood extent has been estimated by using the satellite images (RADARSAT) of the Mekong River and the Delta. In the WUP-JICA study the images were used to verify that the simulated flood extent matches the observed extent. In the WUP-JICA study it has not been attempted to accurately model the flood depths and floodplain function in detail. The parallel TSLVP was devoted to this task.

Comparison between simulated and observed flood extent for the years 2000, 1999 and 2002 has been made, as shown in Fig. III-1-20. It can be seen that the extent of flooding is well reproduced for the peak flood in year 2000. The flooded area caused by backwater effect in Stung Sen at Kompong Thom was not reproduced, since this river was not schematised as a river branch.

The flood extent of year 1999 was smaller than the extreme flood of 2000. It can be seen that in general there is a good match between observations and simulations. The TSLVP also had taken a series of satellite images in the 2002 wet season. Although the images do not cover the entire lake, the flood extent on the 14th of October 2002 was well reproduced by the model.

The model verification on year 2002 has already been made. Through the TSLV project satellite images have been acquired on monthly intervals throughout the monsoon season. The images do not cover the entire lake as shown in Fig. III-1-20(3/4). The model predicts well the dynamics of the flood extent throughout the monsoon. As an example from the TSLV project the observed and simulated flood extent on the 14th of October 2002 is shown in Fig. III-1-20(4/4).

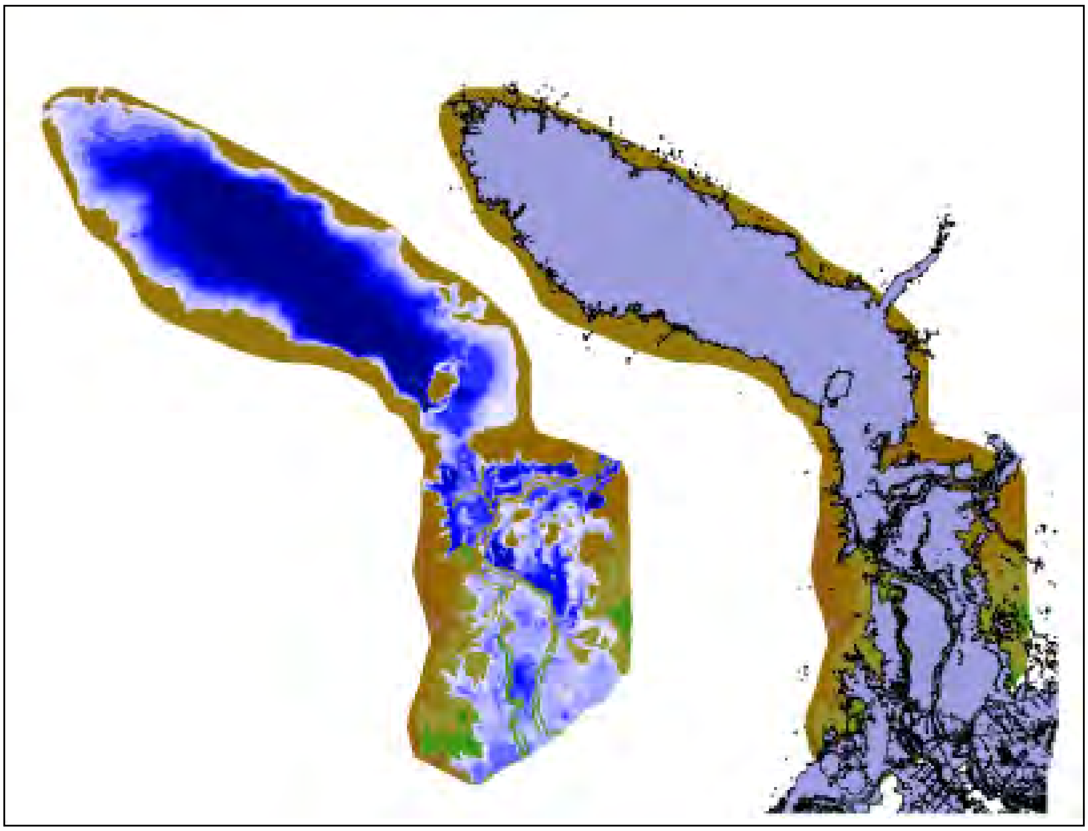


Fig. III-1-20(1/4) Simulated (Left) and Observed (Right) Flood Extent: at the Peak of the 2000 Flood

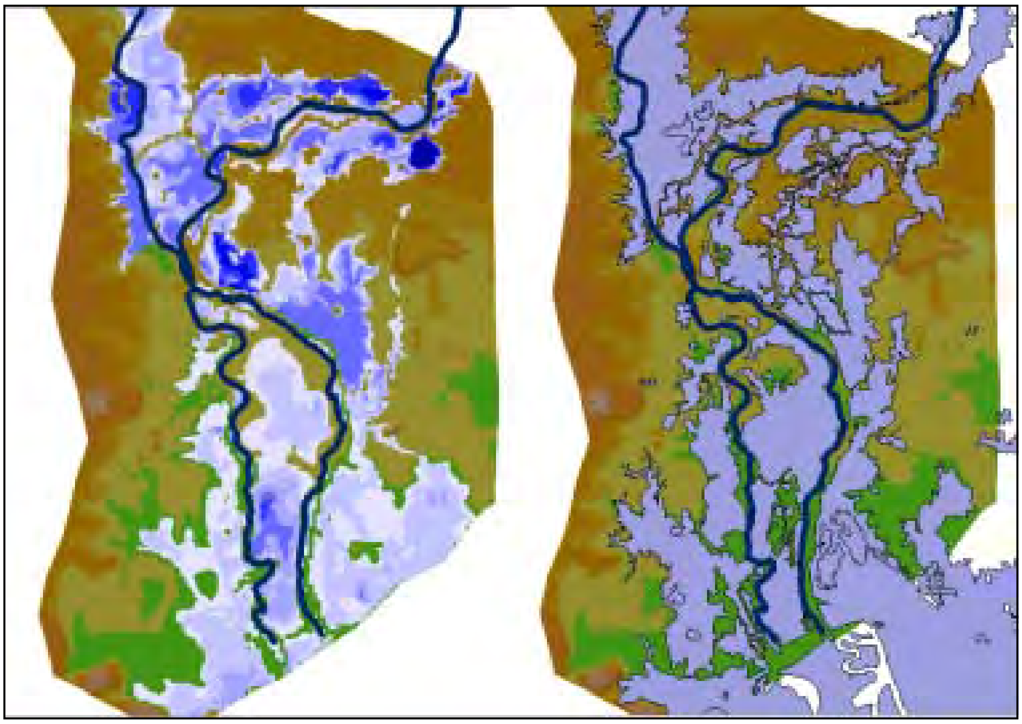


Fig. III-1-20(2/4) Simulated (Left) and Observed (Right) Flood Extent: at the Peak of the 1999 Flood

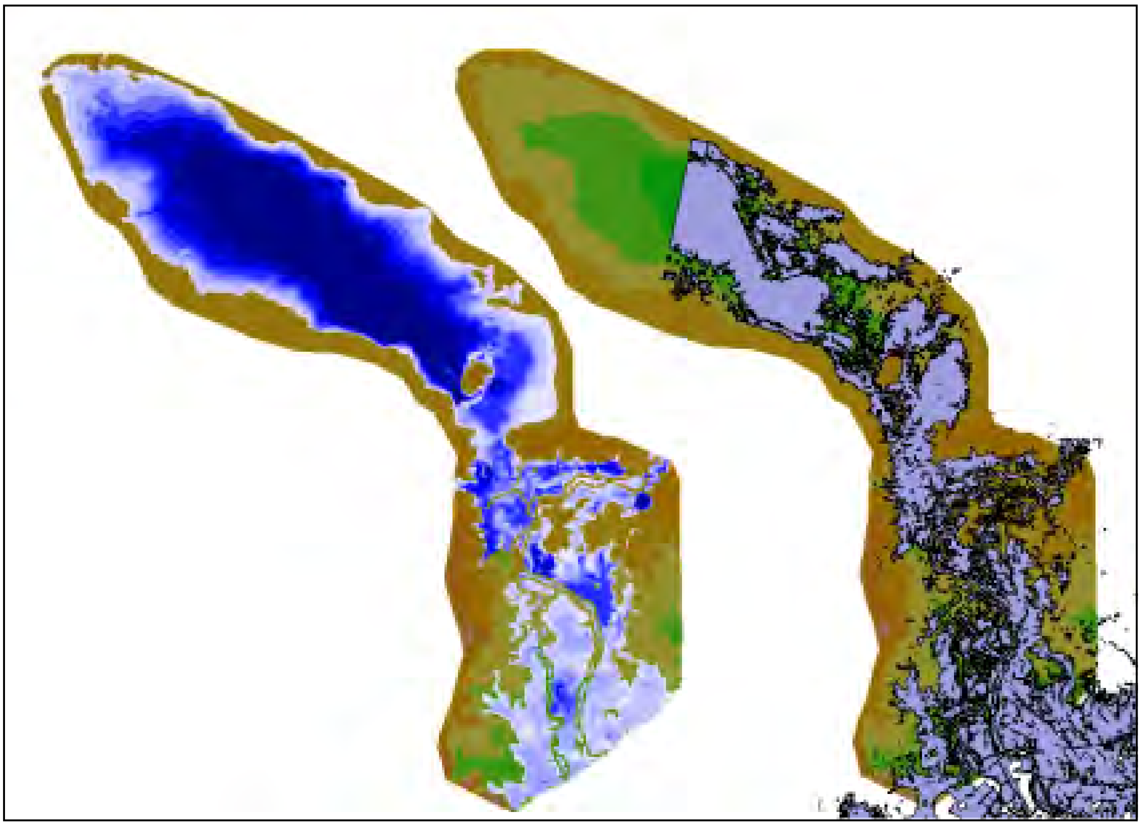


Fig. III-1-20(3/4) Simulated (Left) and Observed (Right) Flood Extent on 14 October 2002

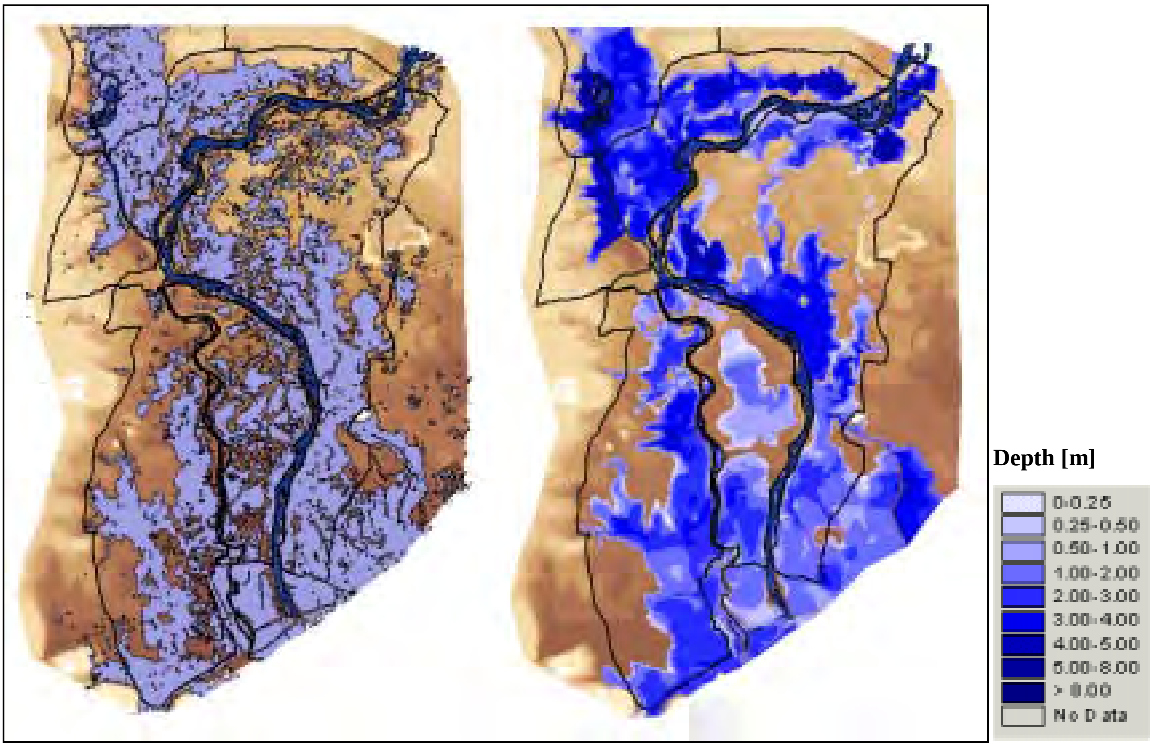


Fig. III-1-20(4/4) Simulated (Left) and Observed (Right) Flood Extent on 14 October 2002

(4) Verification for Year 2002

A verification of the model has been carried out for the year 2002. The WUP-JICA Team carried out intensive discharge measurements using ADCP in 2002. The measurements were carried out on a weekly/bi-weekly basis and covered a number of stations along the Mekong, Tonle Sap and Bassac river systems around Phnom Penh.

Besides using them for the construction of discharge rating curves, the measurements were extremely useful for verification of the river model. The reason is that more detailed pictures of the flow conditions in space and time have been obtained.

Through the TSLV project, the model had been refined to better describe the flow between rivers and floodplains, and to describe the floodplains in more detail. Hence link channels between rivers and floodplains as well as the floodplain schematisation had been updated. Since the 2002 monsoon data was used for calibration of the model in the TSLV project, those data could not be used for the verification. The updated model was then run for the year 2000, which is considered the main calibration event until now. Since it gave acceptable results, it was subsequently used for verification of the years 1998, 1999 and 2001. The results have been discussed in the previous section.

The simulation results for the year 2002 from some of the important stations in the system are presented in Fig. III-1-21. It can be seen that a good match between observed and simulated discharge is presented at Kompong Cham. This confirms that the water level at Kratie can be applied as a boundary condition, and also that the roughness of the river channel between Kratie and Kompong Cham is accurately described.

Likewise the discharge results at Chrui Changvar, Koh Norea, Monivong Bridge and Phnom Penh Port are well reproduced. These modelling results demonstrate that the model can represent the unique flow dynamics and balance at the Chaktomouk junction. Fig. III-1-21(2/2) shows the simulated and observed discharge at Prek Kdam and Phnom

Penh Port. The figure shows that the model had predicted well the flow dynamics at these two stations. An interesting detail is that the model predicted well the observed transition period in which flow is towards Chaktomouk at Phnom Penh and towards the Great Lake at Prek Kdam (around end of September).

There are significant changes in discharges in the Bassac River from Monivong Bridge to Koh Khel, as shown in the middle of Fig. III-1-21(2/2). The reason is that flow is diverted into the floodplains (mainly via a tributary of Prek Thnot and the numerous colmatage canal systems). It can be seen that the diverted flow is not returned to the river along this reach.

The model predicted the hydraulic conditions well at various scales. As an example of a smaller scale discharge (in comparison with the Mekong discharges), the simulated and observed discharge at Spean Dach (Bridge Dach on the embankment of Road No. 70 near Kompong Cham) is also shown at the bottom of Fig. III-1-21(2/2). Compared to the flows in the main river system, flows occurred in a shorter time frame through the bridge. It can be seen that there is an excellent match between observation and simulation results. This implies that the water balance and flood extent on the floodplain in the Beung Thom area (upstream of Spean Dach) can be accurately simulated.

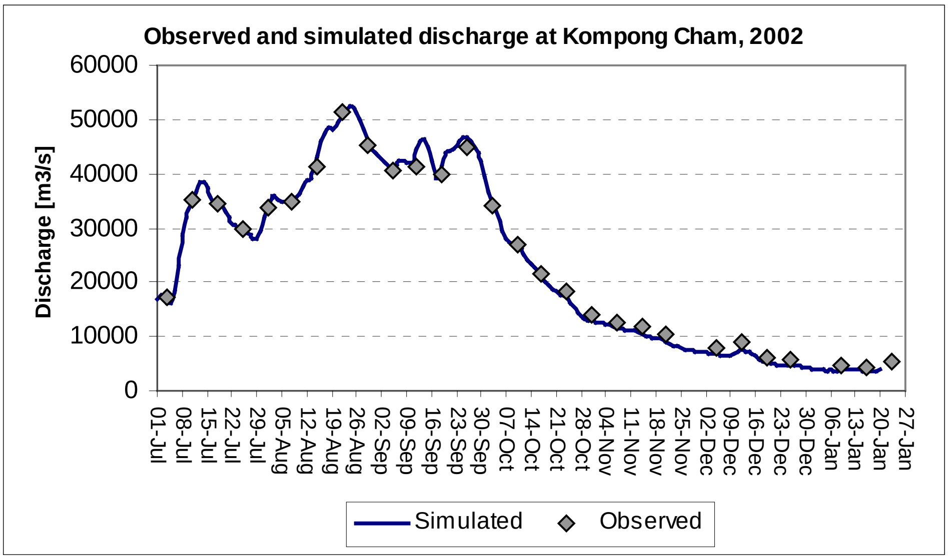
1.5 Conclusion

A hydrological and hydraulic model has been developed as part of the WUP-JICA study. The model is a refinement and significant improvement of the MIKE 11 developed for the Chaktomouk Project. In parallel with the WUP-JICA Project, the Tonle Sap Lake & Vicinities Project made use of the same model. Since both projects had collected hydrological and infrastructure data, both projects contributed to the continuous improvement of the model. As such the model has been useful for the purposes of both projects.

The established model consisted of (1) the rainfall-runoff sub-model, and (2) the river and lake model. The primary purpose of the rainfall-runoff model was to provide input to the hydraulic model of the rivers and lake system. The work presented herein had shown that it is possible to establish a sub-catchment based rainfall-runoff model for Cambodia, despite the lack of long records of good data.

The model had demonstrated in quantitative terms the complex hydraulic behaviour of the Mekong river system and the associated floodplains in Cambodia. The hydraulic behaviour for the years 1998-2002, which contains both extreme dry and extreme wet hydrological years, had been studied. Over these years an increasing amount of data had become available and collected. The number of rainfall stations had increased significantly in Cambodia since the year 2000. Particular improvement in discharge data was observed by the WUP-JICA study in 2002. In 2002 a comprehensive measuring campaign collecting discharges and water levels in the floodplains has been undertaken in connection with the TSLV project. Together with the monthly satellite images of flood extent at monthly intervals as well as the WUP-JICA ADCP discharge measurements, the combined data set represents the most comprehensive collection to date. These data have been of profound value for the modelling work.

The model developed is able to simulate the dynamics of flow and water level in the river system in both of the wet and dry seasons, the water level and inundation on the floodplains, as well as the exchange of flow between rivers and floodplains. The model is therefore very useful for a variety of studies such as flood analysis, flood impact studies, water balance studies, and dry-season flow investigations.



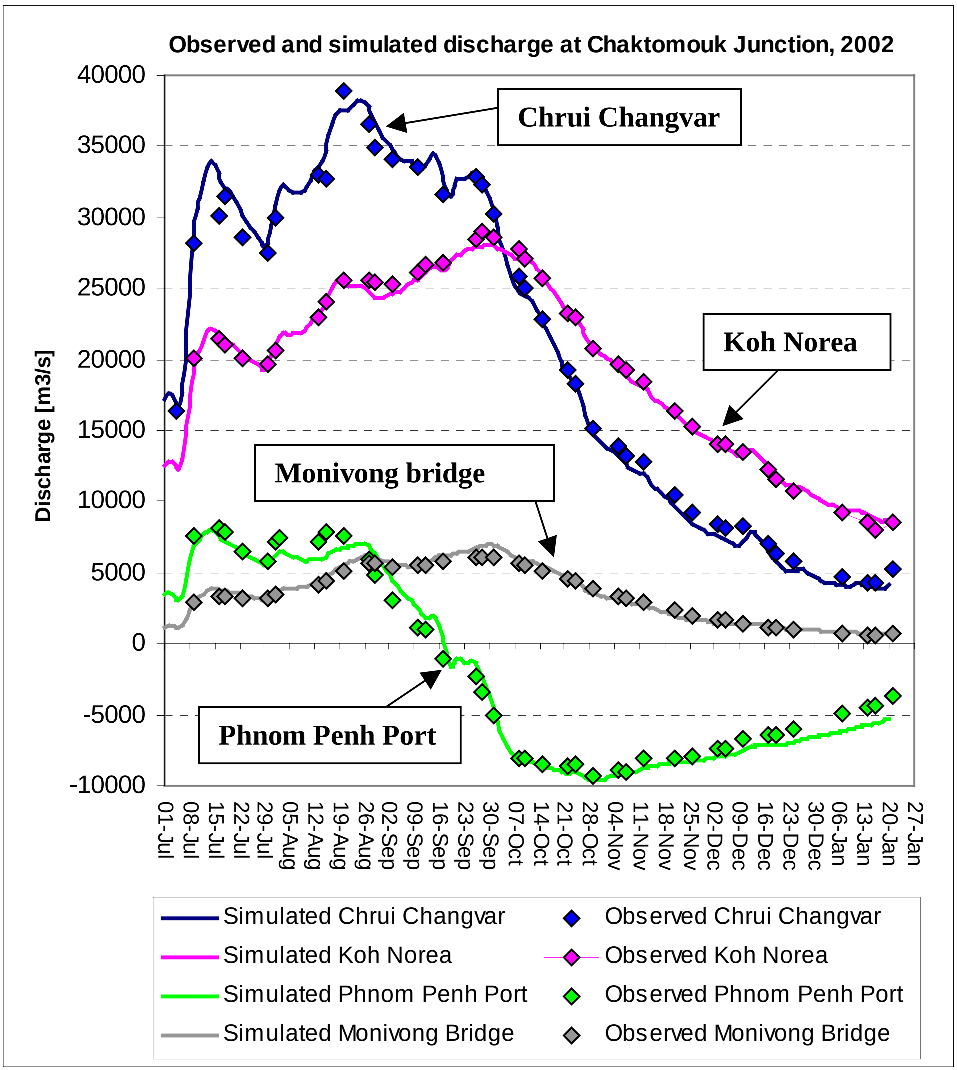
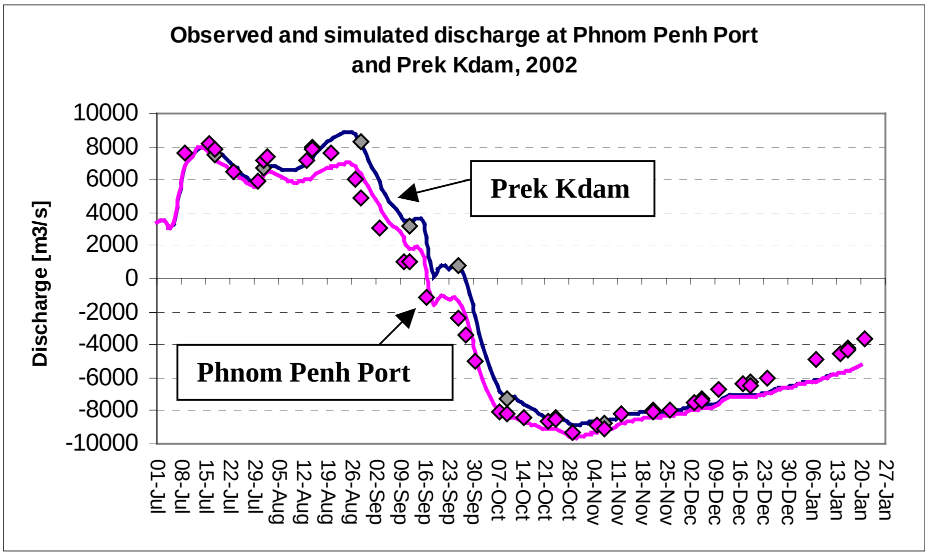
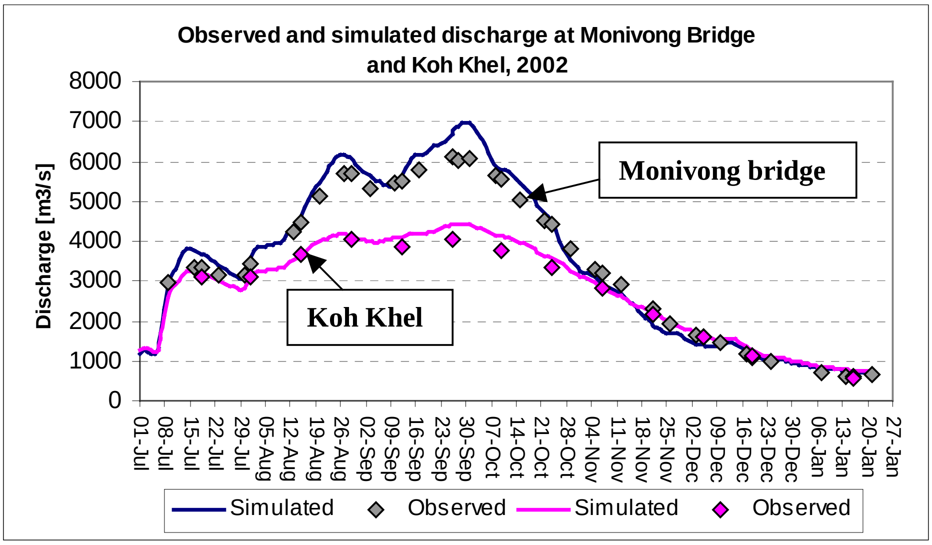


Fig. III-1-21(1/2) Model Verification for the Year 2002: Mekong Mainstream (Unit: m^3/s)





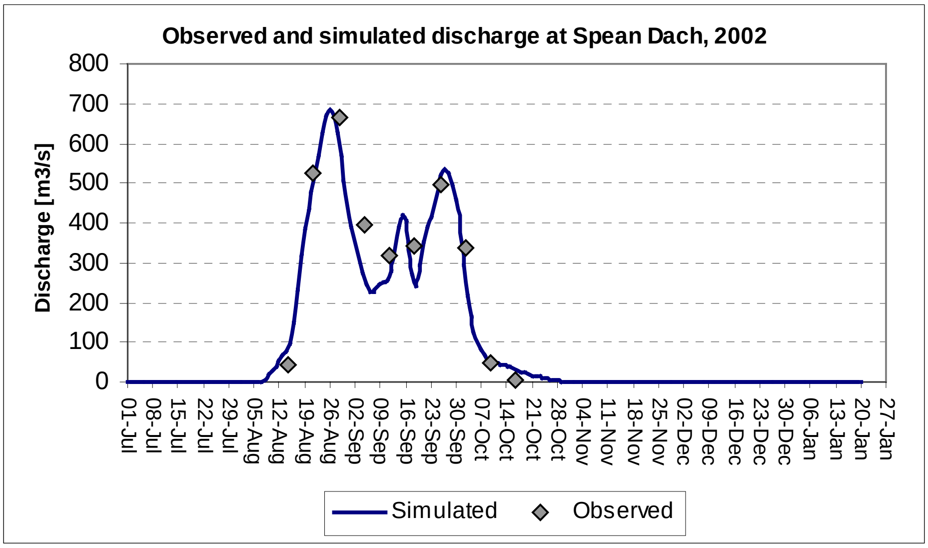


Fig. III-1-21(2/2) Model Verification for the Year 2002: Bassac and Tonle Sap (Unit: m^3/s)

2. APPLICATION OF THE MODEL

2.1 Introduction

This chapter describes the various applications made with the hydro-hydraulic model. The applications comprise:

- Dry-season flow investigation
- Hydraulic impact of road embankments
- Effect of increased bridge openings on flood plain inundation
- Water balance for the Tonle Sap Lake

The purpose of the dry-season flow investigation has been to support the WUP-JICA Team with its work in establishing a dry-season flow management system. The dry-season flow investigation made use of the discharge and water level data that were collected at the Chak Tomuk junction during the 2003 dry season. The dry-season data was used for the model calibration as well as for the application to support the work on dry-season flow management system.

The study on the hydraulic impact of road embankments relates to the conditions during the wet season. The purpose of this activity was to investigate the effect from the major embankment constructions since 1920 up to the present. The activity had contributed to the discussion on changes in flow exchange between the Mekong and the Great Lake.

The study on the effect of increased bridge openings on floodplain inundation was made to demonstrate the hydraulic impact of construction of road embankments and associated bridges. The example presented herein shows clearly the importance of hydraulic studies in connection with infrastructure developments in Cambodia.

The water balance for Tonle Sap Lake was made to obtain a quantification of the various elements in the water balance. The water balance was based on the results of the mathematical model and made on a monthly basis for the years 1998 to 2002. The water balance was useful for understanding the seasonal dynamics of the lake and floodplain system, and it had supported the WUP-JICA work on maintenance of flows.

2.2 Dry-Season Flow Investigation

2.2.1 Necessity of Dry-Season Flow Series

This Subsection of 2.2.1 describes the model simulations carried out for the 2003 dry season, as well as the dry seasons of 1997, 1998, 1999, 2000 and 2001. The simulations for the past years were useful for the model verification and for establishment of data sets upon which a downstream flow prediction can be tested.

The established MIKE 11 model was used to model the dry-season conditions during 2003. During the 2003 dry season, discharges were measured every week in the four branches of the Chak Tomuk junction. During the weekly measurements, each of the branches was measured three times a day. Since the junction is highly affected by tide during the dry season, the discharge measurements within a day show significant variations. Three measurements per day were not sufficient to resolve the complete tidal variation in the discharge.

Since daily average discharges were needed to establish downstream flow relations, it was intended to obtain these (daily average discharges) from the river model that had been calibrated against the measurements obtained during the 2003 dry season.

2.2.2 Available Data

The data available for calibration of the model for the 2003 dry season were:

- Hourly water levels at Tan Chau and Chau Doc
- Daily water level at Kompong Cham
- Weekly discharge measurements at Kompong Cham
- Hourly water levels at Chrui Changvar and at Chak Tomuk
- Three discharge measurements per week (made in one day) at each of the four branches around Chak Tomuk
- Water level data from Chrui Changvar, Koh Norea, Phnom Penh Port and Chak Tomuk stations at the same time as discharge was measured
- Rainfall data at Kompong Cham, Phnom Penh, Neak Luong, Koh Khel and Prek Kdam
- Wind data from Pochentong Airport

The period for which the above-mentioned data are available is January 1st to May 31st 2003, except for the water levels at Tan Chau and Chau Doc, which only cover February to April 2003. For the month of January, therefore, daily water levels at these two stations are used.

The data are in general thought to be quite accurate. The limited number of rainfall stations does not give any significant error or bias in the model simulations because there is only little rain occurring in the period to be simulated.

The wind data stem from only one station, namely Pochentong. The data are daily average velocities and directions. It is obvious that one station cannot represent the wind field of the entire model area, and also that daily average values of wind velocity and direction will not catch the extreme and important events. However, since the wind field is an important force during the dry season, data from one station will still be valuable to use, and will give a more correct result (on hourly basis) than if it is omitted.

For the dry season simulations of 1997-2001, hourly water levels at Tan Chau and Chau Doc are applied as downstream boundary conditions. Daily water level at Kratie has been used as upstream boundary condition for those years. The rainfall data are used in the same manner as the preceding Chapter 1. The means of model verification for the years 1997-2001 are the hourly discharges, which are observed at Tan Chau and Chau Doc.

2.2.3 Model Simulation in the 2003 Dry Season

The MIKE 11 model used for the dry-season simulation was setup in the study.

(1) Simulation Period

The model has been run from January 1 to May 31, 2003. The driving forces in the model are the water level boundaries at Kratie, Tan Chau and Chau Doc, the local rainfall and the wind force. The latter two are included as distributed input, whereas the water levels are inputs in single points.

(2) Roughness Coefficient

It was necessary to further refine the roughness coefficient as compared with the wet season simulation. The reason for this is found in the increasing model dependency on accurate bottom description at low water levels. The roughness coefficient that is used in the dry-season simulation applies in the low level part of the cross-section profiles, which means that there is no violation of the wet season calibration.

(3) Wind

It appears that the wind force plays an important role for the resulting discharge (on hourly basis) in the rivers during the dry season. Relatively small changes in water level slopes within the lake due to wind friction generate an additional discharge in the Tonle Sap, which can be significant compared to the low-flow discharge. The reason for this is that the surface area of the lake is relatively large during the dry season. The wind also plays a role during the wet season, but the runoff is so large that the additional discharge generated by the wind is minor.

2.2.4 Model Results in the 2003 Dry Season

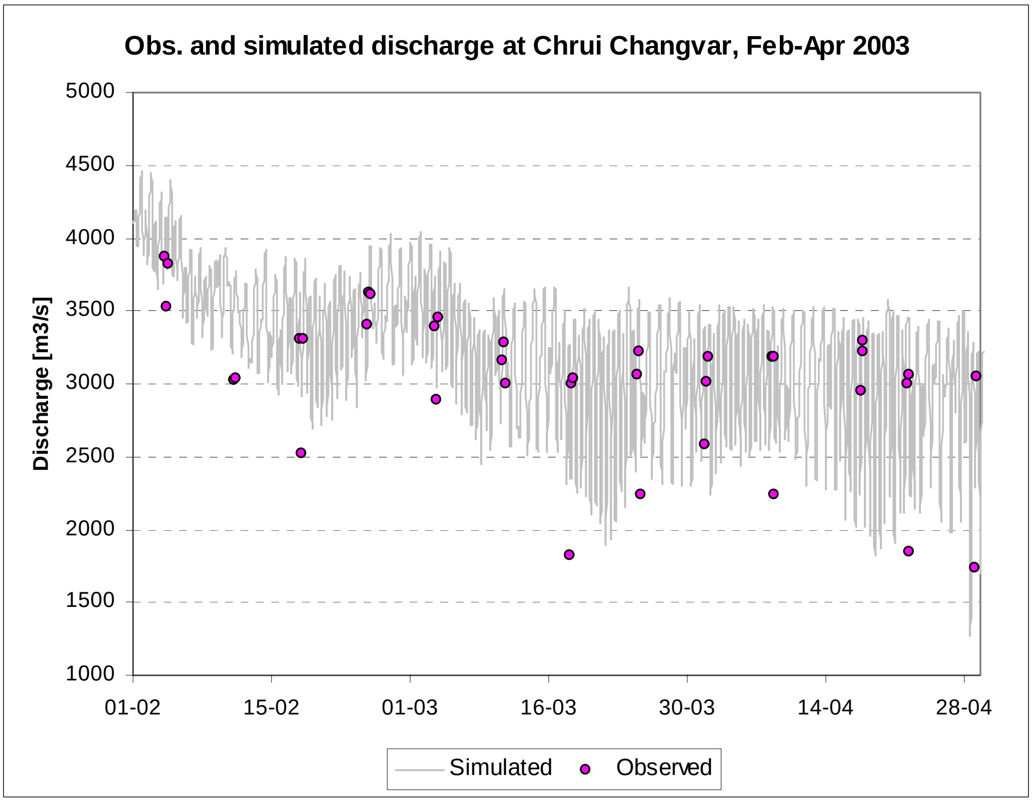
(1) Main Results

The model simulation revealed that it is possible to simulate dry-season discharges with reasonable accuracy. The best prediction was obtained for Koh Norea, but for the other stations, some discrepancy occurred in parts of the simulated period, as shown in Fig. III-2-1. The model predicted the phase and amplitude of the tidal levels relatively well. However, there seemed to be some consistent error related to the absolute water levels at Chak Tomuk, either associated with the model or with the observed data. Results from model tests with changed cross-section configuration appeared to be rather insensitive to the change. Therefore, the uncertainty was thought to be due to the data. A thorough investigation of this issue remains. The accurate prediction of the hourly water levels is on the other hand not very important. The main output, which will be used for the modelling, is the predicted daily discharge. The predicted average daily discharge during the 2003 dry season is shown in Fig. III-2-2.

(2) Detailed Results in Discharge

Fig. III-2-1 shows the simulated and observed discharges at Chrui Changvar, Koh Norea, Phnom Penh Port and Monivong Bridge during the entire simulation period. The simulated and observed discharges at Koh Norea match quite well. The figure shows that the model picks up the rising and falling part of a tidal cycle. One reason why the model predicts fairly well at this location is that the section has a downstream control.

The agreement between simulated and observed discharges is acceptable for Chrui Changvar, although it is less good compared to Koh Norea. This is partly because the station has no downstream control, and is dependent on the conditions in the three other branches at Chak Tomuk. However, the model picks up the daily discharge variation.



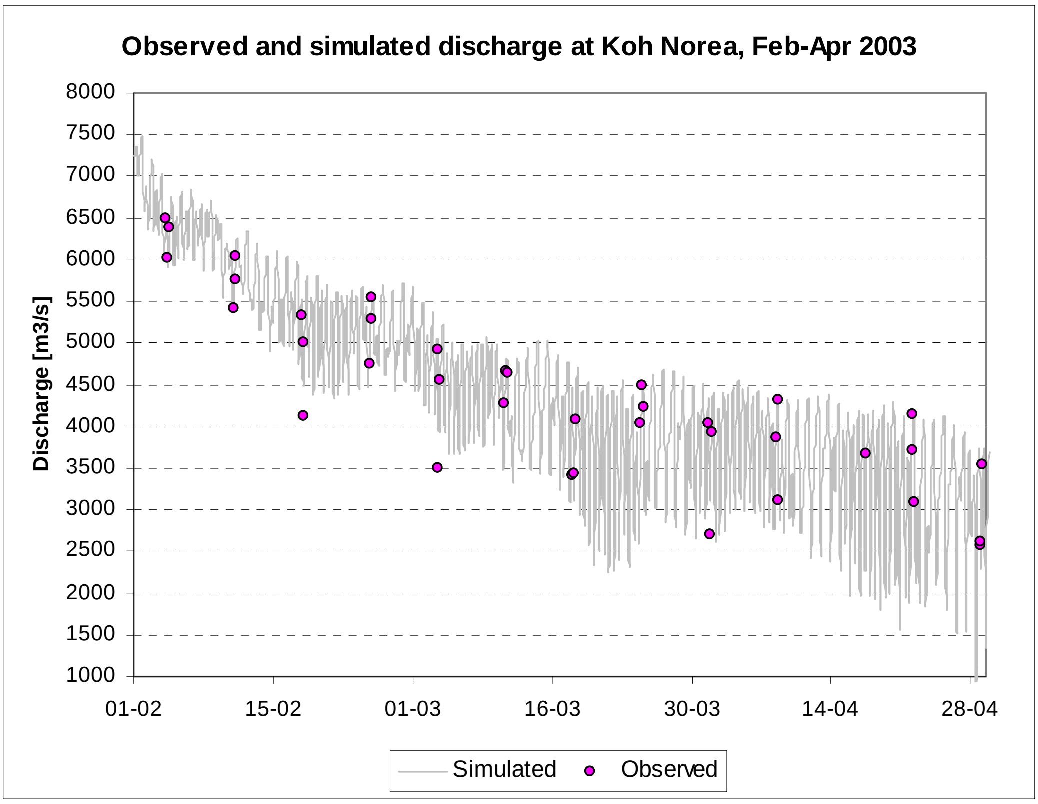
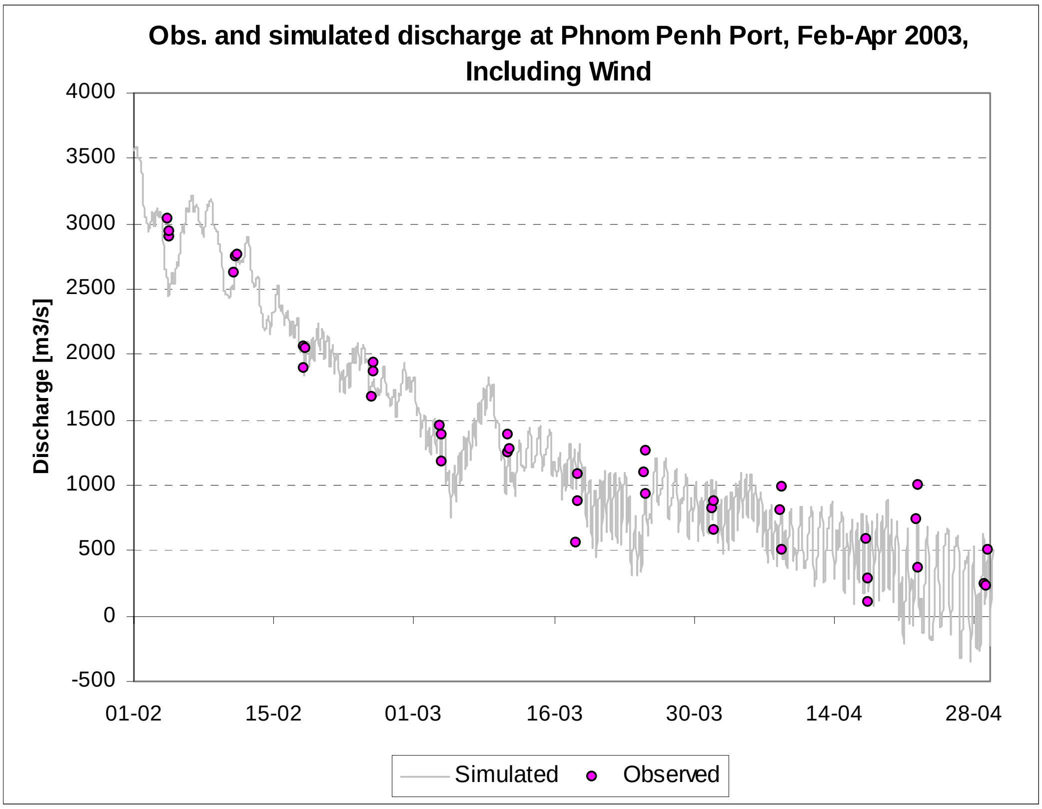


Fig. III-2-1(1/2) Simulated and Observed Discharge in Chak Tomuk Junction, Feb. to Apr. 2003



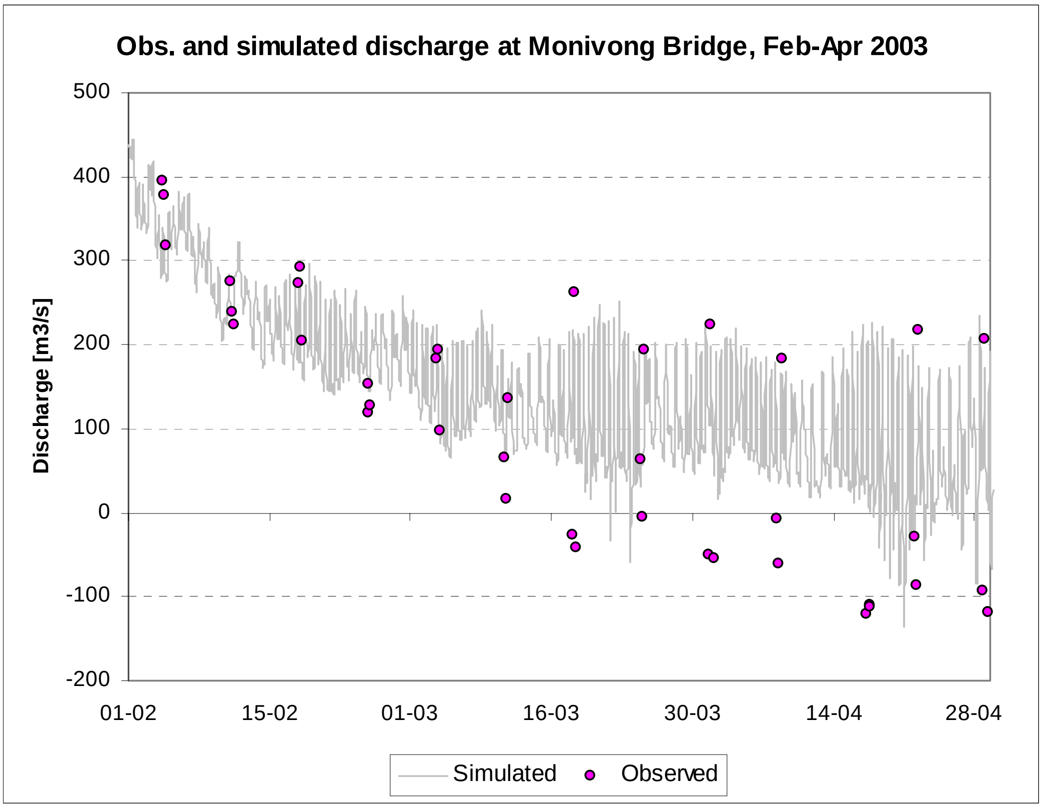


Fig. III-2-1(2/2) Simulated and Observed Discharge in Chak Tomuk Junction, Feb. to Apr. 2003

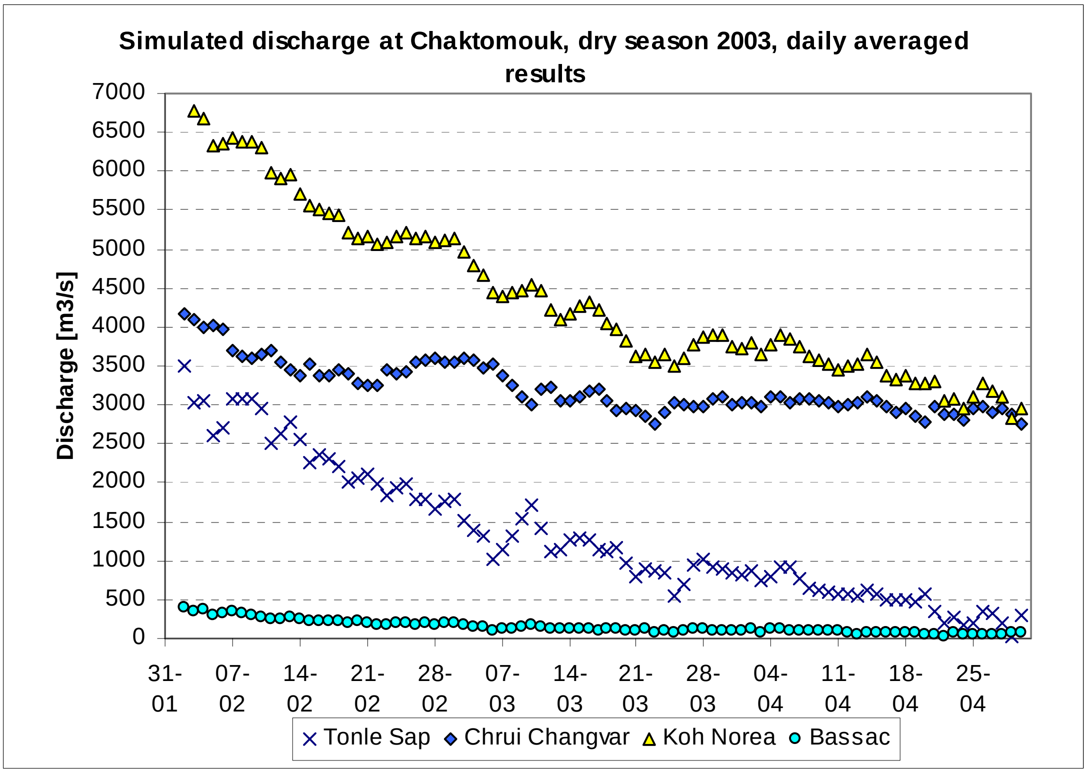


Fig. III-2-2 Simulated Daily Average Discharge in Chak Tomuk Junction, Feb. to Apr. 2003

The simulated discharge in the Tonle Sap at Phnom Penh Port is also acceptable, as presented in Fig. III-2-1(2/2). The simulated and observed discharges at Monivong Bridge are also seen in Fig. III-2-1(2/2). The discharge in the Bassac River is low in the dry season, and even reverse flow occurs. The reverse flow is believed to be associated with wind from the south. In the month of April there are frequent reverse flows in the Bassac River. The model however picks none of these up, although the model simulates a few situations with reverse flow in March/April. The reason for this is probably a combination of lack of extreme wind data, and also inaccuracy of the topographical data. Especially at the entrance to the Bassac River it is important to have accurate topographical data. The present cross-sections in the model at this location originate from the hydrographic surveys in 1998. The configuration of the riverbed at the entrance has most likely changed since then.

(3) Detailed Results in Daily Average Discharge

One of the purposes of the dry-season modelling was to support the discharge-monitoring programme, which had collected three measurements per day in each of the four river branches. Ideally the measurements would provide sufficient data for model calibration, and in return the model would provide hourly results, upon which daily averages or other data extractions could be made. Fig. III-2-2 shows the daily average discharge from the model simulation at the four river branches.

2.2.5 Model Simulations in the Dry Seasons of 1997-2001

The calibrated model for the 2003 dry season was used to simulate the dry-season conditions for the years 1997 to 2001. The reason that these years were selected was that hourly water level at Tan Chau and Chau Doc was available as boundary condition in this period. Using the calibrated model parameters from the 2003 dry-season simulation, the 1997 to 2001 dry-season simulation gives a reasonable prediction of the conditions in the river system in those years.

It was found during the 2003 dry-season simulation that the wind plays an important role for the instantaneous discharge. However, for prediction of the daily averaged discharge, the wind plays a less important role. On this basis it is concluded that the 1997-2001 dry-season simulations for which there are no wind data (for the entire period) still give a reasonable result.

2.2.6 Model Results in the Dry Seasons of 1997-2001

There are no detailed discharge measurements within the model area in the dry seasons of the years 1997-2001. The only discharge records available are the hourly measurements at Tan Chau and Chau Doc, which happen to be the two downstream boundaries of the model. The discharge measurements at these stations served as a verification of the dry season model because water levels were specified as boundary condition at these stations.

Two different types of discharge, the observed and simulated daily average discharge and the observed and simulated hourly discharge, are compared below.

(1) Hourly Discharge

The comparison of simulated and observed hourly discharges at Tan Chau was made for verification of the model. It can generally be concluded that if the hourly discharges compare well, it is possible to extract any time scale from the model results, and they will be reasonably valid. Hence the daily average discharge will be correct if the model represents the hourly data. It will also be possible to extract model results at specific times, e.g., 7 o'clock values.

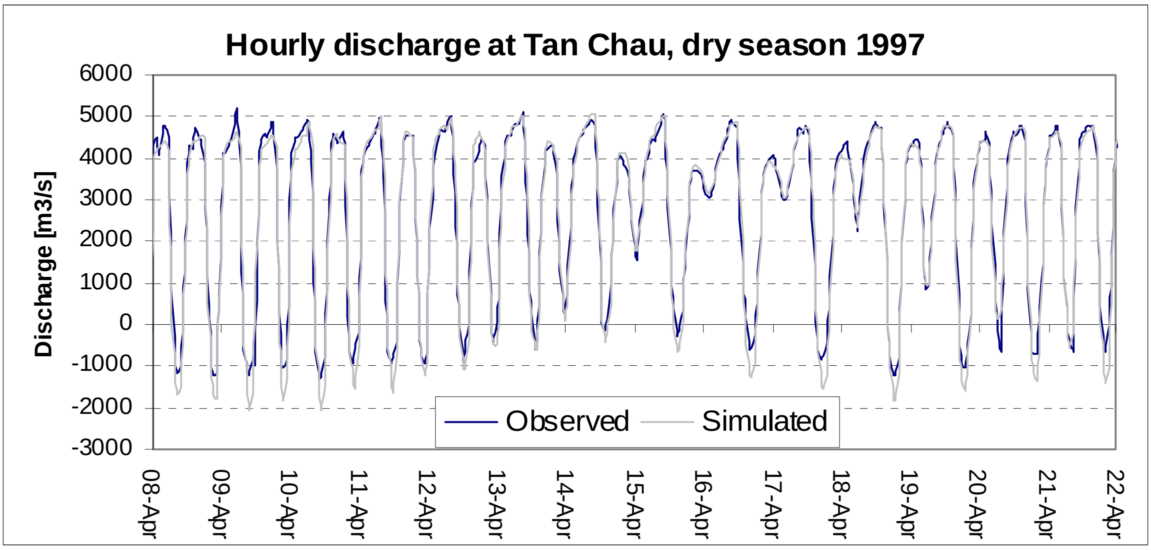
Fig. III-2-3 shows an example of simulated and observed hourly discharge at Tan Chau. Based on the figure, it is concluded that the model is able to predict the tidal dynamics at Tan Chau.

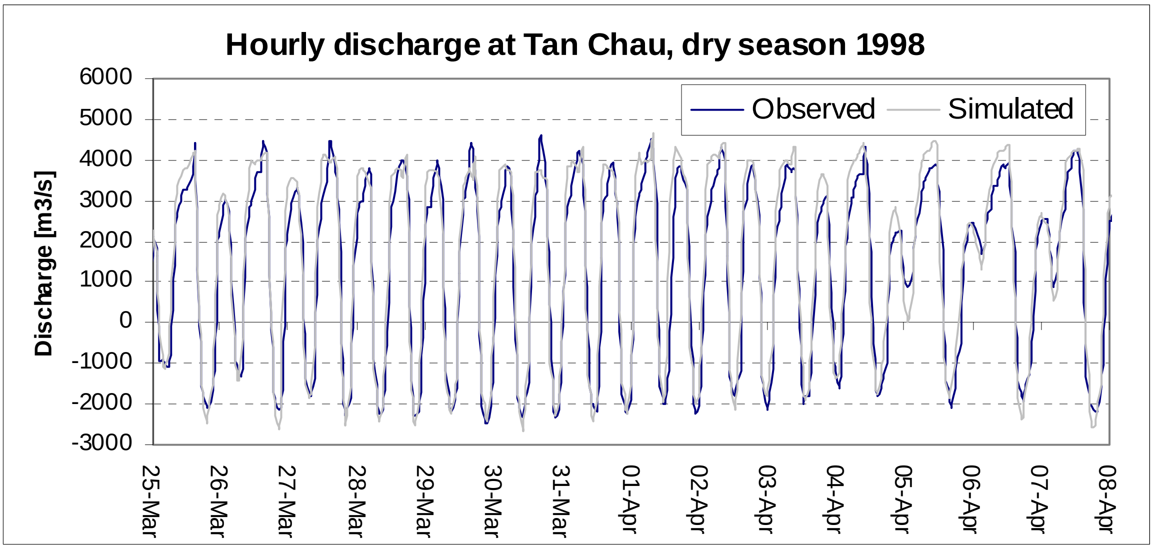
(2) Daily Average Discharge

The observed daily average discharges at Tan Chau were simply obtained by averaging the 24 hourly values of each day. The same averaging was applied to the model results stored for each hour. Fig. III-2-4 shows the observed and simulated daily average discharges at Tan Chau for each of the dry-season periods of the years 1997-2001.

The main conclusion from the figure is that the model is able to predict the measured discharge during the dry season at Tan Chau. This verifies that the model has the correct roughness distribution in Bassac/Mekong branches downstream of Chaktomouk, and also that the discharge contribution from the Great Lake and upstream Mekong are well estimated.

The prediction matches the observations best in the very dry part of the periods, late March and April. However, once the critical period (critical for low flows) occurs, the match between observations and simulation results goes down to only acceptable.





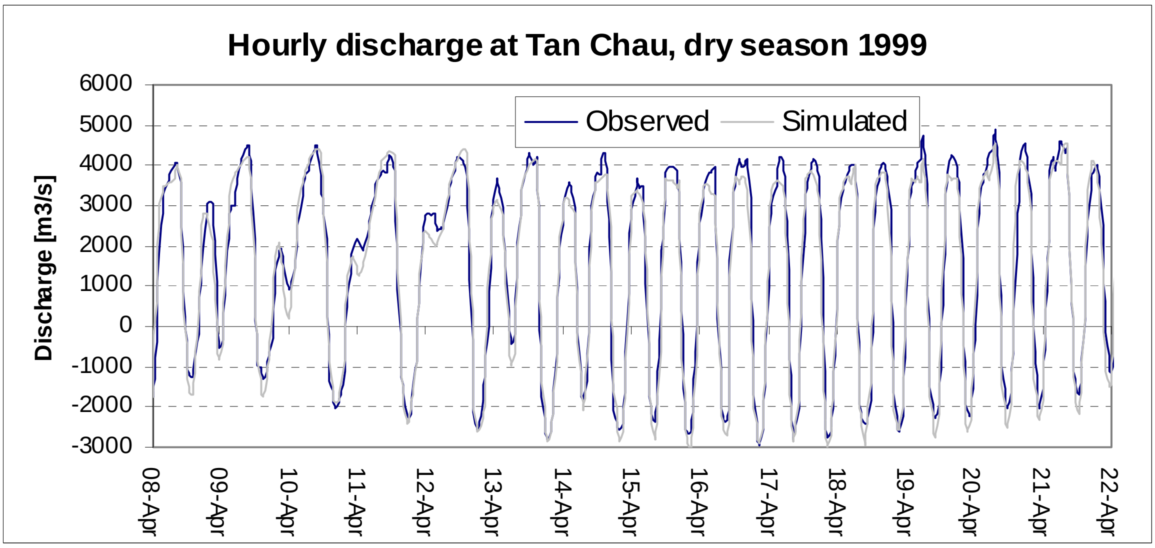
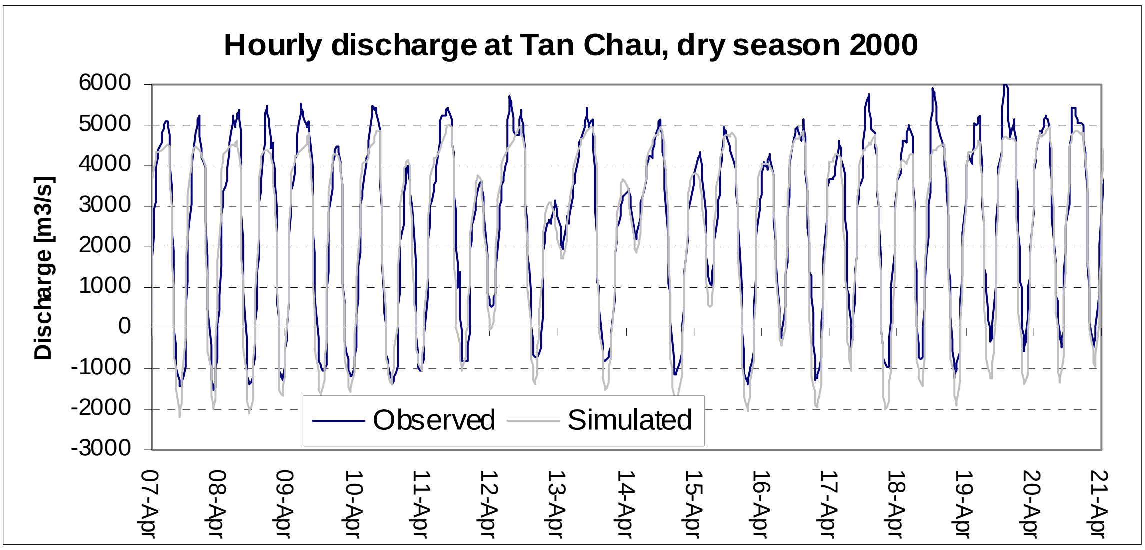


Fig. III-2-3(1/2) Observed and Simulated Hourly Discharge at Tan Chau, in the Dry Season of 1997 to 2001



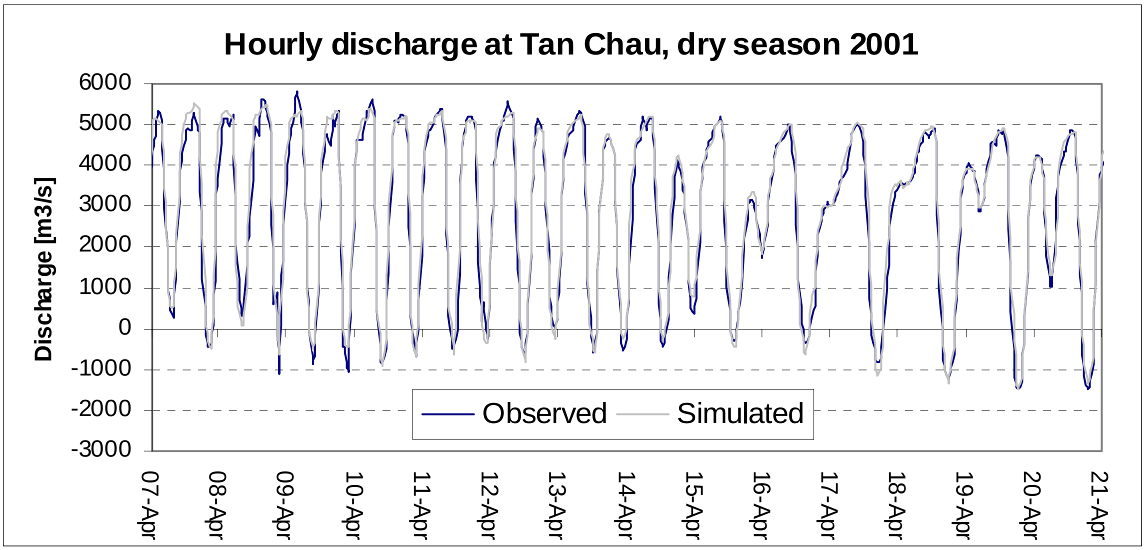
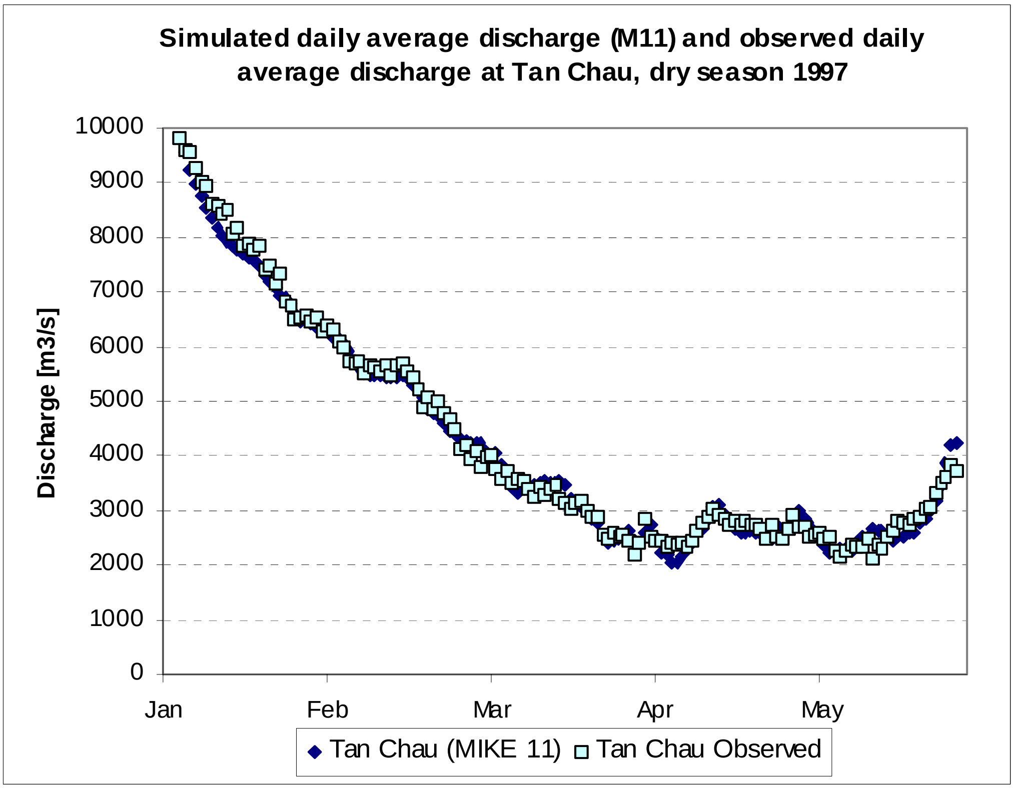


Fig. III-2-3(2/2) Observed and Simulated Hourly Discharge at Tan Chau, in the Dry Season of 1997 to 2001



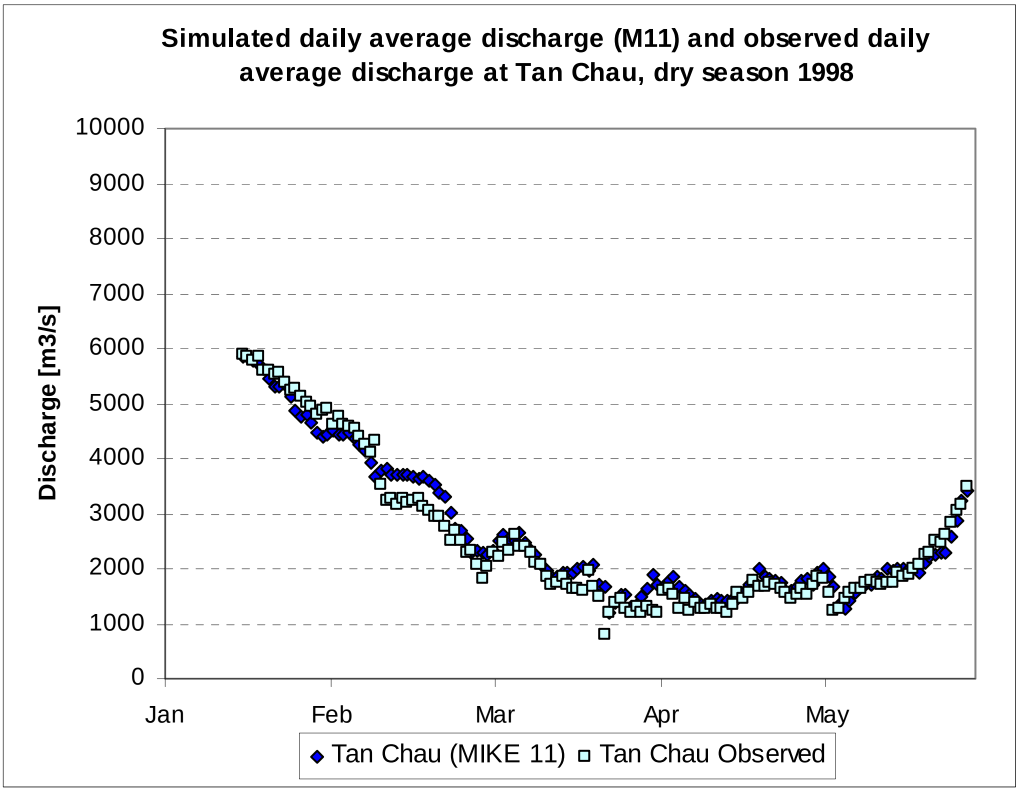
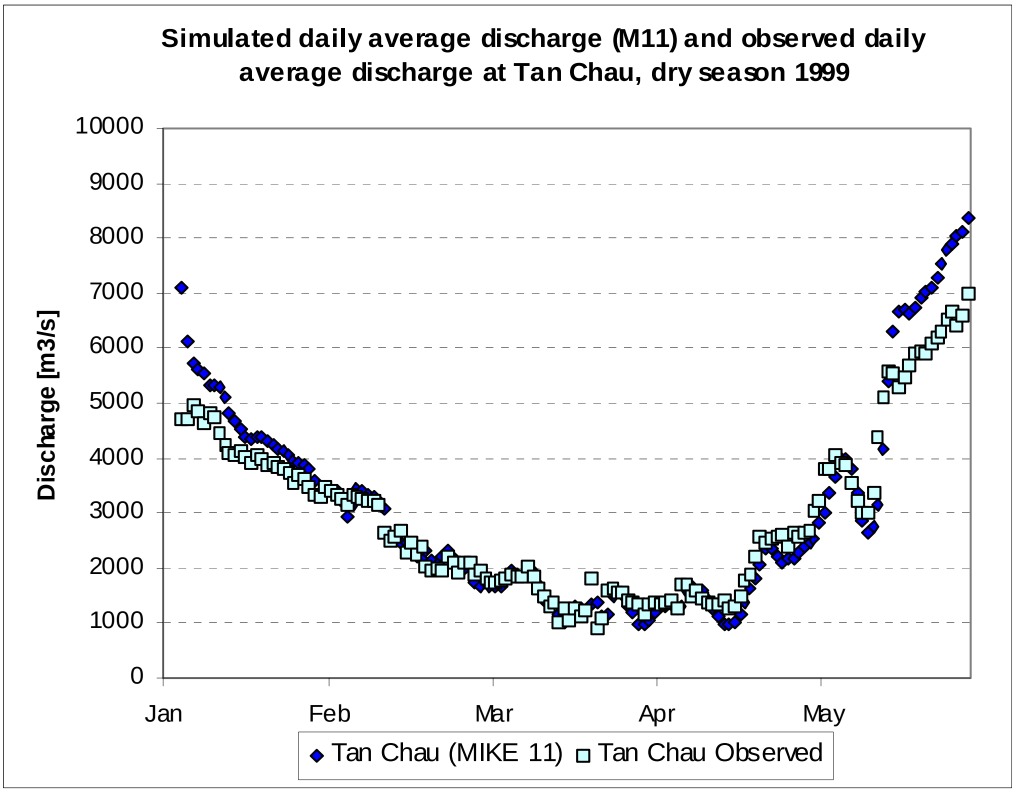


Fig. III-2-4(1/3) Observed and Simulated Averaged Daily Discharge at Tan Chau, in the Dry Season of 1997 to 2001



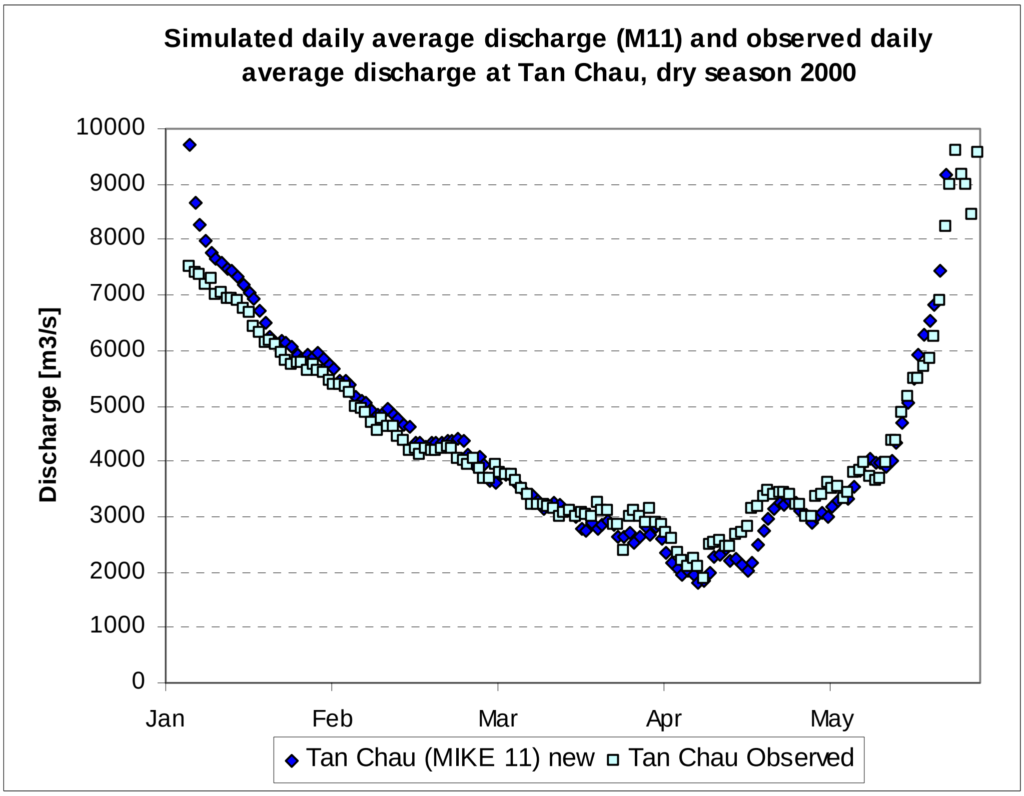


Fig. III-2-4(2/3) Observed and Simulated Averaged Daily Discharge at Tan Chau, in the Dry Season of 1997 to 2001

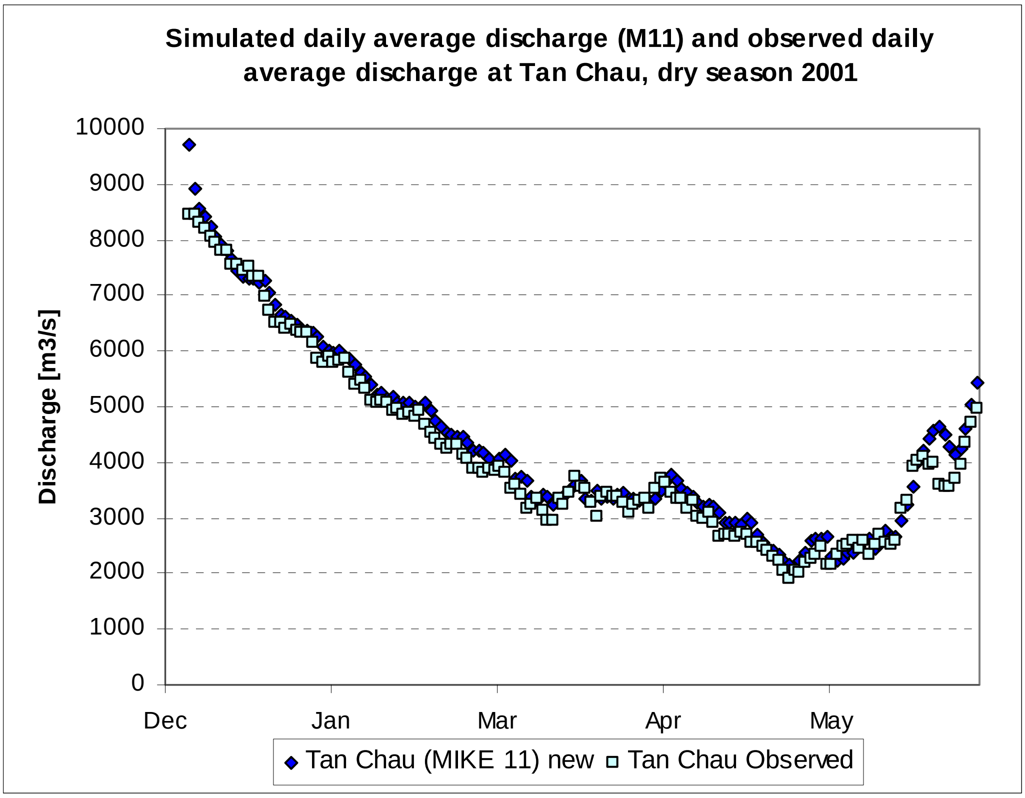


Fig. III-2-4(3/3) Observed and Simulated Averaged Daily Discharge at Tan Chau, in the Dry Season of 1997 to 2001

2.2.7 Conclusion

The mathematical model has been proven as capable to simulate the dry season flow conditions with reasonable accuracy. Since the Chaktomouk junction is highly affected by tide in the dry season, it is not possible to derive daily averaged discharges in this period based on data, unless these are obtained on hourly basis. However, because the model was calibrated against measurements, the model could be used for this purpose and it was decided to use it for the generation of daily average flows in the river branches around the Chaktomouk junction. Prior to the dry-season measuring campaign, the model was used to give indications of the significance of tidal effect, and thereby provide guidance on location and timing of the measurements.

Detailed findings were obtained with regard to the discharge and water level variations at Chrui Changvar, Koh Norea, Phnom Penh Port and Monivong Bridge. The model predicted best the discharge variations at Koh Norea. One of the findings of the study was that the wind plays an important role for the prediction of hourly discharges, which in turn produce the daily average discharges.

The model results were used to derive the possible relation between the discharges in the Mekong and Bassac downstream of the junction as a function of upstream flows. These results have been utilized for the dry-season flow monitoring system described in Part II, Hydrological Monitoring, of this Main Report.

2.3 Hydraulic Impact of Road Embankment

2.3.1 Road Network Development in the Floodplains

The established model has been used to determine the changes in the discharge hydrograph in the river system as a result of the construction of the major road embankments between the Mekong River and Tonle Sap in the last century. This section describes the investigation on how the road network improvement historically affected flow interactions between the Great Lake and the Mekong.

The following major periods representing the different stages in the embankment construction had been identified:

- Prior to 1920s: There were no significant road embankments.
- Between late 1920s and 1940s: Embankments on Road 61 and Road 6 between the left bank of Tonle Sap and Kompong Cham were constructed.
- Between 1940s and 1960s: Embankments on Road 7 on the left bank of the Mekong, Kompong Cham Province were constructed.
- After 1960s: Embankments on Road 6A between Chrui Changvar and the junction of Road 61 were constructed.

The following figure shows the location of roads with embankment.

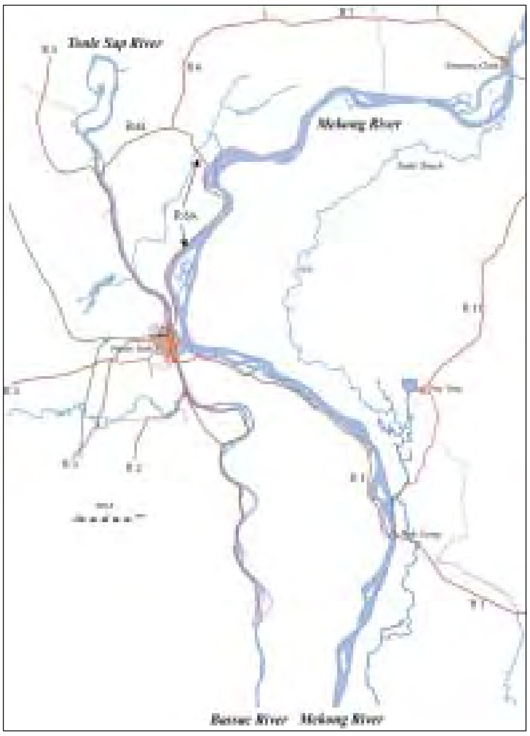


Fig. III-2-5 Location Map of Major Road Network in/around Phnom Penh

The simulations carried out used the then existing model setup and topography as basis. Therefore, the true physical conditions in the periods mentioned above were not represented the simulations, but rather the present day situation if the embankments were removed. To represent the situation of the above periods correctly, it would have been necessary to obtain the river and floodplain topography, discharge and water level hydrographs, as well as rainfall from the different periods in time. Since not all of these data were however available, the adopted approach was the closest representation of the specified historical periods. Given this, it has not been attempted to use hydraulic data in these periods. Instead the hydrographs of years 2000, 2001 and 2002 were used in the simulation. The then existing river model setup was modified in the simulation so as to represent the embankment condition in the four periods mentioned before.

2.3.2 Model Setup

The simulation model has been setup for the situations described below.

(1) After 1960

All embankments of Roads 61, 6, 6A and 7 were constructed after 1960, with the embankment of Road 6A being the latest one built. Obviously, there were changes to the embankment height as well as the number and sizes of e bridges along Road 6 and 6A in recent years, and all of these were reflected in the then existing model setup. Since the purpose of the modelling was to determine the overall effect with/without embankment, there has been no attempt to change the bridge and embankment layout for the period between 1960 and the present day. Hence the model setup used for the period after 1960 was identical to the present day model. A close-up of the model branch layout between the Mekong and Tonle Sap can be seen in Fig. III-2-6 (top).

(2) 1940 to 1960

No embankment on Road 6A existed before 1960. The schematisation of bridges along this road was therefore removed from the then existing model, and two additional link channels were introduced between the Mekong and the floodplains on the southern end of Chrui Changvar. The latter was made to provide for over-banking flow at multiple locations. The embankments of Roads 61, 6 and 7 did however exist and were part of the model schematisation. The model layout for this situation is shown in Fig. III-2-6 (middle).

(3) 1920 to 1940

During the late 1920s, Roads 61 and 6 were constructed to connect Prek Kdam of the Tonle Sap Ferry Port and Kompong Cham. Hence, the schematisation of the road embankment from the then existing model setup was kept unchanged. However, at this time the embankments of Roads 6A and 7 did not exist. The only implication the latter has in the model relates to the Moat Khmong Bridge and the road embankment from Kompong Cham to the bridge. Thus the bridge and embankment schematisation at this location was taken out of the then existing setup to provide a setup that can represent the situation between 1920 and 1940. The model branch layout was identical to the one for the 1940 to 1960, since it was only the cross section at the Moat Khmong Bridge that was changed.

(4) Prior to 1920

No major embankment was constructed prior to 1920. All embankments and bridge schematisations between the Mekong and the Tonle Sap rivers were therefore taken out of the then existing model setup. Besides this it was necessary to introduce two additional floodplain channels to join the northern and southern portions of the floodplain that was later intersected by Road 61. The model layout in this situation is also shown at the bottom of Fig. III-2-6.

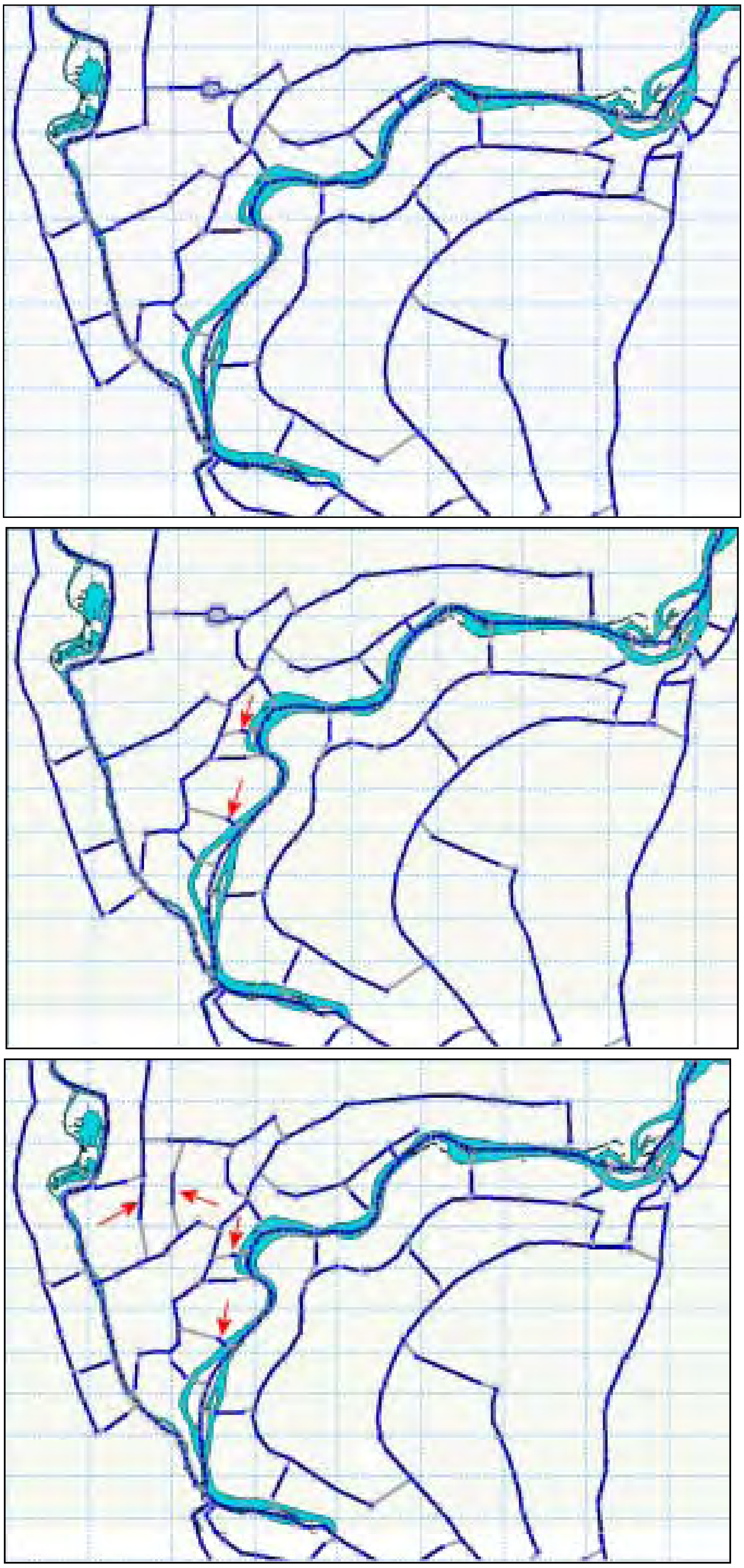


Fig. III-2-6 Model Layout of Historical Situations

Top: After 1960; Middle: Between late 1920 and 1940 as well as between 1940 and 1960; Bottom: Prior to 1920. Arrows indicate new branches.

2.3.3 Simulation Results

Effect on Discharge

The simulated discharge at Chrui Changvar is shown in Fig. III-2-7(1/2), top. It can be seen from the figure that the discharge for the "prior to 1920" situation is significantly lower during peak floods than the other model setups. The discharge is reduced because a large portion of the flow spills into the floodplains towards the Great Lake between Kompong Cham and Chrui Changvar. The three other cases show almost identical discharges at Chrui Changvar.

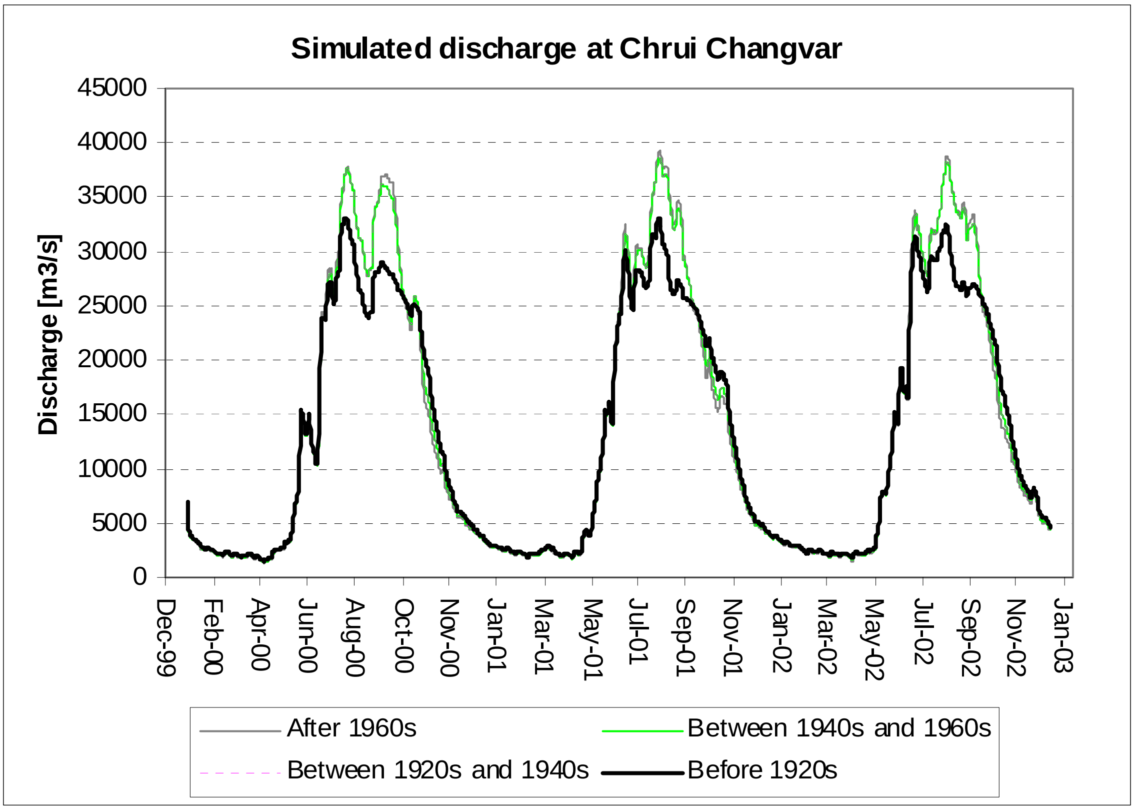
Similarly the simulated discharge at Prek Kdam is significantly different from the other cases that are almost identical, as shown in the bottom of Fig. III-2-7(1/2). A conclusion from the plots on the figure is that the cases describing the 1920-1940, 1940-1960 and the 1960-present situations give almost identical simulation results.

On this background it is only the present model setup (1960-present) and the prior to 1920 setup that are compared and analysed below.

As mentioned, the discharge at Chrui Changvar is significantly reduced if there are no embankments at all between the Mekong and the Tonle Sap [see Fig. III-2-7(1/2), Top]. The discharge is instead diverted to the floodplains between the Mekong and the Tonle Sap, and flows towards the Great Lake. With no embankment, a larger part of the Mekong discharge flows to the Great Lake via the floodplains and, consequently, the peak discharge at Prek Kdam is reduced compared to the present situation with embankment [see Fig. III-2-7(1/2), Bottom]. Since the route to the Great Lake is shorter via the floodplains than via the river system, the lake fills up faster if no embankment is present. This has the consequence that the flow in Tonle Sap reverses towards Phnom Penh two weeks earlier than with the present system with road embankment. This phenomenon can be seen in Fig. III-2-7(1/2), Bottom.

From the figure the changes of flow on the Tonle Sap can also be seen compared with the "prior to 1920" situation; namely, (1) the peak outflow from the lake only slightly increased; (2) the total outflow volumes from the lake became smaller (whereas the inflow volumes were significantly increased); and (3) the low flows by the end of the dry season decreased. The reason for the latter is that the lake receives less water in total due to the present embankment and with the resulting lower water levels in the Great Lake, the dry season flows are decreased.

The simulated discharge at Koh Norea is shown in Fig. III-2-7(2/2), Top. The decreased peak discharge at Koh Norea is mainly caused by a shift in flow proportion between the Mekong and Bassac rivers. Hence the decrease in discharge (during peak) is balanced by the increase in discharge in Bassac, as shown in Fig. III-2-7(2/2), Bottom. Another important feature is that the low-flow discharge at Koh Norea is reduced by about 1,000 m^3/s, due to the embankment of roads.



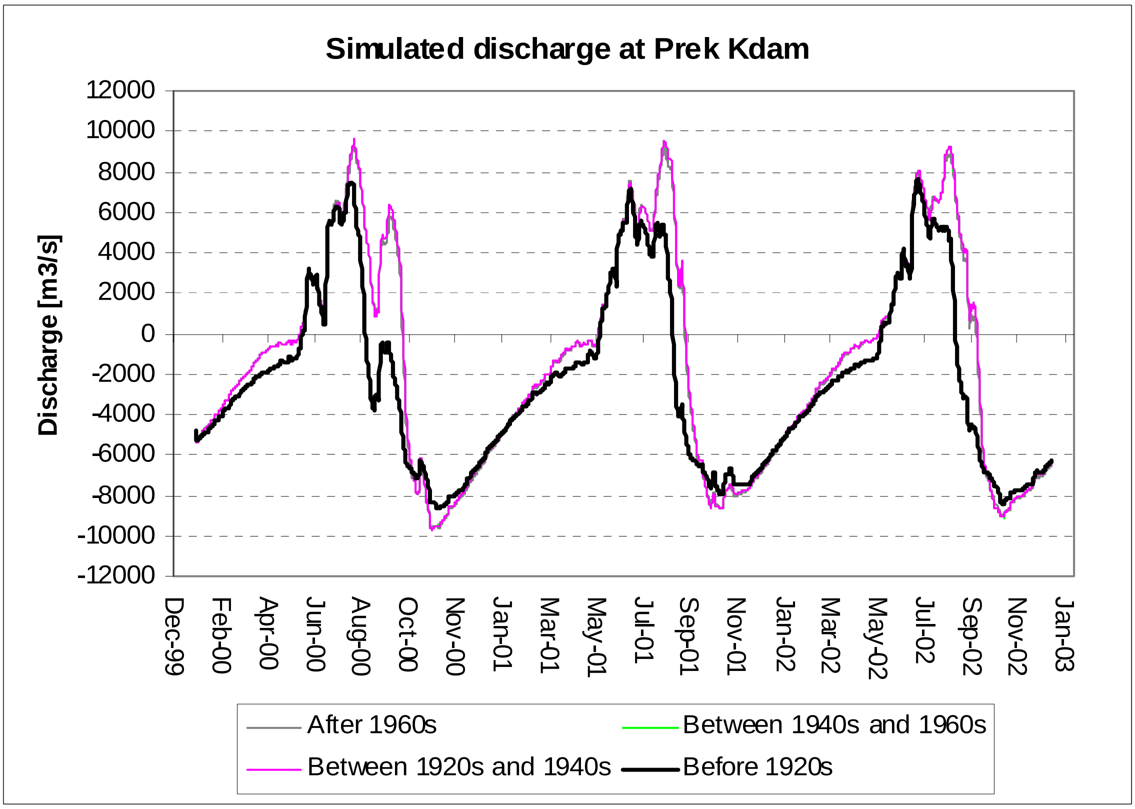
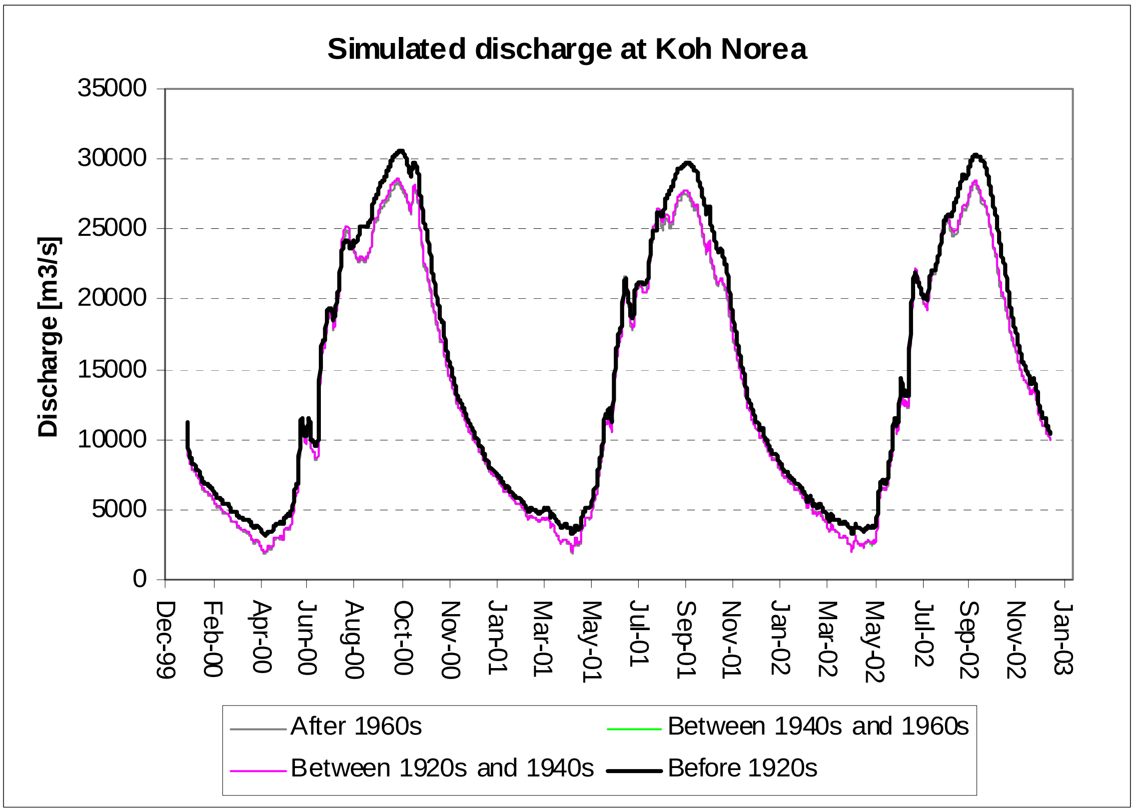


Fig. III-2-7(1/2) Historical Hydrological Changes due to Road Network Improvement in the Upper Part of Cambodian Floodplains



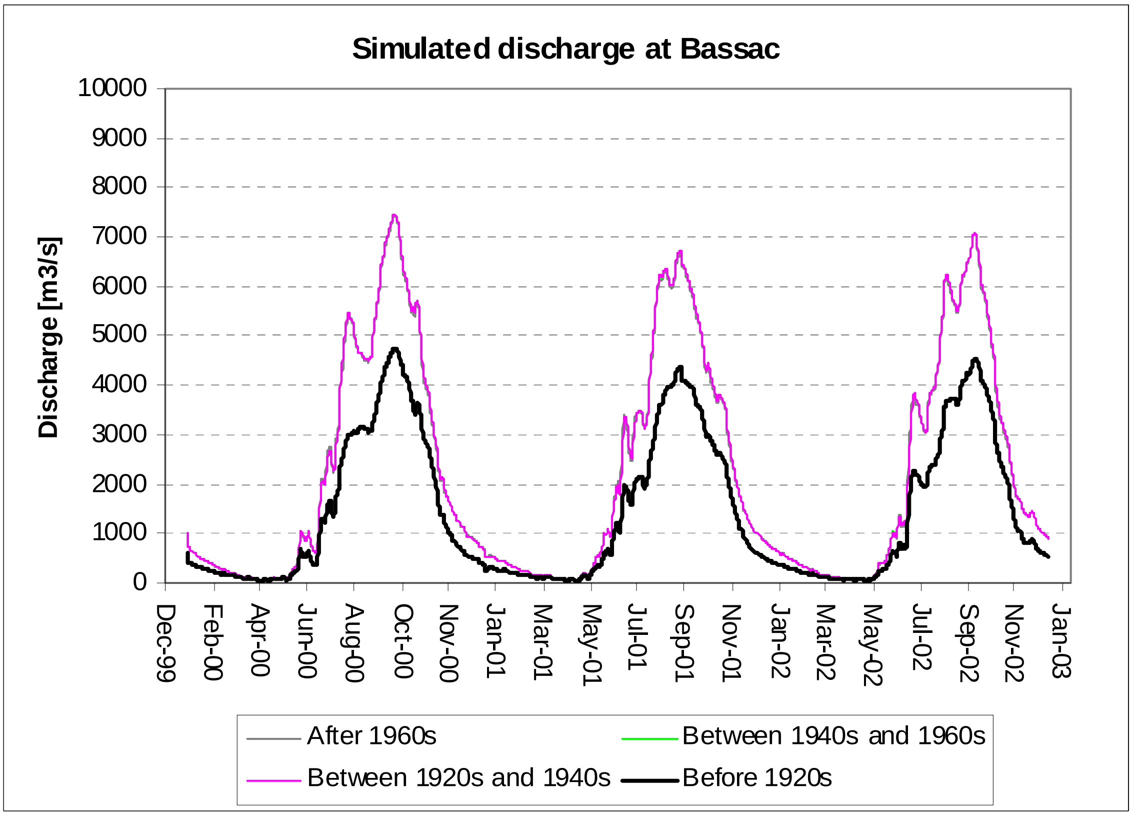


Fig. III-2-7(2/2) Historical Hydrological Changes due to Road Network Improvement in the Upper Part of Cambodian Floodplains

Water Balance

The total water balance simulation was made for the river and floodplain system for each of the three years simulated. The period for which the balance was calculated was 1st of June to 1st of November. The result of the water balance simulation is presented in Fig. III-2-8. The results for each year show the balance under two situations: (1) the existing embankment situation (right); and (2) without any embankment situation (left).

There is no major difference between the water balances derived from the simulations using the different hydrographs of 2000, 2001 and 2002. The reason is that all three years are similar in magnitude.

However, there are significant differences between the water balances of the present embanked situation and the without embankment situation. The main difference relates to the total loss between Kompong Cham to Chrui Changvar as well as to the distribution of floodplain flows to either side along this reach. Thus the total loss is about 12-14% (of Kompong Cham flow volumes) for the embanked situation, and 20-23% in the situation without embankment. Of this loss, roughly 50% flows to each side in the embanked situation, whereas 60% flows into the right bank floodplains in the non-embanked situation.

In terms of actual flow volumes, the flow volume towards the Great Lake via the floodplains is about three times larger in the non-embanked situation than the ones in the embanked situation. This phenomenon has direct effect on the flow volumes in the Tonle Sap, which has become correspondingly smaller.

Downstream of the Chak Tomuk junction there is a difference in the distribution of flow volumes between the Bassac and Mekong rivers. In the Bassac River the volumes with embankment are larger than the ones without embankment.

2.3.4 Conclusions

The conclusions that can be made on the basis of the foregoing analysis are:

- The major changes in the floodplains and river flow pattern occurred when the embankments of Roads 6 and 61 were constructed in the 1920s.
- The various embankment constructions between the Mekong and the Tonle Sap since the embankments of Road 6 and 61 were constructed have had little impact on the flow distribution in and between rivers and floodplains. Thus the embankment of Road 6A has not significantly modified the flow exchange between the Mekong and the Tonle Sap.
- With no embankment between the Mekong and the Tonle Sap, the overland flow on the floodplains towards the Great Lake will increase. As a consequence, less flow occurs at Chrui Changvar and the inflow to the lake through the Tonle Sap decreases.
- In contrast to this, the outflow volumes from the Great Lake as well as low flow in the Tonle Sap increase if no embankment prevails. This is because the lake receives more water (in total) if embankment is not present.
- The flow reversal (from inflow to outflow) in the Tonle Sap occurs about two weeks earlier if embankment is not present. The reason for this is the shorter route of overland flow that causes the lake to fill faster and thus reach its maximum water level earlier.

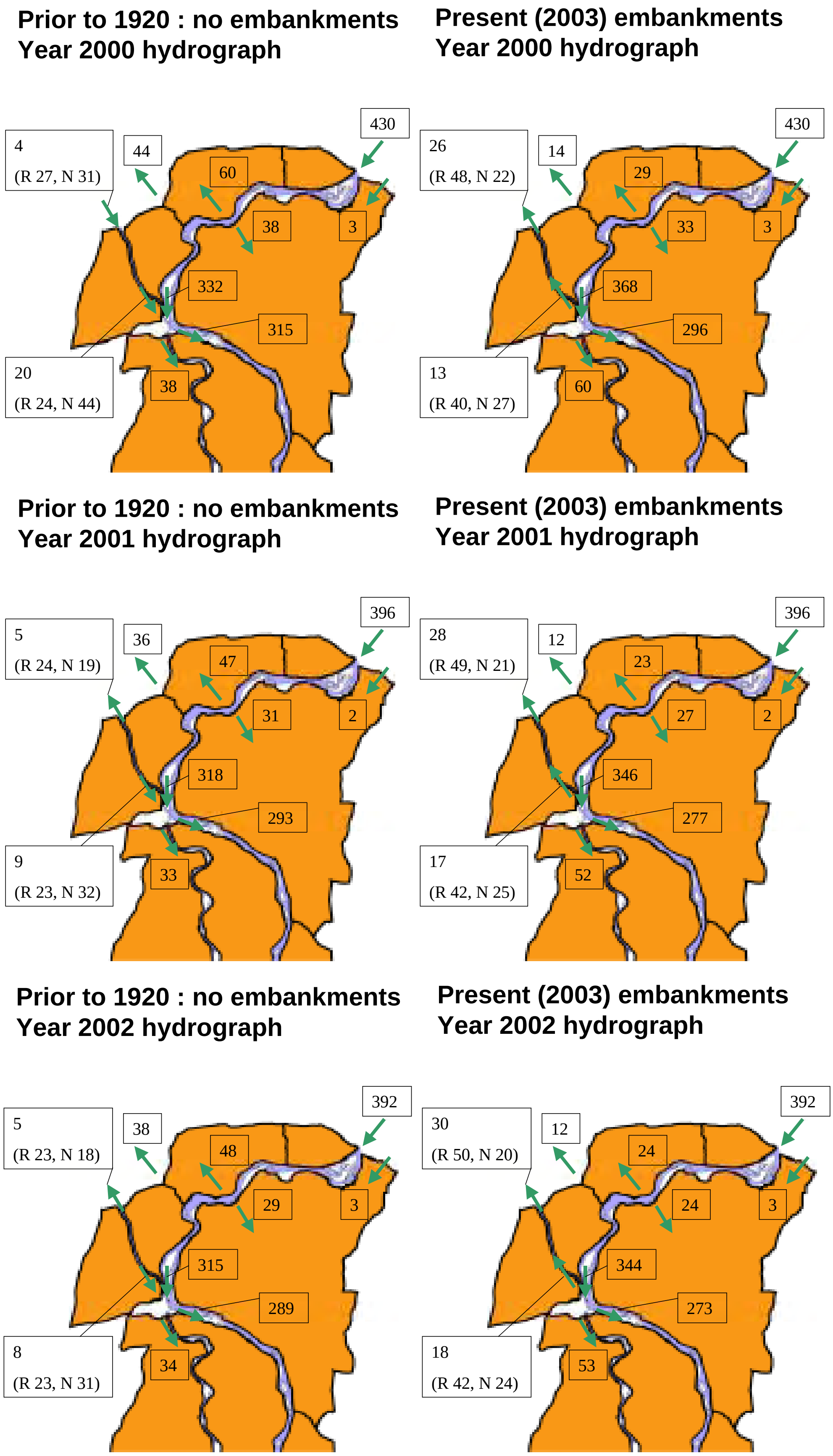


Fig. III-2-8 Comparison of Water Balance for 1st June to 1st November in 2000 to 2002

2.4 Effect of Increased Bridge Openings on Floodplain Inundation

2.4.1 Objectives

The simulations with the model have shown that the existing road embankments and bridge openings in the floodplains are major controls for the flows. There are significant hydraulic gradients across road embankments at various locations in the floodplains, e.g., across Road 6 and Road 1. It appears that floodplain flows are impeded at various locations due to insufficient bridge openings. This creates high flow velocities in the vicinity of the bridges, and damaging effects of local scour has already been observed (e.g., F3 Bridge on Road 6).

As an application example, the model has been used to simulate the effect of increased bridge openings along Road 1 east of Neak Luong. The increase in bridge span was arbitrarily selected. The location of the embankment and Road 1 is shown in Fig. III-2-9.

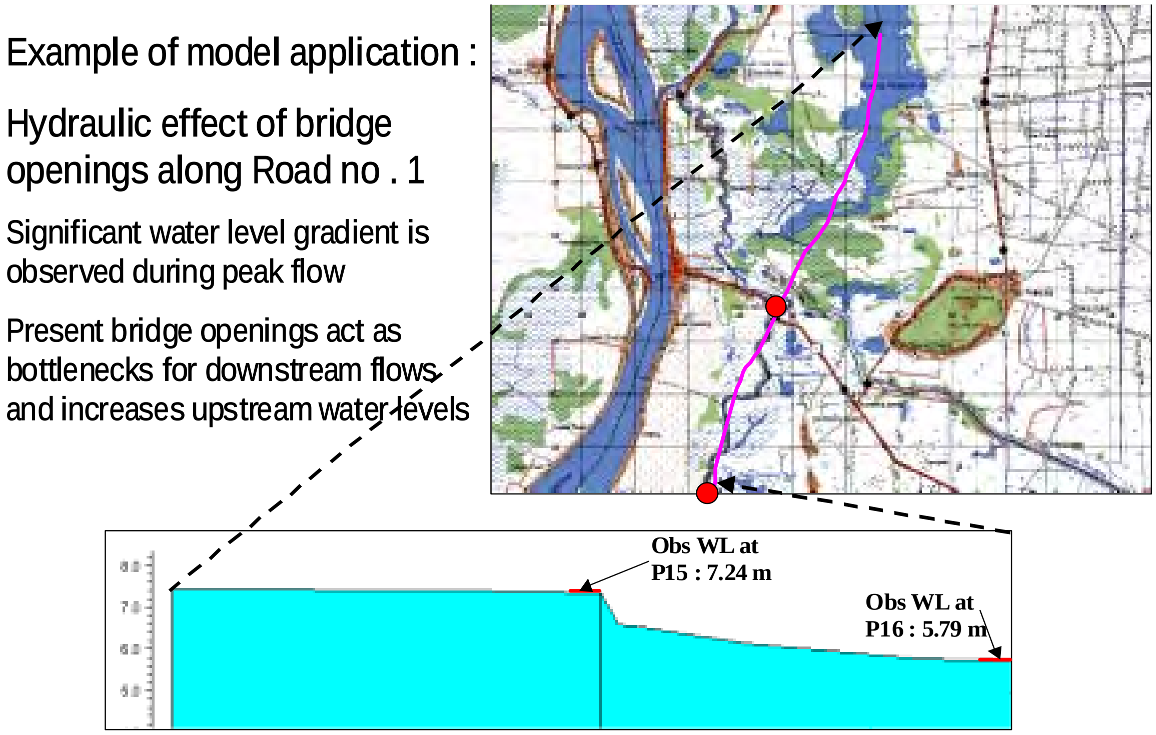


Fig. III-2-9 Simulated Longitudinal Flow Profile of the 2002 Peak Flood

2.4.2 Model Test

The model has been run with the year 2002 hydraulic conditions, both for the existing setup (condition) and for the situation with increased bridge spans.

Fig. III-2-9 shows the longitudinal profile of water level (at the 2002 peak flood) from upstream to downstream of the existing bridge located on Stung Sloat. It can be seen that a significant gradient in the water level exists. There is almost one-meter difference between both sides of the bridge. Part of this is the difference if naturally due to the head loss which the bridges along Road 1 create.

In the test simulation, the bridge openings were increased three-folds, and the 2002 simulation repeated. Fig. III-2-10 shows the effect of increased opening on the water levels up and downstream of the bridge as well as the effect on discharge. The water levels on the upstream side decreases by approximately 0.5 m, and on the downstream side (only vicinity of bridge) the levels increase by 0.2 m. The effect on the discharge is a 500 m^3/s increase from the original 3,000 m^3/s.

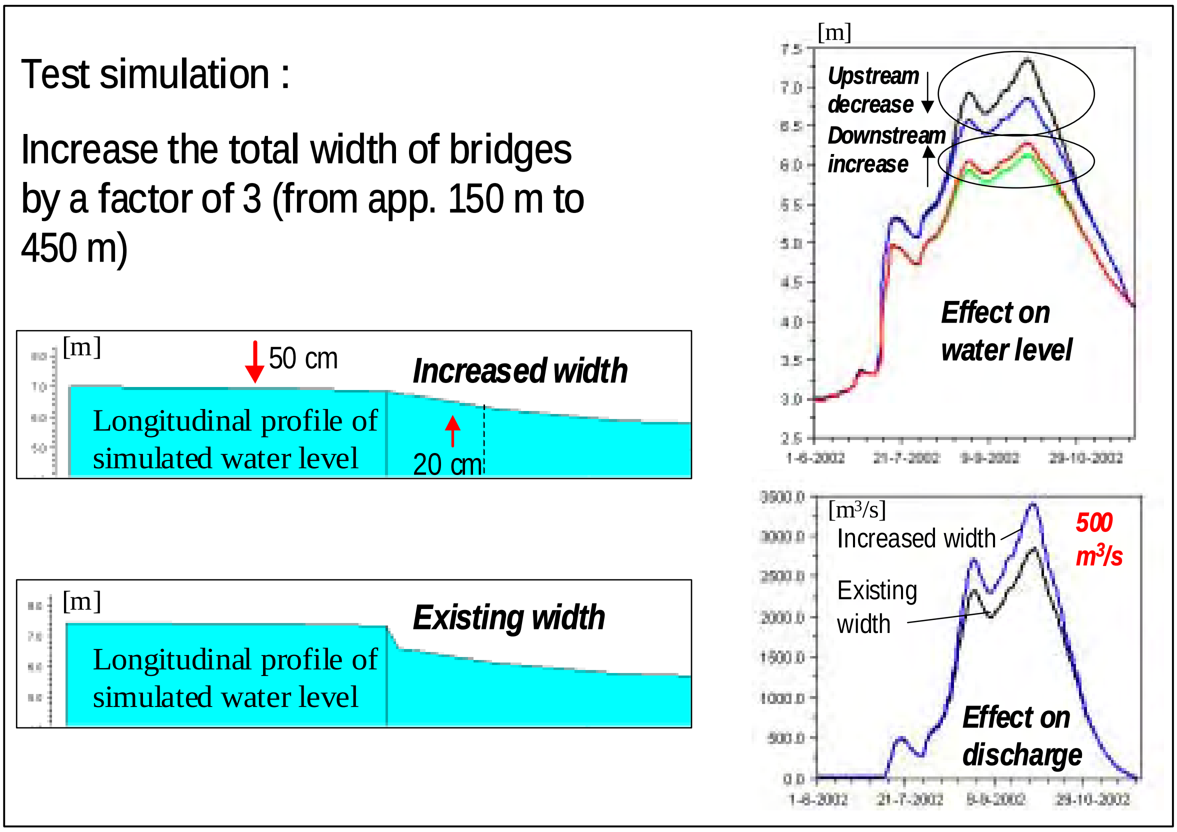


Fig. III-2-10 Effect of Enlargement of Bridge Openings on Water Level and Flow Discharge

The effect on water level is felt over a long distance. This can be seen in Fig. III-2-11 that contains flood maps for the existing and test situations, as well as the water level difference. The latter shows that the upstream effect reaches more than 30 km upstream.

In the particular test simulation, there are only small differences in the upstream flood extent between the existing and the test case. However, the effect on the water levels is pronounced, whereas the effect on the discharge appears smaller. The actual numbers from the test simulation should only be used to illustrate that infrastructure such as road embankment and bridges does not only locally affect the floodplain area.

2.4.3 Conclusions

The application example presented in this section leads to the following conclusions:

- The presence of road embankments in the Cambodian floodplains significantly impedes the flow across the plains.
- The large water level gradients resulting from the presence of road embankment create large flow velocities and potential scour at existing bridge sites.
- Increased bridge spans on the road embankment can lead to a significant reduction of hydraulic gradient and thus eroding power.
- The reduction in water level on the upstream side of road embankments due to increased bridge spans is felt over long distances, for instance of this computation, over 30 km.

- Because there is potential hydraulic impact in larger areas of the floodplains, it is recommended that infrastructure projects be coupled with hydraulic studies.

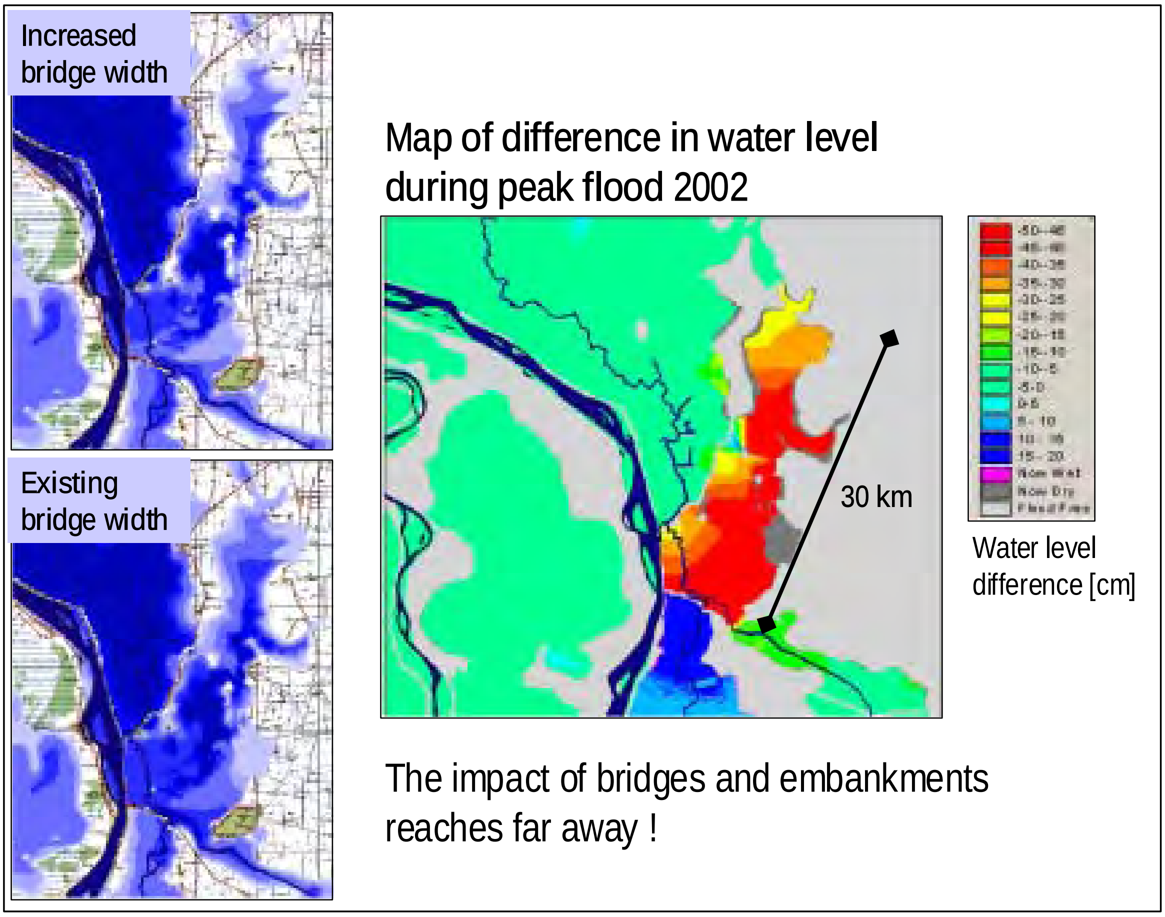


Fig. III-2-11 Flood Inundation Map (Left) and Water Level Differences between Test Cases (Right)

2.5 Water Balance of the Great Lake

2.5.1 Introduction

The present section describes the outcome of water balance study for the Great Lake. The water balance assessment was based on the results of model simulation for the period 1998-2002.

2.5.2 Water Balance Assessment

The water balance of the Great Lake has been assessed with the model for the years 1998 to 2002. The years represent the range from dry years to extreme wet years. The water balance assessment was made on a monthly basis using the model results from the 1998-2002 simulations. Since the 1998-2002 simulations had water level and discharge results stored at daily increments, the discharge results were converted to volumes and lumped together to give monthly results.

The following elements were included in the assessment of water balance of the lake:

- Runoff from the lake basin (sub-catchment around the lake)
- Direct rainfall on the lake
- Evaporation of the lake

- Inflow from the Tonle Sap
- Overland flow from the Mekong River

The model can obtain all of these elements. The monthly contributions from each of the elements have been calculated and added together to give the total monthly volume change in the lake. This total monthly volume change of the lake has been compared with the observed monthly volume change. The observed monthly volume change has been determined by using the observed water level at Kompong Luong and a relation between lake level and lake volume.

(1) Volume Change based on Inflows/Outflows

The five contributions to the volume change of the lake were derived in the following manner:

Runoff from the Great Lake Basin

The rainfall-runoff model is applied to provide the inflows from the tributaries around the lake. For the water balance assessment the total catchment runoff is reduced for the direct rainfall on the part of the sub-catchment that gradually becomes inundated during the wet season.

In the model, direct rainfall is only occurring on the dry season lake area. The direct rainfall on the wet season lake area is indirectly accounted for in the catchment runoff computation because the total sub-catchment areas are used. The net result of this approach is the same as if reduced sub-catchment size due to inundation is accounted for in the runoff modelling and a correspondingly larger lake area is exposed to direct rainfall. However, for the present determination of the water balance, it is necessary to include the changing surface area of the lake.

Direct Rainfall on the Lake

Rainfall is the average for 4 to 7 stations scattered around the lake, the number being dependent on availability in each year. This rainfall is scaled to account for the changed surface area of the lake. The surface area is obtained from the elevation-area relation, which has been derived for the lake, and the observed monthly averaged water level at Kompong Luong. The elevation-area curve for the lake is shown in Fig. III-1-11, Chapter 1. For water levels above 2 m, the lake area can be determined using the following relation:

$A_{lake} = 1197.7 * WL + 1215.7$

The area of lake (A_{lake}) is in km^2 and the water level (WL) is that of Kompong Luong and given in meters.

The direct rainfall on the lake is converted to a volume.

Evaporation on the Lake

The monthly evaporation rates are applied to the changing lake area and converted to a volume. The determination of the lake area is described above.

Inflow from the Tonle Sap

The inflow from the Tonle Sap is extracted from the calibrated river model. Through the branched system, the model separates between river channels and floodplain channels. It is thus straightforward to extract the discharges from the Tonle Sap. The discharges are converted to volumes.

Overland Flow from the Mekong

The same explanation as for the Tonle Sap inflow applies.

(2) Volume Change based on Observations

The observed volume change in the lake is determined using the water level recorded at Kompong Luong in the Great Lake and the established relation between the water level and the lake volume. Taking the average water level in one month and determining the corresponding volume, it is possible to calculate the actual lake volume as well as the monthly volume change.

(3) Results of Water Balance

Fig. III-2-12 shows the results from 1962-63 [(reprinted from reference (4)], and is included for historical reference. Fig. III-2-13 shows the results from each of the years. The figure shows the monthly volume change for five contributions: (1) evaporation of the lake; (2) runoff from the Great Lake Basin; (3) inflow from the Tonle Sap; (4) overland flow from the Mekong; and (5) direct rainfall on the lake. Positive values mean an increase of the lake volume and a negative value is correspondingly interpreted as a decrease in lake volume. By this notation the runoff from the lake basin is always positive or zero, the evaporation is always negative, and the flow from/to the Tonle Sap is positive during the rising monsoon and negative in the falling part when the flow reverses.

The figure shows some important features. First of all the contributions to volume change have the following ranking in order of significance: (1) Flow from the Tonle Sap; (2) runoff from the lake basin; (3) Overland flow from the Mekong; (4) Direct rainfall on the lake; and (5) Evaporation on the lake. This is concluded when all years are considered and accumulated values taken. The ranking is however changing with years (compare, e.g., 1998 with 2001) and also on a monthly basis.

It is noteworthy that the largest monthly contribution of runoff from the Great Lake basin itself always occurs in October (with the exception of 1999). October is also the month when the flow is reversed in the Tonle Sap and water flows out of the lake. Therefore, the volume contribution becomes negative. This holds for all years simulated. This was also the case in 1962-63. Except for 1999 the maximum volume flowing out of the lake occurs in November.

The overland flow contribution from the Mekong is dependent on the magnitude of the flood, i.e., the conditions upstream of Cambodia. Thus in a dry year like 1998, there is an almost zero overland flow, and in wet years like 2000 and 2001, this contribution is significant.

One important observation is that the local runoff from the Great Lake Basin does not change proportionally to the magnitude of the flood (i.e., compare the dry year of 1998 with the wet year of 2000). Thus the results reflect also the regional variation of rainfall pattern.

The results of volume change based on observations are seen in Fig. III-2-14. The absolute volumes have been determined by a combination of the observed water levels at Kompong Luong and a relation between level and volume for the lake. The figure shows the absolute lake volumes in each month from 1998-2001 as well as the monthly volume change. The latter is determined as the difference between the absolute monthly volumes. The observed monthly volume change is compared with the volume change based on inflows/outflows. It could be seen that there is a relatively good match, considering all the uncertainties and assumptions in the modelling of inflows/outflows.

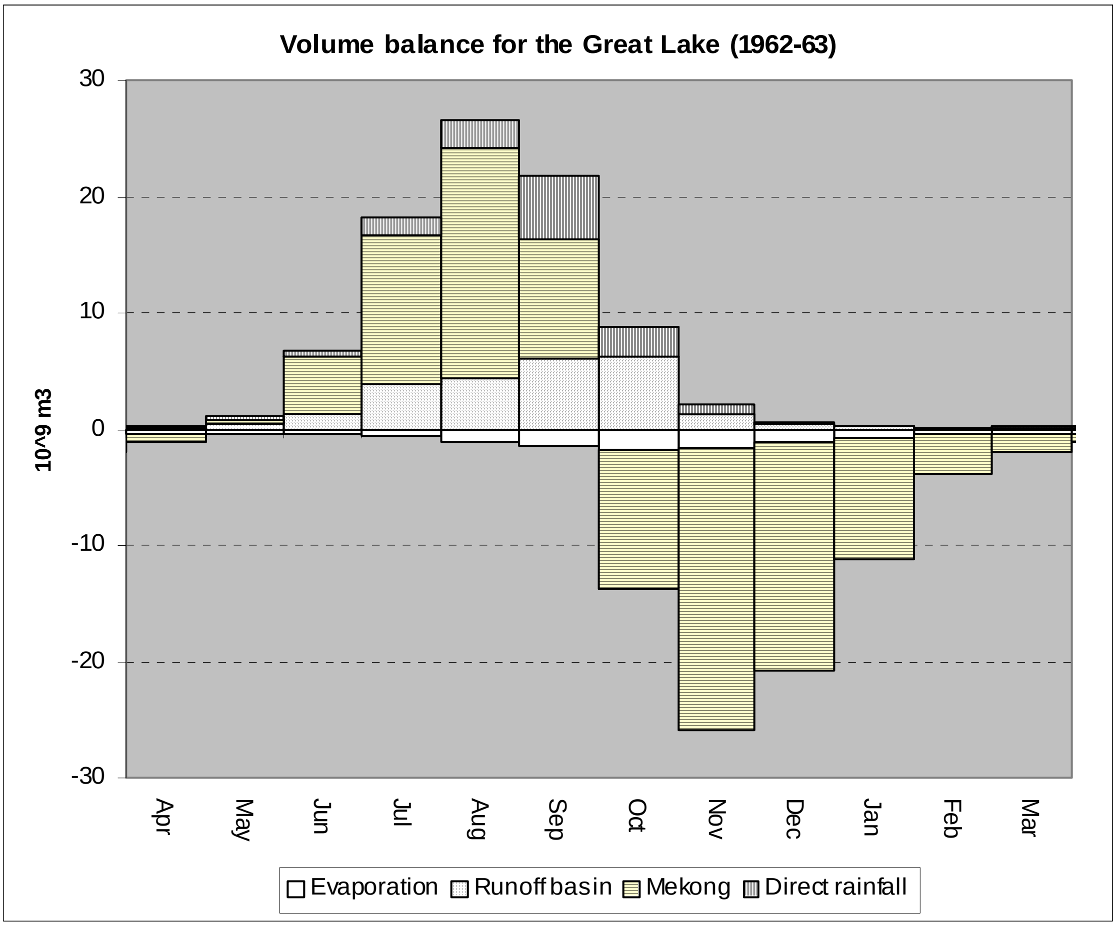
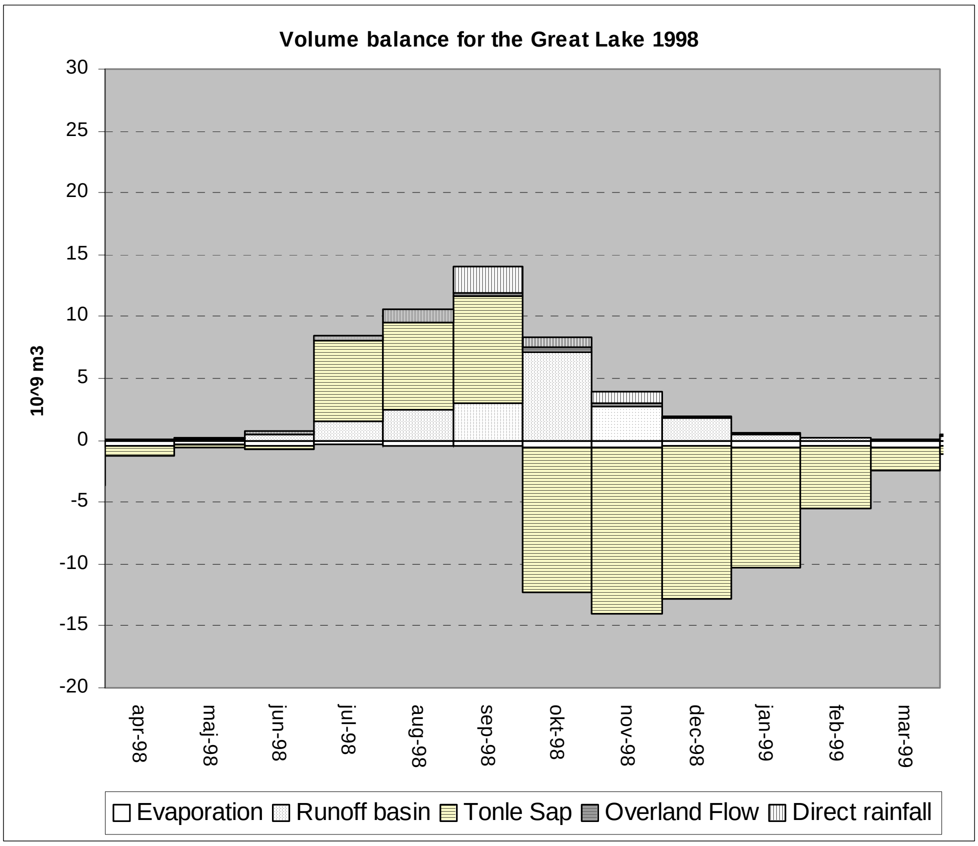


Fig. III-2-12 Volume Balance in Hydrological Year 1962[(4)]



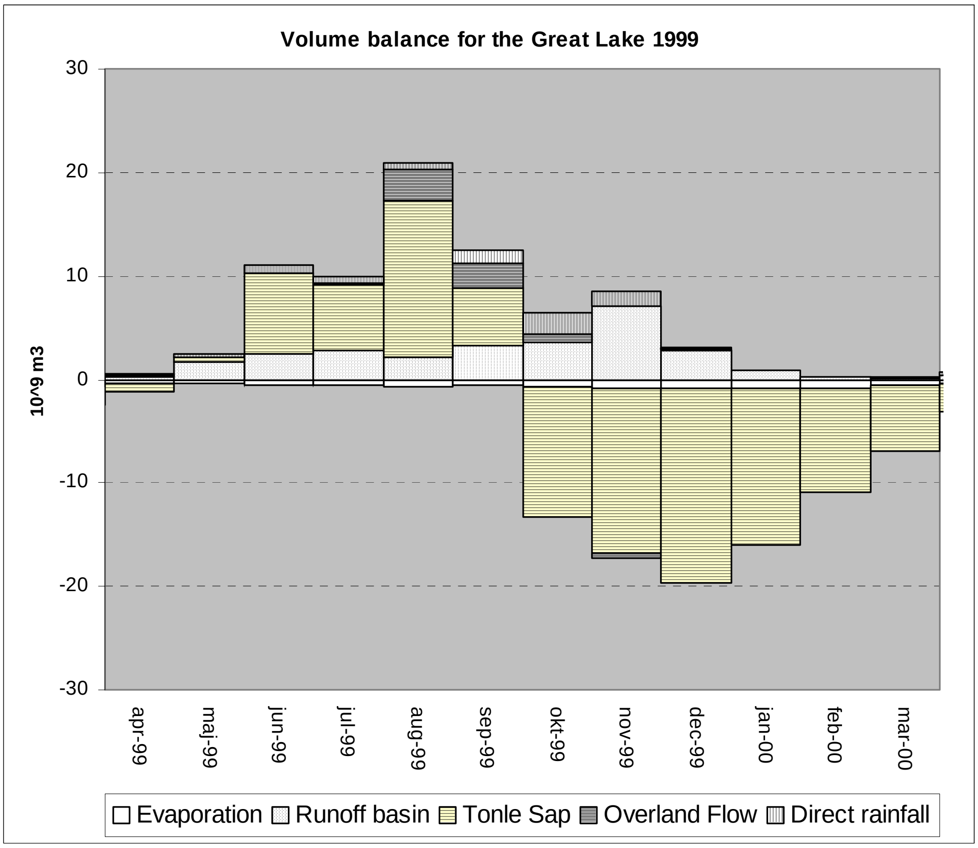
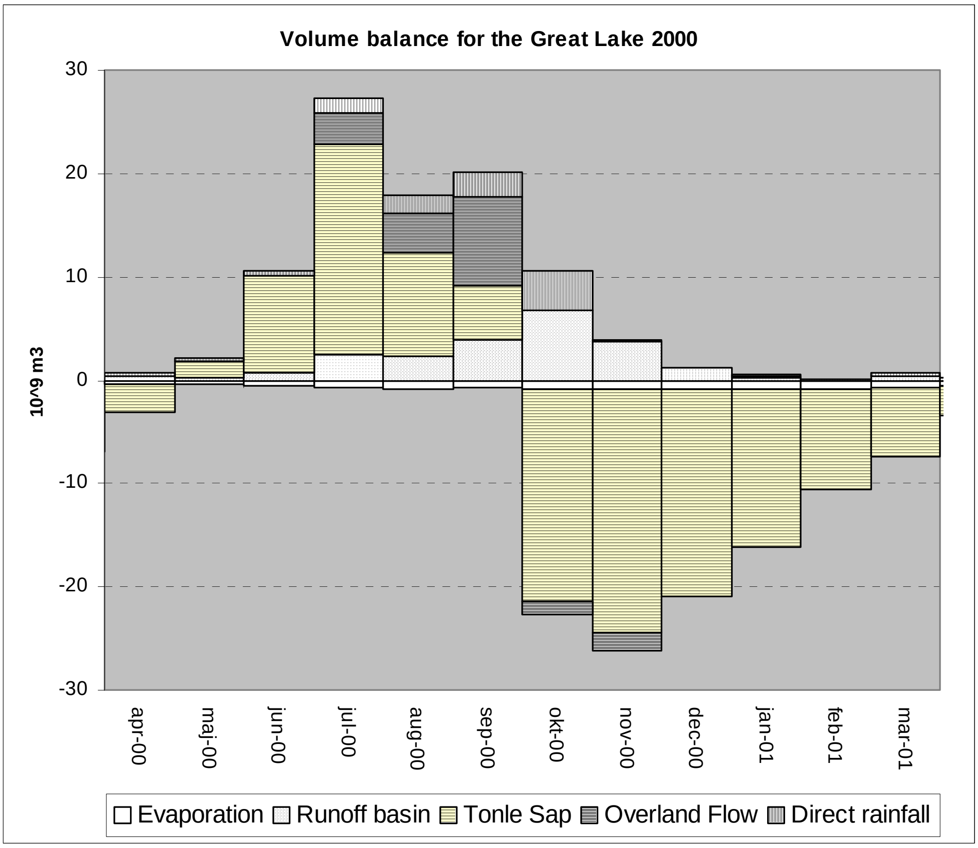


Fig. III-2-13(1/3) Volume Balance for Hydrological Year 1998 to 2002



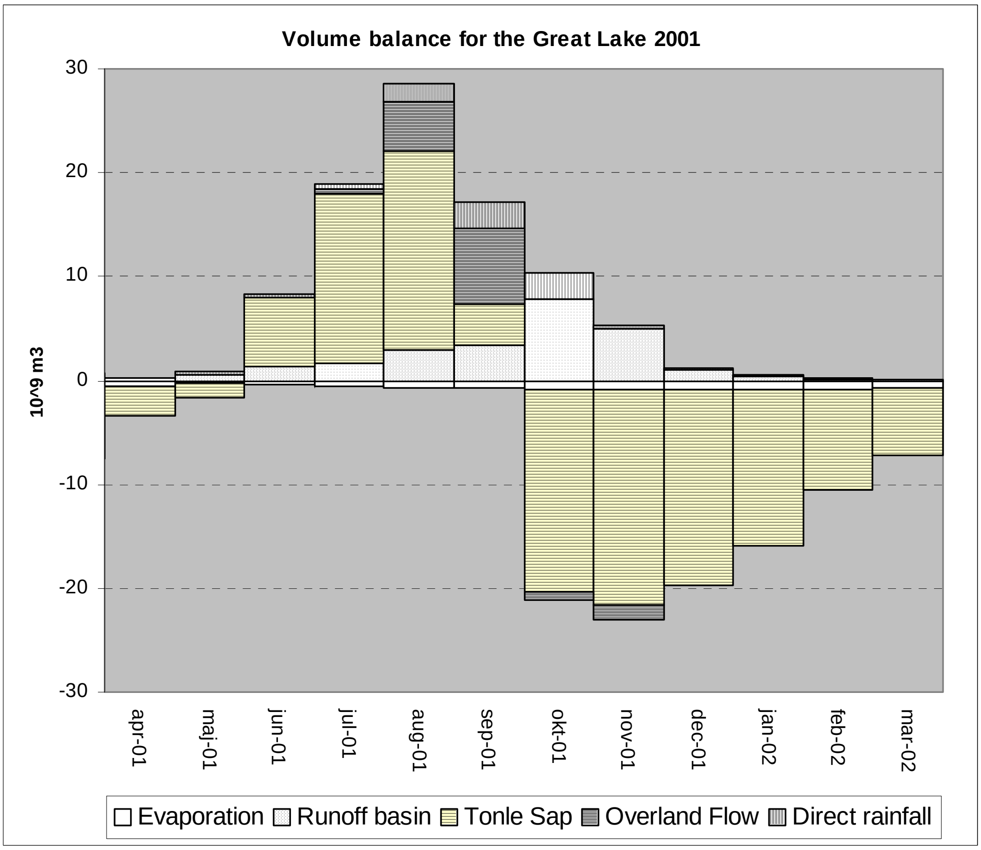


Fig. III-2-13(2/3) Volume Balance for Hydrological Year 1998 to 2002

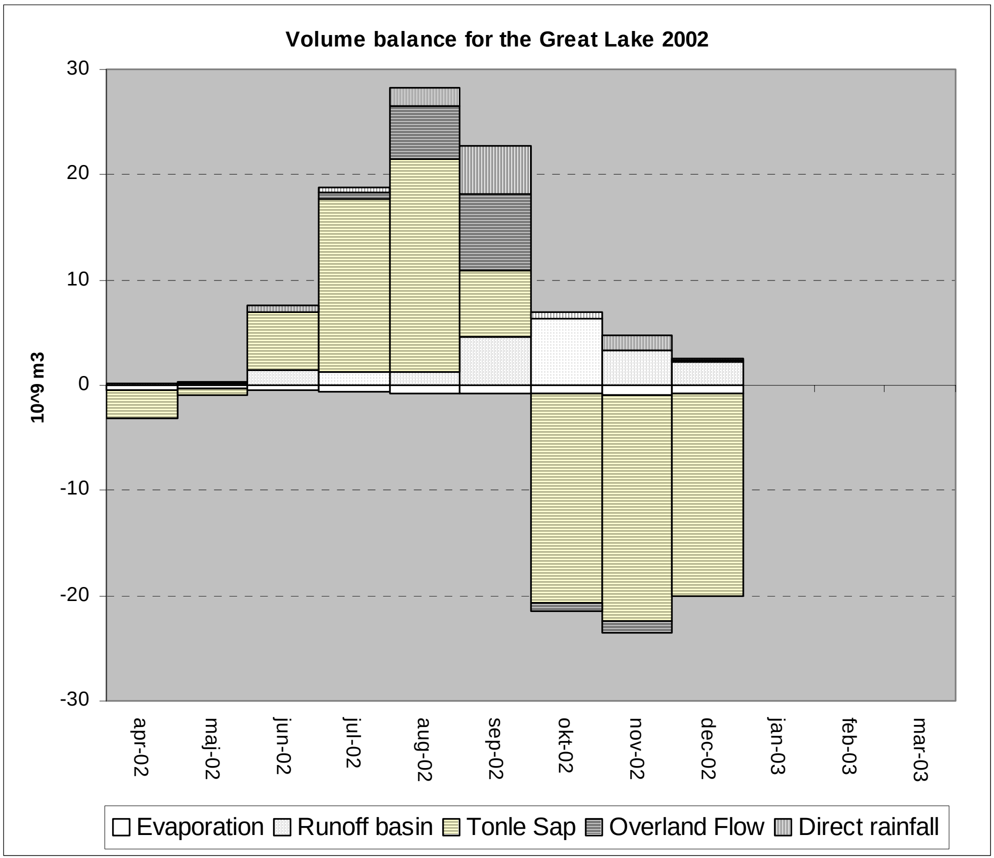


Fig. III-2-13(3/3) Volume Balance for Hydrological Year 1998 to 2002

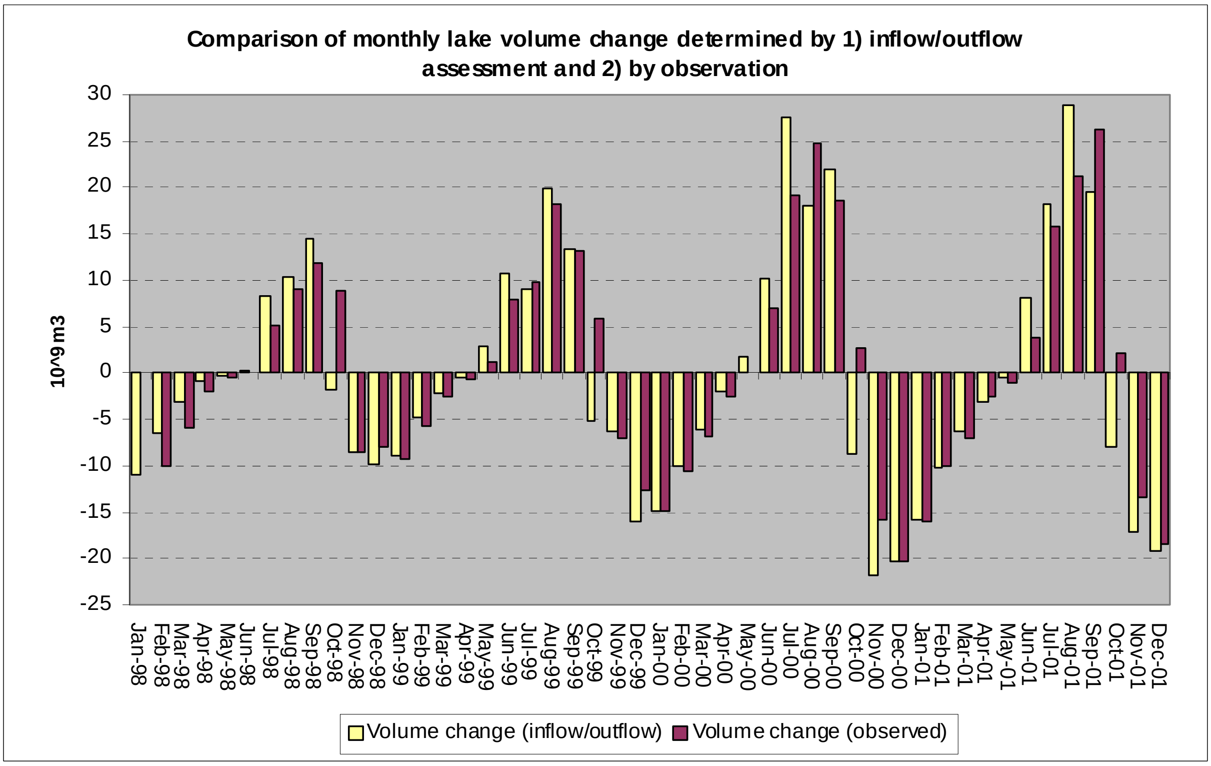


Fig. III-2-14 Comparison of Monthly Volume Change of the Great Lake

2.5.3 Conclusions

By using the modelling results, the water balance analysis of the Great Lake has been made on a monthly basis for the years 1998 to 2002. The seasonal dynamics of all the elements in the balance (Tonle Sap flow, overland flow, basin runoff, direct rainfall, evaporation) have been consistent from year to year, and proportionally as well as in absolute terms compared to the findings in 1962/63, which were based on observations.

Detailed conclusions of the analysis include:

- The contributions to the lake have the following ranking in order of significance: (1) Flow from the Tonle Sap; (2) Runoff from the lake basin; (3) Overland flow from the Mekong; (4) Direct rainfall on the lake; and (5) Evaporation from the lake.

- The month of October has the largest contribution of local basin runoff. During this month the net flow in Tonle Sap River is towards Phnom Penh.

- The local basin runoff does not show as much year-to-year variation as the Tonle Sap flow or the overland flow.

- The dry year of 1998 had almost no overland flow.

- The monthly volume changes in the lake based on inflows/outflows are comparable to the monthly volume changes that can be determined by combining the observed lake water levels with the elevation-volume relation of the lake.

2.6 Overall Review of the Applications

The mathematical model established as part of the WUP-JICA Study has been applied for a number of applications. These include: (1) Dry season modelling; (2) Hydraulic impact of road embankment; (3) Effect of increased bridge openings; and (4) Water balance assessment for the Great Lake. The overall review from each of these applications is found at the end of each section in this chapter.

The following are general conclusions and recommendations:

- The model system is fully capable of simulating both wet- and dry-season conditions in the Mekong river system and associated floodplains of Cambodia.

- The model has been used in the cooperative project, Tonle Sap Lake and Vicinities Project [(2)], for detailed assessment of the functional role of the floodplain compartments, exchange of flows between rivers and floodplains, and detailed water balance assessment for the floodplains. The combined data sets provided by the WUP-ICA and the TSLV projects are essential for model verification.

- The model is at a stage where it can be used for detailed hydrologic studies, regardless of whether these are concerned with wet or dry seasons. The applications made so far are mainly concerned with the wet season (impact of road embankment and bridges). The dry season application has given support to the WUP-JICA work in establishing the dry-season flow monitoring system.

- The MRC staffs had used the model system during the 2003 monsoon to provide daily and forecasted flood maps. The flood maps have been published in the MRC Flood Information Webpage.

- The model system is flexible, and can be expanded/improved in future as necessary. It also has the capability to easily link with two-dimensional models for very detailed floodplain studies.

- Staffs from CNMC and the Department of Hydrology and River Works under the Ministry of Water Resources and Meteorology, Cambodia, have received training in the use of MIKE 11 and the actual model set up for the Mekong River and floodplain system.

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PART IV

HYDROLOGY AND WATER USE IN THE LOWER MEKONG BASIN

PART IV HYDROLOGY AND WATER USE IN THE LOWER MEKONG BASIN

1. HYDROLOGY IN THE LOWER BASIN

1.1 Introduction

The WUP-JICA Team had conducted various kinds of studies for three years in a wide range of fields comprising hydrological station improvement, hydrological monitoring, hydrodynamic modelling and technical assistance on rule formulation. In the course of the study, the Team performed hydrological investigations from time to time, as required, to prove the validity of the proposed outputs from the hydrological points of view. The results could be useful for the further understanding of Mekong hydrology by the succeeding hydrologists.

This chapter summarizes the results of hydrological investigations that had been made through data collection, compilation and analysis. The results mainly cover the following areas:

(1) General hydrological features of the Lower Mekong mainstream;

(2) Drought situations; and

(3) Hydrological functions of Cambodian floodplains.

In particular, the activities of the WUP-JICA Team had concentrated on the study on maintenance of flows as stipulated in Article 6 of the 1995 Mekong Agreement. Among three types of flows, the determination of acceptable minimum monthly natural flow was considered the most important, so that the Team examined the drought situation in 1998. The 1998 drought might be the most serious drought in recent years. The study on such severe drought would give useful information to understand the situation.

Furthermore, the WUP-JICA Team conducted discharge measurements in and around Phnom Penh for the period from July 2002 to October 2003, because there were big hydrological data gaps in the Cambodian territory in terms of flow data of the mainstream. In parallel with normal discharge measurements, which means periodical measurements at the stations to develop flow-rating curves, simultaneous discharge measurements along the Mekong mainstream, Tonle Sap and the Bassac River were conducted in the 2002 flood season at the longitudinal interval of some 10 km to understand the flooding mechanism in the Cambodian floodplains including the Great Lake. This work was made in good coordination with the project “Consolidation of Hydro-Meteorological Data and Multi-Functional Hydrologic Roles of Tonle Sap Lake and its Vicinities” that was carried out under the Technical Support Division (TSD) of MRCS. The results of these activities are presented herein focusing on the flow mechanisms in the Cambodian floodplains.

1.2 General Hydrological Features of the Lower Mekong Mainstream

In the Lower Mekong Basin, flow measurements reportedly started in the early 20th century. In the 1910s, discharge measurements at both the stations of Stung Treng in Cambodia and Vientiane in Laos commenced as a pioneer in this field, followed in the 1920s by the discharge measurements at Mukdahan in Thailand, Pakse in Laos and Kratie in Cambodia. At Phnom Penh it also commenced in 1940 as reported. However, these facts were known only referring to presently available literature, because the data in those days may have been scattered or got lost. Since the Mekong Committee was established in 1957, hydrological data throughout the Mekong mainstream have been observed and compiled consistently and continuously.

The following figure shows the location of major hydrological stations on the Mekong mainstream. Most of them are being upgraded into telemetering stations under the "Appropriate Hydrological Network Improvement Project" of TSD, MRCS.

Fig. IV-1-1 Major Hydrological Stations on the Mekong Mainstream

Table IV-1-1 summarizes the flow data observed at the twelve (12) major hydrological stations since the 1960s. The data source was the hydrological database of MRCS. Fig. IV-1-2 presents the flow conditions of the Mekong mainstream in which the parameters of average annual minimum, mean and maximum flows at the major stations are depicted to their drainage areas. Even this simple figure could imply the general hydrological characteristics of the Mekong River Basin.

Table IV-1-1 Flow Parameters of Major Hydrologic Stations on the Mekong Mainstream

Station	Distance from River-mouth (km)	Drainage Area (km^2)	Recorded Period (Year)	Average Discharge for Recorded Periods		
				Annual Minimum (m^3/s)	Annual Mean (m^3/s)	Annual Maximum (m^3/s)
Chiang Saen	2,363	189,000	1961-1999	720	2,690	10,580
Luang Prabang	2,010	268,000	1961-2001	920	3,990	15,320
Chiang Khan	1,717	292,000	1968-1999	910	4,180	15,880
Vientiane	1,580	299,000	1961-2000	1,010	4,410	16,060
Nong Khai	1,551	302,000	1970-1999	1,000	4,480	16,250
Nakhon Phanom	1,217	373,000	1961-1999	1,320	7,090	24,750
Mukdahan	1,123	391,000	1961-1999	1,380	7,570	27,410
Khong Chiam	910	419,000	1966-1999	1,600	8,980	34,870
Pakse	869	545,000	1961-2001	1,610	9,890	37,810
Stung Treng	668	635,000	1961-2002	1,590	13,790	51,400
Kratie	545	646,000	1961-1999	1,950	13,180	51,220
Phnom Penh	332	663,000	1960-1999	1,780	12,740	43,110

Note: Discharges at Phnom Penh are simulation results of the Decision Support Framework.

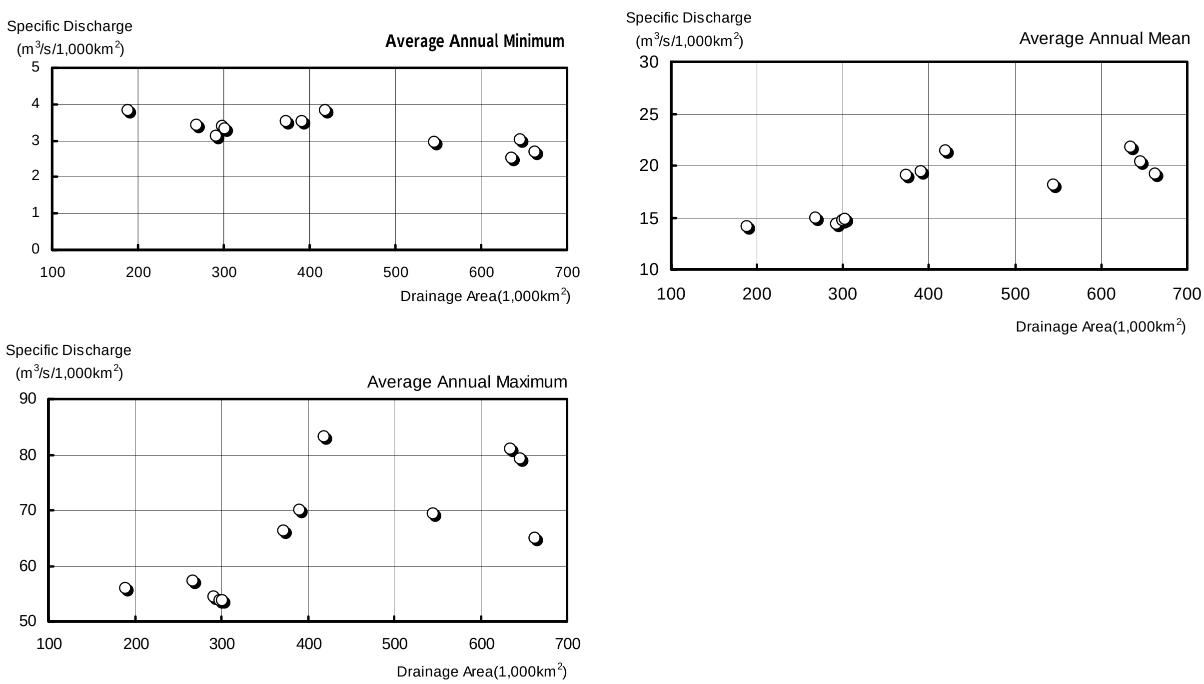


Fig. IV-1-2 Flow Parameters of Major Hydrological Stations on the Lower Mekong Mainstream

The annual minimum flow representing the dry-season flow indicates that inflow from China may be dominant compared with inflow from the tributaries in the Lower Mekong Basin, because the specific discharges gradually tend to decrease in proportion to the increase of drainage areas. Compared with the flow in Phnom Penh, the minimum flow of 40% (= 720 m^3/s / 1,780 m^3/s) is contributed at Chiang Saen, although the drainage area accounts for 29% (= 189,000 km^2 / 663,000 km^2) of the entire Mekong River Basin in which the territory of China mainly dominates.

On the other hand, from the data plots of annual mean and maximum, it could be seen that the monsoon rainfall in the Annan Highlands and Bolovens Plateau in Laos gives a big contribution to form the wet-season flow. Even though there are some discrepancies in longitudinal distributions and data among the hydrological stations, the annual mean and maximum flows receive the predominant flow contributions from the tributaries originating in those mountains. When such swelling flood hydrograph reaches the Cambodian floodplains and expands widely from the apex of Kratie downwards every year, almost 15% of the flood flow would attenuate through flooding over the floodplains up to Phnom Penh. After Phnom Penh, the flood flow as well spreads over the Mekong Delta very widely and finally empties into the South China Sea.

1.3 Drought Situations in the Lower Mekong Basin

1.3.1 Comparison of Probabilities of Occurrence of the 1998 Drought on the Mekong Mainstream

Actual hydrological events are changeable and their behaviours largely fluctuate. The occurrence of events is probabilistic and stochastic. Thus hydrological events (flow regime) may vary from season to season, from year to year and from place to place. This is easily understandable in terms of difference of occurrence probabilities of hydrological events. In order to illustrate this, the probability of occurrence of the 1998 drought at nine stations from Chiang Saen to Pakse on the Mekong mainstream was estimated by means of the total flow volume in the wet season from June to November. The figure below presents the comparison of estimated probabilities of occurrence along the Mekong mainstream.

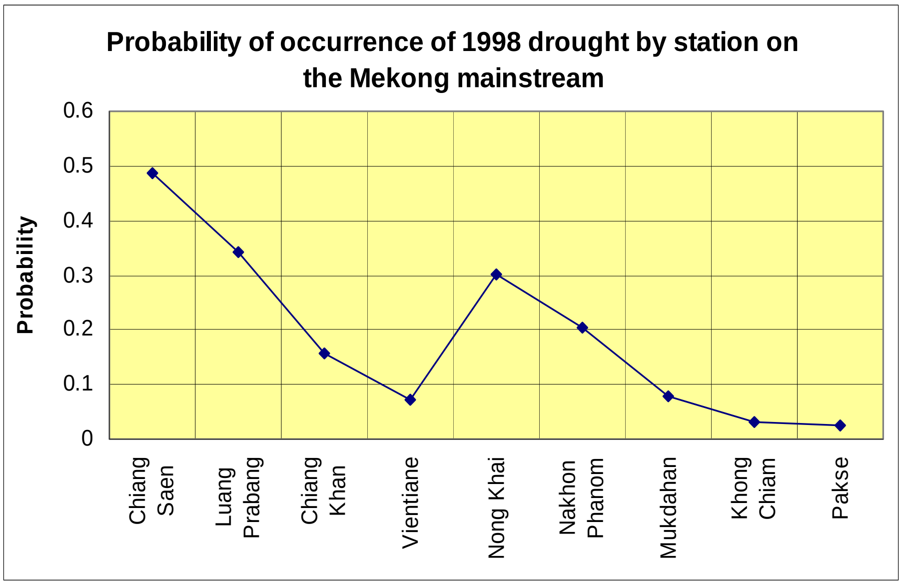


Fig IV-1-3 Comparison of Probabilities of Occurrence of 1998 Drought

As seen above, the probability of occurrence of the 1998 drought is different from station to station on the Mekong mainstream. The probability of the 1998 drought varies from 0.5 (once in 2 years) at Chiang Saen to 0.025 (once in 40 years) at Pakse. Considering that probabilities are below 0.1 from Mukdahan to Pakse, the 1998 severe drought may have occurred in a wider range around the contributing left bank tributaries in Lao PDR and Vietnam, i.e., the Se Bang Hien, Se Sang, Se Kong and Sre Pok rivers. Fig. IV-1-4 shows the flow contribution of major sub-basins to the annual runoff of the Mekong River as a result of the water balance study in the Lower Mekong Basin in the 1980s. As can be seen in this figure, these tributaries contribute around 22% of the annual runoff of the Lower Mekong Basin, although area contribution is only 13%. It could be argued that these tributaries are dominant influences on the incidence and severity of drought in the Mekong Delta. Comparing the total inflow volume at the Nam Ngum reservoir in the wet season of the 1998 drought year with those in 1972-2001, the probability of the 1998 drought was estimated at 0.2 (once in 5 years). This occurrence probability of the 1998 drought coincides with the probability at Nakhon Phanom. The Nam Ngum River joins the Mekong River in the upstream reaches of Nakhon Phanom.

Fig. IV-1-4 Annual Water Balance of the Lower Mekong River Basin

Monthly mean discharges in the 1998 drought at the nine stations on the Mekong mainstream were compared with the estimated monthly mean discharges with non-exceedance probabilities of 10%, 50% and 90%. From the hydrological point of view, the monthly mean discharge of 90%

non-exceedance probability means that the mean monthly river flow below the 90% discharge is expected to occur once in 10 years. The results of comparison among the stations of Chiang Saen, Vientiane and Pakse are given in Fig. IV-1-5.

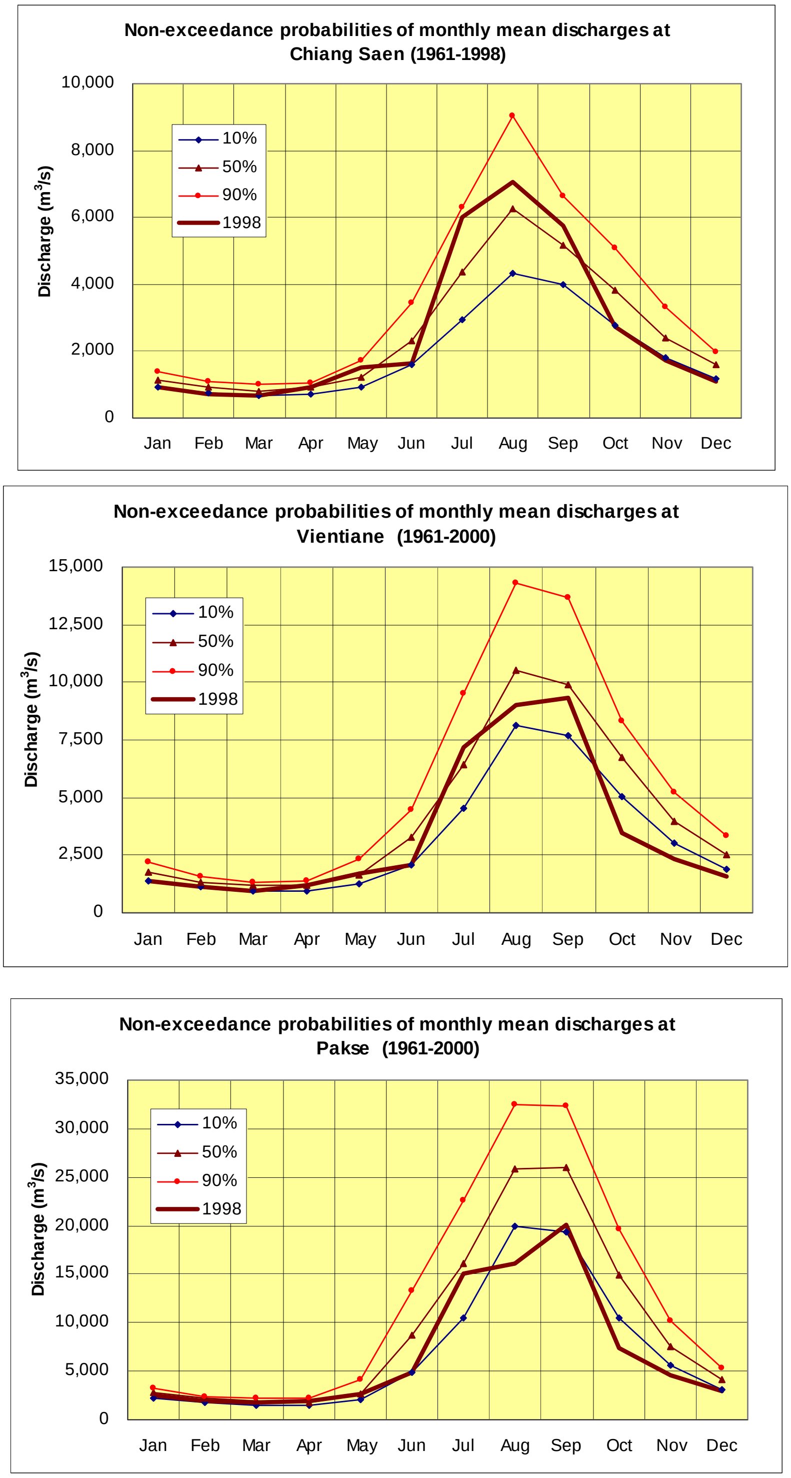


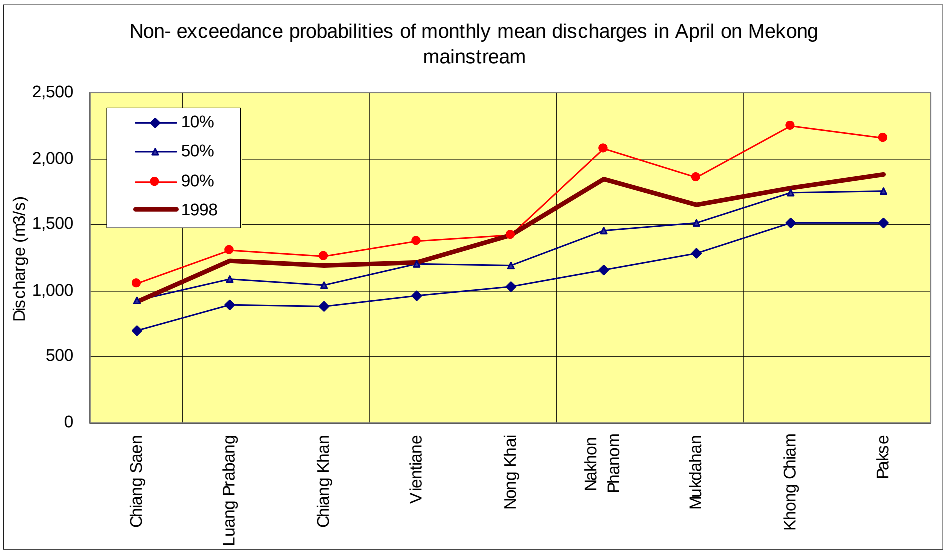
Fig. IV-1-5 Comparison of Monthly Mean Discharges in 1998 to Drought Discharges at Chiang Saen, Vientiane and Pakse

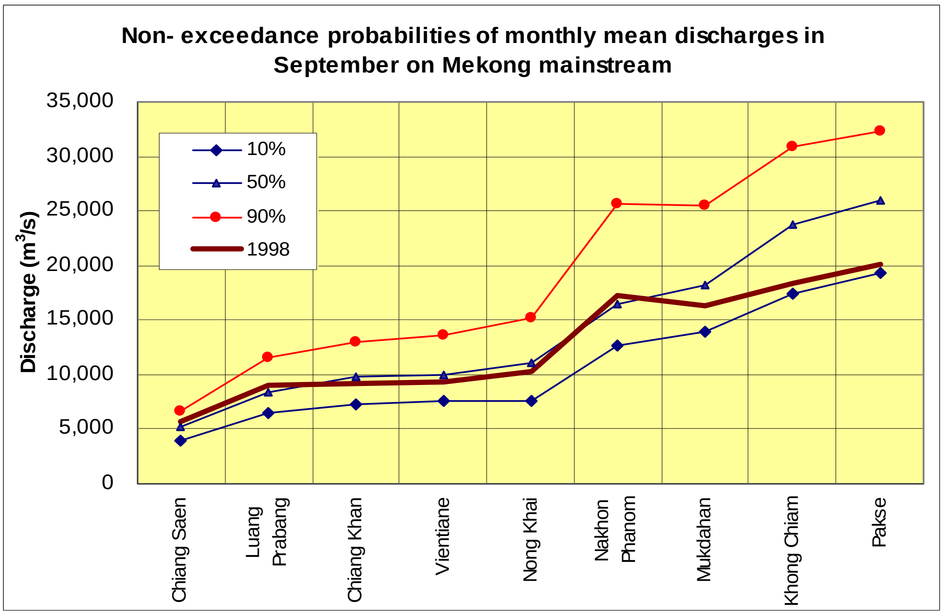
As mentioned above, monthly mean discharges in the 1998 drought year vary widely in quite different probabilities of non-exceedance from station to station on the Mekong mainstream. At Chiang Saen, river flows in the wet season (from July to September) are over 50% of the monthly mean discharges. Focusing on the wet season flows, it may be assumed that river flows in 1998 were those of normal years (once in 2 years). However at Vientiane, river flows in the wet season became 50% of the monthly mean discharges. Further, at Pakse, river flows became far less in the wet season. Discharges in the flood recession period in October to December show serious drops under the respective 10% discharges at all the stations.

Monthly mean discharges in the 1998 drought had been plotted on the monthly distribution profiles of monthly mean discharges on the Mekong mainstream with non-exceedance probabilities of 10%, 50% and 90%, as shown in Fig. IV-1-6.

The annual mean discharge at Pakse was 12,666 m^3/s in 2000. This was the largest in the recent 20 years, while it was 6,807 m^3/s in the dry year of 1998. The year 2000 was a hydrological wet year. Besides Pakse, discharge records in 2000 are available only at Luang Prabang and Vientiane. Monthly mean discharges in both 1998 and 2000 were compared with the estimated drought discharges with non-exceedance probabilities of 10%, 50% and 90%. Fig. IV-1-7 presents the comparison results.

Besides the year 2000, the year 1996 was also relatively abundant in water. The annual mean discharge at Pakse was 10,422 m^3/s in 1996. Monthly mean discharges are available at all of the nine stations on the Mekong mainstream. Monthly mean discharges in 1996 and 1998 have been plotted to compare the monthly discharge profiles of non-exceedance probabilities, as shown in Fig. IV-1-8. These results reveal that occurrences of drought events vary in space, even in the upstream area of Pakse.





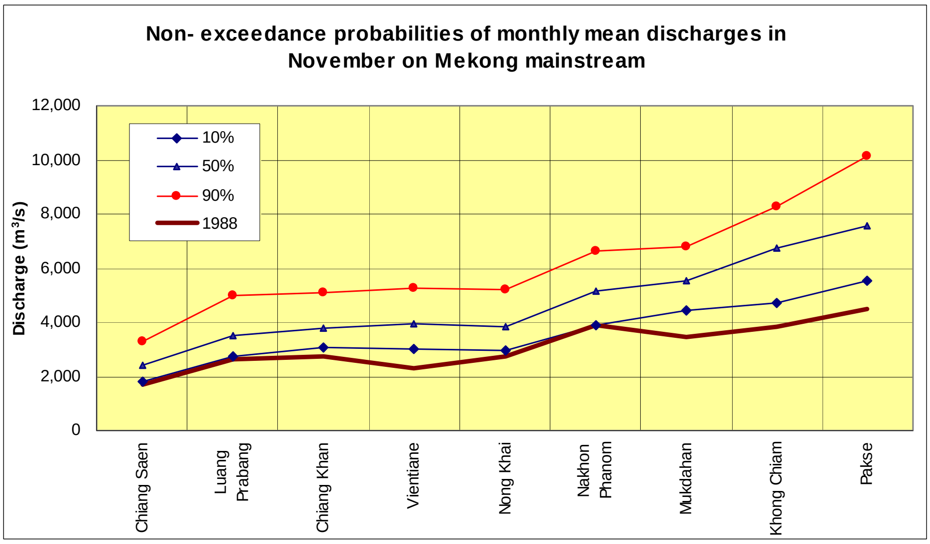


Fig. IV-1-6 Comparison of Monthly Mean Discharges in 1998 to Drought Discharges in April, September and November

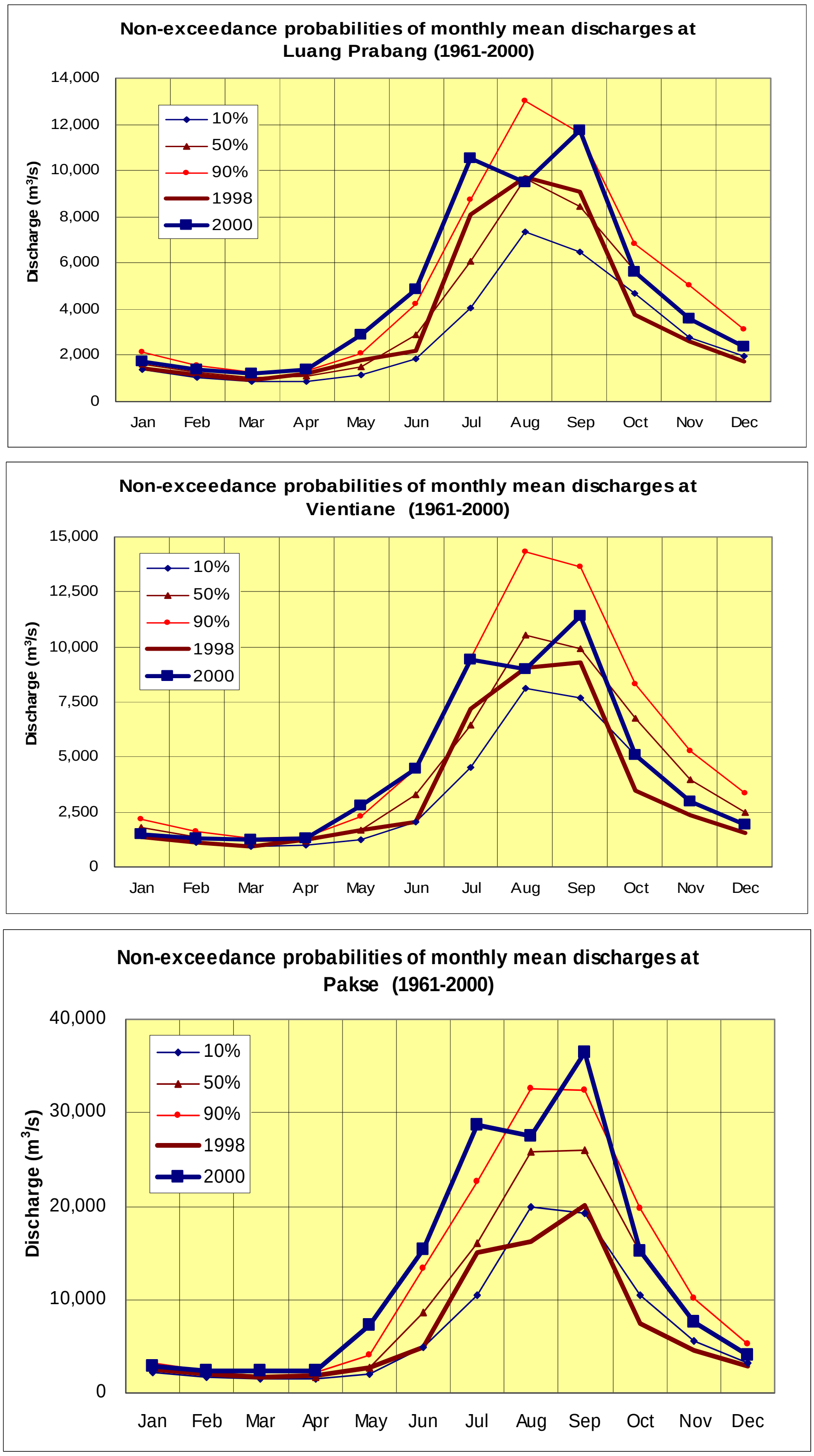
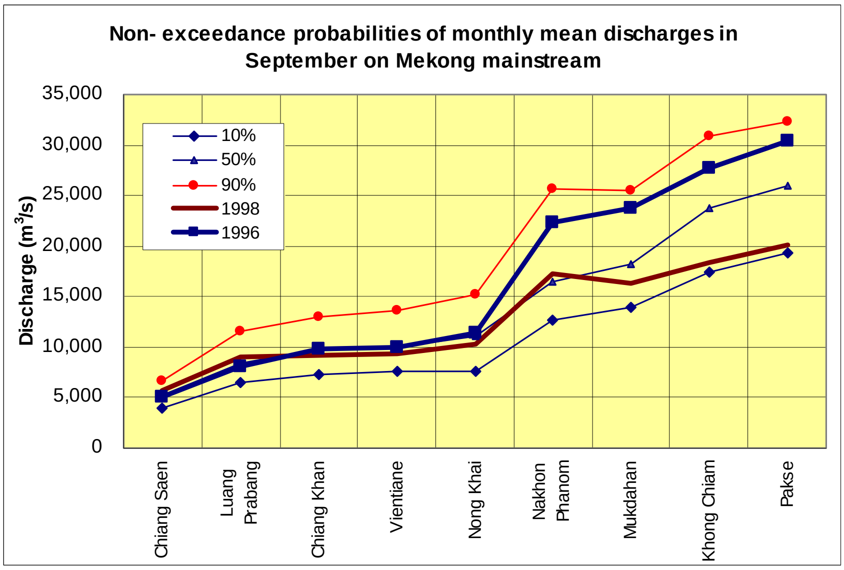


Fig. IV-1-7 Comparison of Monthly Mean Discharges in 1998 as Drought Year and in 2000 Water-Rich Year to Drought Discharges at Luang Prabang, Vientiane and Pakse



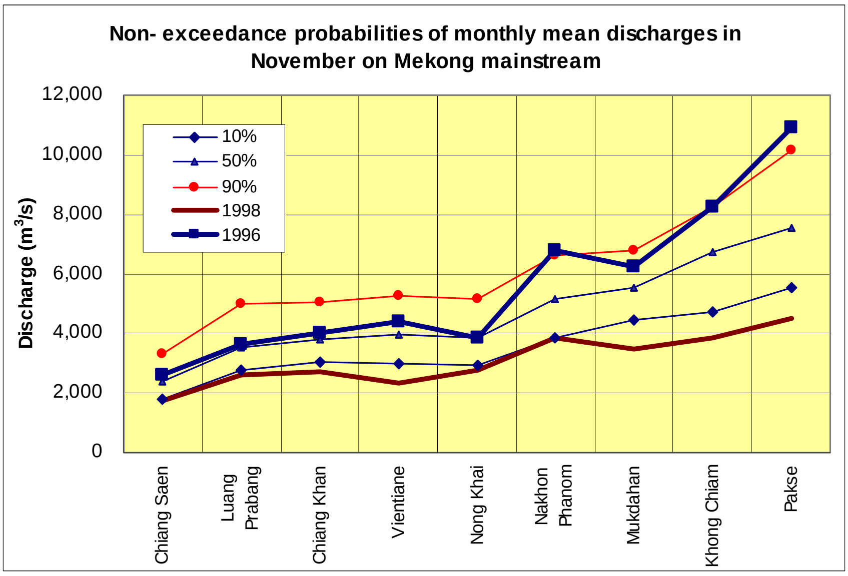


Fig. IV-1-8 Comparison of Monthly Mean discharges in 1998 Drought Year and 1996 Water-Rich Year to Longitudinal Plots of Drought Discharges in September and November

1.3.2 Categorization of Drought Events

Annual flow regimes from 1961 to 2000 at the nine hydrologic stations from Chiang Saen to Pakse on the Mekong mainstream have been evaluated in view of variations of occurrence probabilities of drought. Drought probabilities have been computed in the evaluation of total flow volume in the wet season from June to November. Even though within an annual flow regime, occurrence probabilities are different from station to station on the Mekong mainstream. This is due mainly to the great variety of contributions of lateral inflow from tributaries caused by the unequal and stochastic distribution of annual rainfall over the basin.

From these results of probability distributions, six (6) distribution patterns of annual flow regime had been categorized for easier understanding of drought events in the basin. Out of the annual flow regimes, several typical years had been selected for each pattern, as follows:

Table IV-1-2 Categorization of Typical Annual Flow Regimes

Type	Typical Year	Description
Type-A	1970, 1981, 1995	Water abundant year when drought probability is far over 0.5 (occurrence of once in 2 years) at all stations
Type-B	1974, 1982, 1990	Normal year when drought probability is almost 0.5 at all stations
Type-C	1987, 1992	Historically basin-wide severe drought when drought probability is far below 0.1 (occurrence of once in 10 years) at all stations
Type-D	1977, 1998	Historical but partial drought when drought probability varies from station to station. Severe drought occurs only in the downstream reaches.
Type-E	1972, 1986	Historical but partial drought when drought probability varies from station to station. Severe drought occurs only in the upstream reaches.
Type-F	1989, 1993	Historical but partial drought when drought probability varies from station to station. Severe drought occurs in limited reaches.

Source: WUP-JICA Study Team

Plots of probability distribution of the selected annual flow regimes are shown in the following Fig. IV-1-9.

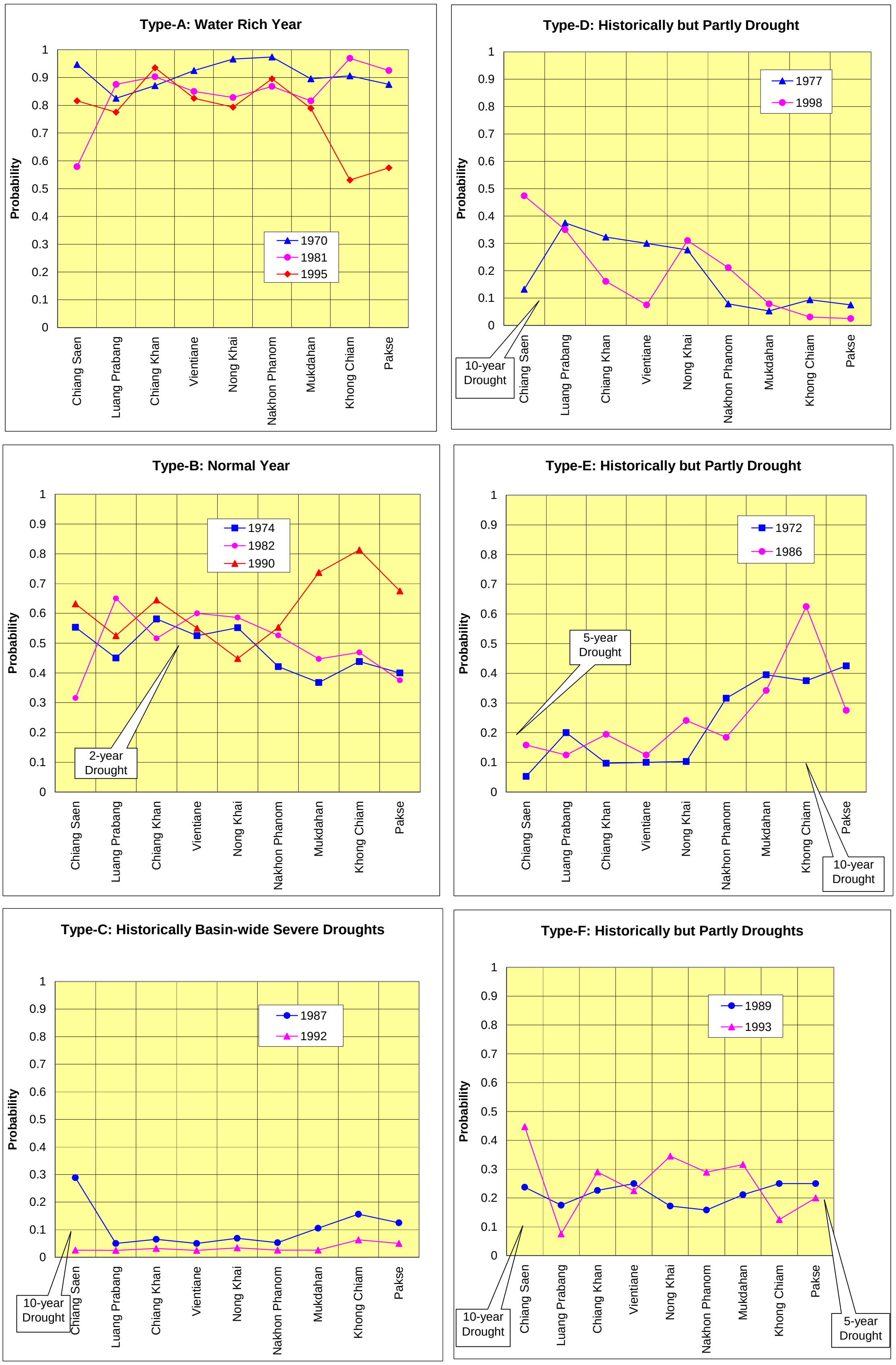


Fig. IV-1-9 Longitudinal Plots of Occurrence Probabilities of Categorized Annual Flows

1.4 Hydrological Functions of Cambodian Floodplains

1.4.1 Previous Study Results

The most intensive discharge measurements covering the Mekong Delta were made by SOGREA under the UNESCO Project from 1963 to 1965. Discharge measurements as well as water level observations covered almost all major flow paths of the branches of the Mekong River system from Kratie to the downstream ends.

The primary objective of this discharge measurement campaign was to construct the mathematical simulation model of the Mekong Delta including the Cambodian floodplains. As anticipated, the target areas were too large and mobilization capacity was limited due to the insufficient transportation system. Thus inconsistencies and inconveniences in understanding the flow balance were encountered in the project.

However, a part of the measured data is still very useful and helpful in understanding the water balance, in particular, during the flood season. Useful information is summarized below from the reports of the above-mentioned project.

Kratie to Chrui Changvar

Intensive discharge measurements were made during the 1964 flood season. In particular, discharge measurements were made at various points along the mainstream in the stretch from Kratie down to Chrui Changvar (Phnom Penh) for 4 days from September 29 to October 2. The results can be regarded as similar to the simultaneous measurements. Combining the discharge data tabulated in the hydrological yearbook, the results are schematised in Fig. IV-1-10. The figure characterizes the following flood conditions.

(1) Kratie to Kompong Cham

From Kratie to Kompong Cham, floodplains on the right bank along the mainstream are narrow and have no flood paths connecting them with the lower floodplains. Thus the flood retarding capacity is relatively small. On the other hand, the hills on the left bank are situated further back from the river course and the area in-between is comparatively flat. At high water the floodplain between Chhlong and Kompong Cham (Tonle Bet) can act as a lateral outfall and as a wide flood path parallel to the Mekong.

Fig. IV-1-10 shows that the total discharge regulated is 3,650 m^3/s, which is equivalent to 8% regulation of the Kratie flood discharge of 48,000 m^3/s. Some 880 m^3/s returns to the mainstream upstream of the Kompong Cham Station, and the discharge of 2,080 m^3/s passes through the Moat Khmung Bridge site after regulation of the floodplain's storage function.

The flood hydrographs of Kratie, Kompong Cham and Phnom Penh are depicted from the hydrologic yearbook in Fig. IV-1-11. The flood retarding effects could not be detected from this figure due to insufficient reliability of rating curves.

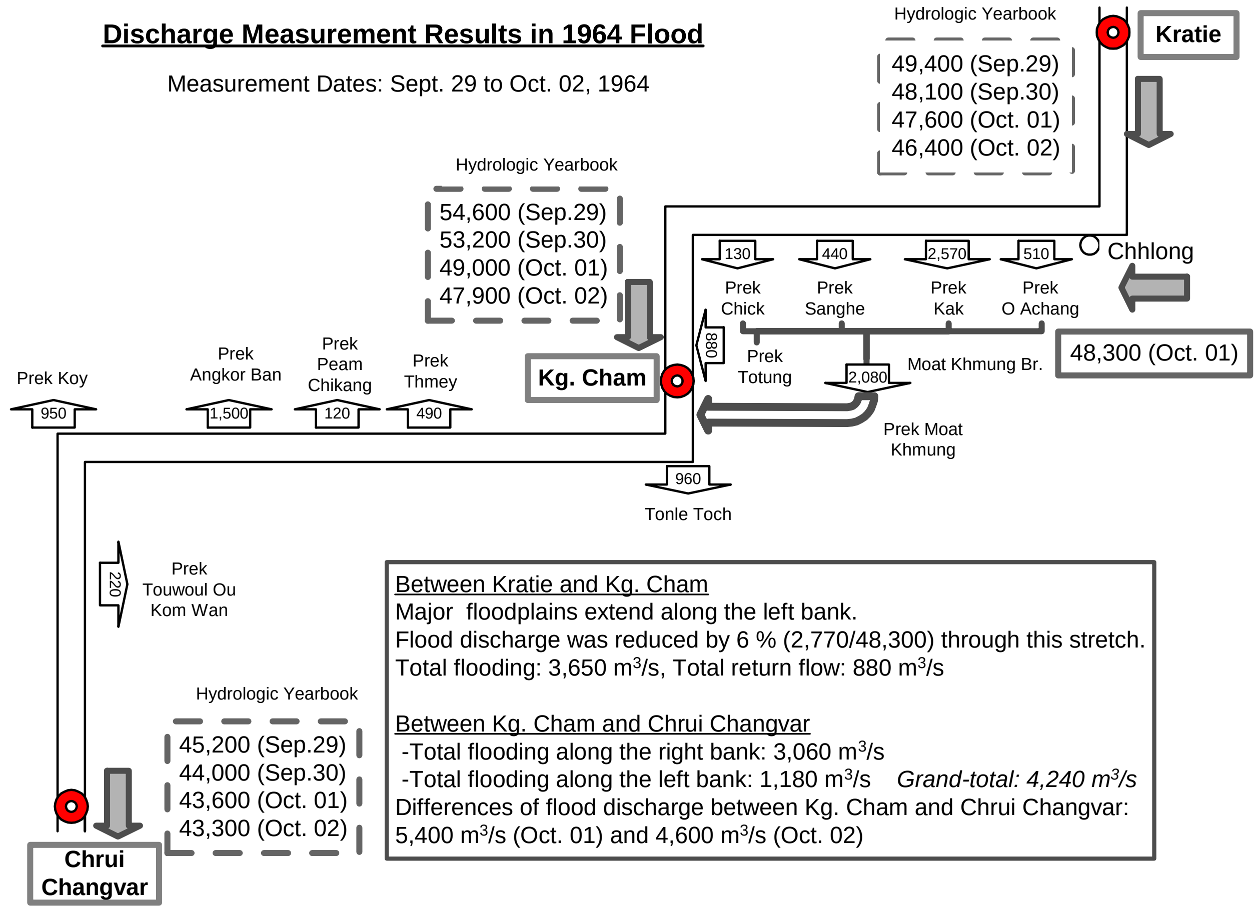


Fig. IV-1-10 Floodwater Balance Measured during the 1964 Flood

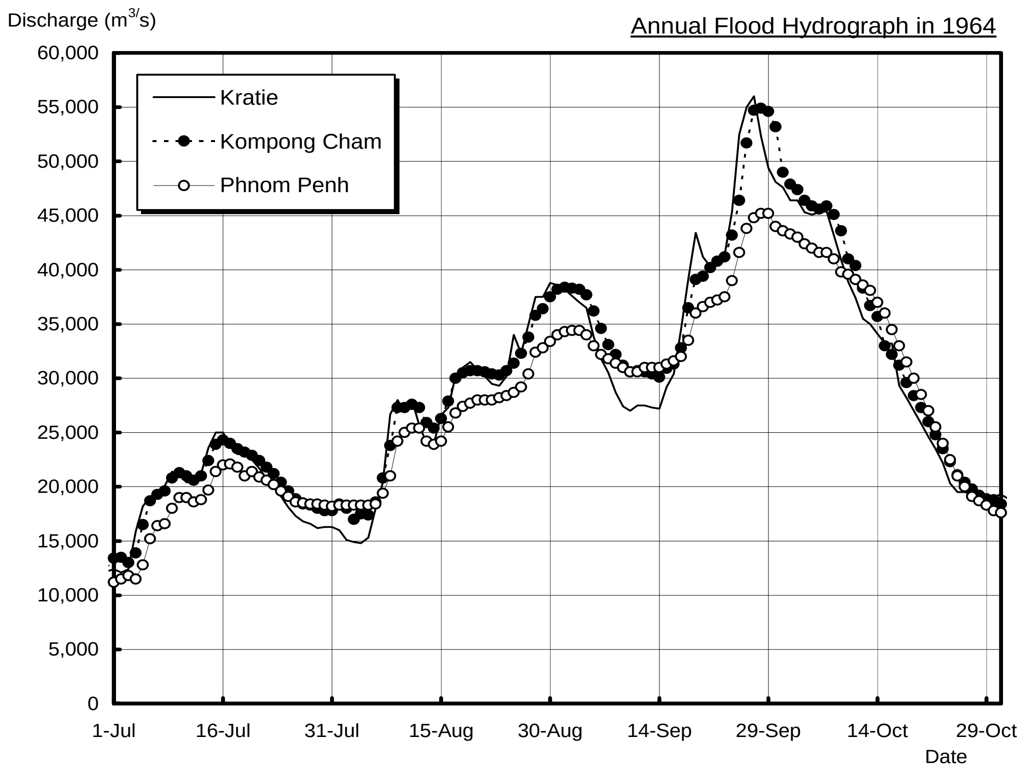


Fig. IV-1-11 Annual Flood Hydrograph in 1964

(2) Kompong Cham to Chrui Changvar (Phnom Penh)

There are several major flood outfalls between Kompong Cham and Chrui Changvar along the Mekong mainstream. These are Prek Moat Khmung, Tonle Touch and Prek Touwoul Ou Kom Wan on the left bank, and Prek Thmey, Prek Peam Chikang, Prek Angkor Ban and Prek Koy on the right bank, as shown in Fig. IV-1-10.

As seen from the measurements in Fig. IV-1-10, the flood discharge at Kompong Cham was reduced from 48,000 m^3/s to 43,000 m^3/s at Chrui Changvar by the outflow into the outfalls and over-bank flooding in October 2. Measured flood discharges on the right and left banks were 3,060 m^3/s and 1,180 m^3/s respectively. Within these figures, 960 m^3/s of outflow into Tonle Touch is not the actually measured data, but the estimated value using measured data observed around those days. Furthermore, the inflow of Prek Moat Khmung is not known.

Under such uncertainties, the measurements imply the following facts:

- 72% of the total flooding occurred along the right bank;
- 28% of the total flooding occurred along the left bank; and
- 10% of the flood discharge at Kompong Cham was regulated in the course of flow to Chrui Changvar.

In addition, the report mentions that, according to the model outputs, 9.1% of the flood discharge at Kompong Cham was absorbed by lateral flooding down to Chrui Changvar during the 1963 and 1964 floods. Also based on the model outputs, the right bank drew off roughly twice as much as the flow on left bank.

Chrui Changvar (Phnom Penh) to Neak Luong

Measurements were not made in a simultaneous manner in the stretch from Chrui Changvar to Neak Luong. Thus there was only little information to understand the flow balance in this stretch.

Tonle Sap

There were two measurements along the Tonle Sap in 1963. The reverse flow was measured from August 24 to 26. The discharge of 6,220 m^3/s was observed at Phnom Penh Port, and 8,120 m^3/s was observed at Prek Kdam. Clearly, there was a significant inflow of approximately 2,000 m^3/s in-between. Detailed measurements were, however, not conducted so that the source and route of inflow is not known.

On the other hand, other measurements were made in October 19 during the normal flow period. The discharge of 8,100 m^3/s was measured at Prek Kdam, and 8,200 m^3/s was measured at Phnom Penh Port. Around 110 m^3/s of inflow through four canals on the right bank was also observed at the western side.

According to the above observation, the reverse flow diverged from the Mekong mainstream flow through the Tonle Sap Channel, resulting in a significant overland flow flooding on the right bank between Kompong Cham and Chrui Changvar. On the other hand, the normal flow discharged from the Great Lake passed through the Tonle Sap Channel and down to the Chak Tomuk junction without significant inflows.

Bassac River

Discharge measurements were made along the Bassac River only once in a simultaneous manner from August 28 to August 30 in 1963. In August 30 the flood discharge at Chrui Changvar was 33,800 m^3/s, and it occurred two weeks after the 1963 flood peak of 43,300 m^3/s. From Ta Khmao down to Koh Khel, measurements were made at eleven canals (preks) on the left bank and at three canals on the right bank. At that time the discharge at Ta Khmao was 4,840 m^3/s. Total outflows into the floodplains were 355 m^3/s and 216 m^3/s on the left bank and the right bank, respectively. At Ta Khmao, 12% of the flow was absorbed through the colmatage canals.

1.4.2 Flow Balance along the Major Watercourses

The WUP-JICA survey team conducted longitudinal discharge measurements along the major watercourses, Mekong, Tonle Sap and Bassac, every other week from July 2002 until January 2003. The results were combined with the discharge measurements and water level observations on the floodplains made by the TSLV Project. Since then until October 2003, the WUP-JICA Team continued discharge measurement activities at major stations in and around the Phnom Penh area. Utilizing and analysing the data measured, the following facts have been clarified in the hydrological functions of the Cambodian floodplains.

Upstream of Kompong Cham on the Mekong

The longitudinal discharge measurements started at Kompong Cham and proceeded downward. Some significant flooding had occurred in the stretch from Chhlong to Kompong Cham. A reliable rating curve has been developed at Kratie using data measured by the DHRW to detect the flood-retarding effects in comparison with the flood hydrographs of Kratie and Kompong Cham, as presented in Fig. IV-1-12.

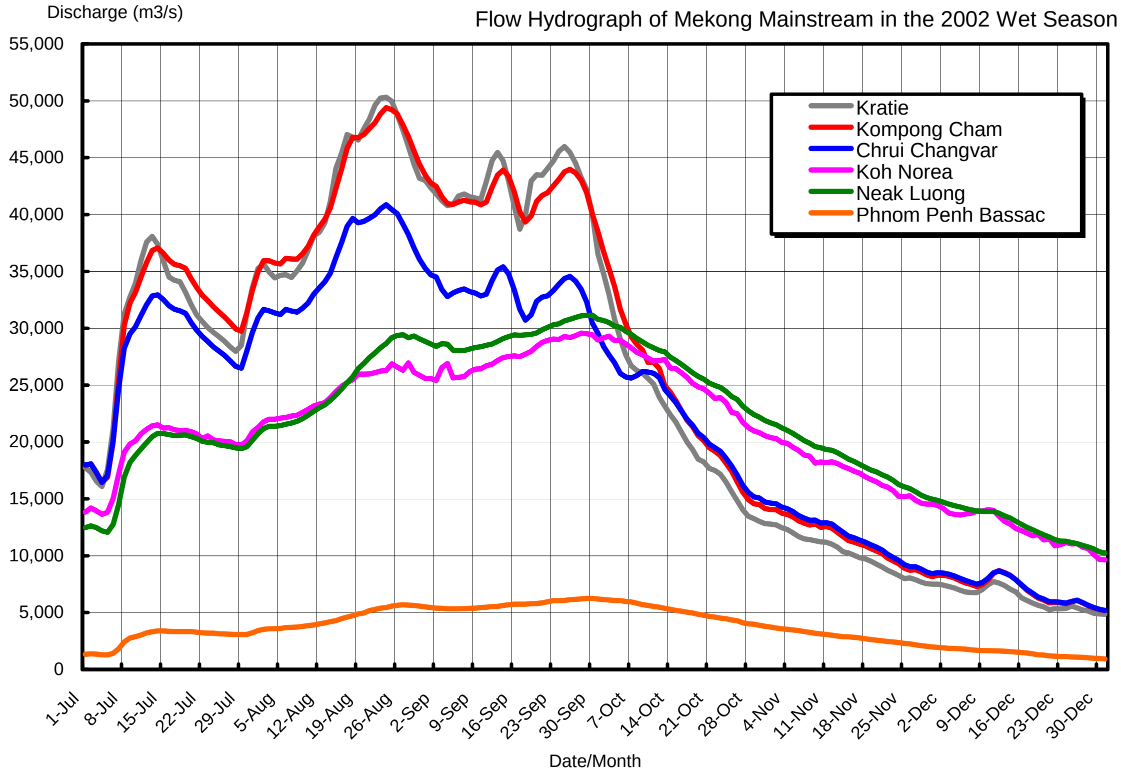


Fig. IV-1-12 Flood Hydrograph in Cambodian Floodplains in the 2002 Wet Season

Fig. IV-1-12 shows three flood peaks in the 2002 wet season. As summarized in the following table, the flooding functions of flood peak attenuation had been estimated at 900 to 2,240 m^3/s. These functions are equivalent to 2 to 5% of the flow discharge at Kratie.

Table IV-1-3 Flooding Functions between Kratie and Kompong Cham in the 2002 Wet Season

Date	Flood Discharge (m^3/s)		Flood Attenuation Rate (m^3/s)
	Kratie	Kompong Cham	
August 24	50,300	49,400	900
September 13	45,460	43,480	1,980
September 25	45,980	43,740	2,240

In addition, the related hydrological data of project-based observations have been obtained for this area. In the 2002 wet season, the improvement project of National Road No. 7 was implemented in the stretch from Kizuna Bridge to Suong under Japan's Grant Aid Programme. Under this project, the water level over the project area was observed in the flood season.

Fig. IV-1-13 shows the observed water level at Moat Khmung Bridge during the floods in 2002. According to the report of the project office, reverse flow from the river mouth occurred in the initial stage of the flood season. Then normal downward flow occurred after full impoundment of floodwaters in the floodplains. The normal flow started on August 8, 2002, according to the report of the project office. This fact may be reasonable compared with the water levels at Kompong Cham and the Bridge, as shown in Fig. IV-1-13.

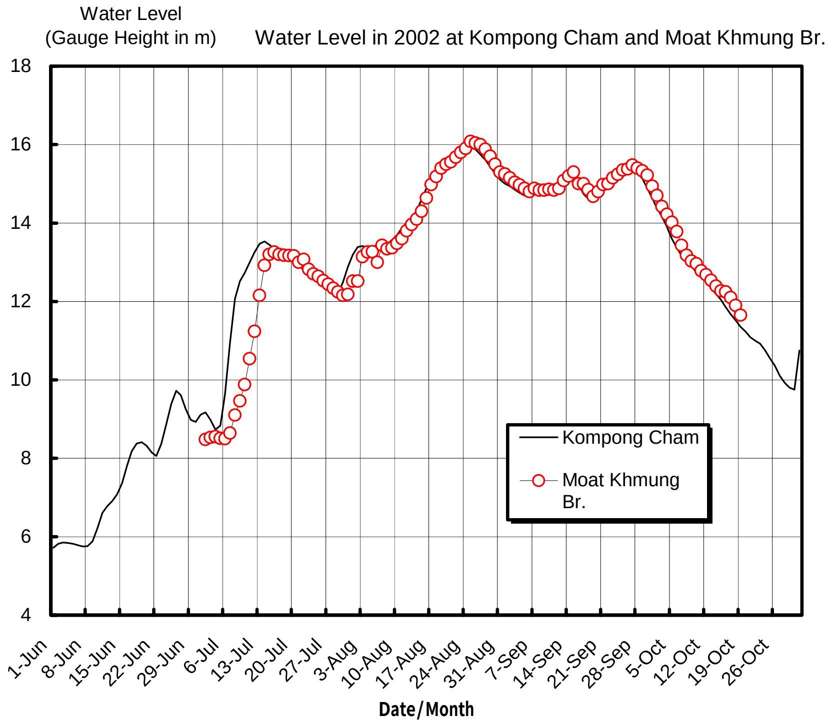


Fig. IV-1-13 Observed Water Level at Moat Khmung Bridge in 2002

Furthermore, the project office measured floodwater velocities at their major water level stations by a current meter during the 2000 floods. Thus the following procedures were taken for estimation of the flood hydrograph in 2002, utilizing the velocity measurement data:

- Basic data such as bridge cross-section, observed water level and flood velocity were collected from the project office.

- Roughness coefficients in the Manning's Formula were calculated back using the cross-section, water level at the bridge, and hydraulic gradient between water levels at the Bridge and river mouth of Prek Moat Khmung. (Roughness coefficient has been estimated at 0.020.)

- Using water levels observed at the bridge and the river mouth and cross-section of new bridge, flood discharges were computed from the beginning of normal flow in August 8 during the 2002 flood.

Furthermore, the MRCS and DHRW measured the flood discharge passing through the bridge in the recession period from October 1 to November 22, 2002. The computation results show a good fit to the measured discharges. Thus finally the flood hydrograph was formed combining the computed major part with the measured recession part.

The estimated flood peak passing through the bridge was 3,070 m^3/s. The peak appears coincidentally with the peak of water level at Kompong Cham on August 26, 2002. The flood hydrograph passing through the bridge is depicted in Fig. IV-1-14.

After passing the bridge, some parts of the floodwater returned into the Mekong mainstream, and the remaining part joined the Tonle Touch flowing down in parallel with the Mekong. This divergence rate strongly depends on the unsteady hydraulic balance between water levels of the Mekong and the related floodplains.

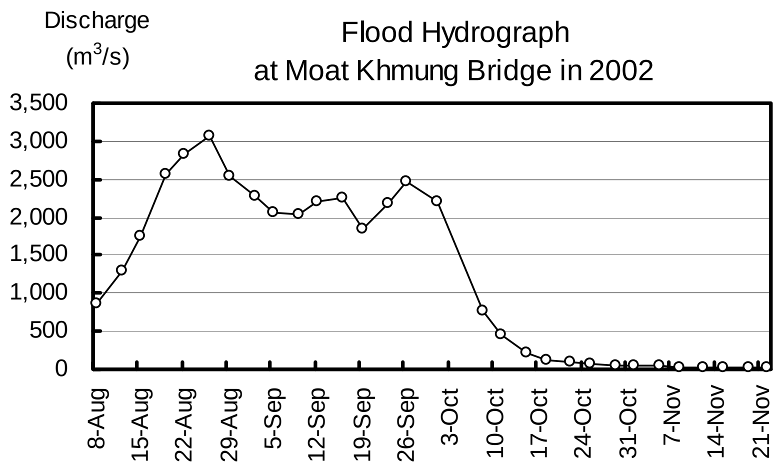


Fig. IV-1-14 Flood Hydrograph Passing through the Moat Khmung Bridge in 2002

<u>Downstream of Kompong Cham on the Mekong</u>

In the stretch of Kompong Cham down to Neak Luong, 12 longitudinal discharge measurements have been conducted since July 18, 2002. A part of the results is illustrated in Fig. IV-1-15.

This figure implies the following hydrological facts:

- The flood discharges of 45,100 m^3/s and 44,800 m^3/s on August 29 and on September 26 respectively were the observation data nearest to the peak of the 2002 flood at Kompong Cham. The large discharge of some 45,000 m^3/s was regulated through overland flooding and outflow into the flood paths. Some 25% of the discharge was reduced on the way down to Chrui Changvar.

- Fig. IV-1-16 depicts the relationship between the discharges at Kompong Cham and Chrui Changvar. The flooding might start at Kompong Cham when discharge is about 25,000 m^3/s (Gauge height: 11 m in the rising stage). Beyond the discharge of 35,000 m^3/s (Gauge height: 13 m in the rising stage), extensive flooding might occur.

- In addition, the flood flow below 25,000 m^3/s can be conveyed smoothly down to Chrui Changvar without flooding.

- Flow divergence conditions down to the Mekong at Chak Tomuk junction dominantly depend on the absorbing capacity of the Great Lake.

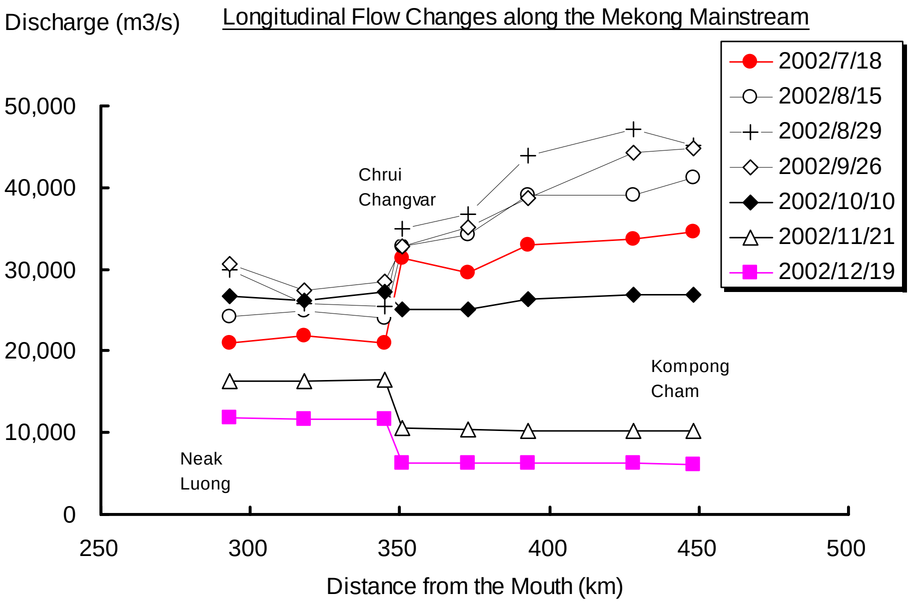


Fig. IV-1-15 Longitudinal Flow Changes along the Mekong Mainstream

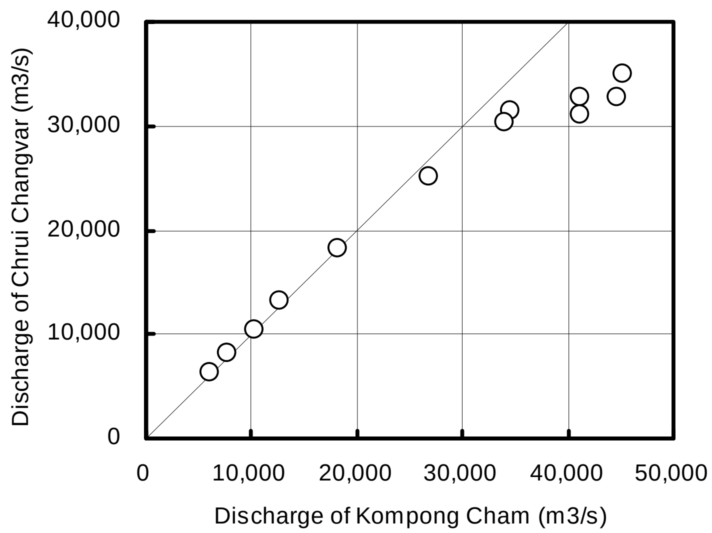


Fig. IV-1-16 Relationship between Flood Discharges of Kompong Cham and Chrui Changvar

The above flood reduction rate is much bigger than the estimation of the UNESCO Project, as mentioned in Subsection 1.4.1. Such reduction rate should be observed directly by longitudinal discharge measurements, because accuracy of the rate in this survey may be higher than the one by the UNESCO Project.

Tonle Sap

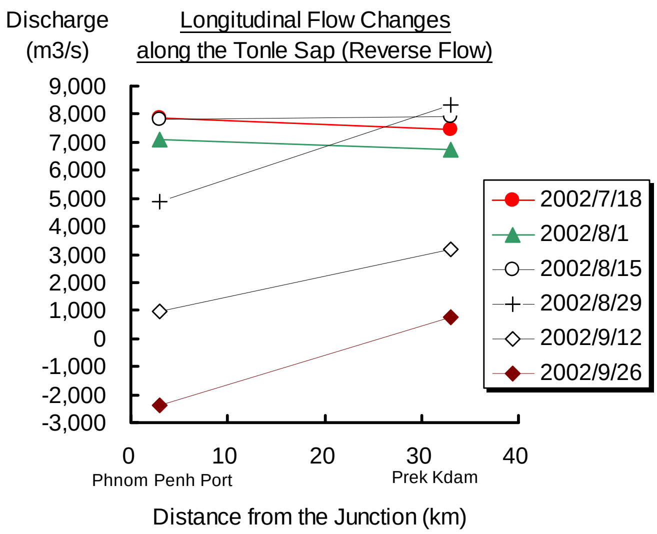
Flow balance along the Tonle Sap might be complicated since flow direction drastically changes during the flood season. The results of longitudinal measurements are illustrated in Fig. IV-1-17. In due consideration of the flooding process along the Mekong mainstream, the flow balance between Phnom Penh Port and Prek Kdam can be easily understood following the temporal changes of the balance.

- In the initial stages of the floods from July to the middle of August, extensive flooding did not occur along the Mekong mainstream. Furthermore, some parts of the reverse flow diverged into canals to fill the back swamps (Boeng) with floodwater.

- From the middle of August to the end of September, extensive flooding occurred along the Mekong mainstream. Some part of the floodwaters over the right bank of the Mekong flowed down through the bypass channels connecting with the Tonle Sap. The remaining part was discharged directly into the swelling Great Lake. Thus the reverse flow increased starting at Chak Tomuk junction (Phnom Penh Port) up to Prek Kdam, receiving the floodwaters of the Mekong.

- Once the Great Lake was filled with floodwater, the Tonle Sap changed its flow direction. The floodplains, however, still contained the floodwater, and discharged it into the Tonle Sap in October. Thus the normal flow starting at Prek Kdam increased up to Phnom Penh Port, receiving the water detained in the floodplains.

- After the water emptied in the floodplains, the normal flow was almost balanced between Prek Kdam and Phnom Penh Port.



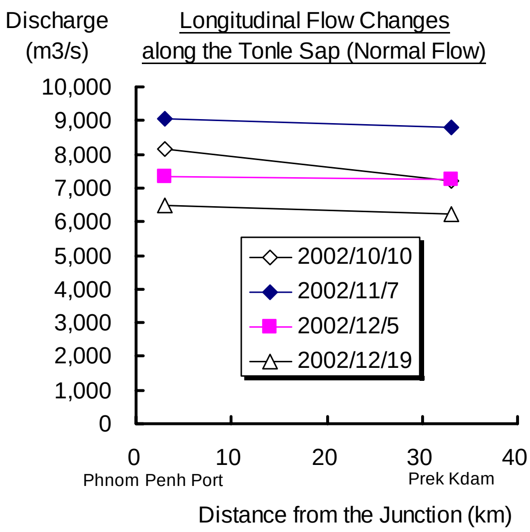


Fig. IV-1-17 Longitudinal Flow Changes along the Tonle Sap

Bassac River

The flow balance along the Bassac River is relatively simple compared with the other major watercourses and floodplains. There are numerous colmatage canals on both sides along the river course. For instance, such canals aggregate to 254 in Kandal Province. Colmatage means impoundment of silt-laden water to build up a low-lying area. Thus the primary objective of the canals is to divert the floodwater into the back swamp.

Fig. IV-1-18 illustrates the results of discharge measurements. As the flood discharge increases, the rate of discharge reduction also increases. When the peak discharge of 6,100 m^3/s occurred at Monivong Bridge in September 26, 2100 m^3/s of flow was absorbed by the floodplains through the canals in the stretch down to Koh Khel. Absorbed flow was equivalent to one-third of the peak discharge at Monivong Bridge. This rate was also much bigger than the one measured by the UNESCO Project.

Furthermore, diverted floodwaters did not return in this stretch even through the same canals according to the figure. The floodwaters diverted may have flown down the floodplains and discharged through the far downstream tributaries or canals.

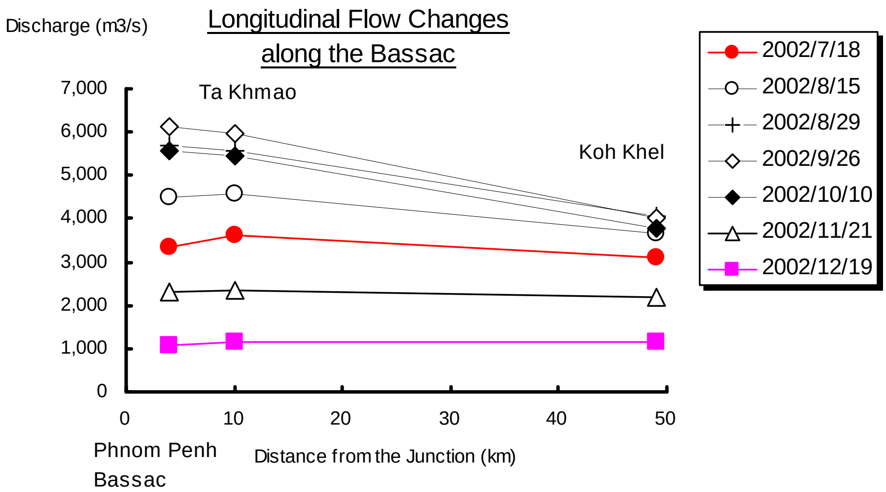


Fig. IV-1-18 Longitudinal Flow Changes along the Bassac River

1.4.3 Hydrological Functions of the Cambodian Floodplains

Since the flooding conditions have been examined in the preceding section, the hydrological functions of the Cambodian floodplains will be described as a summary.

Flooding Conditions and Effects in the Cambodian Floodplains

By comparing the mainstream flow at Kompong Cham and the Tonle Sap flow, the flooding conditions in the Cambodian floodplains could be described as follows:

(1) At some time near the onset of the rising limb of the Mekong mainstream flow, the Tonle Sap changes its flow direction from normal to reverse during which stream water flows towards the Great Lake.

(2) When the water level at Kompong Cham becomes higher than 11 m in gauge height, flooding will start in the floodplains and reverse flow of the Tonle Sap starts to increase at the same time. At this moment, the discharge at Kompong Cham reaches 25,000 m^3/s.

(3) Further, the water level increases in the flood season. When it exceeds 12 m in gauge height at Kompong Cham, intensive flooding occurs over the floodplains. At this moment, the discharge reaches 30,000 m^3/s.

(4) Flood peak on the Tonle Sap coincides with the peak on the mainstream.

(5) At some time after flood peak, flow-direction of the Tonle Sap changes from reverse to normal towards the downstream.

(6) When water level at Kompong Cham becomes lower than 11 m in gauge height, flooding will subside and floodwaters can be conveyed smoothly in the Mekong mainstream channel. At this moment, the discharge at Kompong Cham decreases to 23,000 m^3/s.

These phenomena are illustrated in the following figure, using the hydrograph of the 2002 wet season.

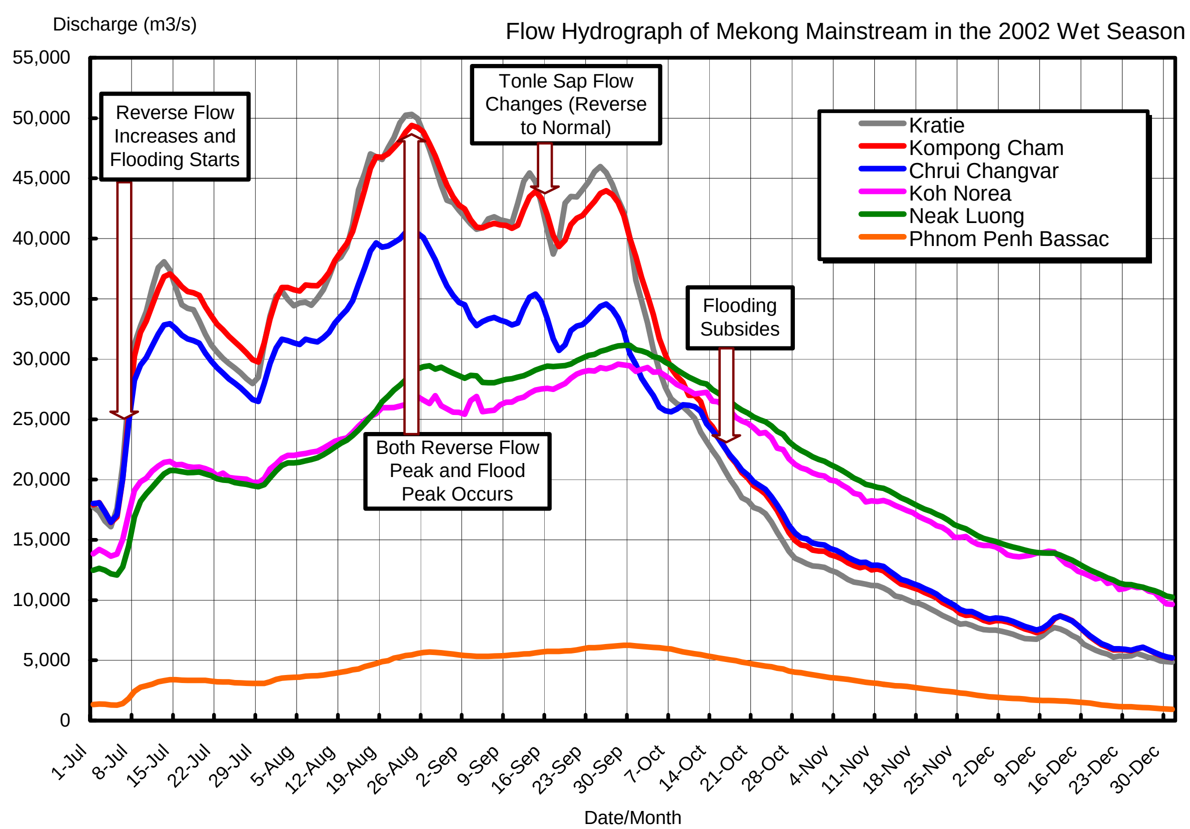


Fig. IV-1-19 Flooding Situations in the Cambodian Floodplains

The following three elements could be categorized from hydrological viewpoints of the floodplain functions including river channels:

(1) Flow conveyance in the mainstream;

(2) Flow divergence at the Chak Tomuk junction; and

(3) Over-bank flooding and overland flow conveyance in the floodplain.

Flood balance between Kompong Cham and Phnom Penh has been computed utilizing a series of the work results, such as flood hydrographs at major stations, water balance in the floodplains, and hydrodynamic simulation outputs. Fig. IV-1-20 summarizes the flood balance in the 2002 wet season.

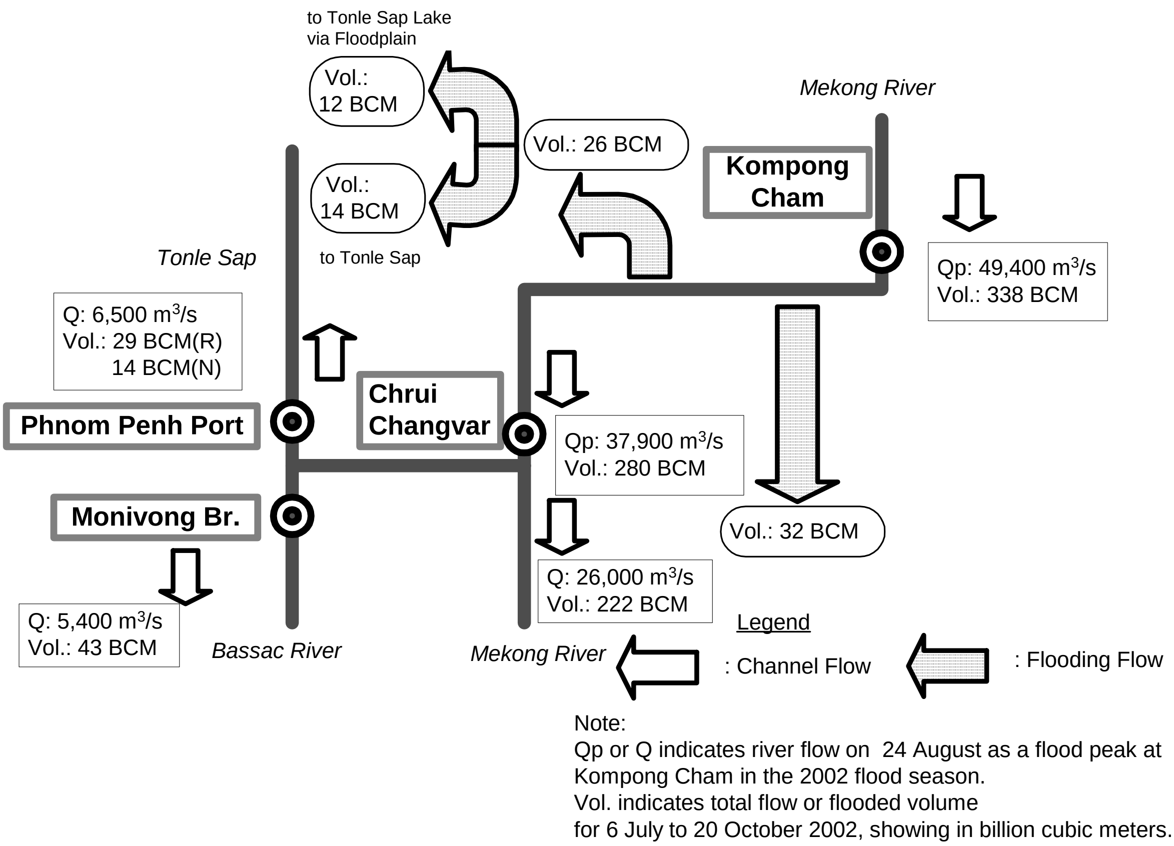


Fig. IV-1-20 Flood Balance between Kompong Cham and Phnom Penh in the 2002 Wet Season

From the above figure, the flood mitigation elements were estimated as follows:

(1) Flow conveyance: Flood flow of 37,900 m^3/s conveyed in the channel between Kompong Cham and Phnom Penh even though accompanied by over-bank flooding.

(2) Flood divergence: Flood flow of 11,900 m^3/s (= 37,900 - 26,000) into two channels, 30% of flow reduction at the Chak Tomuk junction.

(3) Over-bank flooding: Flood flow reduction of 11,500 m^3/s (= 49,400 – 37,900), equivalent to 23% reduction.

Under the above hydrological mechanism, the area downstream of Kompong Cham, in particular, the Capital City of Phnom Penh, is protected by the natural flood mitigation functions; namely, the flood peak reduction by over-bank flooding in the floodplains and the flood risk dispersing through flood flow divergence into three channels.

In addition, flood flow conveyance to the Great Lake is as well a crucial natural function in terms of conservation of the environment of Great Lake. An almost equivalent volume of overbanking flooding water compared with the Tonle Sap reverse flow occurs in the same period. Therefore, these natural functions should be conserved for the protection of human lives and assets in the cities and towns against floods, as well as protection of the natural environment and resources of the Great Lake and floodplains against unregulated development. These functions are indispensable for the sustainable development in Cambodia.

Tonle Sap Reverse Flow

The 1995 Mekong Agreement stipulates "Maintenance of Flows on the Mainstream" in Article 6. There are three types of flows to be maintained in accordance with annual hydrological cycles. They are: (1) the acceptable minimum monthly natural flow in the dry season;, (2) the acceptable natural reverse flow of the Tonle Sap during the wet season; and (3) some daily peak flows during the flood season. As presented in Fig. IV-1-20, the flooding functions of the floodplains in particular, also play an important role towards conservation of the Great Lake as a natural retarding reservoir.

The following are descriptions on storage of the Great Lake and reverse flow of the Tonle Sap in the 1995 Agreement:

Chapter II. Definition of Terms:

Acceptable natural reverse flow: *The wet season flow level in the Mekong River at Kratie that allows the reverse flow of the Tonle Sap to an agreed upon optimum level of the Great Lake.*

Article 6. Maintenance of Flows on the Mainstream:

B. To enable the acceptable natural reverse flow of the Tonle Sap to take place during the wet season; and
----

For the establishment of an acceptable natural reverse flow, it is indispensable to clarify the kind of hydrological factors that are closely related to the annual storage of the Great Lake. After this clarification, the optimum level of the Great Lake shall be discussed and agreed upon among the various stakeholders. Thus the task of hydrological study was to clarify the former issue.

To make the approach easier, the flow data of Kompong Cham were used instead of the data of Kratie, because the WUP-JICA Team continued to measure the discharge at Kompong Cham for more than one year from July 2002 to October 2003. Once the hydrological relation between the Kompong Cham flow and the Great Lake storage was developed, conversion work from Kompong Cham flow to Kratie flow had been easier because the rating curve at Kratie was also developed as presented in Part II of this report.

(1) Development of Relation between Flow at Kompong Cham and Great Lake Storage

As described in the preceding discussion, overland flooding gives a significant effect to the Great Lake storage. Furthermore, reverse flow of the Tonle Sap increases at the same time as the occurrence of overland flooding. Thus the threshold discharge of overland flooding at Kompong Cham might be an important factor to develop the relation. Further the storage of Great Lake must be closely related to the flood duration above certain levels of flow. The flood duration can be represented by the flood volume estimation above the threshold discharge.

From such analogical thinking, the flood volumes above the flow rate of 25,000 m^3/s as a threshold discharge at Kompong Cham were computed for the recent floods. Herein, the flow rate of 25,000 m^3/s is the discharge to trigger the start of flooding at Kompong Cham as mentioned in the preceding paragraphs. Fig. IV-1-21 illustrates the recent flood hydrographs and the threshold discharge. From the figure, differences of the flood volume in each year can be easily recognized.

Flood volumes at Kompong Cham and maximum storages of the Great Lake have been estimated for each year. The storage was estimated using the maximum water level at Kompong Luong Station and the elevation-storage relation curve developed by the WUP-JICA Team. The results are given in Table IV-1-4.

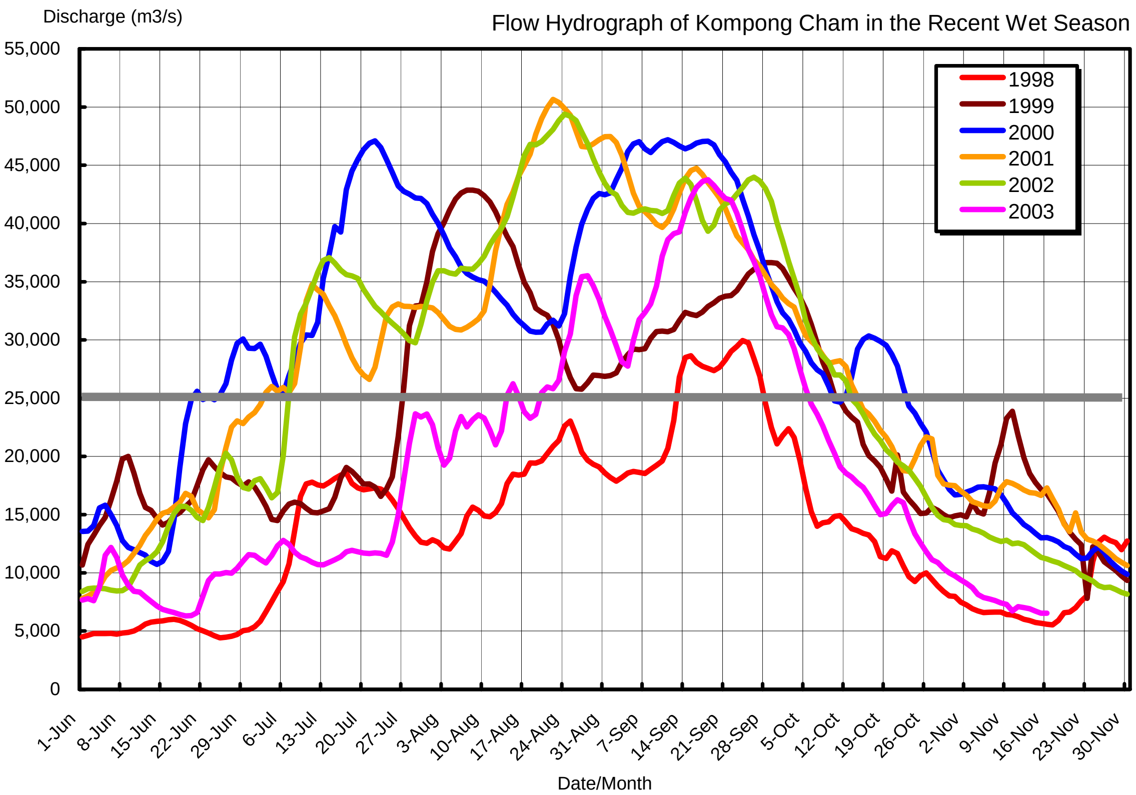


Fig. IV-1-21 Flood Hydrographs at Kompong Cham in Recent Years and Threshold Discharge of 25,000 m^3/s

Table IV-1-4 Estimated Flood Volume and Great Lake Storage

Year	Kg. Cham Flood Volume (BCM)	Great Lake	
		Maximum Water Level at Kg. Luong (MSL m)	Storage Volume (BCM)
1998	4.233	6.86	34.242
1999	54.342	8.97	57.050
2000	119.143	10.36	75.155
2001	103.640	9.89	68.767
2002	113.708	10.10	71.556
2003	38.209	8.26	48.837

Based on the above estimated figures, the regression analysis was made between flood volume and lake storage. The result is depicted in Fig. IV-1-22. The figure shows a high correlation between the two parameters.

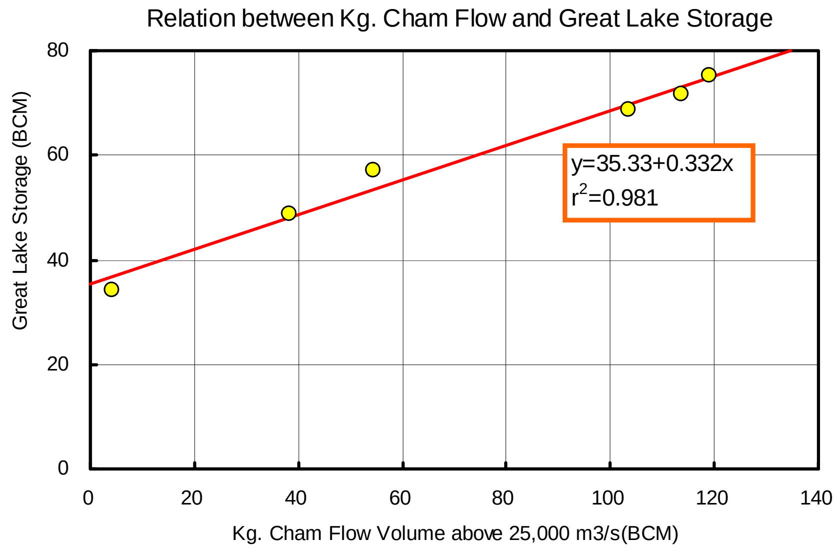


Fig. IV-1-22 Relation between Kg. Cham Flood Volume and Great Lake Storage

(2) Recommendation for Rule Formulation

Flood volume and lake storage shows a high correlation. The stakeholders should determine the necessary lake storage to keep a good balance between the conservation of natural resources such as fishery and other aquatic lives and the flood mitigation efforts to protect assets and human lives. The "optimum level of the Great Lake" as stipulated in the 1995 Mekong Agreement should be placed on some midpoint between the lowest of the 1998 event and the highest of the 2000 event. Since fish catch suddenly and sharply dropped in the 1998 drought event, the optimum level should be higher than the level in 1998. However, since the 2000 flood brought serious damage to Cambodia, the optimum level be lower than the level in 2000.

2. WATER USE IN THE LOWER MEKONG BASIN

2.1 Introduction

There are many water resources development projects in the Mekong River Basin. Water of the Mekong River has been utilized for various sectors such as irrigation and hydropower generation, as well as for domestic and industrial purposes. Such water uses had influenced more or less the low flow (dry season) regimes on the Mekong mainstream. It is evident that large-scale consumptive water extraction from rivers in the dry season had made impacts on the low flow regimes in the downstream as the dry season flows decrease. On the other hand, low flows had increased due to water released by the operation of seasonal-regulating reservoirs. Thus river flow regimes have historically changed due to the enhanced water usage and development activities in the basin.

This chapter presents the current water use condition in the Lower Mekong Basin including the hydropower development in China based on the results of data collection and compilation for profound understanding of water use in the region.

2.2 Existing Water Resources Facilities in the Mekong River Basin

2.2.1 Existing Large Reservoirs

Table IV-2-1 presents the salient features of the existing large-scale seasonal reservoirs in the entire Mekong River Basin. It is highly likely from the hydrological viewpoints that historical operations of large-scale reservoirs have influenced the flow regimes in the downstream, reducing the high flows in the wet season and increasing the low flows in the dry season.

The total effective storage of major reservoirs in each riparian country is summarized in Table IV-2-1 below.

Table IV-2-1 Salient Features of Existing Large Reservoirs

Country	Name of Dam	River/ Major Tributary	Purpose	Catchment Area (km^2)	Com-pletion Year	Dam Height (m)	Gross Storage (mil. m^3)	Effective Storage (mil. m^3)
China	Manwan	Mekong	HY (Run-of-river)	114,500	1993	132	920	258
	Dachaoshan	Mekong	HY (Run-of-river)	121,000	2000	118	890	240
Lao PDR	Nam Ngum	Nam Ngum	HY	8,460	1971-85	75	7,030	4,700
	Houay Ho	Se Kong	HY	193	1999	93	620	523
	Nam Leuk	Nam Leuk	HY (water diversion to the Nam Ngum dam)	274	2000	45	185	-
Thailand	Lam Dong Noi (Sirindhorn)	Nam Mun	HY (36MW), IR (24,000 ha)	2,097	1968	42	1,966	1,191
	Lam Takong	Nam Mun	IR (22,000 ha)	1,430	1970	-	-	290
	Lam Phra Ploeng	Nam Mun	IR (10,097 ha)	807	1967	-	-	145
	Chulabhorn (Nam Phrom)	Nam Chi	HY (40MW), IR (9,600 ha)	545	1971	-	-	145
	Ubolratana (Nam Pong)	Nam Chi	HY (25MW), IR (40,700 ha)	14,000	1966	32	2,010	1,695
	Lam Pao	Nam Chi	IR (50,416 ha)	5,960	1971	-	-	1,260
	Huai Luang	Nam Luang	IR (12,800 ha)	666	1984	-	-	113
	Nam Oon	Nam Oon	IR (29,728 ha)	1,100	1973	-	-	475
	Huai Mong	Nam Mong	IR (8,640 ha)	1,307	1988	-	-	26
	Nam Pung	Nam Pung	HY (6.3MW), IR (32,000 ha)	297	1965	40	150	122
Vietnam	Ialy (Yali)	Se San	HY	7,455	2000-01	65	1,037	779

Note: HY: Hydropower, IR: Irrigation
Source: MRCS and other related reports

Table IV-2-2 Comparison of Total Storage Volume by Riparian Country

Country	No. of Reservoirs	Storage Volume (million m^3)
China (22%)	2	498
Myanmar (3%)	0	0
Lao PDR (25%)	3	5,408
Thailand (23%)	9	5,462
Cambodia (19%)	0	0
Vietnam (8%)	1	779
Total	15	12,147

Note: Figure in parentheses is the area in % of the total Mekong River Basin
Source: JICA Study Team

2.2.2 Overview of Water Resources Development in the Mekong Countries

China

In China, the Mekong River is known as the Lancang River, which flows mostly through Yunnan Province. The Lancang River drains a watershed area of 165,000 km^2, or 22% of the total area of the Mekong River Basin. Topographically, the Lancang watershed is quite steep. The northern part of the Lancang River Valley sets in parallel to the Gaoligonshan, Rushan and Yunling mountains and characterized by high mountains of 3,500 to 5,000 m and valleys of above 2,000 m. The southern part is characterized by medium and low mountains, and valleys below 1,000 m, with small population centers scattered along the mainstream and limited arable land.

Fig. IV-2-1 Hydropower Development Projects on the Mekong Mainstream in China

The hydropower potential of the Lancang River has been demonstrated in terms of an average elevation drop of 6.5 m per kilometer (average river gradient of 1/154). Two dams have already been completed on the Lancang mainstream provided with run-of-river type hydropower generation station as a series of cascade hydropower development. In total fourteen (14) hydropower schemes have been planned on the Lancang mainstream including two large reservoir-type projects. A series of cascade hydropower projects on the Lancang mainstream is illustrated below.

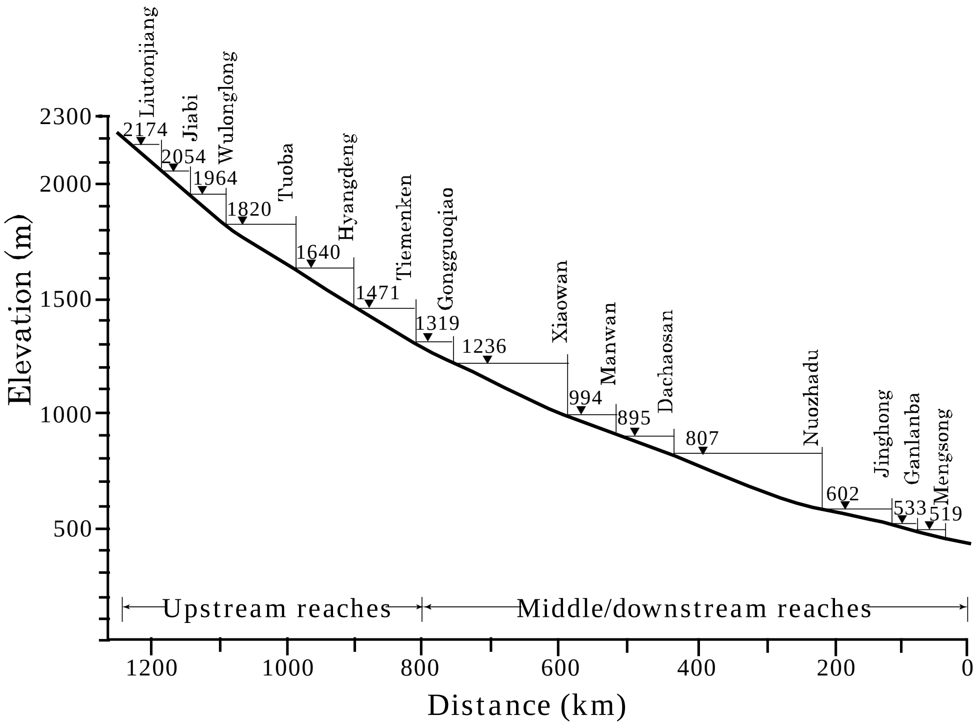


Fig. IV-2-2 Longitudinal Profile of Cascade Hydropower Development on the Mekong Mainstream in China

It has been reported that construction of the Xiaowan Hydropower Project had started as one of two large-scale reservoir-type projects (Xiaowan and Nuozhadu projects). Salient features of the cascade development are summarized in Table IV-2-3.

Large-scale reservoir projects will have significant impacts on the downstream flow regime. It is highly expected that the ongoing Xiaowan Dam with active storage capacity of 11,500 million m^3 for seasonal flow regulation will increase the dry-season flow by around 555 m^3/sec. The expected low-flow increase due to full development of cascade projects was reported to be around 1,230 m^3/s in total. Sustainable development of irrigation in the Lancang River Basin is unlikely because of the shortage of suitable land and the low fertility of soils. Over 86% of Yunan Province has a ground slope greater than 15%. Irrigation and dry-land agriculture areas are 3.5% and 17.4% of the entire Lancang basin, respectively. Table IV-2-4 indicates the predicted impacts of the cascade development on the Lancang River in Yunnan Province in China in terms of the contribution to dry-season flows at selected stations on the Mekong downstream.

The implications from Table IV-2-4 are:

(1) The ongoing large-scale reservoir development will have drastic impacts on the hydrological low-flow regime of the Lower Mekong;

(2) Large quantity of the dry-season base flow will be generated by large-scale regulation by reservoirs in China; at Chiang Saen the dry-season flow increases are more than 80% in March and April; and

(3) From the viewpoint of water resources availability in the Lower Mekong, this significant contribution in the low-flow regime would be crucially important.

Table IV-2-3 Hydropower Development in the Lancang River in China

No.	Name of Plant	Catchment Area (km^2)	Dam Height (m)	Gross Storage (mil. m^3)	Installed Capacity (MW)	Annual Output (GWh)	Average Inflow (m^3/s)	Low Flow Increase (m^3/s)	Status of Project
1	Liutonjiang	83,000	-	500	550	3,360	698	11	Desk Study
2	Jiabi	84,000	-	320	430	2,650	720	6	Desk Study
3	Wulonglong	85,500	-	980	800	4,890	754	22	Desk Study
4	Tuoba	88,000	-	5,150	1,640	7,630	809	219	Pre-F/S (?)
5	Hyangdeng	92,000	-	2,290	1,860	8,500	898	71	Pre-F/S (?)
6	Tiemenkan	93,400	-	2,150	1,780	8,270	929	62	Pre-F/S (?)
7	Gongguoqiao	97,300	130	510	900	4,670	985	8	F/S (?)
8	Xiaowan	113,300	290	15,130	4,200	18,540	1,220	555	Ongoing
9	Manwan	114,500	132	920	1,500	7,870	1,230	26	Completed in 1993
10	Dachaosan	121,000	118	880	1,350	7,090	1,340	15	Completed in 2000
11	Nuozhadu	144,700	260	24,670	5,000	22,670	1,750	212	Pre-F/S (?)
12	Jinghong	149,100	107	1,040	1,500	8,470	1,840	14	Pre-F/S (?)
13	Ganlanba	151,800	10	-	150	1,010	1,880	-	F/S (?)
14	Mengsong	160,000	28	-	600	3,740	2,020	-	F/S (?)
Total			-	32,340	22,260	109,360	-	1,230	

Source: Yunnan Provincial Science and Technology Commission and Yunnan Institute of Geography (1993), Investigation and Study of the Current Status of the Lancang River-Mekong River Basin in Yunnan, P.R.C.
Other related reports and international symposium papers.

Table IV-2-4 Percent Increase to Mean Monthly Flow on the Mekong Mainstream due to Cascade Power Development in China

Location	Dec	Jan	Feb	Mar	Apr	May
Chiang Saen	32	48	73	89	80	28
Luang Prabang	22	38	52	80	66	27
Vientiane	22	38	52	72	60	27
Mukdahan	17	27	37	43	40	17

Source: David Plinston and He Daming, Australian Mekong Research Network, Water Resources and Hydropower in the Lancang River Basin (quoted from the paper entitled China's Mekong Dam Plans, David Blake, February 2001)

Myanmar

The Mekong River forms part of the eastern border of Myanmar. A 350 km long reach of the Mekong River separates Myanmar from the north-western region of Lao PDR. The Mekong watershed drains an area of 28,000 km^2, or 3% of the total Mekong Basin. The major river in Myanmar is the Ayeyarwady River draining a catchment area of 193,000 km^2. Thus, the water resources of the Mekong catchment are quite few. Only a number of mini-scale hydropower plants have been constructed on the tributaries of the Mekong. Major projects are listed below.

Table IV-2-5 Existing Hydropower Projects in Myanmar

Project	Installed Capacity (kW)	Completed Year
Kyaington No.2	480	1991
Mainglor No.1	60	1992
Selu	20	1992
Kyaington No.1	3,000	1994

Source: MRC (1997), Mekong River Basin Diagnostic Study, Final Report

Lao PDR

Lao PDR is water rich and topographically favourable for hydropower generation. Thus Lao PDR has a large potential for hydropower development. A number of potential hydropower projects on the Mekong tributaries have been identified. However, only a few of its many possible projects have been developed. Currently, there are five hydropower schemes generating a total of 615 MW. The total generation capacity is 640.6 MW, including those of the small-scale hydropower plants with less than 10 MW of installed capacity and the diesel plants. Of the above, three projects are reservoir type development. They are the Nam Ngum and Nam Leuk hydropower development projects in the Nam Ngum River, and the Houay Ho project in the Se Kong River. The total capacity of effective storage amounts to 5,200 million m^3. These projects on the tributaries involve seasonal storage that will influence the flow regime in the downstream reaches of the Mekong mainstream as improved regulations of dry-season flows. It is readily apparent that the hydropower potential of Lao PDR exceeds its own electric demands. Prospects for future hydropower development depend on external demands from riparian countries such as Thailand and possibly Vietnam. Hydropower developments are likely to become one of the mainstays of the future economic growth of Lao PDR. The Nam Theun-2 Project of 1,080 MW will commence soon. This project is a large reservoir type development (effective storage of 2,607 million m^3) involving the water diversion from the Nam Theun River to a power station in the upper reaches of the Se Bang Fai River. The table below shows the annual power generation and supply balance from 1990.

Table IV-2-6 Power Generation and Supply Balance in Lao PDR

Year	Capacity (MW)	Annual Output (GWh)	Power Supply (GWh)			
			Domestic	Export	Import	Net Export
1990	163.56	833	165	595	28	567
1991	209.21	834	221	563	35	528
1992	209.90	752	253	460	41	419
1993	211.75	920	265	596	48	548
1994	217.39	1,199	279	829	57	772
1995	218.25	1,085	338	676	77	599
1996	218.60	1,248	380	792	88	704
1997	221.80	1,219	434	710	102	608
1998	415.00	948	513	405	142	263
1999	580.60	1,169	566	598	173	425
2000	640.60	1,579	640	863	163	700

Source: Electricite du Laos (EDL)

At present there are twenty-three IPP projects on tributaries of the Mekong. The table below shows the present status of IPP schemes.

Table IV-2-7 Present Status of IPP Schemes in Lao PDR, as of End 2001

No.	Project	Capacity (MW)	Sponsor	Agreement Type	Signing
1	Theun-Hinboun	210	THPC	PPA	Jun. 1996
2	Houay Ho	150	Daewoo	PPA	Jun. 1997
3	Hongsa Lignite	720	Thai-Lao Lignite	CA	Jun. 1994
4	Nam Theun 2	980	NTEC	PPA (provisional)	Feb. 2002
5	Nam Ngum 2	615	Shlapak	CA	Mar. 1998
6	Nam Ngum 3	440	GMS Power	PDA	Nov . 1997
7	Xe Pian-Xe Namnoy	390	Dong Ah	CA	Aug. 1994
8	Xe Kaman 1	468	ALP Mgt	CA	Nov. 1997
9	Southern Laol Trans.	-	ALP Mgt	CA	Nov. 1997
10	Nam Theun 3	237	Heard Energy	PDA	Aug. 1994
11	Nam Mo	105	Mahawongse	PDA	Nov. 1999
12	Nam Tha 1	263	SPS	MOU	Oct. 1995
13	Nam Theun 1	540	SUSCO	MOU	Mar. 1994
14	Nam Lik	100	Hainana STT	MOU	Feb. 1994
15	Nam Ngum 5	90	Melkyma	MOU	Sep. 1996
16	Nam Ou	600	Pacific Rim	MOU	Nov. 1994
17	Xe Katam	100	Hydro Power	MOU	Oct. 1994
18	Nam Khan 2	126	Hydro Quebec	MOU	Jun. 1994
19	Nam Suang 2	190	VKS	MOU	Mar. 1995
20	Nam Niep 2+3	565	VKS	MOU	Mar. 1995
21	Xe Kong 5	250	Sondel	MOU	Apr. 2000
22	Phapheng (Thakho)	30	True Assess Ltd	MOU	
23	Nam Bak (Cha) 2B	120	Nisho Iwai	MOU	

Note; MOU: Memorandum of Understanding, PDA: Project Development Agreement, CA: Concession Agreement, PPA: Power Purchase Agreement

Source: Power Sector Strategy Study, Draft Final Report, February 2001

Thailand

In North-eastern Thailand, the Mekong River drains an area of 170,000 km^2, which amounts to about 22% of the Mekong River Basin and one-third of the total area of the country. The easterly flowing Nam Mun River and its major tributary, Nam Chi River (together known as the Nam Mun-Chi River drain the southern two-thirds of the Mekong River Basin (120,000 km^2). The remaining one-third of the Mekong River catchment (50,000 km^2) is drained by a series of northerly and easterly flowing tributaries. The Nam Mun-Chi River Basin consists of a shallow saucer-shaped plateau (part of the Korat Plateau of North-eastern Thailand), which has an average height of 100-200 m above sea level. Farmlands cover about 43% of the total area, of which paddy fields account for about two-thirds (27%). Forests cover only 21% of the total area. Most surface water development projects in this area are based on the three rivers. The figure below is the mean monthly discharge at Ubon (1961-1966 before intensive water resources development in the Nam Mun-Chi Basin), which is the growth centre in the basin and located in the downstream of the confluence of the Nam Mun and Chi rivers.

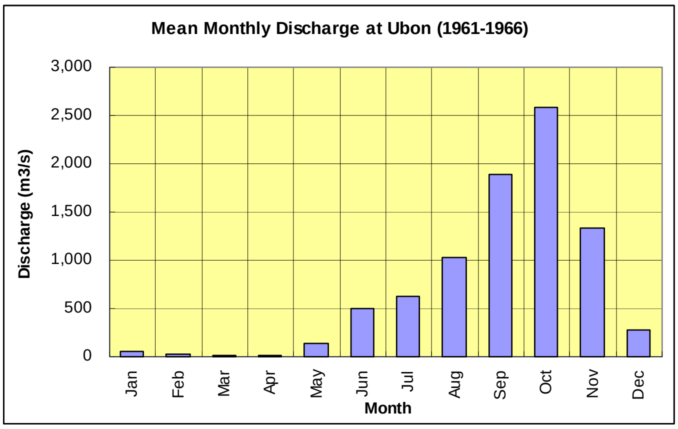


Fig. IV-2-3 Mean Monthly Discharge at Ubon Station

The Nam Mun-Chi River Basin is hydrologically characterized by relatively small annual rainfall (1,200-1,800 mm) and large difference of river flows between the wet and dry seasons. At Ubon, over 95% of the annual runoff occurs in the wet season. Only 3% occurs in the dry season (January to May). In this area the agriculture sector has been the predominant one and thus irrigation is essential for cultivated crops. In the dry season, irrigation virtually depends on the source of water.

Under the condition above, intensive water resources development mainly for irrigation development has been made from the mid-1960s to early 1970s. At present there are nine seasonal-regulating large reservoirs supplying the supplementary water for dry-season irrigation. Of the nine reservoirs, four projects are provided with hydropower generating facilities. The total capacity of effective storage is approximately 5,460 million m^3. The location map of major reservoirs is shown in Fig. IV-2-4.

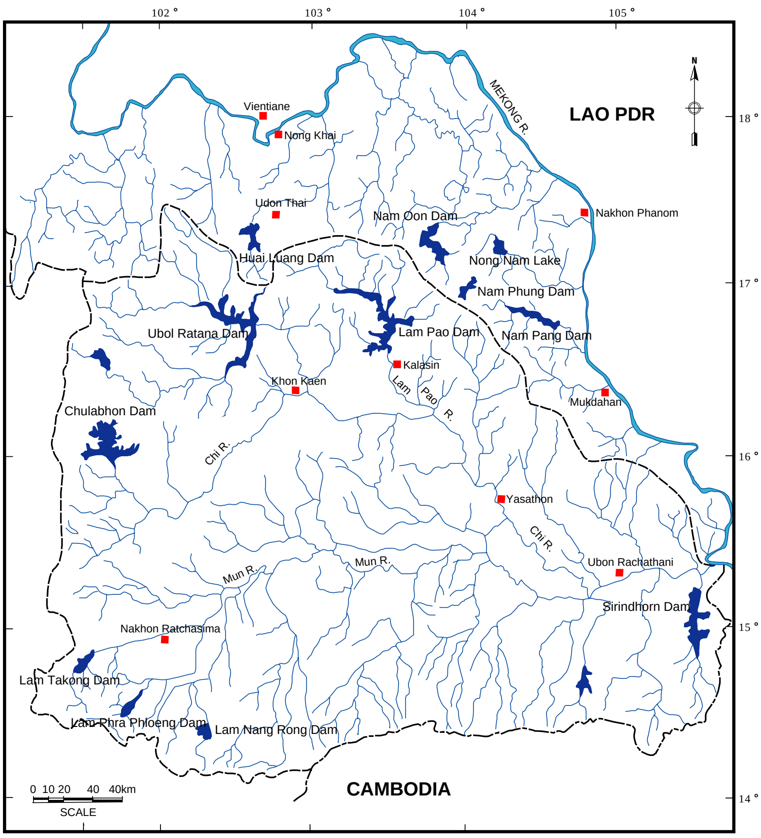


Fig. IV-2-4 Location Map of Major Reservoirs in Northeastern Thailand

Historic water resources development in terms of the accumulation of developed effective storage in reservoirs is shown in Fig. IV-2-5 below. The total irrigation service area covered by the reservoirs is around 240,000 ha. Besides the large reservoirs, there are numerous small and medium scale irrigation reservoirs (ponds) in the area.

In Thailand, oppositions against new hydropower development projects are increasing. The Pak Mun run-of-river type hydropower project constructed at almost the outlet of the Nam Mun-Chi River into the Mekong River has been interrupted (full gate opening at the intake weir) due to triggered local protests. It appears that Thailand has almost utilised the obvious hydropower potential of the major Mekong tributaries. Further medium to large-scale developments on the tributaries are unlikely.

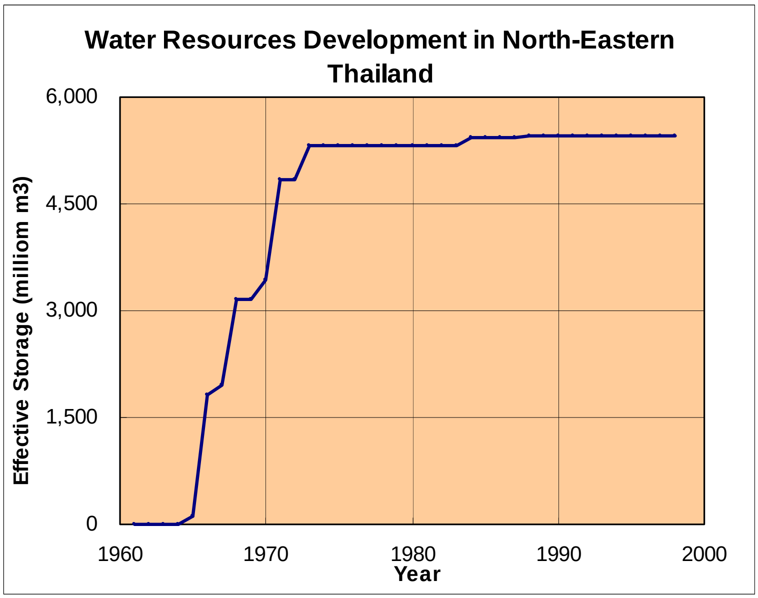


Fig. IV-2-5 Historical Water Resources Development in Northeastern Thailand

Cambodia

Cambodia is predominantly a low-lying country that occupies the central plains of the Mekong Basin. The Mekong River drains a catchment area of 155,000 km^2 in Cambodia, which amounts to about 19% of the whole Mekong Basin and about 90% of the total area of the country. The Tonle Sap is a major tributary of the Mekong in Cambodia. At Prek Kdam located on the Tonle Sap some 30 km upstream from its confluence with the Mekong, the Tonle Sap has a drainage area of 84,000 km^2, or nearly 54% of the total Mekong catchment in Cambodia. The principal feature of the Tonle Sap catchment is the Great Lake, which covers an area of 13,750 km^2 and is the largest freshwater lake in Southeast Asia. The lake provides vital inland migrating fisheries to Cambodia and mitigates significantly downstream into the Mekong Delta in Vietnam during floods. The total natural storage capacity of the Great Lake is estimated to be some 150 billion m^3. During the flood season, the water surface of the lake expands from 250,000-300,000 ha. In the dry season it is 1.0-1.4 million ha.

In Cambodia there are no existing reservoirs at present. The construction of Prek Thnot Multipurpose Dam has been suspended in 1973 due to the political disturbance in the country as well as the financial situation. There was a development plan of a series of run-of-river type hydropower schemes on the Mekong mainstream at Don Sahong, Stung Treng and Sambor. Cambodia is highly dependent on a migrating fishery for its annual protein. Construction of barrages on the mainstream has significant adverse effects on the existing fishery. In this respect, the possibility of implementing hydropower development on the mainstream might be very low.

Vietnam

There are two distinct regions in the Vietnam part of the Mekong River Basin: the Mekong Delta (39,000 km^2) and the Highland of Central Region (48,500 km^2). The Highland of Central Region is a part of the upstream watersheds of the Se San (14,800 km^2 in the territory of Vietnam) and Sre Pok (18,200 km^2) rivers. The Mekong Delta includes the Mekong and Bassac rivers and several branches.

According to the 1987 Indicative Plan, the upper part of the Highland has the highest potential for hydropower generation with its relief. On the other hand, the lower part has areas suitable for irrigation development. The Ialy (Yali) reservoir-type hydropower development project was completed in the Se San River in 2000. The Yali Reservoir is the first seasonal regulation reservoir in the Mekong watershed in Vietnam. The effective storage capacity is reportedly around 779 million m^3. Although the operation procedure of Yali Reservoir is not known at the moment, it is highly expected that the low flow regime of the Se San River would be influenced due to the hydropower generating operation. The Mekong Delta is the richest agricultural zone in Vietnam where irrigation and drainage infrastructure for around 2.4 million hectares of rice and mixed crops has been intensely developed.

2.2.3 Existing Hydropower Plants

As of 2000, there were 13 hydropower plants with an installed capacity of above 10 MW in the whole Mekong River Basin. The salient features of the existing hydropower plants are presented in Table IV-2-8, and their locations are presented in Fig. IV-2-6.

Table IV-2-8 Salient Features of Existing Hydropower Plants

Country	Name of Plant	River	Type	Capacity (MW)	Completion Year	Annual Output (GWh)	Rated Head (m)	Plant Discharge (m^3/s)
China	Manwan	Mekong	RoR	1,500	1993	7,870	99	-
	Dachaoshan	Mekong	RoR	1,350	2000	5,931	80	-
Lao PDR	Nam Ngum	Nam Ngum	SS	150	1971-85	900	32	220
	Xeset	Xe Don	RoR	45	1991	180	157	-
	Theun Hinboun	Nam Theun, Nam Hinboun	RoR	210	1998	1,645	230	100
	Houay Ho	Se Kong	SS	150	1999	600	765	10.4
	Nam Leuk	Nam Leuk	SS	60	2000	184	-	-
Thailand	Sirindhorn	Nam Mun	SS	36	1968	115	30.3	-
	Chulabhorn	Nam Chi	SS	15	1971	62	85	-
	Ubolratana	Nam Chi	SS	25	1966	75	16.75	75
	Pak Mun	Nam Mun	RoR	136	1997	462	-	-
Vietnam	Dray Ling	Se Srepok	RoR	13	1995	70	-	-
	Ialy (Yali)	Se San	SS	720	2000-01	3,642	189	105

Note: SS: Seasonal storage, RoR: Run-of- river
Source: MRCS and other relating reports

Fig. IV-2-6 Location Map of Existing Hydropower Projects in the Mekong River Basin

Source: MRC, MRC Hydropower Development Strategy, 2001

2.2.4 Surface Water Extraction for Domestic Water Supply

Actual domestic water usage by riparian countries is summarized below from the available information and reports. As discussed below, actual water usage is negligibly small compared to the flow in the Mekong River.

<u>Lao PDR</u>

As of 1999, the available surface water extraction at major pumping stations for domestic water supply in Lao PDR is summarized below.

Table IV-2-9 Major River Intakes for Domestic Water Supply in Lao PDR (1999)

Name	River	Water Extraction Amount
Luang Prabang	Nam Khan	8,000 m^3/day
Kaolieo (Vientiane)	Mekong	20,000 m^3/day
Chinaimo (Vientiane)	Mekong	77,800 m^3/day
Thangone (Vientiane)	Nam Ngum	480 m^3/day
Savannakhet	Mekong	7,200 m^3/day
Salavan	Xe Done	1,530 m^3/day
Pakse	Mekong	17,280 m^3/day
Total		132,290 m^3/day (= 1.53 m^3/sec)

Source: JICA Expert Report in Lao PDR, 2000

Based on the water extraction capacities above, the annual water supply in Lao PDR was roughly estimated at 48.3 million m^3/year in 1999, 74% of which was in Vientiane. In Luang Prabang, Sabanakhet and Pakse, the water productions are of the order of 3-6 million m^3 annually.

Thailand

No figures are available on the recent domestic water usage in the north-eastern part of Thailand. According to ESCAP's Assessment of Water Resources and Water Demand by User Sectors in Thailand in 1991, the average annual volume of urban and rural water supply (1980-1989) in North-eastern Thailand was estimated at 92.3 million m^3, of which 77.3 million m^3 was for urban water supply and 15.0 million m^3 for rural water supply.

Cambodia

In Phnom Penh, there are three intakes on the Mekong, Tonle Sap and Bassac rivers for urban water supply, as listed below.

Table IV-2-10 Major River Intakes for Domestic Water Supply in Cambodia (2002)

Name	River	Water Extraction Amount
Chrui Changvar	Mekong	65,000 m^3/day
Phnom Penh Port	Tonle Sap	100,000 m^3/day
Chang Kamong	Bassac	20,000 m^3/day
Total		185,000 m^3/day (= 2.14 m^3/sec)

Source: Phnom Penh Water Works

Urban water usage is estimated to be around 68 million m^3 annually based on the water extraction amount in the table above. The water extraction capacity of 2.14 m^3/sec represents about 0.09% of the mean monthly dry-season flow of the Mekong at Phnom Penh (reportedly 2,500 m^3/sec in April when the flow becomes lowest in the dry season).

Vietnam

According to the Mekong Delta Master Plan in 1993, abstractions for urban and domestic water supply in the delta in 1990 were 52 million m^3, of which approximately 30% were from groundwater. All of the 33 million m^3 of rural domestic water supply and the 12 million m^3 of industrial water supply were supplied from groundwater. The total domestic water supply is less than 1% of the estimated agricultural water supply. Groundwater abstractions for urban and rural domestic water supply were projected to double by 2000. Total projected domestic demand for the delta in 2000 was estimated at 400 million m^3, and total industrial demand for 2000 was estimated at 230 million m^3. These figures are over six times of the 1990 supply figures.

Table IV-2-11 Water Abstractions for Domestic Water Supply in 1990

(Unit: m3/day)

Purpose	Surface water	Groundwater
Urban	101,000 (1.2)	41,000 (0.5)
Rural	0	90,000 (1.0)
Industrial	0	34,000 (0.4)
Total	101,000 (1.2)	165,000 (1.9)

Note: Figures in a parenthesis are in terms of m^3/s.
Source: Mekong Delta Master Plan, 1993

Table IV-2-12 Projected Domestic Water Demand in 2000 and 2015 for Entire Mekong Delta

(Unit: m^3/day)

Year	Domestic	Other	Total
2000	1,087,000 (12.6)	630,400 (7.3)	1,717,400 (19.9)
2015	2,238,700 (25.9)	1,202,000 (13.9)	3,441,200 (39.8)

Note: Base year for projection is 1990. Figures in a parenthesis are in terms of m^3/s.
Source: Mekong Delta Master Plan, 1993

2.2.5 Operation Records of Existing Flow-Regulating Facilities

At the writing of this document no historical operational records of the existing water-regulating facilities were available at MRCS with the exception of Nam Ngum Reservoir in Lao PDR. Records of these facilities are very important and useful for evaluating the historical water usage in the whole Lower Mekong Basin. Furthermore, they might be essentially required for calibration of the basin modelling when it appears that historical water usage has significant effects on the hydrologic flow regime of the Lower Mekong mainstream.

The historic operational records to date (physical performance of the water resources development projects) might be available at respective responsible agencies in member countries. Limited operational records are available in several past planning studies.

2.2.6 Seasonal Regulation Rate of Mekong Flow by Major Reservoirs

At present the total capacity of existing large-scale reservoirs in the entire Mekong River Basin amounts to approx. 12,147 million m^3. As mentioned earlier two existing large reservoirs in China would have no seasonal regulating capacity on the Mekong River water, because they are basically operated for run-of-river type of power generation. Thus it is suggested that the total capacity of seasonal regulation reservoirs should be around 11,649 million m^3.

The seasonal regulation rate of all of the existing major reservoirs is roughly estimated to be around 2.5% as follows:

- Average annual flow volume of the entire Mekong River = 475,000 million m^3
- Seasonal regulation rate = 11,649 / 475,000 x 100 = 2.5%

Note: Average annual flow volume data is from the Mekong River Basin Diagnostic Study, MRC, 1997.

2.3 Available Information on Irrigation Area in the Lower Mekong Basin

2.3.1 Overview of Land Use in the Lower Mekong Basin

With a total area of 795,000 km^2, the approximately 75 million inhabitants of the Mekong Basin (as of 1999) depend on the natural resources to sustain livelihood. The Lower Mekong Basin (LMB) covers Cambodia, Lao PDR, Thailand and Vietnam with an area of 606,000 km^2 accounting for 76% of the entire Mekong Basin as tabulated below.

Table IV-2-13 Drainage Area of Mekong River Basin

Country	Area (km^2)	Area (%)	Area in LMB (km^2)	Area in LMB (%)
China	165,000	21	-	-
Myanmar	24,000	3	-	-
Lao PDR	202,000	25	202,000	33
Thailand	184,000	23	184,000	30
Cambodia	155,000	20	155,000	26
Vietnam	65,000	8	65,000	11
Total	795,000	100	606,000	100

Source: MRC

The table below gives an overview of the estimated areas of land use in each riparian country within the Lower Mekong Basin as also illustrated in Fig. IV-2-7.

Table IV-2-14 Land Use in the Lower Mekong Basin in 1997

(Unit:%)

Land Cover	Lao PDR	Cambodia	Thailand	Vietnam Delta	Vietnam Highlands	Viet Nam Total
Forest	40	54	16	0	43	21
Woodland/ grassland	42	15	3	0	25	13
Agriculture	14	23	79	84	29	57
Wetlands/water	1	5	1	10	0	5
Others	2	0	0	4	0	2

Source: MRC Land Cover Dataset, 2001

The data is based on interpretations of remotely sensed Landsat TM imagery from 1997 and is a simplified version of a land cover map kept by the MRC. Extensive areas of agriculture (mainly rice cultivation) are dominant on the Korat Plateau, the floodplains in Cambodia, the Mekong Delta in Vietnam and around the Great Lake. More than one-third of the Lower Mekong Basin remained under forest cover in 1997. Much of this area is low-density deciduous forest in the north and east of the Cambodian plains. The main areas of tropical forest are in the more mountainous areas of Cambodia and southern and eastern Lao PDR. Northern Lao PDR is characterized by mixed forest with large areas of woodland, often associated with shifting cultivation.

In Vietnam there are significant differences of land use between the Mekong Delta and the Central Highland region. The delta consists of almost entirely agricultural land with the majority of this being developed to paddy cultivation. Thus there is no significant forest area in the delta. On the other hand, the Central Highlands is 68% covered by forest, woodlands and grasslands. The Korat Plateau, and the rest of the North-eastern region of Thailand, following rapid deforestation in the 1980s, is now almost 80% agricultural land. The soil is generally low in fertility and highly saline.

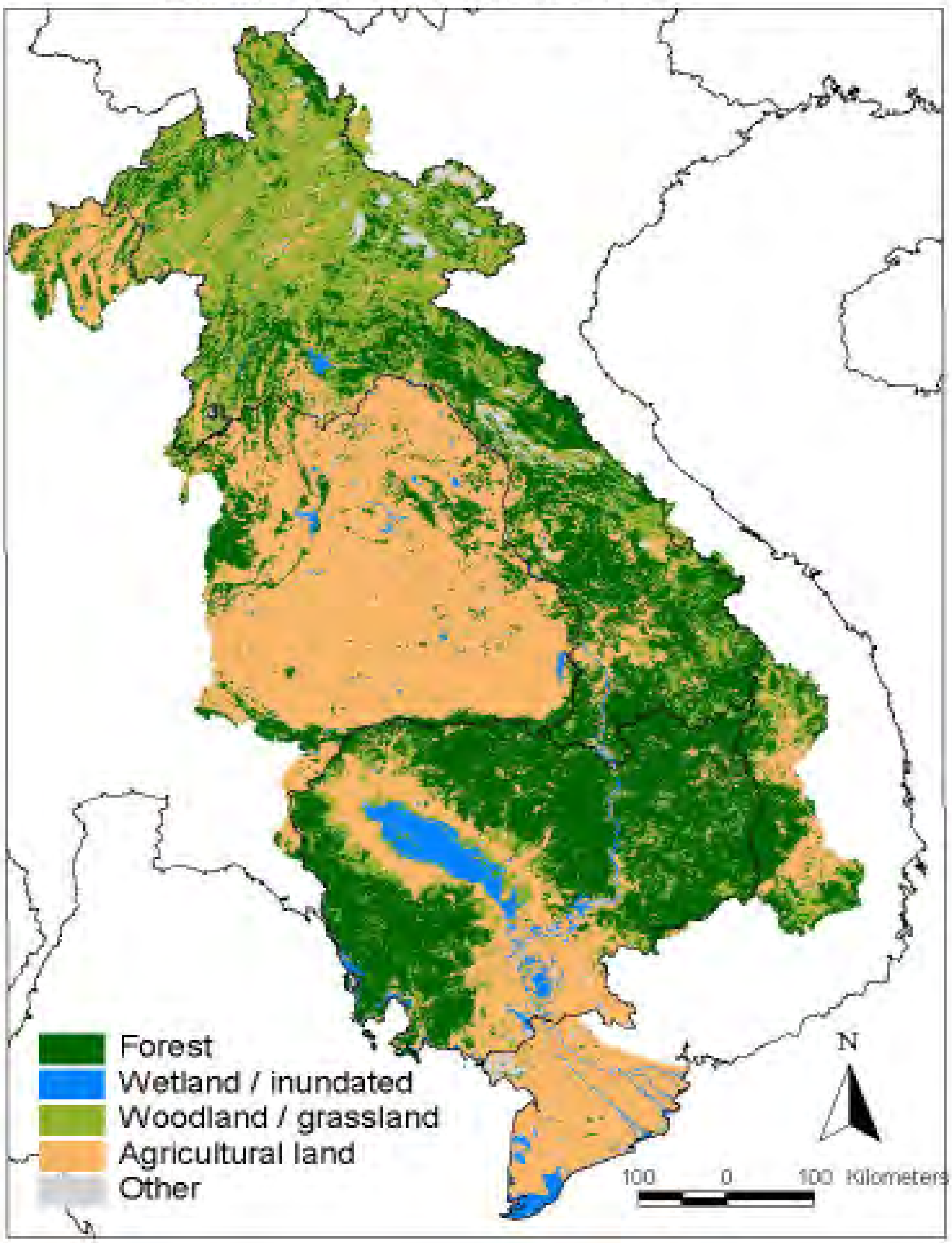


Fig. IV-2-7 Land Use in the Lower Mekong Basin (Source: MRC)

2.3.2 Overview of Irrigation Areas

Agriculture is a predominant economic sector in the Lower Mekong Basin. About 75% of the region's population are dependent on agriculture and fisheries. Agriculture, with its vital issue of food security, has always been considered as one of the key sectors in development strategies of the riparian countries. It is also an important source of foreign-currency for Thailand and Vietnam, while agricultural activities are the mainstays of the Cambodian and Lao PDR economies and major providers of employment. Table IV-2-15 and IV-2-16 show the contributions of the sector to GDP and national exports in the Lower Mekong basin area.

Table IV-2-15 Contributions of Agriculture and Forestry to GDP by Each Riparian Country

(Unit: %)

Sector	Cambodia		Lao PDR		Thailand		Vietnam	
	1995	1999	1990	1999	1993	1997	1990	1999
Crops	26.1	21.3	36.7	28.7	16.6	14.8	-	20.4
Livestock/Fisheries	13.4	15.2	20.7	18.5	4.3	3.5	-	2.3
Forestry	6.6	3.9	3.2	4.9	0	0	-	0.9
Total Share of GDP	46.1	40.4	60.6	52.1	20.9	18	38.7	23.6

Report Source: MRC, Basin Development Plan, Regional Sector Overview, Agriculture and Irrigation, November 2002
Source: Lao PDR Ministry of Agriculture and Forestry (2000), Thailand National Statistics Office (2000), Viet Nam General Statistical Office (1999), IMF (2002), IMF (2002), * includes entire country rather than only Mekong Basin Area.

Table IV-2-16 Contributions of Agriculture and Forestry to LMB Country Exports

(Unit: %)

Sector	Cambodia		Lao PDR		Thailand*		Vietnam	
	1995	1999	1995	1999	1993	2000	1995	1998
Share of Total Exports								
Agriculture	15	5	13	6	30	22	32	24
Forestry	69	16	39	29	0	0	3	2

Report Source: MRC, Basin Development Plan, Regional Sector Overview, Agriculture and Irrigation, November 2002
Source: Thailand National Statistics Office (1997, 2001), Viet Nam General Statistical Office (1999), IMF (2002), IMF (2002), * includes entire country rather than only Mekong Basin Area.

2.3.3 Land Resources Inventory for Agricultural Development Project

The Land Resources Inventory for Agricultural Development Project (LRIAD), funded by the Ministry of Agriculture, Forestry and Fisheries of Japan, was completed in June 2002. The main objective of LRIAD was to provide decision-makers and planners of the riparian governments with up-to-date data on land resources for sustainable agricultural development in the Lower Mekong Basin in coordination with MRC. Main outcomes of LRIAD are the irrigation, inundation and soil databases in the Lower Mekong Basin. The developed databases are of spatial GIS database with a good grounding.

The irrigation database consists of the following data sets for information:

(1) Irrigation projects: Each irrigation project has been digitised as a point that represents its location.

(2) Irrigation head works: Where the location of the project head works has been clearly defined, these have been digitised as a point.

(3) Irrigation area: Command area of irrigation scheme has been digitised as a polygon.

(4) Irrigation canals: For the larger schemes, irrigation canals have been defined and digitised.

(5) Reservoirs: Reservoirs for irrigation purpose have been digitised as a polygon.

(6) Irrigation data: Attribute tables giving information on the irrigation projects are included in DBF (data base files) format possibly to link with the spatial information files. These tables

provide key information on the project, including general description, project status, irrigated cropping data, investment information, government administration, hydrology and others.

The collected number of irrigation projects was 12,469, as summarized below.

Table IV-2-17 Summary of Irrigation Projects in Lower Mekong Basin under LRIAD

Country	Number of Scheme	Area of Wet Season Irrigation (ha)	Area of Dry Season Irrigation (ha)	Area of 3rd Season Irrigation (ha)	Irrigated Area (ha)
Lao PDR	2,532	224,232	151,940	0	224,232
Thailand	8,764	-	-	-	941,425
RID (medium/large)	441	330,056	72,140	0	330,056
RID (other)	291	-	-	-	-
RID (small)	5,497	-	-	-	-
DEDP	1,072	-	-	-	517,205
MOI	1,463	-	-	-	94,164
Cambodia	1,012	248,842	181,506	0	392,117
Vietnam	161	1,719,102	1,424,839	351,506	1,719,102
Mekong Delta	85	1,683,094	1,417,549	351,506	1,683,094
Highlands	76	36,008	7,290	-	36,008
Total	12,469	-	-	-	3,276,876

Note: Irrigation in Thailand is managed by three separate agencies; namely, RID (Royal Irrigation Department, Ministry of Agriculture and Cooperatives); DEDP (Department of Energy Development and Promotion, Ministry of Science, Technology and Environment); and MOI (Ministry of Interior).

Source: MRC (2002), Land Resources Inventory for Agriculture Development Project, Technical Report, Part II.

Thailand had no comprehensive wet or dry season cropping data; therefore, in the table above, the irrigable area has been taken as the common measure of the irrigated area. Where wet and dry season irrigated areas are the measures of area irrigated, the irrigable area has been taken as the largest of the wet or dry season area. Further, irrigation area data on other 291 schemes has been considered unreliable and were not included. As for 5,491 small schemes in Thailand, there is no data on the actual irrigation area.

The table below presents the summary of status of the irrigation database under LRIAD.

Table IV-2-18 Summary of Status of Irrigation Database under LRIAD

Category	Lower Mekong Basin	Cambodia	Lao PDR	Thailand	Vietnam
Irrigation Project	12,469	803	2,532	8,764	161
Irrigation Area	4,449	361	701	2,218	196
Irrigation Head Works	12,460	324	2,532	8,764	258
Irrigation Canals	3,420	208	115	1,968	1,129
Irrigation Reservoirs	992	No data	414	578	No data

Source: MRC (2002), Land Resources Inventory for Agriculture Development Project, Technical Report, Part II.

Assuming that irrigation projects with a service area of less than 100 ha are regarded as minor water users, the total number of projects and irrigation areas are summarized as follows:

Table IV-2-19 Summary of Projects and Irrigation Areas under LRIAD

Item	Lao PDR	Thailand	Cambodia	Vietnam	Total
Intake from Mainstream					
No. of Projects	101	143 1)	62	85 3)	
Whole Area (ha)	28,785	37,459 1)	32,190	1,683,094	1,781,528
Dry Season Area (ha)	23,085	No data	27,847	1,417,549	
Intake from Tributaries					
No. of Projects	602	1,283 2)	324	None	
Whole Area (ha)	136,543	886,939 2)	237,452	None	1,260,934
Dry Season Area (ha)	89,995	No data	110,619	None	
Total Intake					
No. of Projects	703	1,426	386	85 3)	
Whole Area (ha)	165,328	924,398	269,642	1,683,094	3,042,462
Dry Season Area (ha)	113,080	No data	138,466	1,417,549	

Note: 1): Data from the Study of Potential Development of Water Resources in Mae Khong River Basin, May 1994, Asian Institute of Technology.
2): JICA Study Team estimate (Total Intake – Intake from Mainstream).
3): Number of irrigation blocks that are further divided into many small projects.

Source: JICA, Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin, Interim Report (Vol. 2), Water Use Management and Monitoring, February 2003

Fig. IV-2-8 gives an example of the irrigation database maps.

Fig. IV-2-8 Irrigation Canals and Salinity Control Structures in Mekong Delta
(Note: Salinity control structure is shown as a point)

In the figure above, 334 primary and 795 secondary irrigation canals in the Mekong Delta have been digitised.

2.3.4 Surface Water Extraction by Pump Irrigation

In the Lower Mekong Basin, surface water extraction for pump irrigation is active mainly in Lao PDR and Thailand.

Lao PDR

Irrigation projects larger than 100 ha in the dry season have been selected from the MRC irrigation database. Number of projects, project sizes and irrigation areas by irrigation type are summarized below.

Table IV-2-20 Major Irrigation Projects in LMB in Lao PDR

Item	G	Pump Type				Total
		EP	DP	P	Total	
Nos. of Project	63	324	80	27	431	494
Project Size (ha)	100-2,300	100-2,300	100-450	100-1,500	-	-
Irrigation Area (ha)	22,239	65,276	10,693	5,256	81,225	103,464

Note: G: gravity, EP: electric fixed pump, D: diesel fixed pump, P: fixed pump (type: unknown)
Source: MRC (2002), Land Resources Inventory for Agriculture Development Project

As seen above, pump irrigation is a significant portion of the existing irrigation systems in Lao PDR. The pump irrigation area accounts for around 80% of the total irrigation area in the Lower Mekong Basin. Out of these, electric fixed pump is around 80%. In Lao PDR, there is a firm policy directed at the development and expansion of small to medium-scale irrigation in the tributary systems and, as the electricity transmission line network expands, there will no doubt be an associated and significant growth in electric pump river abstractions. This reflects the affordability and availability of electricity in the country.

Thailand

Pump irrigation is very active in the northeastern part of Thailand, where many pump stations have been erected along the Nam Mun-Chi River as well as the Mekong mainstream. However, limited information is available in past planning studies on pump irrigation in North-eastern Thailand. A majority of the pump irrigation schemes on the Mekong mainstream as of 1982 is summarized as follows:

Table IV-2-21 Major Pump Irrigation Schemes on the Mekong River in Northeastern Thailand (1982)

Province	No. of Schemes	Total Pump Capacity (m^3/s)
Nong Khai	55	15.5 (4)
Nakhong Phanom	29	1.8 (23)
Mukdahan	15	0.3 (14)
Ubon	1	N.A.
Total	100	17.6

Note: N.A. means not available
Source: Lower Mekong Basin Water Balance Study, Phase 2 Report, May 1984

In the above table, number in parenthesis reflects the number of schemes for which no data were available to compute the total pump capacity. Thus the total pump capacity on the Mekong mainstream in 1982 shows a figure smaller than the actual one.

Pump irrigation projects in Thailand have been constructed by the three responsible agencies; namely, the Royal Irrigation Department (RID), the Department of Energy Development and Promotion (DEDP), and the Ministry of Interior (MOI). The pump irrigation areas are normally within a 1 km distance from rivers. Historic increase of the number of irrigation pump stations implemented by

DEDP in the period 1974-1989 is shown in Fig. IV-2-9 (ESCAP, Assessment of Water Resources and Water Demand by User Sectors in Thailand, 1991). Further, the location map of pump station is given in Fig. IV-2-10.

According to the Study of Potential Development of Water Resources in the Mekong River Basin by AIT in 1994, DEDP pumping irrigation stations amount to 283 projects in the Nam Mun-Chi River Basin and 247 projects in the other Mekong tributaries as well as the Mekong mainstream.

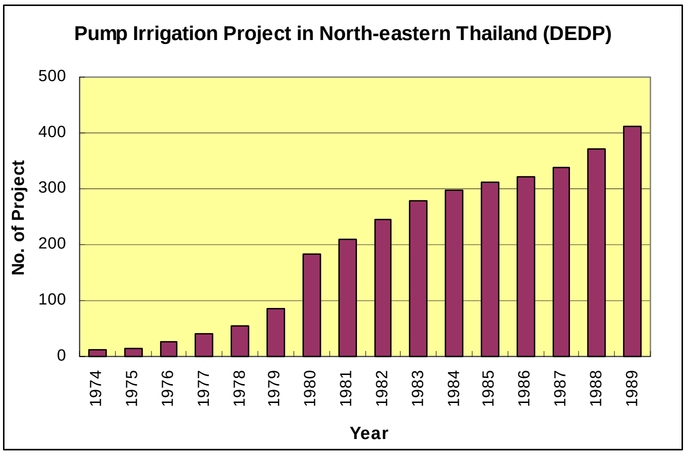


Fig. IV-2-9 Number of Irrigation Pump Stations in Northeastern Thailand

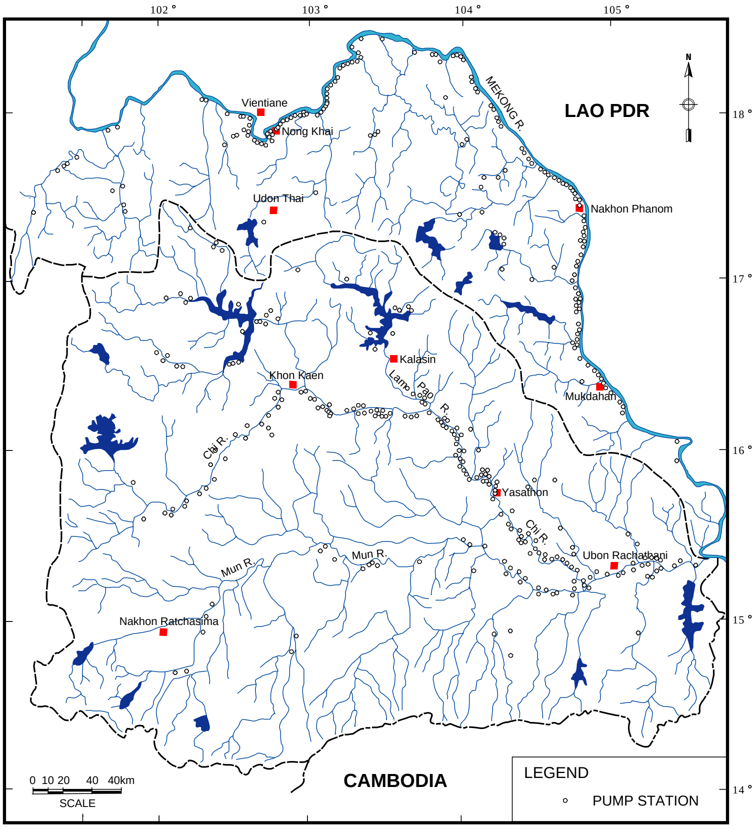


Fig. IV-2-10 Location Map of Pump Irrigation Projects by DEDP as of 1989

As shown in Fig. IV-2-10, pump irrigation is active mainly along the Mekong River, in the middle and downstream reaches of the Chi River, and in the downstream reaches of the Mun River.

Table IV-2-22 below gives as summary of irrigation projects consisting of RID large/medium-scale projects, all DEDP projects and all MOI projects extracted from the MRC irrigation database. All of these projects are larger than 100 ha in service area. RID small projects were excluded since their data were not available. The RID projects are irrigated by gravity, DEDP by mostly electric fixed pump, and MOI by gravity, fixed pump, mobile pump, traditional lift and their combinations. The irrigation projects of MOI are mostly small and their irrigation type is complicated.

Table IV-2-22 Major Pumped Irrigation Schemes in Northeastern Thailand

Item	RID	DEDP	MOI	Total
No. of Projects	157	950	319	1,426
Project Size (ha)	112–50,416	101–90,411	100–1,200	
Total Irrigation Area (ha)	327,783	513,178	83,437	924,398
Irrigation Type	G	Mostly Elec. P.	G, P, M, T, Mixed	

Note: G: gravity, P: fixed pump, M: mobile pump, T: traditional lift
Source: Lower Mekong Basin Water Balance Study, Phase 2 Report, May 1984

2.4 Current Water Use in the Lower Mekong Basin

2.4.1 Approach

The Basin Modelling and Knowledge Base Development Project (WUP-A) has been undertaken by the consultants under Component-A of the Water Utilization Program (WUP) of MRC. Important and expected outcomes of this project are the Decision Support System (DSF), which contains a knowledge base, the Basin Modelling Package and the Impact Assessment Tools. The Model shall not only accurately and reliably simulate the hydrology and hydraulics of the basin, but also water use, the important linkages and effects that changes or variations in water use flow and water level have on the environment including important water related functions. The current and future water use data including the irrigation water usage will be collected and stored in the database (Knowledge Base) to support the formulation of modelling as well as future use within the proposed DSF. Irrigation demands are simulated for all sub-catchment in the Lower Mekong Basin because of significant limitations of available data on irrigation water use and abstractions. Irrigation is already practiced in the Mekong Basin. Irrigated crop is almost exclusively rice. Herein, current irrigation water use is summarized through the review of available reports and information.

2.4.2 Current Water Use in Thailand

Surface water resources development projects in Thailand are classified and defined in the following categories:

(1) Large-scale/Multipurpose projects

(2) Medium-scale projects

(3) Small-scale projects

(4) Pump irrigation projects

(5) Trans-basin projects

The following project features are from the main report of the Study of Potential Development of Water Resources in the Mae Khong River Basin, prepared by the Asian Institute of Technology, Office of the National Economic and Social Development Board (NESDB), 1994.

(1) Large-Scale/Multipurpose Project

Agencies with primary responsibility for the implementation of large-scale water resources projects are the Royal Irrigation Department (RID), the Electricity Generating Authority of Thailand (EGAT) and the Department of Energy Development and Promotion (DEDP).

Among them, EGAT is responsible for large-scale power generation schemes including multipurpose projects that generate hydropower as well as provide irrigation, fisheries and flood control. RID constructs, operates and maintains all large-scale irrigation projects, but where the projects include hydropower, EGAT shares responsibility. While RID has responsibility for gravity schemes, those utilizing pumped abstractions from rivers are generally executed by DEDP. In addition, DEDP has responsibility for certain power generation projects, which have an installed capacity of less than 6 MW. Large-scale projects usually are defined as follows:

(a) Construction Cost: More than 200 million Baht

(b) Storage Volume: More than 100 million m^3

(c) Water Surface Area: More than 15 km^2

(d) Irrigation Area: More than 80,000 Rai (= 12,800 ha)

(e) Construction Period: More than 5 years

(2) Medium-Scale Project

A medium scale project is classified as that costing more than 4 million Baht and less than 200 million Baht. Its construction period is longer than one year but shorter than 5 years. The storage capacity is from 10 to 100 million m^3. Most of the medium scale projects are used for supplementary wet-season irrigation and extended dry-season cropping. Some of the projects are used for domestic supply and flood protection. Most of the medium scale projects are constructed, operated and managed by RID. In practice, most of the projects are initiated based more on social considerations, while the economic returns are considered a second priority. A survey of existing development indicates that various government agencies participate in this type of water resources development. They are RID, DEDP, EGAT, etc.

(3) Small-Scale Project

Significant distinction between small and medium-scale projects is that in the former, no compensation is paid for land occupied by the scheme. The project budget provides only for the water storage/diversion facility. No provision is made for distribution works. The operation and maintenance is the responsibility of the beneficiaries. The construction cost of a small-scale project is less than 4 million Baht and the construction period is less than one year.

(4) Pump Irrigation Project

Agencies with primary concern in pumping schemes are DEDP and RID. The DEDP schemes are permanent with electricity driven pumps and generally serving a formal irrigation layout. The RID schemes are diesel driven mobile pumps providing supplementary and compensation water supplies to informal irrigation schemes. In addition, there are some privately owned pump stations along the main river systems. The irrigation area by pump is approximately 80-480 ha.

(5) Trans-basin Project

Currently there are no trans-basin (inter-basin) or intra-basin diversion projects within the Mekong River Basin in Thailand. However, a number of trans-basin schemes have been so far considered. The table below provides the main feature of the identified schemes. Location map of projects is shown in Fig. IV-2-11.

Table IV-2-23 Principal Features of Trans-basin Projects in Thailand

No.	Project	Agency	Status	Pumping Capacity (m^3/s)	Irrigation Area (ha)	Diversion Length (km)	Lift (m)
1	Kok-Ing-Nan	RID	F/S (199?)	175	270,000	107	-
2	Kok-Ing-Yom-Nam	EGAT/ RID	Pre-F/S (1982)	-	130,000	105	
3	Mekong (at Pamong) -Chi-Mun	DEDP	Pre-F/S (1978)	100	70,000		
4	Mekong (at Nong Khai) -Chi-Mun		Desk Study	400	320,000	125	25
5	Mekong-Songkharam		Pre-F/S (1983)	100	70,000	6	50
6	Mekong-Udon Thani		Pre-F/S (1989)	83	68,000		
7	Mekong (at Mukdahan) -Yasothon		Pre-F/S (1978)	110	88,000	28	49
8	Mekong (Ban Bung Khieo)-Amnat Charoen	NESDB	Pre-F/S (1978)	270	143,000	23	91
9	Khong-Chi-Mun	DEDP	F/S (1993)	310	800,000		
Total					1,959,000		

Source: Office of the National Economic and social Development Board (1994), Study of Potential Development of Water Resources in The Mae Khong River Basin, prepared by Asian Institute of Technology

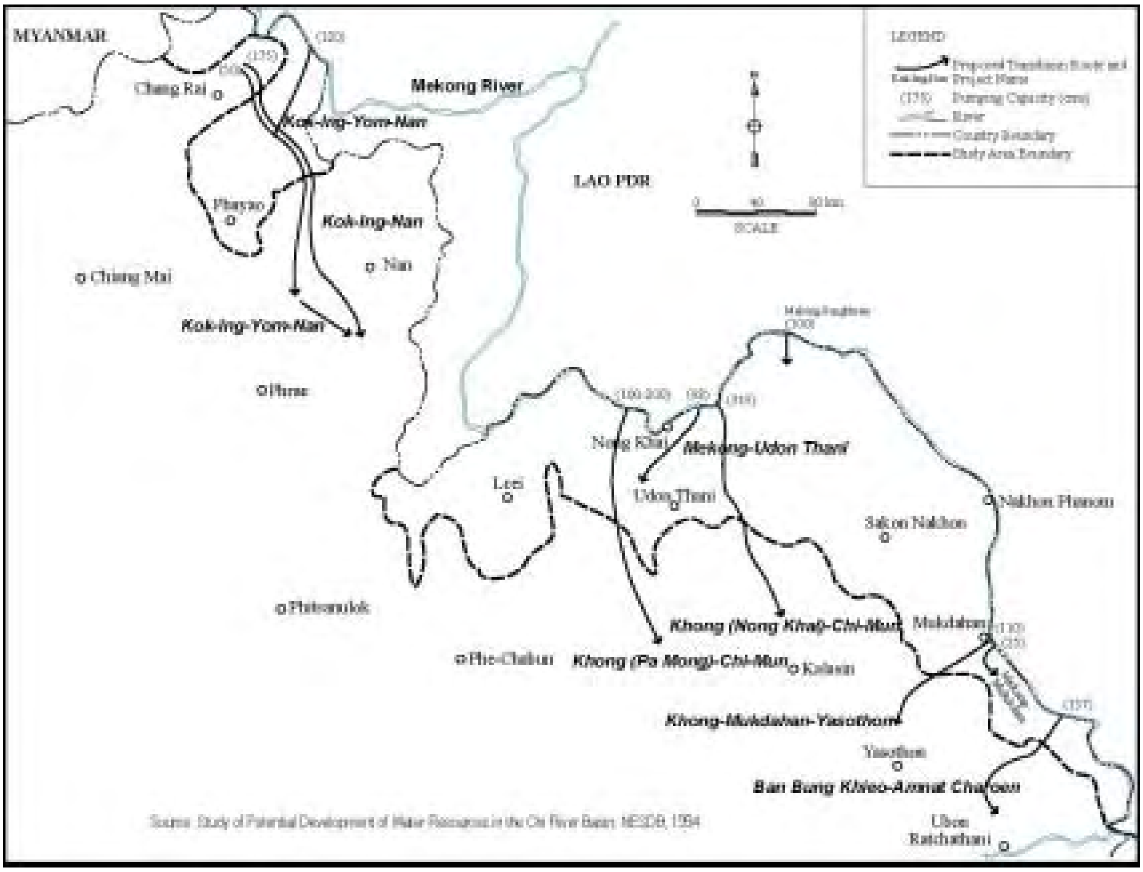


Fig. IV-2-11 Proposed Trans-basin Projects in Thailand

<u>Current Water Use</u>

For large-scale irrigation projects, the average annual volume of water use for irrigation and the annual irrigated areas (wet season and dry season) available from RID are as given below.

Table IV-2-24 Average Seasonal Water Use of Large Irrigation Projects in Northeastern Thailand

Irrigation Project	Dry Season		Wet Season		Data Available Years
	Water Amount (mil m^3)	Area (ha)	Water Amount (mil m^3)	Area (ha)	
Nong Wai	206.84	8,740	335.81	31,300	1980-1989
Huai Luang	15.10	132	42.80	13,051	1980-1989
Lam Pao	144.28	1,271	267.42	33,420	1980-1989
Nam Oon	98.22	28	173.83	28,982	1980-1989
Lam Prapleong	29.29	3,586	74.77	11,603	1980-1989
Siringdhorn	53.33	2,550	142.50	21,858	1980-1989
Lam Takhong	86.11	5	143.64	20,644	1980-1989
Total	633.17	16,312	1,180.77	160,858	

Note: Dry season is from January to June. Wet season is from July to December.
Source: Data from Water Operation Center, RID (1990) from Assessment of Water Resources and Water Demand by User sectors in Thailand, ESCAP, United Nations, 1991

According to the agricultural statistics of Thailand (Ministry of Agriculture and Cooperatives, 1989), the annual volume of water use and the annually irrigated areas of all irrigation projects in the country are around 1.3 times those of RID's large-scale projects. The factor of 1.3 was calculated from the available data on annually irrigated areas in the whole country and of RID. This ratio is assumed to be applicable also to the annual volume of water use for irrigation. The average ratio between dry season and wet season irrigated areas from 1984 to 1989 is 0.236 (Assessment of Water Resources and Water Demand by User sectors in Thailand, ESCAP, United Nations, 1991).

Table IV-2-25 shows details of estimated irrigation demand in three major river basins in North-eastern Thailand. As shown in the table, the storage associated with small-scale irrigation schemes provides around 1,000 million m^3. The total active storage of reservoir schemes is around 7,440 million m^3, of which 5,440 million m^3 (73%) is provided by large-scale reservoir and 2,000 million m^3 (27%) is by both medium- and small-scale reservoirs. The estimated irrigation demands are 5,140 million m^3 in the wet season and 2,689 million m^3 (moderate cropping intensity) in the dry season, or around 7,830 million m^3 in total.

Table IV-2-25 Estimated Irrigation Demand in Northeastern Thailand

Scheme	Total Irrigation (ha)	Active 3) Storage (Mm^3)	Irrigation Demand (Mm^3)				
			Wet Season	Dry Season 1)		Dry Season 2)	
			(Mm^3)	(Mm^3)	CI (%)	(Mm^3)	CI (%)
Chi Basin							
Large scale	102,259	3,100	818	1,080	60	720	40
Medium scale	49,491	346	396	79	20	40	10
Pumping	72,480	-	413	545	60	364	40
Chi Total	224,230	3,446	1,627	1,704		1,124	
Mun Basin							
Large scale	56,097	1,570	449	592	60	395	40
Medium scale	48,912	342	391	78	20	39	10
Pumping	28,800	-	164	217	60	145	40
Mun Total	133,809	1,912	1,004	887		579	
Mekong tributaries							
Large scale	83,168	769	665	878	60	586	40
Medium scale	44,328	310	354	71	20	35	10
Pumping	61,440	-	350	463	60	308	40
Mekong Total	188,936	1,079	1,369	1,412		929	
Northeast Sub Total	546,975	6,437	4,000	4,003			
Northeast small scale	200,000	1,000	1,140	114	10	57	5
North-east Total	746,975	7,437	5,140	4,117		2,689	

Note: 1) High cropping intensity; 60 percent values are well above presently realized; 20 and 10% are high values limited by reservoir water available; 2) Moderate cropping intensity; 3) CI: cropping intensity; 4) Medium scale reservoir storage estimated at 7,000 m^3/ha and small scale storage at 5000 m^3/ha

Source: International Development Research Center of Canada, State-of-the-Art Study of the Mekong River and the River Basin Area in Thailand, Working Paper, 1995

Table IV-2-26 shows the water extraction volume of pump irrigation schemes in the North-eastern Thailand in the period 1983-1989.

Table IV-2-26 Water Extraction Volume of Pump Irrigation in Northeastern Thailand (1983-1989)

Season	1983	1984	1985	1986	1987	1988	1989
Dry (Jan-Jun)	98.53	109.30	101.58	71.56	85.79	129.60	142.36
Wet (Jul-Dec)	22.18	23.18	28.63	47.00	83.12	71.51	67.27

Note: Irrigation pump stations only by DEDP, Unit: million m^3
Source: ESCAP (1991), Assessment of Water Resources and Water Demand by User Sectors in Thailand

Table IV-2-27 gives details of estimated irrigation demand of future proposed schemes (16 schemes in the Chi basin and 20 schemes in the Mun basin) around in 1995 for reference. If all schemes were implemented, the total irrigation area in Northeastern Thailand could increase by 835,878 ha. At this moment, the progress of implementation is rather hard for confirmation although all of the Mekong transfer schemes are still of preliminary study level and large-scale irrigation projects associated dam construction might be at the same level in 1995 almost without progress.

Table IV-2-27 Estimated Irrigation Demand of Proposed Projects in Northeastern Thailand

Description	Total Irrigation Area (ha)	Irrigation Demand		
		Wet Season (Mm^3)	Dry Season	
			(Mm^3)	CI (%)
Chi Basin				
Large scale	62,170	497	656	60
Medium scale	26,337	210	42	20
Chi total	88,507	707	698	
Mun Basin				
Large scale	81,988	657	865	60
Medium scale	56,869	455	91	20
Barrage	44,230	353	467	60
Mun total	183,087	1,465	1,423	
Mekong tributaries				
Large scale	82,198	658	868	60
Medium scale	24,926	199	40	20
Barrage	7,160	57	76	60
Mekong total	114,284	914	984	
Northeast small scale[1)]	50,000	285	29	10
Northeast pumping schemes[1)]	50,000	285	377	60
Northeast Sub Total	485,878	3,656	3,482	
Mekong transfers				
Pa Mong-Chi-Mun	140,000	1,551	543	
Kong-Chi-Mun	320,000	3,546	1,240	
Mekong-Udon Thani	67,960	753	263	
Mekong Transfer total[2)]	350,000	3,880	1,355	
North-east Total	835,878	7,538	4,837	

Note: 1) Provisional figure; 2) Diversion schemes partially overlap is a provisional estimate avoiding overlap; 3) CI: cropping intensity
Source: International Development Research Center of Canada, State-of-the-Art Study of the Mekong River and the River Basin Area in Thailand, Working Paper, 1995

2.4.3 Current Water Use in Lao PDR

The main use of irrigation in Lao PDR is the supplementary irrigation of wet season rice. There are a number of small-scale pump irrigation projects that use water from the Mekong River to irrigate dry season crops. There is little definitive data and reports on current water use.

Table IV-2-28 Current Water Demand, Lao PDR

Sector	1995
Agriculture	
Supplementary Irrigated Area (ha)	155,000
Dry Season Irrigated Area (ha)	31,000
Irrigation Water Use (Mm^3)	2,000

Source: LAOS – Environmental Values and Resource Sectors in Lao PDR, 1995

Herein, preliminary rough estimate of the current water use is made by use of available data and information. According to the existing irrigation area in 2000 obtained from Department of Irrigation, Ministry of Agriculture and Forestry in Lao PDR, the current irrigation areas within the Mekong watershed are estimated to be 129,000 ha in the dry season and 176,000 ha in the wet season. From collected diversion requirements, they are assumed to be 1,900 mm in the dry season and 700 mm in the wet season, respectively. By applying these figures, the current water use could be estimated at 2,450 million m^3 in the dry season and 1,230 million m^3 in the wet season.

2.4.4 Current Water Use in Cambodia

Rice production in Cambodia has increased in efficiency slowly since the early 1990s due to the ongoing post-war rehabilitation and infrastructure reconstruction. Total wet season cultivated area has increased during the period from 1.7 million ha in 1993 to 2.1 million ha in 2000 as given below.

Table IV-2-29 Rice Production in Cambodia, 1993-2000

	1993	2000
Wet Season Rice		
Area harvested ('000 ha)	-	1,846
Production ('000 ton)	-	3,333
Yield (ton/ha)	-	1.81
Dry Season Rice		
Area harvested ('000 ha)	-	233
Production ('000 ton)	-	708
Yield (ton/ha)	-	3.04
Total Rice		
Area harvested ('000 ha)	1,685	2,079
Production ('000 ton)	2,221	4,041
Yield (ton/ha)	1.31	1.94

Source: Cambodia National Institute of Statistics (1994, 2000)

In Cambodia, paddy is cultivated under management measures; namely, (1) rainfed lowland cultivation; (2) rainfed upland cultivation; (3) deepwater cultivation (floating rice); and (4) dry season cultivation. The following table shows the area and production of the said cultivation systems in 1992-1993.

Table IV-2-30 Rice Production in Cambodia, 1992-1993

Cultivation System	No Irrigation		Irrigation		Flood Recession		Total	
	(1,000 ha)	(1,000 tons)	(1,000 ha)	(1,000 tons)	(1,000 ha)	(1,000 tons)	(1,000 ha)	(1,000 tons)
Rainfed Lowland	1,422	1,485	173	311	-	-	1,595	1,796
Dry Season	-	-	25	60	79	190	104	250
Rainfed Upland	24	29	-	-	-	-	24	29
Deep Water	121	146	-	-	-	-	121	146
Total	1,567	1,660	198	371	79	190	1,844	2,221

Note: Area means the cultivated area.
Source: Cambodia Statistics, Interim Mekong Committee, 1992

As seen from the table above, dry season rice cultivation accounts for only about 6% of the whole cultivated area. Dry season cultivation is either from the fully irrigated scheme or grown as a “flood recession crop.” Under the flood recession crop, low embankments are used to store floodwaters during flood recession, which are then used to subsequently irrigate the crop. The productivity of the dry season rice is more than 1 ton/ha greater than wet season rice because of greater sunshine and better water control. The dominant production system is rainfed lowland rice, which is concentrated near the Mekong, Bassac, and Tonle Sap rivers. Deepwater and floating rice is also found around the shores of Tonle Sap and the Great Lake, as well as the inundated areas of the Mekong and the Bassac rivers near Vietnam. There is also small-scale dry land rice production in hilly areas of the country. Definitive data about the current water use in Cambodia is lacking. Assuming that the dry season irrigation demand amounts to 1,700 mm, which was obtained from the relevant report, for 104,000 ha as shown in Table IV-2-30, the irrigation demand is estimated at 1,770 million m^3.

The following table shows the identified potential new and upgraded cropping areas in 1994.

Table IV-2-31 Potential Cropping Areas and Water Resource Constraints, Cambodia

No	Catchment	Potential Crop Area (ha)				Water Resources Category
	Name	Wet Season	Double Cropping	Flood Recession	Total	
1	SE Catchment	6,292	9,089	310	15,691	2
2	Stung Slakou	650	19,748	1,050	21,448	2
3	Prek Toul Lokok	250	2,875	600	3,707	2
4	Prek Tnol	3,597	26,995	550	31,142	2
5	Stung Tonle Bati	0	1,135	0	1,135	2
6	Lake side 1a	9,175	0	0	9,175	3
7	Lake side 1b	510	410	2,000	2,920	1
8	Stung Krang Punley	960	2,503	0	3,463	2
9	Stung Baribo	5,190	0	0	5,190	2
10	Stung Pursat	4,590	40,320	0	44,910	2
11	Stung Daunti	10,800	0	0	10,800	2
12	Stung Daunti	1,317	1,345	0	2,662	2
13	Lake side 2b	4,070	4,800	0	8,870	2
14	Stung Sanker	2,270	25,600	0	27,870	2
15	Stung Mongkol Borey	2,160	55,000	0	57,160	2
16	Stung Pheas	0	11,500	0	11,500	2
17	Stung Sisophon	1,000	4,000	0	5,000	3
18	Stung Svay Chek	0	1,750	0	1,750	3
19	Stung Praneth Preah	0	12,000	0	12,000	3
20	Stung Sreng	6,050	1,100	150	7,300	3
21	Stung Siem Reap	2,700	13,500	100	16,300	2
22	Stung Rolous	5,750	0	0	5,750	2
23	Stung Chikreng	4,000	0	0	4,000	3
24	Stung Ataung	2,550	14,500	0	17,100	2
25	Stung Sen	6,010	4,100	0	10,110	3
26	Stung Sraka Moan	2,750	0	0	2,750	3
27	Stung Chinit	3,963	16,050	0	20,013	2
28	Stung Taing Krasing	0	600	0	600	2
29	Great Lake	1,800	960	5,695	8,455	1
30	Mekong Riverine	11,785	49,672	86,785	148,242	1
31	Prek Kampi	527	0	0	527	3
32	Prek Te	212	0	112	324	3
33	Prek Chhlong	2,912	1,400	480	4,792	3
34	South Catchments	479	18,450	2,130	21,095	3
35	Catchments unknown	4,330	0	0	4,330	-
Total		108,640	339,402	99,962	543,715	-

Notes:

Category 1: Predominantly recession cropping. Recession cropped systems can be treated independently for the purpose of irrigation rehabilitation.

Category 2: Catchments with overall water shortage where catchment planning is recommended.

Category 3: Catchments without identified water contain

Source: Irrigation Rehabilitation Study in Cambodia, Final Report, 1994

2.4.5 Water Demand in Vietnam

The present irrigation water demand in the delta has been estimated on a yearly basis by SIWRP (Sub-Institute for Water Resources Planning) in Ho Chi Minh City by using the developed hydraulic simulation model in which the current irrigation system network is built. The estimated water demand is on a 10-day basis. Water demands estimated in several years are available from several reports. The following table is the estimated dry-season irrigation water demands in 1990, 1998 and 2000.

Table IV-2-32 Estimated Dry Season Irrigation Water Demands of the Mekong Delta in 1990, 1998 and 2000

1990	Irrigation Water Demand						Total
	Jan	Feb	Mar	Apr	May	Jun	
million m^3	2,420	1,560	1,120	1,490	1,660	1,140	9,300
m^3/s	904	645	418	575	620	440	-

Source: Sub-Institute of Water Resources Planning and Management (SIWRPM)

1998	Irrigation Water Demand						Total
	Jan	Feb	Mar	Apr	May	Jun	
million m^3	2,686	2,088	2,017	2,179	2,179	1,363	12,512
m^3/s	1,003	863	753	841	814	526	-

Source: Sub-Institute for Water Resources Planning (SIWRP)

2000	Irrigation Water Demand						Total
	Jan	Feb	Mar	Apr	May	Jun	
million m^3	2,582	2,692	2,072	1,400	1,473	1,290	11,509
m^3/s	964	1,113	774	540	550	498	-

Source: Sub-Institute for Water Resources Planning (SIWRP)

The estimated total dry season irrigation demands from January to June are 9,300 million m^3 in 1990, 12, 512 million m^3 in 1998 and 11,509 million m^3 in 2000. The dry season demand in 1990 is divided into two demands in the freshwater area and the saline water area affected by saline water intrusion. They are 9,000 million m^3 in the freshwater area and 300 million m^3 in the saline water area. Considering that the Mekong flow becomes lowest in April, the period of critical water usage is April.

The table below shows the estimated irrigation water usage for 1985 and 1990 over the period January to June by the Mekong Delta Master Plan in 1991. The delta was divided into eight separate climatic zones. Effective rainfall was estimated on the basis of a 75% likelihood of exceedance. An irrigation efficiency of 80% was adopted.

Table IV-2-33 Estimated Dry Season Irrigation Water Demands of the Mekong Delta in 1985 and 1990

Year	Irrigation Water Demand (m^3/sec)					
	Jan	Feb	Mar	Apr	May	Jun
1985	425	310	120	140	275	190
1990	802	724	264	319	214	194

Source: Government of Vietnam, WB and UNDP (1991), Mekong Delta Master Plan, Working Paper No.3, Irrigation, Drainage and Flood Control