CHAPTER 3 HYDRO-HYDRAULIC MODELLING

3.1 Development of Hydro-Hydraulic Model for the Cambodian Floodplains

3.1.1 Background

In the initial stage of the study, some hydro-hydraulic simulation models were needed to verify the observed data and to clarify the hydrological or hydraulic mechanisms in parallel with the monitoring activities. After a series of discussions with the MRCS due to apprehension on the overlapping of work with the WUP-A and WUP-FIN projects, it was decided that the WUP-JICA team would take over and further develop the model that was developed in the recently completed project of MRC.

3.1.2 Process of Model Development

Chaktomouk Project Model

The Chaktomouk Project was conducted from 1999 to 2000 as one of the MRCS projects funded by the Government of Japan. As part of the Chaktomouk Project, a MIKE 11 model was established for the Mekong-Tonle Sap-Bassac river system. The purpose of the MIKE 11 model was to provide boundary conditions for a detailed two-dimensional morphological river model (MIKE 21C) 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, which could not be obtained by data alone.

The MIKE 11 model was set up with its upstream boundary at Kratie on the Mekong, and the downstream boundaries at Tan Chau on the Mekong and at Chau Doc on the Bassac in Vietnam. The model included the Tonle Sap and the Great Lake. The reasons for this extent of the model were: (1) records of water level and discharge did not exist in the four river branches close to the Chaktomuk junction; and (2) the boundaries of the MIKE 11 should be unaffected by the changes in the junction caused by the various options studied with the two-dimensional model.

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 the model in order to meet the specific purposes of the WUP-JICA study. The improvement of the model was made in a continuous process as data and information became available during the study.

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

(1) To study 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) To support the preparation of water utilization rules, including assessment of average monthly flow conditions at key locations and the 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 a revision, and improved with regard to schematisation of rivers, bridges, floodplains and the lake. Besides this, the model has been updated with a detailed calibration of rainfall-runoff in the Great Lake tributaries. The model is thus able to simulate full hydrological years ranging from historical dry to wet years.

The model has been calibrated/verified with events from 1998-2001. Preliminary testing was made in 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.

Relation to Tonle Sap Lake and Vicinities Project

A project parallel to the WUP-JICA Study was carried out at MRCS under the title “Consolidation of Hydro-Meteorological Data and Multifunctional Hydrologic Role of Tonle Sap Lake and its Vicinities.” In short, this project was called “Tonle Sap Lake & Vicinities Project” or TSLVP.

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, the exchange of flow between river courses and floodplains as well as between floodplain compartments inside of floodplains. 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 comprised continuous measurements of water level at 20 stations located over the floodplains as well as discharge measurements on important tributaries using both conventional methods and the advanced ADP measurement technique. Altogether 9 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 intervals, and show the gradual process of flooding and draining of the floodplains.

A substantial part of this project was concerned with hydrological/hydraulic modelling. The purpose of the modelling was to provide the functional relationships for the floodplain dynamics studied, i.e., volume change, filling/release of floodplain water, and to support water the 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 study ran in parallel with each other and hence the modelling work was made by both projects. Since both projects can benefit from the development made in the other project, the goal was to develop one common model, which would suit both project purposes. The presently improved model represents the combined efforts of the two projects, and was thus applied for the purposes of both.

3.1.3 Rainfall-Runoff Model

A main portion of the annual flow volumes in the Mekong-Bassac-Tonle Sap river system within Cambodia originates from upstream. However, the local rainfall in Cambodia contributes significantly to the total flow volumes in the initial and final stages of the monsoon season. During the peak monsoon, although the local contribution is likely to be insignificant from the hydrological viewpoints considering the total Mekong runoff, the local runoff is important for flood protection and management works in the major tributaries.

Given this it is clear that there was a need to include the local rainfall in a model description of the main river and the lake system in Cambodia. The contribution of local rainfall was divided into two components: one was the direct rainfall occurring on the open water bodies, i.e. the inundated floodplains, river branches and the Great Lake itself. The other component was 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 have been limited. With the improvement of the rainfall network since 2000, the amount and quality of rainfall data has been increasing. At the same time a measuring campaign during 2001 under the TSD-MRCS, 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 a direct calibration of a rainfall-runoff model.

Model Concept and Sub-catchment Divide

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 lumped-conceptual type of model for continuous simulation. 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 ground water 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.

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 topographic map and the French study in the 1963-64 were also used as information sources for the sub-catchment delineation and characteristics.

Fig. 3-1 and Table 3-1 show the locations of the delineated sub-catchments and their areas.

Table 3-1 Sub-catchments for Rainfall-Runoff Modelling

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

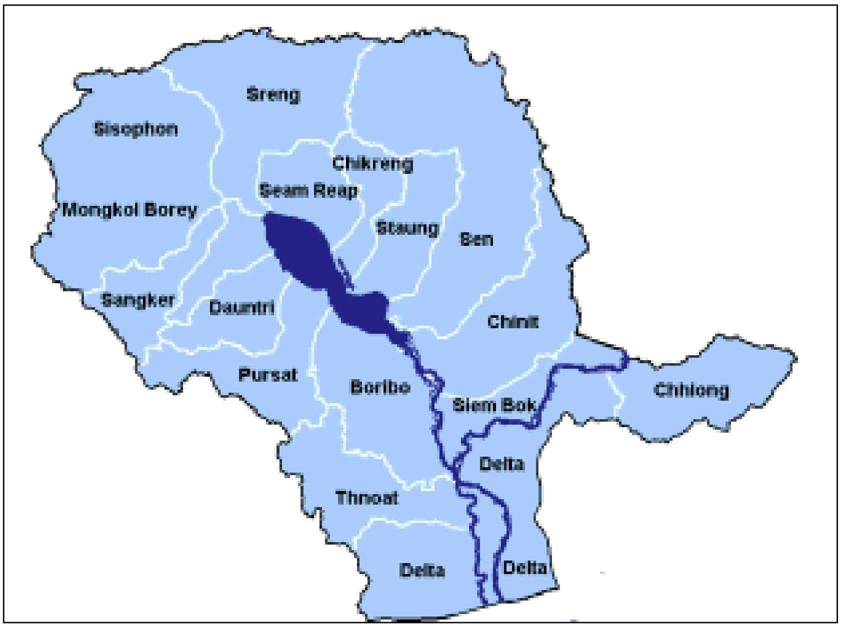


Fig. 3-1 Sub-catchments for Rainfall-Runoff Modelling

<u>Runoff Analysis in the Tonle Sap Basin</u>

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

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 their limitation was their dependency on the water level at Bac Prea Station. The latter data cover only 1999 and 2000. Despite some fluctuations, the water level and hence the rated discharges at Stung Boribo were used. The remaining stations showed fluctuations or irregularities in the observed water levels that lead to less reliable rated discharges. The following table summarises the situation on rating curve development in this study.

Table 3-2 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	-

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 the amount of data varied from one catchment to the other. 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.

The most complete discharge hydrographs are the rated discharges from Stung Chinit and Stung Boribo, as shown in Figs. 3-2 to 3. In both catchments the relative difference between low and high flows is large. The recession period appear to be shorter and ‘steeper’ for Stung Boribo than for Stung Chinit. The peaks (or spikes) during the monsoon are direct runoff from the catchments and they appear in both catchment types, although they are mostly pronounced for Stung Boribo. Stung Chinit has a larger proportion of flow, which is in-between base flow and direct runoff. This flow is interflow and occurs in the upper rootzone.

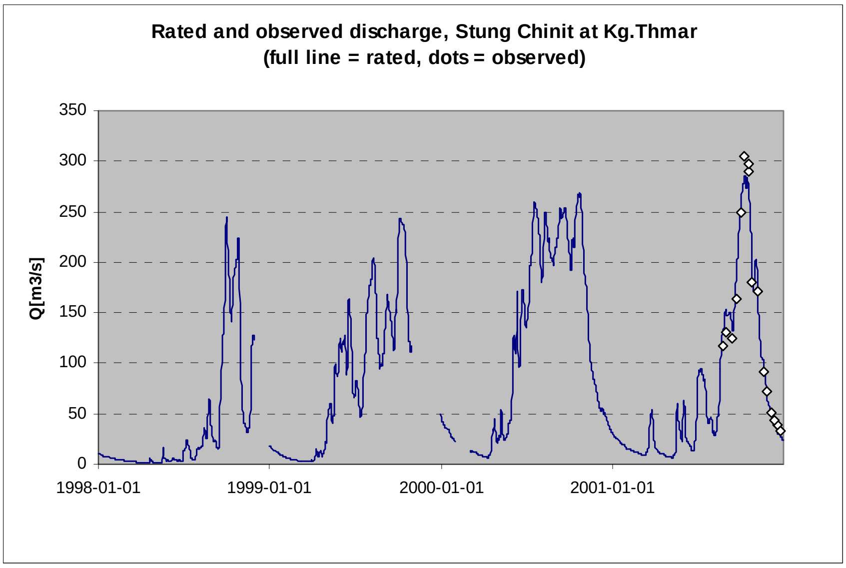


Fig. 3-2 Rated and Observed Discharge at Kg. Thmar, Stung Chinit

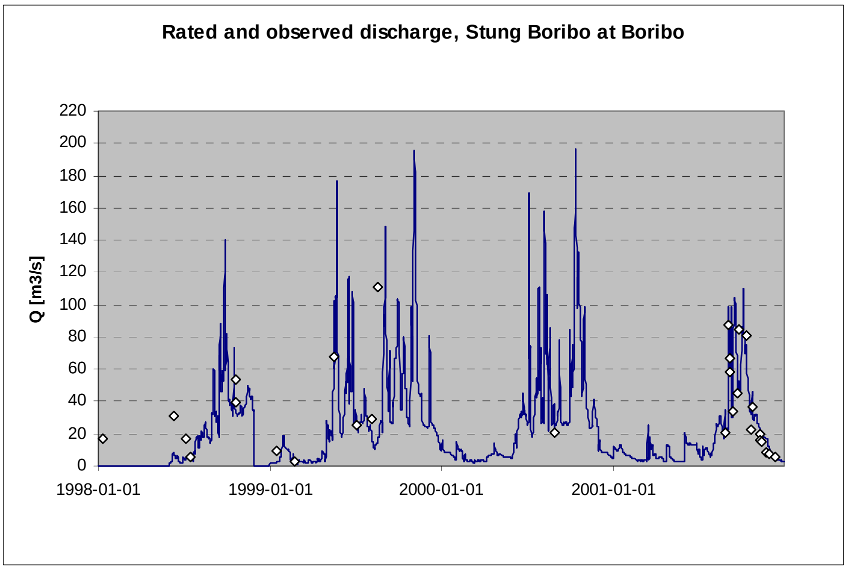


Fig. 3-3 Rated and Observed Discharge at Boribo, Stung Boribo

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

(1) Rainfall

After selection of appropriate stations for the catchments, a simple mean area rainfall was calculated with each station having equal weight. With the relative large uncertainty in some of the rainfall data as well as the non-uniform distribution of rainfall network, no attempt was made to apply any sophisticated weighting of the individual stations.

Ideally the rainfall stations applied for runoff simulation in each sub-catchment should be 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.

(2) Evaporation

The mean value of the monthly averaged daily evaporation rates was used for all sub-catchments model.

(3) Model Parameters

Based on the evaluation of discharge hydrographs, the initial values of the model parameters were approximated. Then fine-tuning of the parameters was carried out in order to obtain the best fit of model predictions to the observed data.

(4) Modelling results in Stung Chinit and Stung Boribo Basins

The MIKE 11 NAM model was set up for each individual sub-catchments. The rainfall and evaporation input described above was used in the model together with initial choice of model parameters. Through the iterative process with result evaluation and fine-tuning of model parameters, both the sub-catchments of Stung Chinit and Stung Boribo were calibrated for the period 1998-2001. The results are presented in Figs. 3-4 to 3-5.

Fig. 3-4 shows the observed, rated and simulated discharge from Stung Chinit for the period of 1998 to 2001. In general there is good agreement between all three data sets. Peak levels, minimum levels as well as the model simulated the shape of the recession part. Some of the direct runoff peaks during the monsoon were not picked up precisely. This is not expected either, since a few rainfall stations can be used. Moreover, the dotted line is rated discharge, and it is subject to some uncertainty. In general, however, it was 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 are simulated quite well.

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.

The sub-catchments on the southern side of the lake exhibited larger fluctuations in water level and discharges than the northern side sub-catchments. This may have been due to the local rainfall pattern in combination with the shape of the terrain.

The calibration results for Stung Boribo are depicted in Fig. 3-5. It is 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. The reason for this could be that the rated discharges for the recession period are not accurate. However, the calibration of the Stung Boribo shows that it is possible to reproduce the runoff pattern, which is the hydrological characteristic of catchments south of the lake.

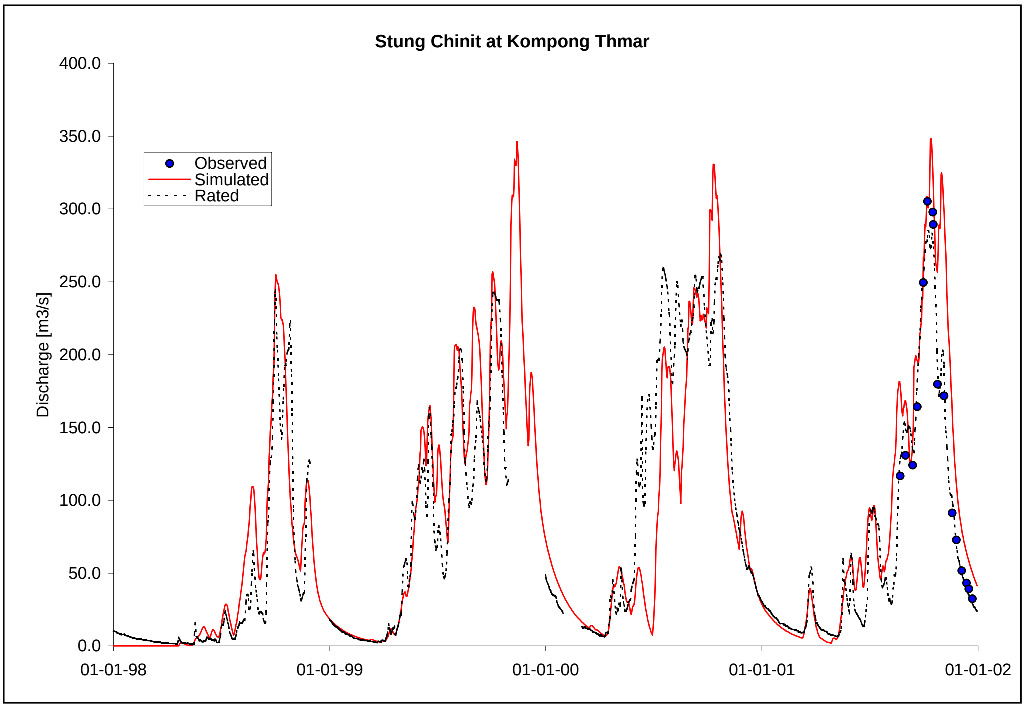


Fig. 3-4 Comparison among Observed, Rated and Simulated Discharges at Kg. Thmar, Stung Chinit

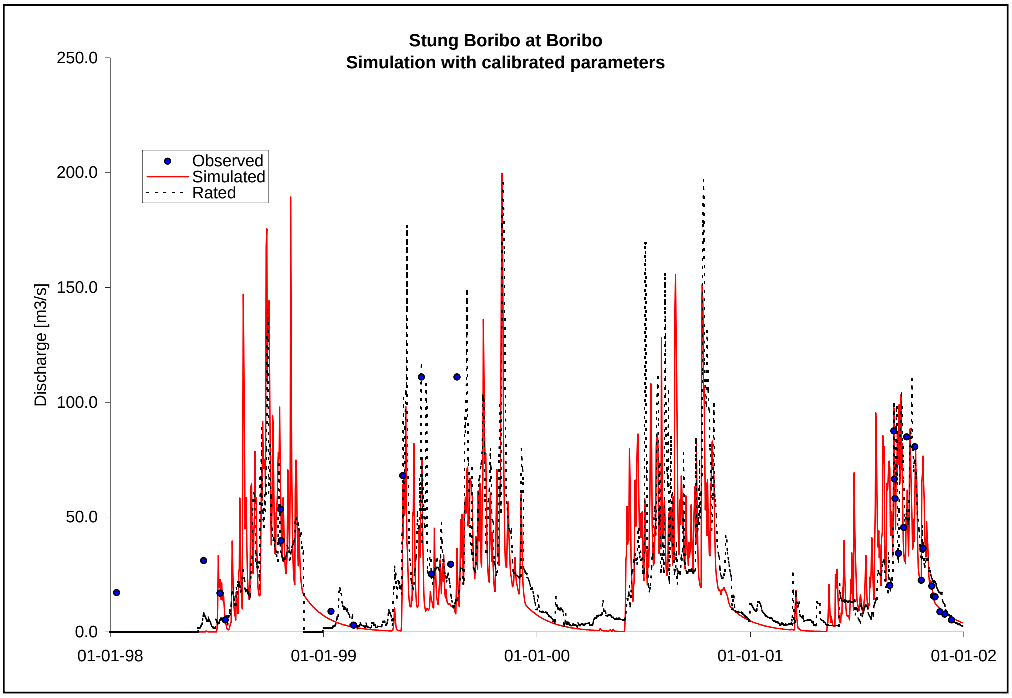


Fig. 3-5 Comparison among Observed, Rated and Simulated Discharges at Boribo, Stung Boribo

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, continuous measurements of discharge is required and extended to cover also the rising part of the monsoon. Further, 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. Due to the mild slopes of their terrain, they are likely more similar to the catchments north of the lake than those south of the lake. Hence, model parameters for these catchments shall be similar to those catchments.

3.1.4 Hydraulic Model

The WUP-JICA Project took over model construction and development from the Chaktomouk Project. Since the Chaktomouk model was too simple for the purposes of the WUP-JICA study, particular improvements on the description of the floodplains as well as the linkages between river and floodplains has been necessary.

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 were 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 flood plains
- Floodplains in Cambodia: Sogreah Map (1963)

Regarding the topography of the Great Lake, merging of two data sources; namely, the CHO survey in 1999 and the Philippine Map from 1963, had derived the topography for the Tonle Sap Lake. There seems to be no major inconsistency between the two data sources in relation to datum levels, because there is a smooth transition from the plain to the water body of the lake. The merged data set was 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 was derived for the lake as a whole. The result is shown in Figure 3-6. The southern border of the lake is located at Kompong Chhnang.

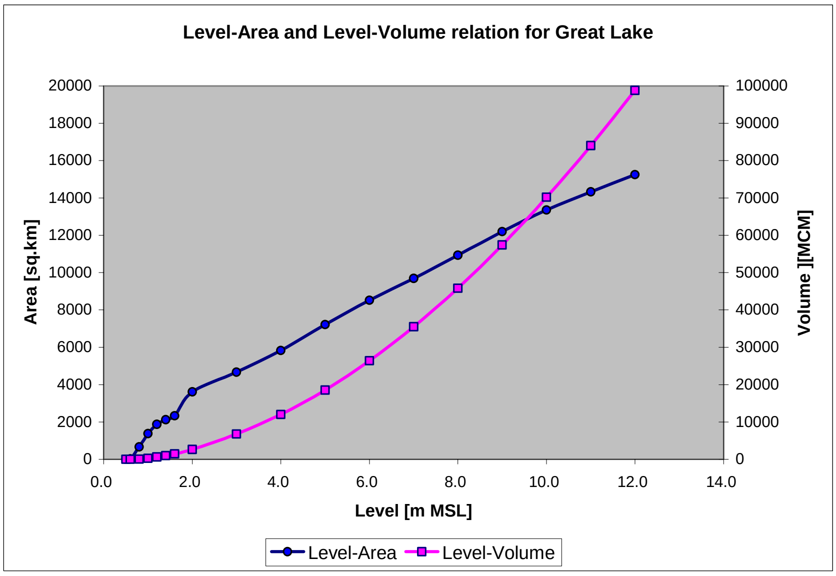


Fig. 3-6 Elevation, Area and Storage Volume Relation of the Great Lake

Regarding the topography of floodplains, contour lines of the various data sources covering the floodplains are as shown in Fig. 3-7. For the plains along the Mekong, Tonle Sap and Bassac rivers, the Sogreah data are the most reliable. From the Sogreah data of the

Cambodian Delta, a Digital Elevation Model (DEM) with a grid cell size of 100 by 100 meters was created.

Besides the DEM, the JICA map produced for the Ministry of Transportation was 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 levee, etc.

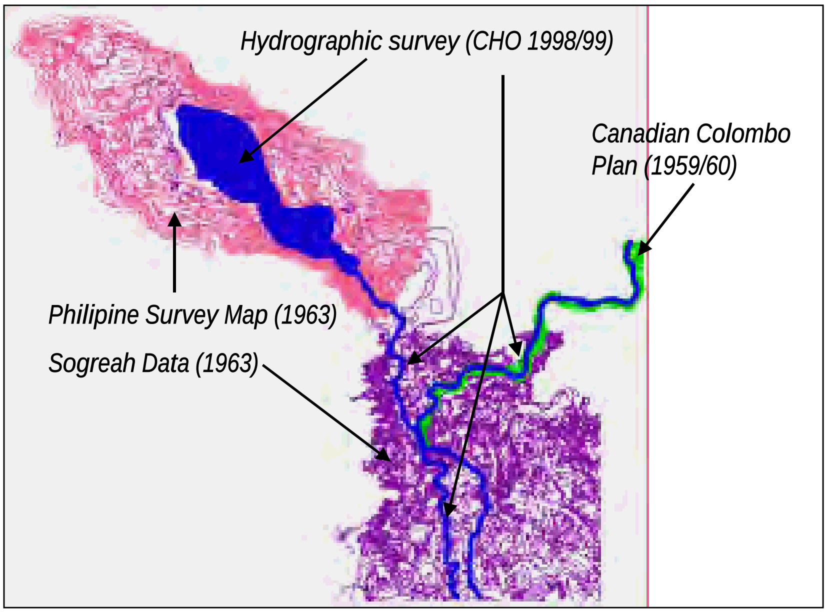


Fig. 3-7 Topographic Information Sources Available for the Model Construction

(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. Besides the effect of increasing water levels upstream of the bridges as well as the velocities at the bridge sites, the pillars of these bridges diminish the cross-section area of the river at those locations. These bridges do not act as control points in the same manner as the bridges on the floodplains, because the flow is confined in the river channel. 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 were either incorporated individually in the model or lumped together with other bridges. The bridges that are described individually comprise important flow control points, and discharges at these sites were measured during the 2001/2002 monsoons through the TSLVP.

The bridges that were included individually in the model area are: (1) Bridge No. 14, 17, 23 and 24 on National Road 6A; (2) Bridge No. 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) the 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 sources of information for bridges were the road improvement projects carried out by JICA in recent years. From the reports and design drawings of these projects, it was 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.

(3) Hydraulic Data

The hydraulic data necessary for the modelling were divided into data for boundary conditions and data for internal model calibration. At the model boundaries, either water levels or discharges were needed. For internal model calibration/verification of a system like the Mekong-Bassac-Tonle Sap, both water levels and discharges were needed. These hydrological stations are illustrated in Fig. 3-8.

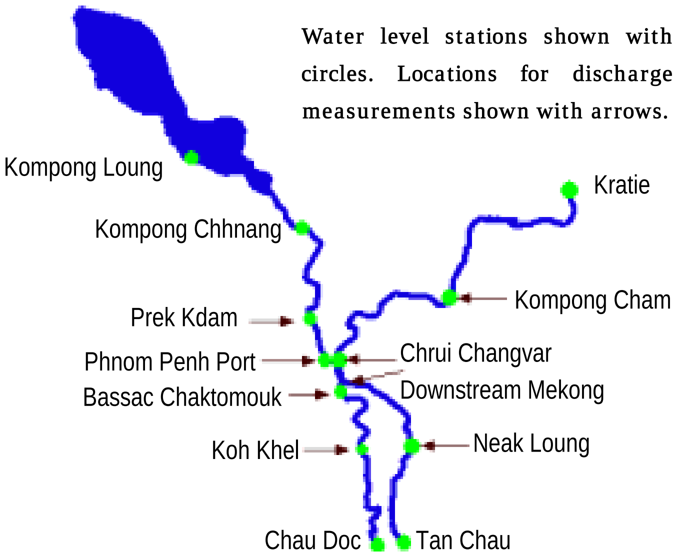


Fig. 3-8 Hydrological Stations for Hydraulic Modelling

(4) Water Use Data

Water use data is one of the elements of the hydrological cycle, which is lacking most in Cambodia. The WUP-JICA team did 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 was made.

The estimation gave 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 were applied at estimated locations in the various river branches. The abstraction rates were assumed to be applicable for each of the years to be simulated.

(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 the TSD. 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 basis for verification of the modelling results on the floodplains.

Model Area and Schematisation

From the DEM derived on the basis of contour lines, a number of cross-sections for description of the floodplains were extracted and distributed on the quasi-two-dimensional network of the floodplains. Fig. 3-9 shows the network on the floodplains as well as the location and extent of the cross-sections. Fig. 3-10 shows in detail the schematisation of river and floodplain branches together with cross-sections for the area around Phnom Penh.

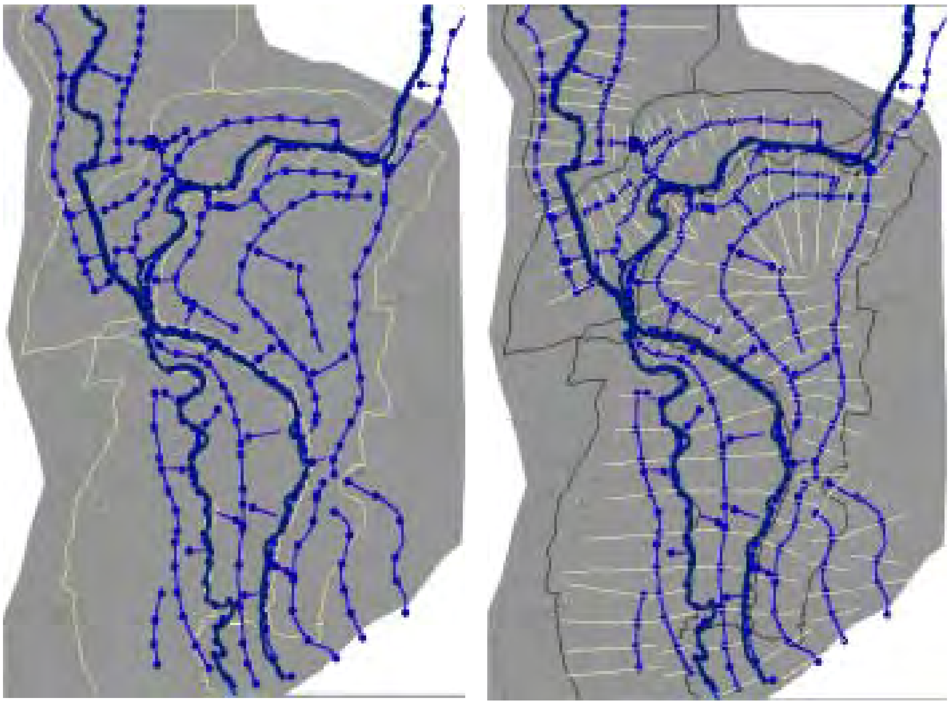


Fig. 3-9 Detailed View of Quasi-Two-Dimensional Network for the Floodplain Modelling and Cross Sections Overlaid (Right)

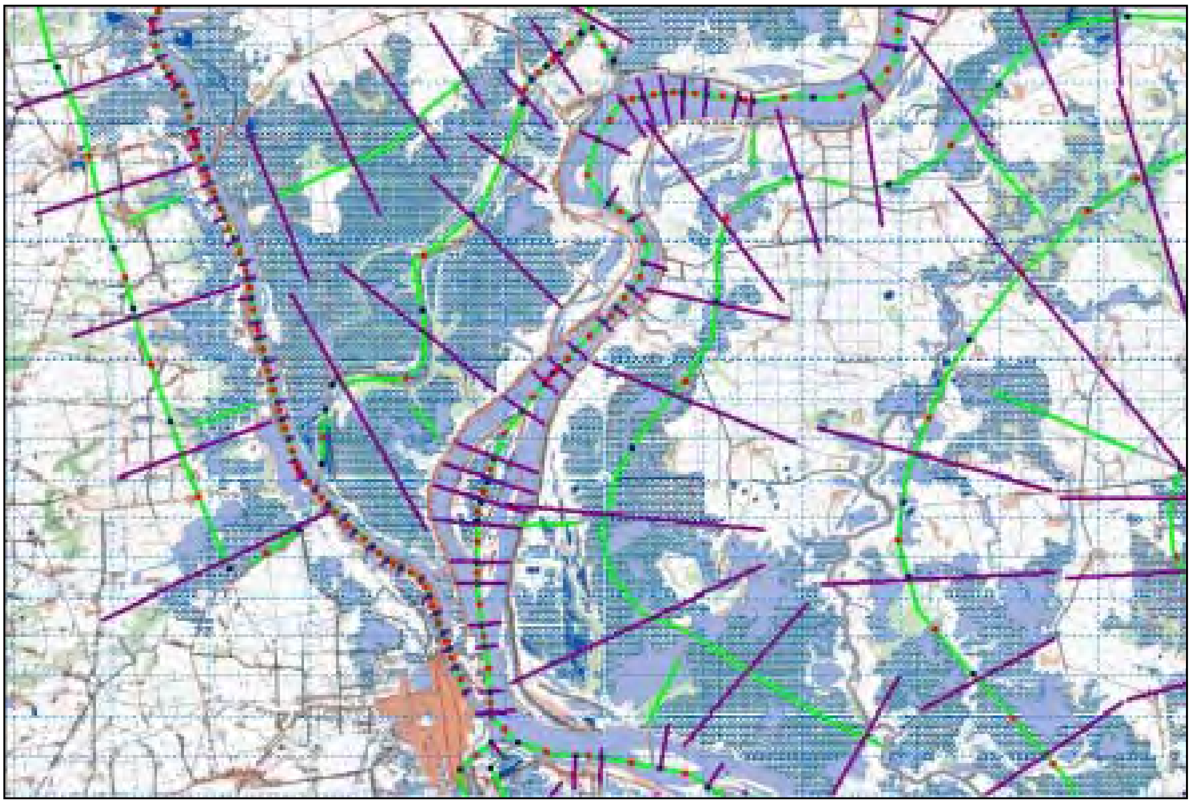


Fig. 3-10 Detailed View of Branch and Cross Section Layout around Phnom Penh Area

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 were implemented and distributed on the river network.

Fig. 3-10 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.

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. 3-11 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 is 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.

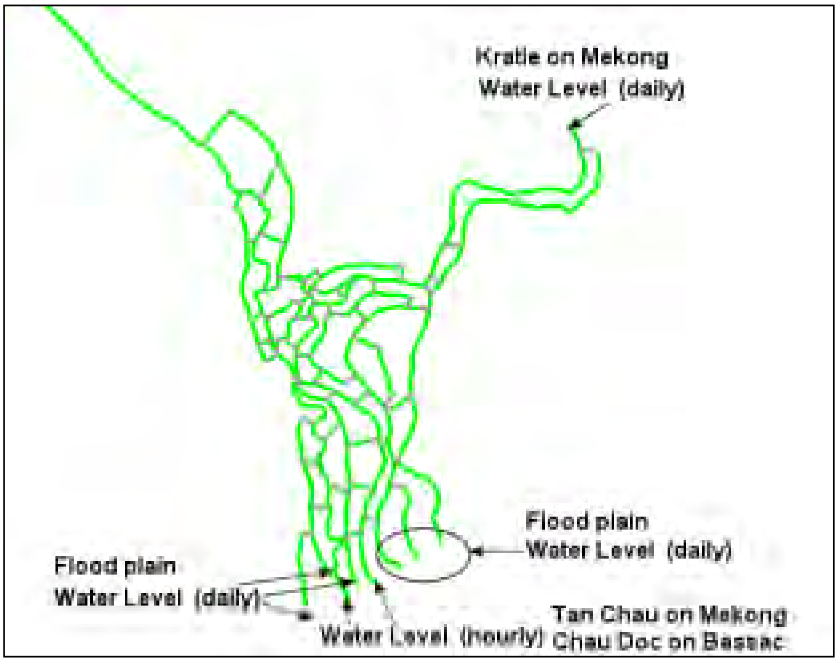


Fig. 3-11 Location and Type of Boundary Conditions Applied

<u>Calibration and Verification of Hydraulic Model</u>

The flood extent was estimated by the use of satellite images (RADARSAT) of the Mekong River and Delta. In the WUP-JICA study the images were used to verify that the simulated flood extent is matching 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.

The model verification on year 2002 was made. The satellite images were acquired on monthly intervals throughout the monsoon season. The images do not cover the entire lake as shown in Fig. 3-12. The model predicts well the dynamics of the flood extent throughout the monsoon. As an example of the 2002 flood extent, the observed and simulated flood extent on the 14th of October 2002 is shown in Fig. 3-13. This figure also well describes the flooding situation over the floodplains.

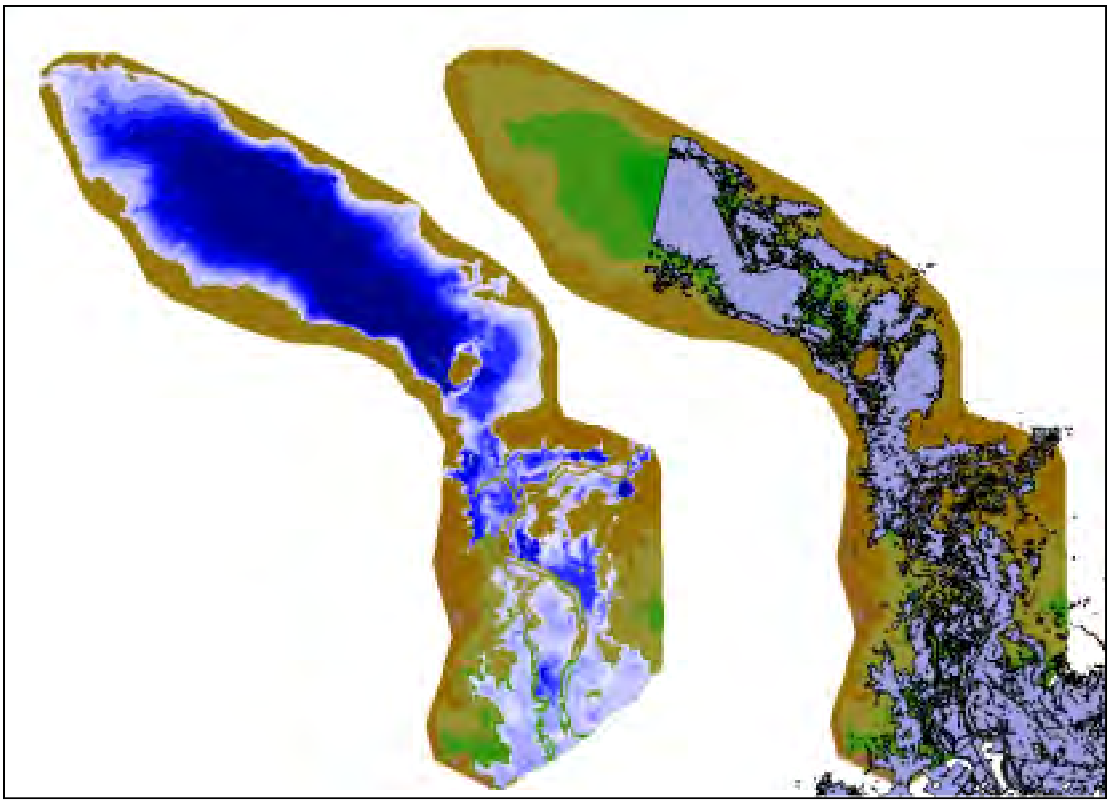


Fig. 3-12 Simulated (Left) and Observed (Right) Flood Extent on 14 October 2002

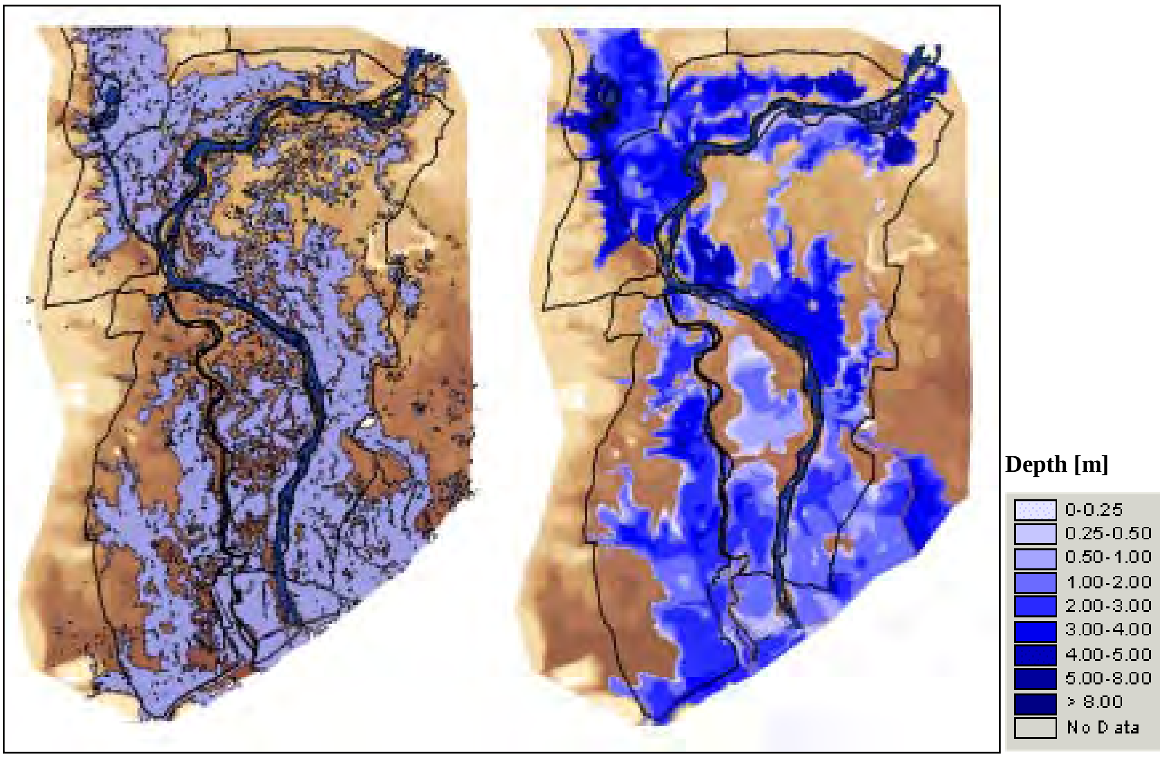


Fig. 3-13 Simulated (Left) and Observed (Right) Flood Extent on 14 October 2002

The WUP-JICA team carried out intensive discharge measurements using ADCP in 2002. The measurements were carried out on a weekly/bi-weekly basis covering a number of stations along the Mekong, Tonle Sap and Bassac river systems around Phnom Penh. Besides being used for 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 was 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 were updated. Since the 2002 monsoon data was used for calibration of the model in the TSLV project, but those data could not be used for the verification. The simulation results for the year 2002 from some of the important stations in the system are presented in Fig. 3-14(1/2). It is seen that a good match between observed and simulated discharge is presented for Kompong Cham.

Likewise the discharge results at Chrui Changvar, Koh Norea, Monivong Bridge and Phnom Penh Port are well reproduced. These model results demonstrate that the model can represent the unique flow dynamics and its balance of the Chak Tomuk junction. The Fig. 3-14(2/2) shows the simulated and observed discharge at Prek Kdam and Phnom Penh Port. It shows that the model predicts well the flow dynamics at these two stations. An interesting detail is that the model predicts well the observed transition period in which flow is towards Chak Tomuk 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. 3-14(2/2). The reason is that flow is diverted into the floodplains (mainly via a tributary of Prek Thnot and the numerous colmatage canal system). It is seen that the diverted flow is not returned to the river along this reach.

The model predicts 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. 3-14(2/2). Compared to the flows in the main river system, flows occur in a shorter time frame through the bridge. It is seen that there is an excellent match between observations and simulation results. The implication of this is that the water balance and flood extent on the floodplain in the Beung Thom area (upstream of Spean Dach) can be accurately simulated.

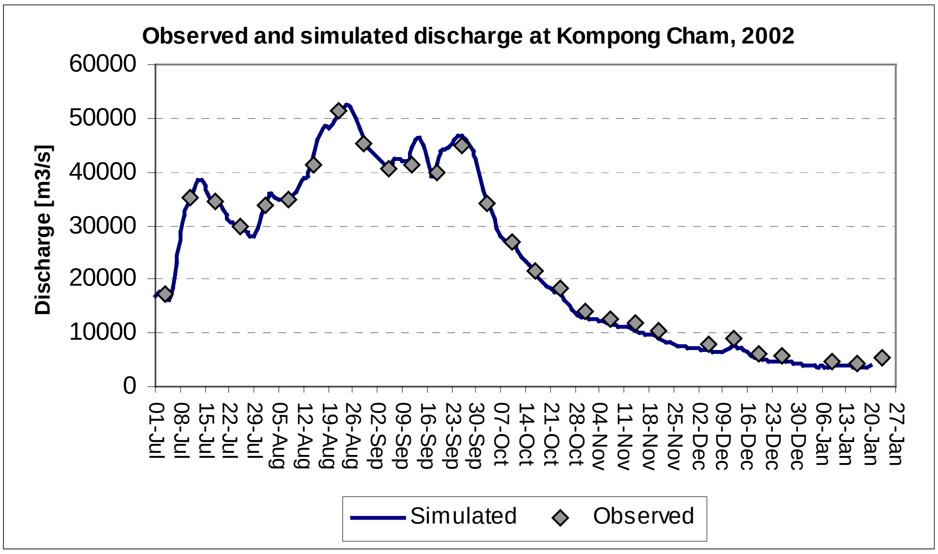
3.1.5 Conclusion

A hydrological and hydraulic model has been developed as a part of the WUP-JICA study. The model is a refinement and significant improvement of the MIKE 11 developed for the Chaktomuk project. In parallel with the WUP-JICA study, the Tonle Sap Lake & Vicinities Project (TSLVP) made use of the same model. Since hydrological and infrastructure's data were collected in both studies, both projects contributed to a continuous model improvement, and the model was as such useful for both projects.

The established model consists of: (1) rainfall-runoff sub-model, and (2) 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 has 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 has demonstrated in quantitative terms the complex hydraulic behaviour of the Mekong river system and associated floodplains in Cambodia. The hydraulic behaviour was studied for the years of 1998-2002, which contains both extreme dry and extreme wet hydrological years. Over these years an increasing amount of data has become available and been collected. The number of rainfall stations has increased significantly in Cambodia since year 2000. Particular improvement in discharge data was obtained from the WUP-JICA study in 2002. In 2002 a comprehensive measuring campaign collecting discharges and water levels in the floodplains was obtained in connection with the TSLVP. Together with 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 are of profound value to the modelling work.

The model developed is able to simulate the dynamics of flows and water levels in the river system in both of the wet and dry season, the water levels and inundation on the floodplains as well as the exchange of flows 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.



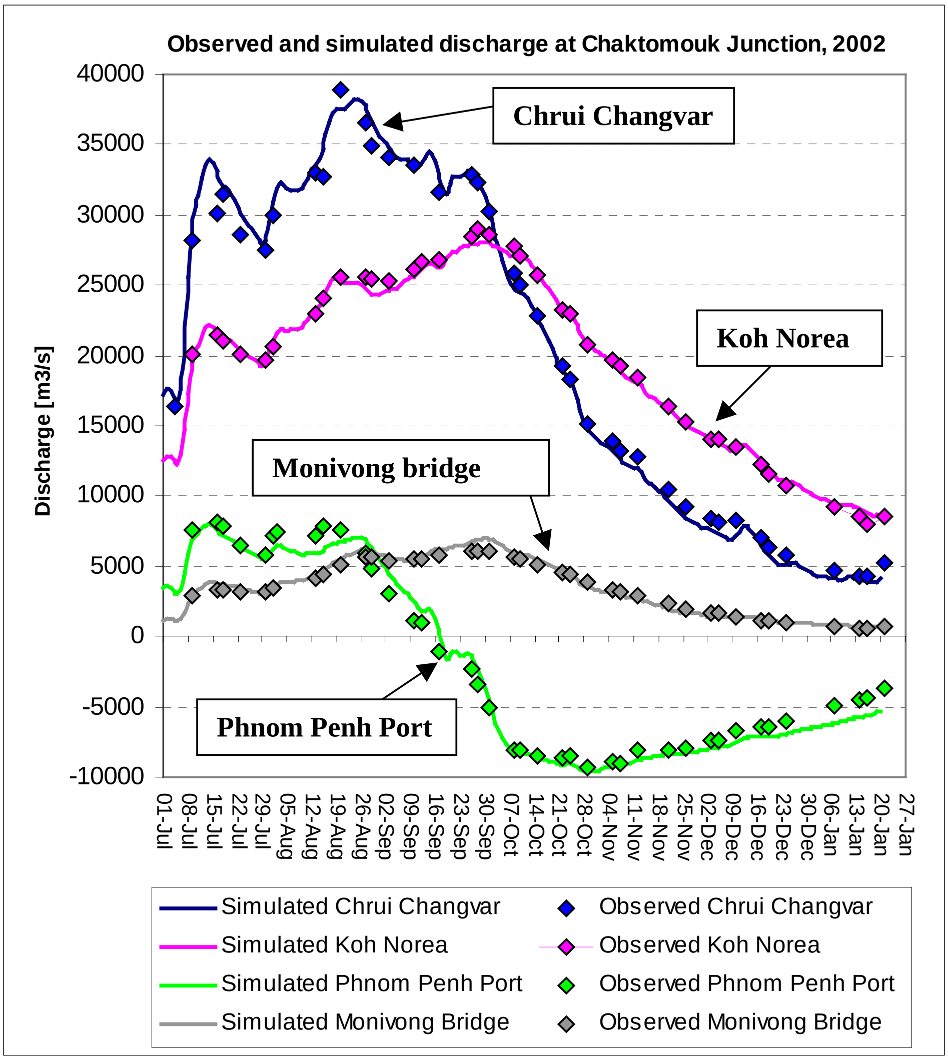
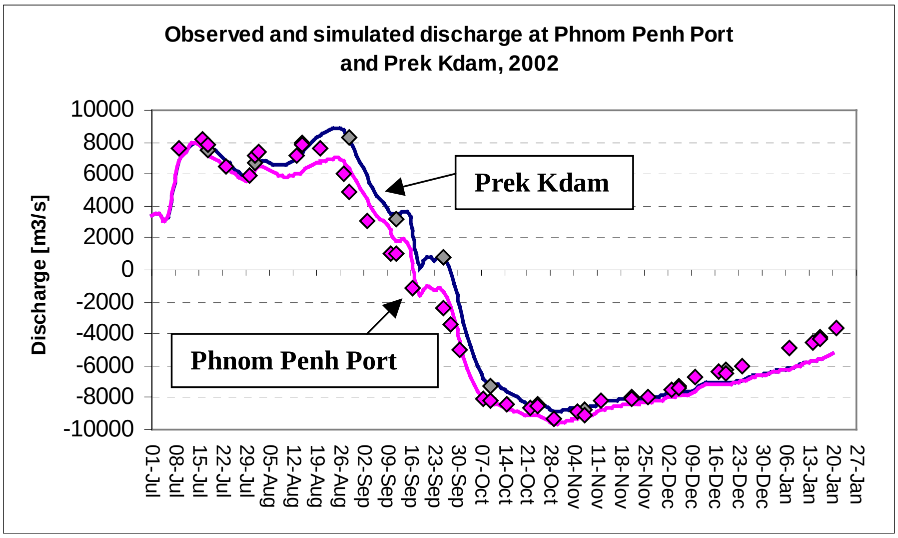
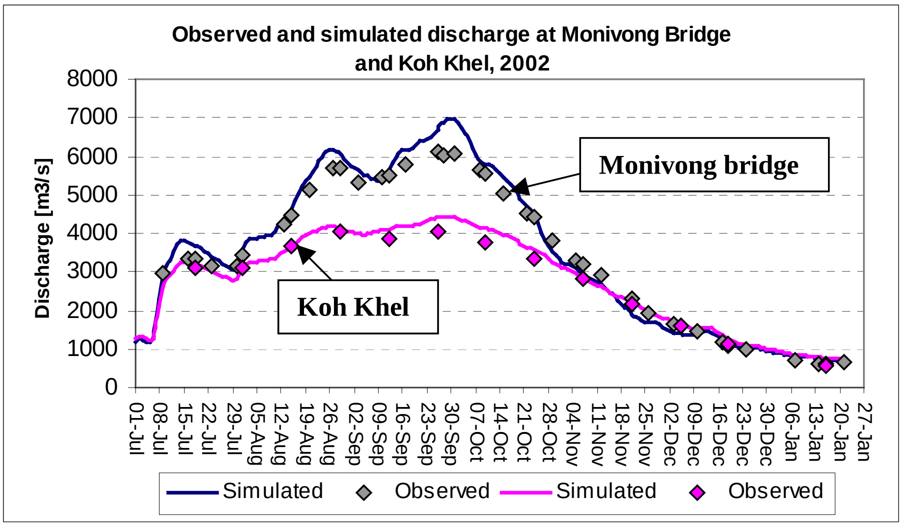


Fig. 3-14(1/2) Model Verification for the Year 2002: Mekong Mainstream (Unit: m^3/s)





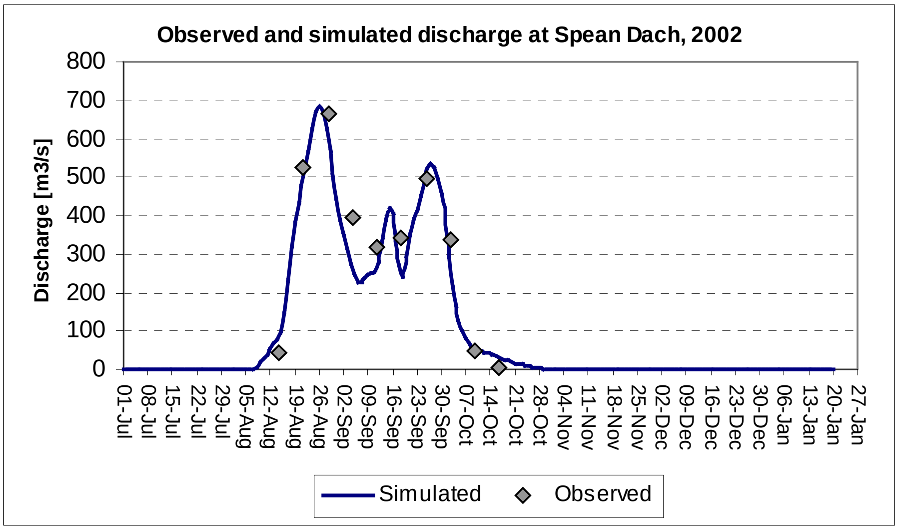


Fig. 3-14(2/2) Model Verification for the Year 2002: Bassac and Tonle Sap (Unit: m^3/s)

3.2 Application of the Model

This section describes the various applications made with the hydro-hydraulic model. The applications comprise the following four areas.

The purpose of the dry-season flow investigation was 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 collected at the Chak Tomuk junction during the 2003 dry season. The dry-season data were used for the model calibration as well as for the application to support the work on dry-season flow monitoring 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 effects 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.

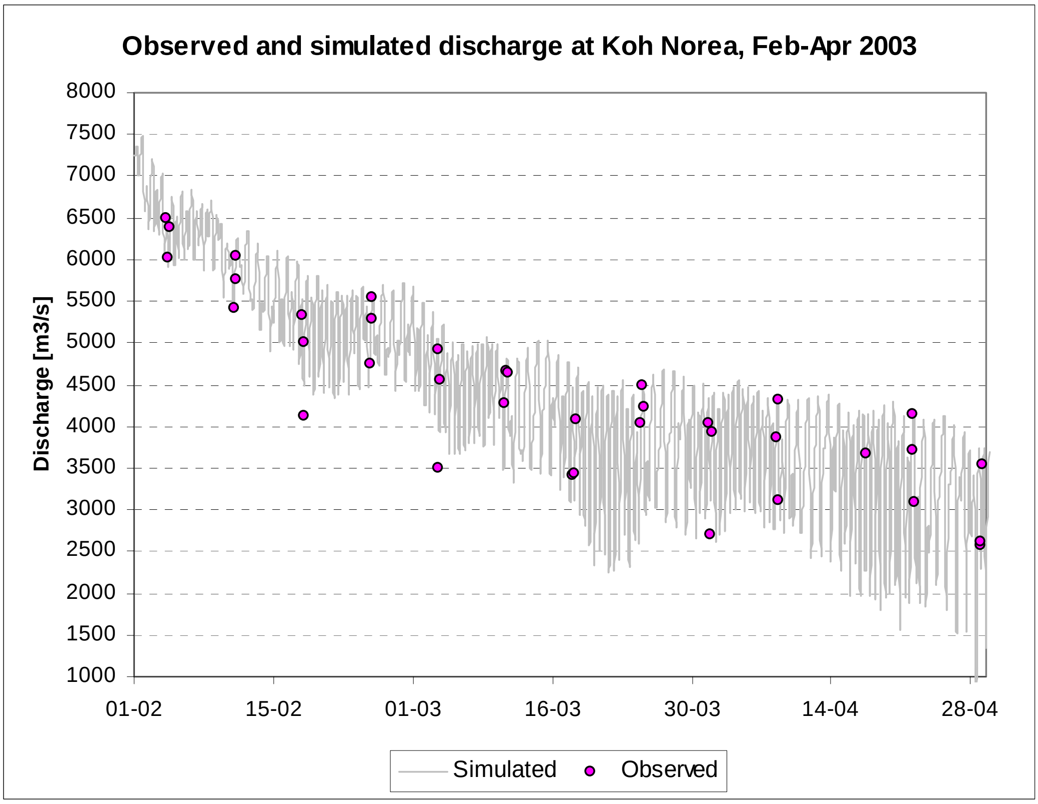
The study on the effect of increased bridge openings on floodplain inundation was made to demonstrate the hydraulic impact of construction of road embankments and associated bridges. The example presented herein shows clearly the importance of hydraulic studies in connection with infrastructure development 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 is useful for understanding the seasonal dynamics of the lake and floodplain system, and it has given support to the WUP-JICA work on maintenance of flows.

3.2.1 Dry-Season Flow Investigation

The model simulation revealed that it is possible to simulate the dry-season discharges with a 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. 3-15. The model predicts the phase and amplitude of the tidal levels relatively well. However, there seems 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. At present, therefore, the uncertainty is 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 from the modelling, is the predicted daily discharge. The predicted average daily discharge during the 2003 dry season is shown in Fig. 3-16.

The mathematical model has proven 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 average discharge 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 the tidal effect, and thereby provide guidance on location and timing of the measurements.



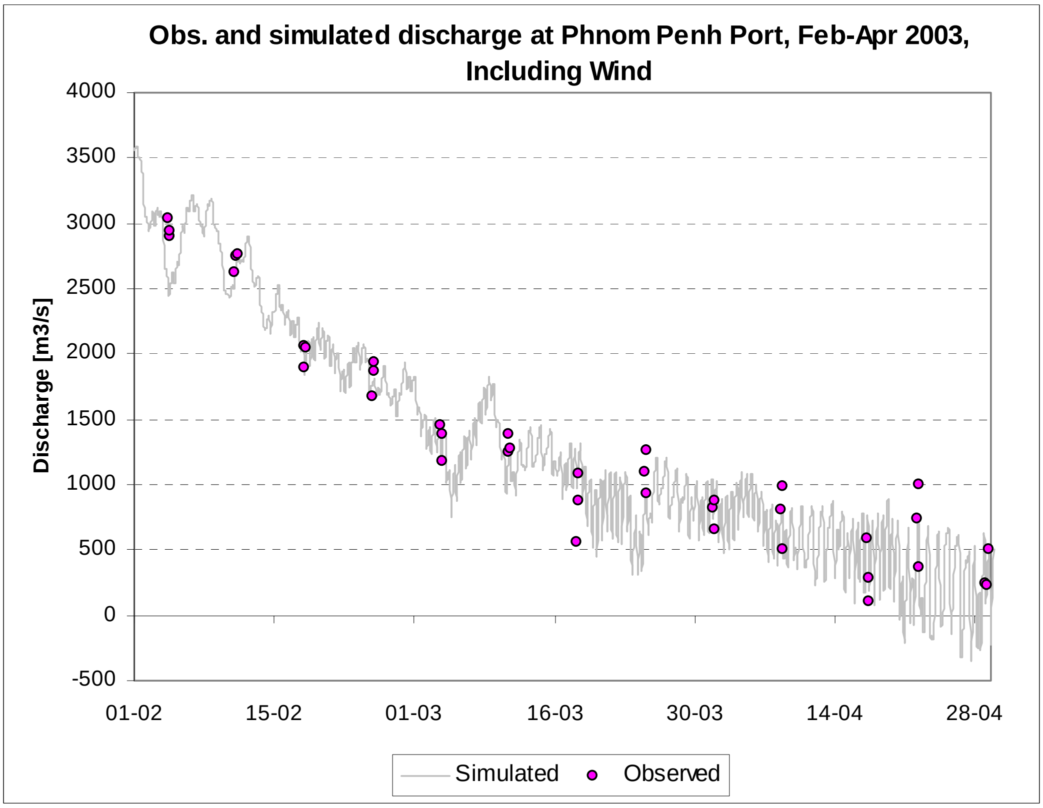


Fig. 3-15 Simulated and Observed Discharge at Chak Tomuk Junction, Feb. to Apr. 2003

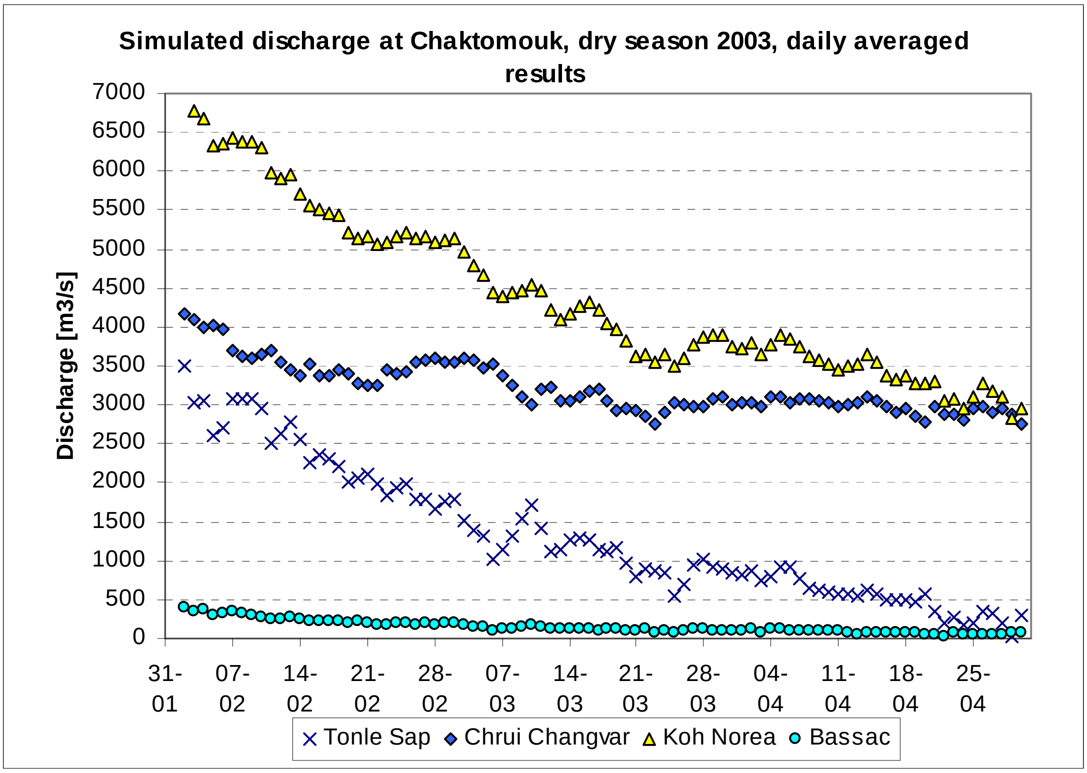


Fig. 3-16 Simulated Daily Average Discharge at Chak Tomuk Junction, Feb. to Apr. 2003

3.2.2 Hydraulic Impact of Road Embankment

Investigation was made 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 were identified:

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

The different roads with embankment locations are shown in the following figure.

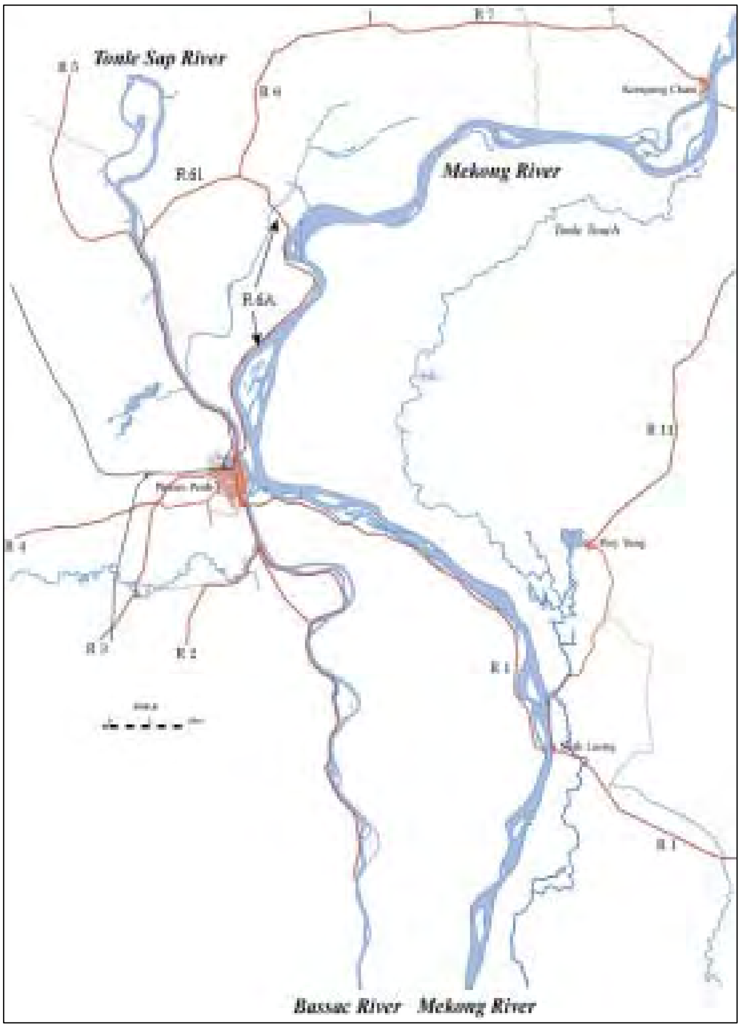


Fig. 3-17 Location of Major Road Networks in/around Phnom Penh

To represent the situations of the above periods correctly, it is necessary to obtain the topography of rivers and floodplains, discharge and water level hydrographs as well as rainfall from the different periods in time. Since not all of these data were available, the approach adopted was the closest representation of specified historical periods. Given this, no attempt was made to use hydraulic data from these periods. Instead the hydrograph from years 2000, 2001 and 2002 were used in the simulation. The existing river model setup was modified to represent the embankment conditions in the four periods mentioned.

<u>Simulation Results</u>

The simulated discharge at Chrui Changvar is shown in Fig. 3-18, top. It is seen that the discharge for the “prior to 1920” situation is significantly lower during peak flood than the other model setup. The discharge was reduced because a large portion of the flow had spilled into the floodplains towards the Great Lake between Kompong Cham and Chrui Changvar. The three other cases show almost identical discharges at Chrui Changvar.

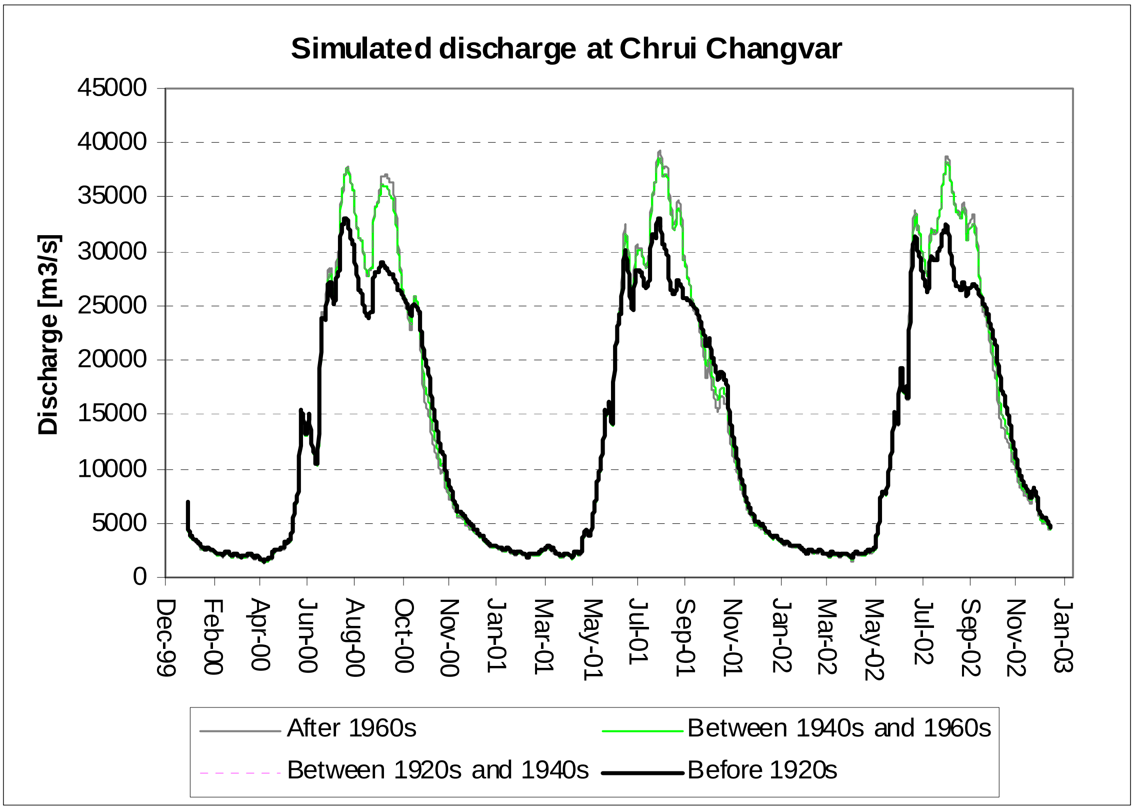
Similarly the simulated discharge at Prek Kdam is significantly different from the other cases that are almost identical, as shown in the bottom of Fig. 3-18. A conclusion from the plots on the figure is that the cases describing the 1920-1940, 1940-1960 and the 1960-present periods give an almost identical simulation results.

Regarding hydrological effects on water balance, there are significant differences between the water balances of the present embanked situation and the situation without embankment as presented in Fig. 3-19. 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.

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 road embankment of Road 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 2 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.



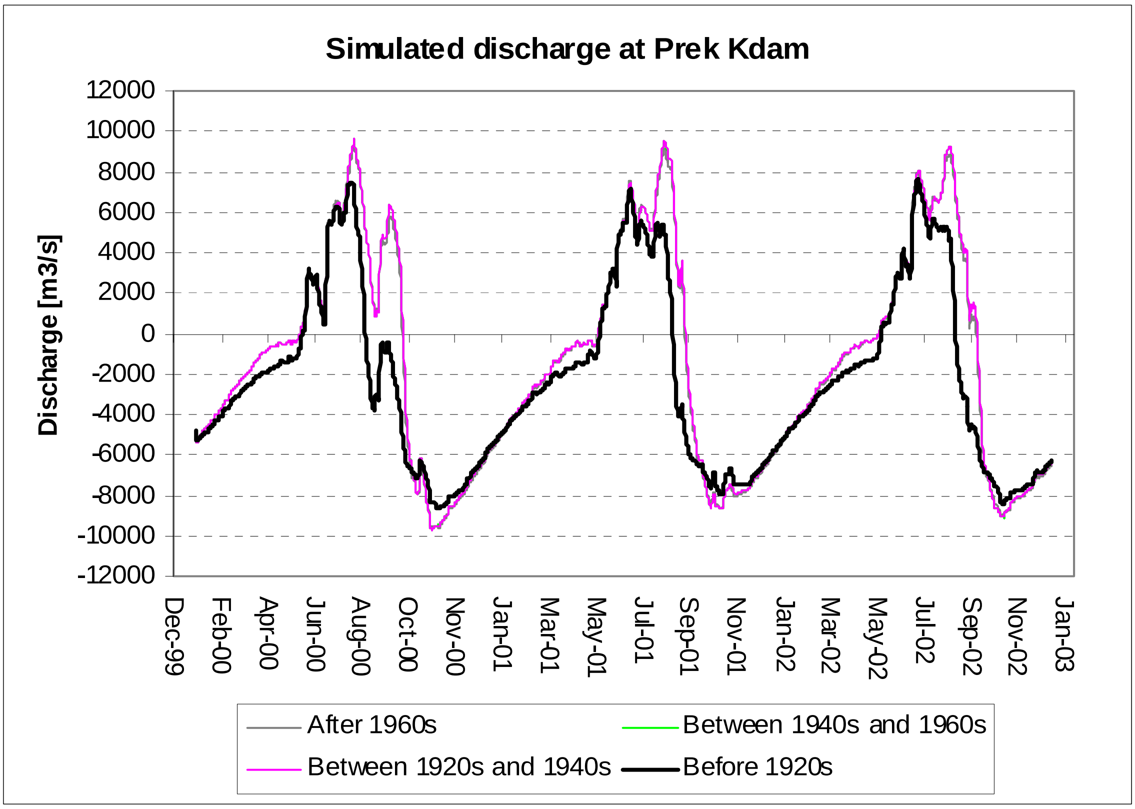


Fig. 3-18 Historical Hydrological Changes due to Road Network Improvement in the Upper Part of the Cambodian Floodplains

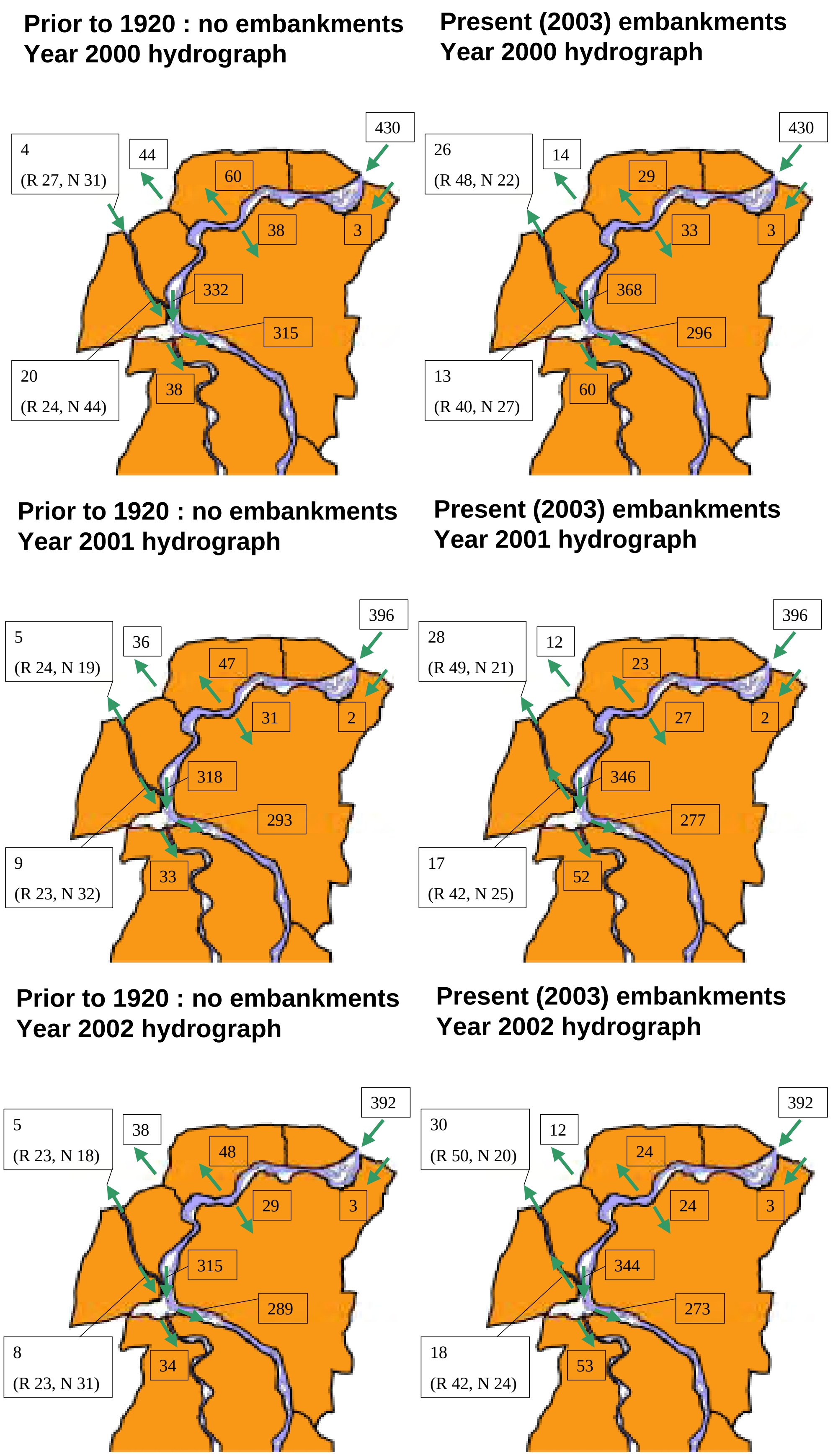


Fig. 3-19 Comparison of Water Balance for 1st June to 1st November in 2000 to 2002

3.2.3 Effect of Increased Bridge Opening on Floodplain Inundation

The simulations with the model have shown that the existing road embankment 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., Bridge F3 on Road 6).

As an application example, the model was 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. 3-20.

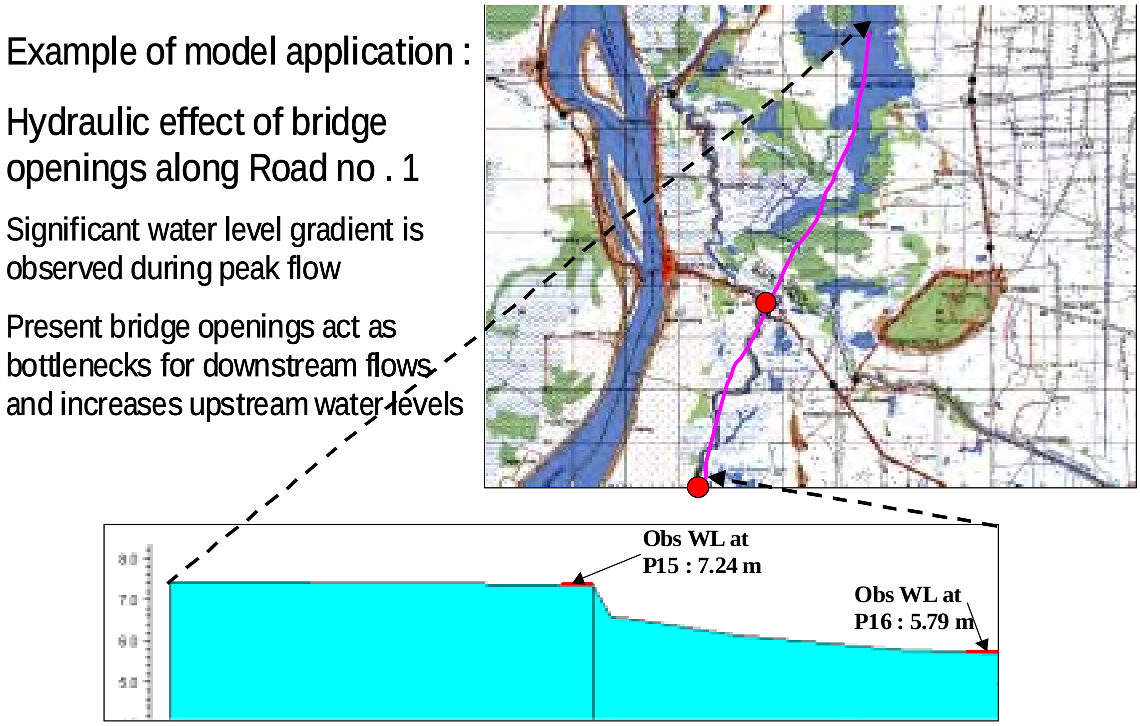


Fig. 3-20 Simulated Longitudinal Flow Profile of the 2002 Peak Flood

In the test simulation, the bridge openings were increased threefold, and the 2002 simulation was repeated. Fig. 3-21 shows the effect of the increased opening on the water level up and downstream of the bridge as well as the effect on the discharge. The water level on the upstream side decreases by approximately 0.5 m, and on the downstream side (only vicinity of bridge) the level increases by 0.2 m. The effect on the discharge is a 500 m^3/s increase from the original 3,000 m^3/s.

The effect on the water level is felt over a long distance. Simulation result on the water level difference shows that the upstream effect reaches more than 30 km upstream.

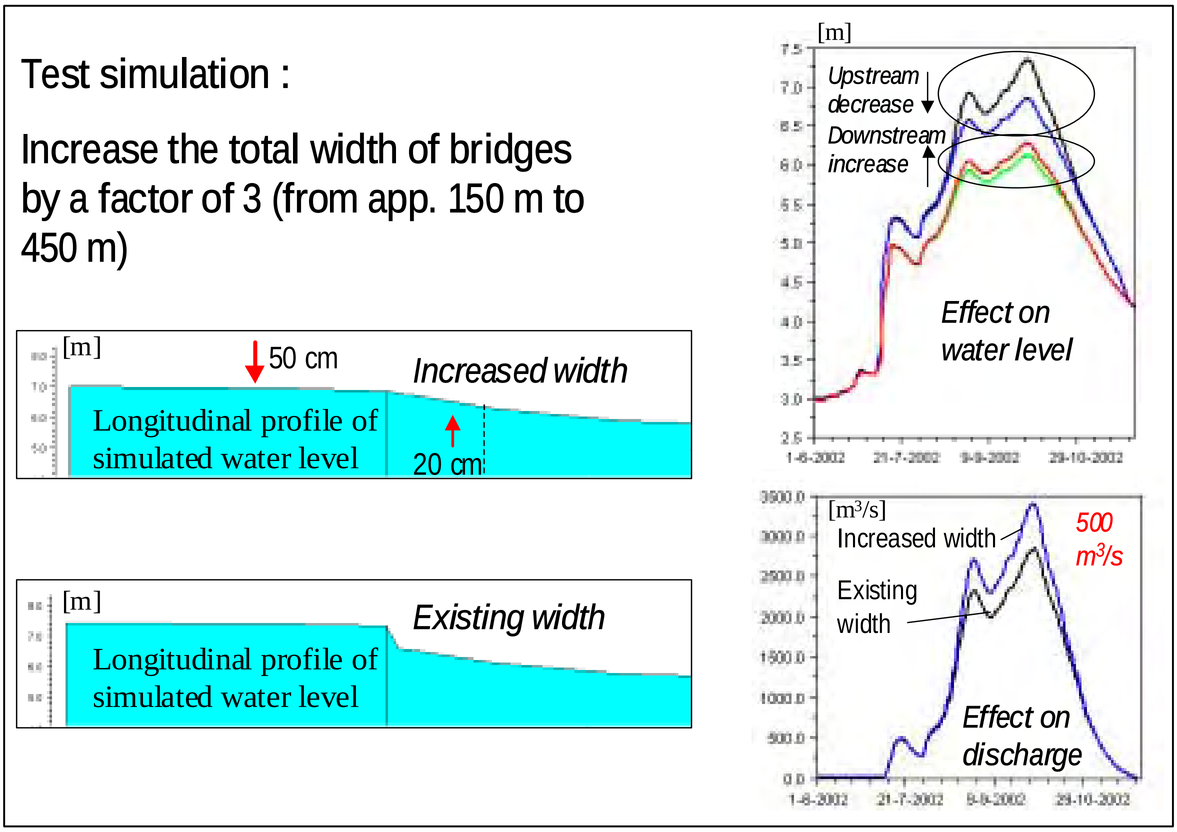


Fig. 3-21 Hydrological Effects of Enlargement of Bridge Openings on Water Level and Flow Discharge

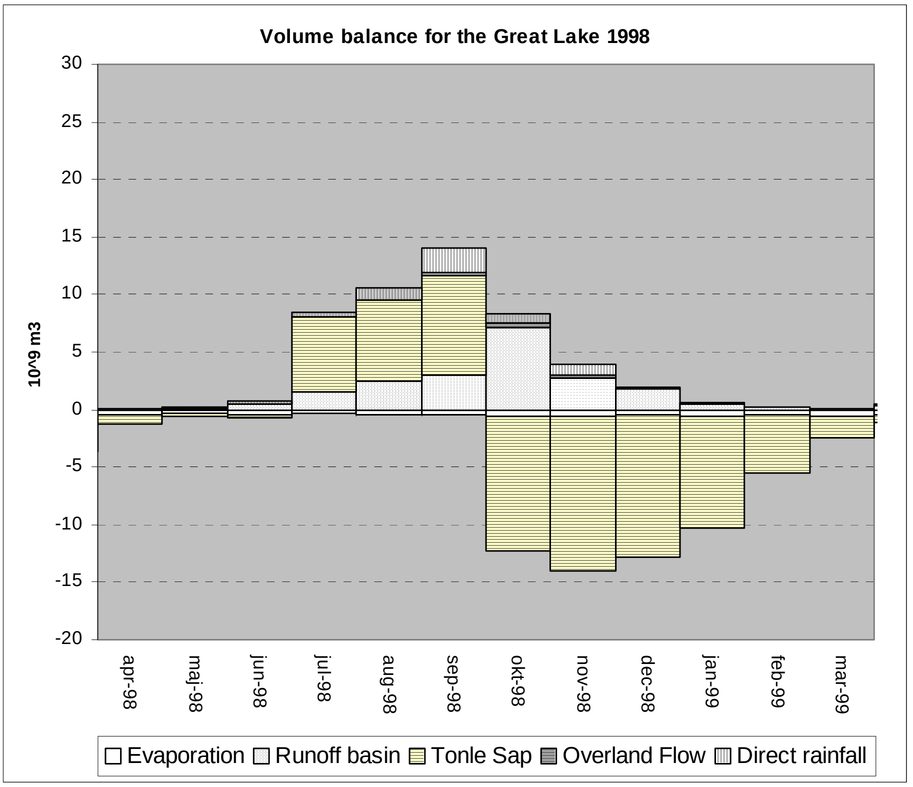
The application example presented in this section leads to the following conclusions:

- 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 the road embankments 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 the hydraulic gradient and thereby 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 associated with hydraulic studies.

3.2.4 Water Balance of the Great Lake

The present subsection 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.

The water balance of the Great Lake was 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 was made on a monthly basis using the model results from the 1998-2002 simulations. The 1998-2002 simulations had water level and discharge results stored at daily increments; hence, the discharge results were converted to volumes and lumped to give monthly results. Fig. 3-22 presents examples of water balance in 1998 as the dry year and in 2000 as the wet year.



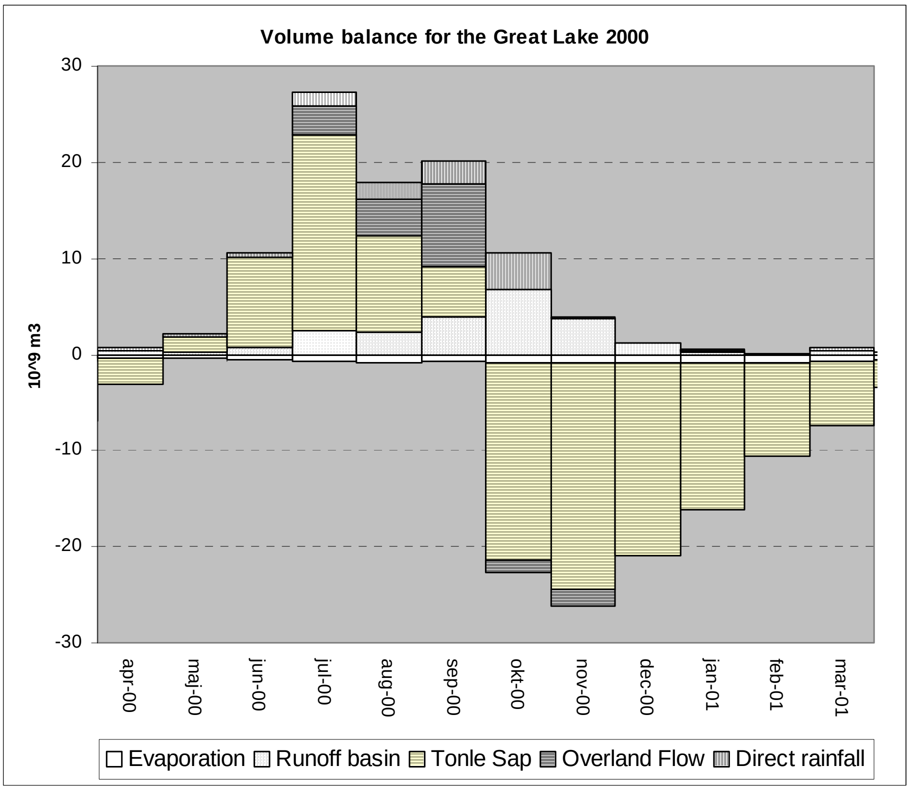


Fig. 3-22 Volume Balance for Hydrological Years 1998 and 2000

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.

CHAPTER 4 HYDROLOGY AND WATER USE IN THE LOWER MEKONG BASIN

4.1 Hydrology in the Lower Mekong Basin

4.1.1 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 for 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.

This section summarizes the results of hydrological investigations that were 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.

4.1.2 General Hydrological Features on the Lower Mekong Mainstream

Fig. 4-1 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.

Table 4-1 summarizes the flow data observed at the twelve (12) major hydrological stations since 1960s. The data source is the hydrological database of MRCS. Fig. 4-2 presents 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.

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

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, Laos, gives a big contribution to form the wet-season flow. Even though there might be some discrepancies on longitudinal distributions and data among the hydrological stations, the annual mean and maximum flow receive the predominant flow contributions from the tributaries originating in those mountains. Every year when such swelling flood hydrograph reaches the Cambodian floodplains, which expands widely from the apex of Kratie downwards, almost 15% of 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.

Fig. 4-1 Major Hydrological Stations on the Mekong Mainstream

Table 4-1 Flow Parameters of Major Hydrological 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.

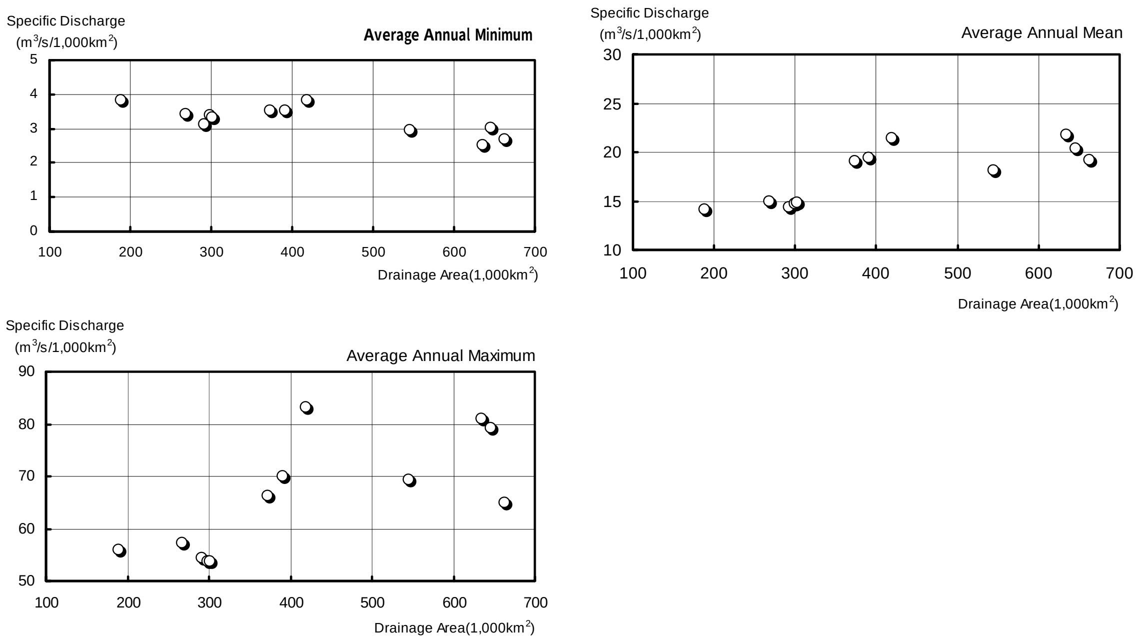


Fig. 4-2 Flow Parameters of Major Hydrological Stations on the Lower Mekong Mainstream

4.1.3 Drought Situations in the Lower Mekong Basin

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

Actual hydrological events are changeable and of large fluctuation in behaviour. 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. To illustrate this, the probability of occurrence of the 1998 drought was estimated at nine stations from Chiang Saen to Pakse on the Mekong mainstream 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.

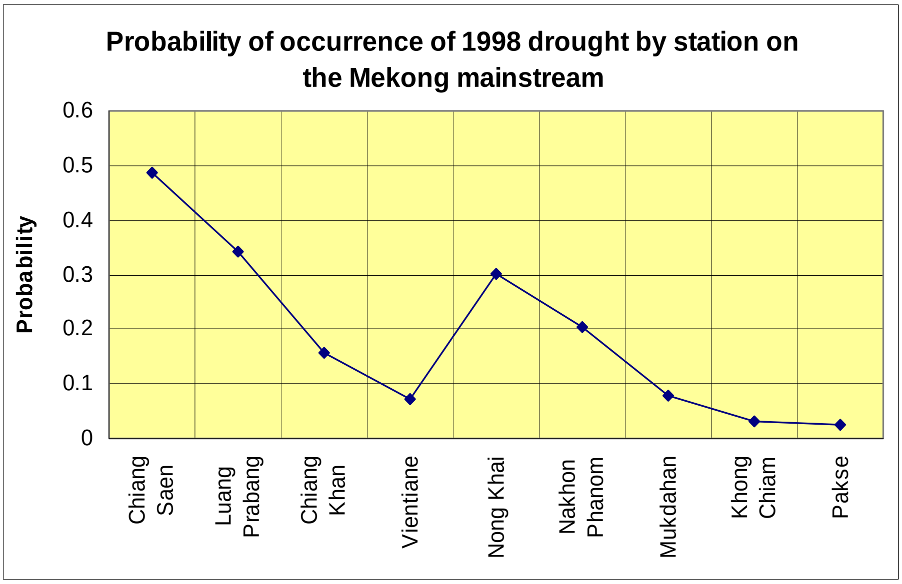
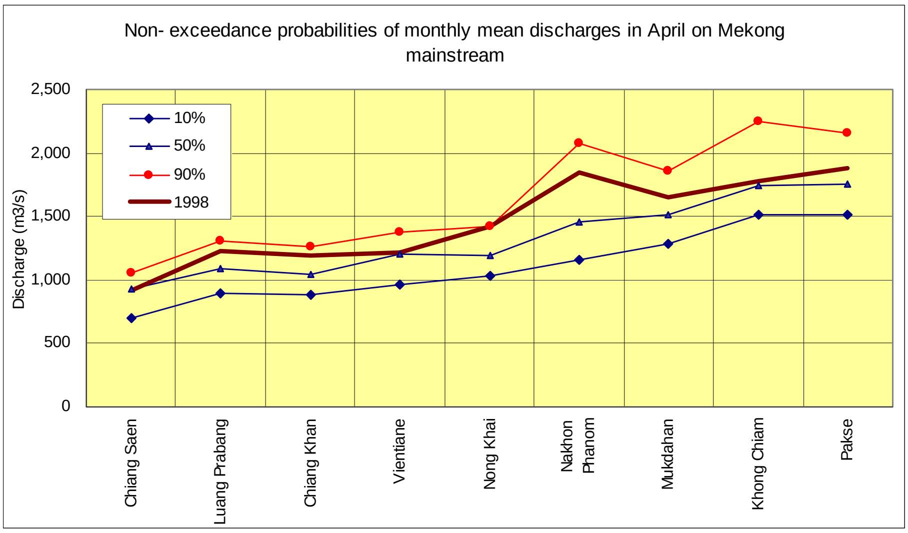


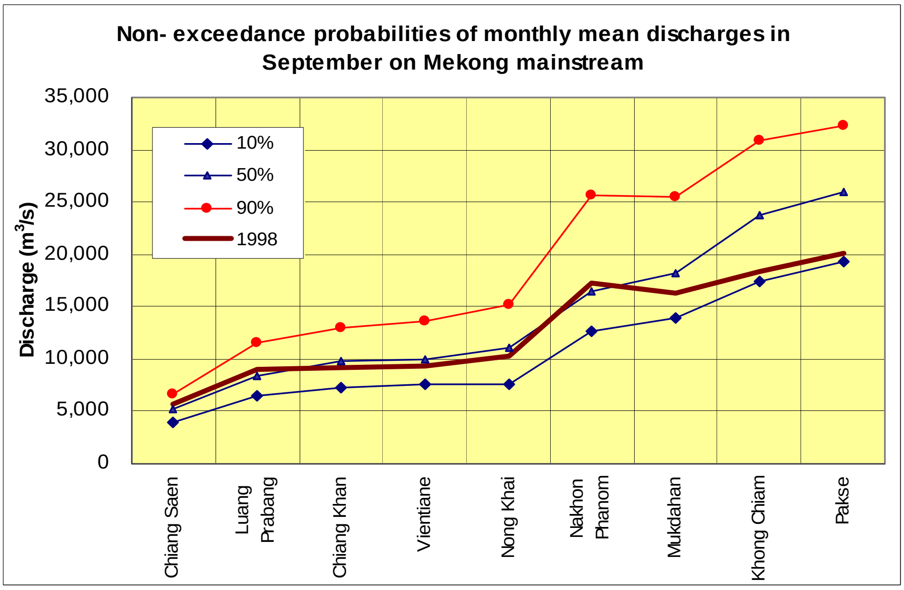
Fig 4-3 Comparison of Probabilities of Occurrence of 1998 Drought

As seen above, the probabilities of occurrence of the 1998 drought are 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.

Monthly mean discharges in the 1998 drought were 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. 4-4.

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 1998 of the dry year. 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. 4-5 presents the comparison results.





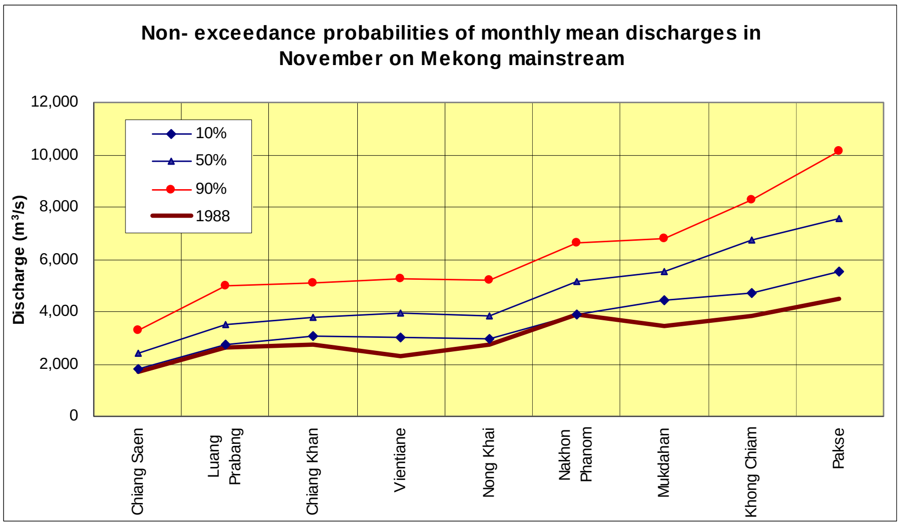
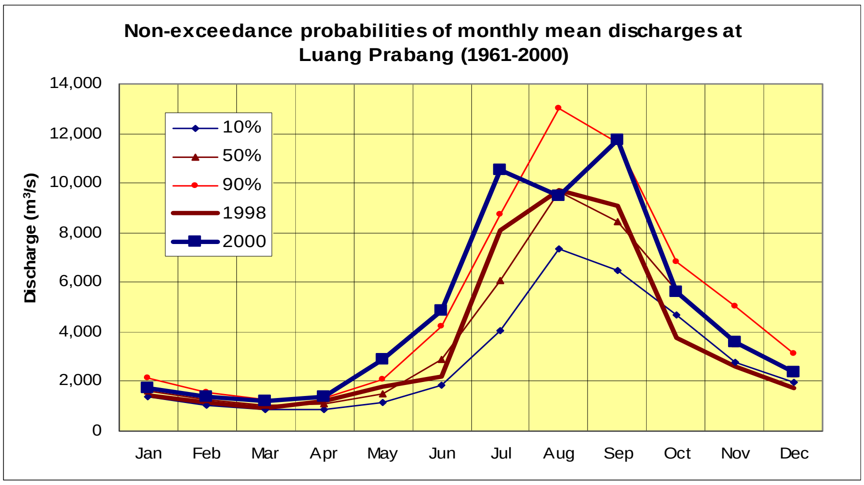
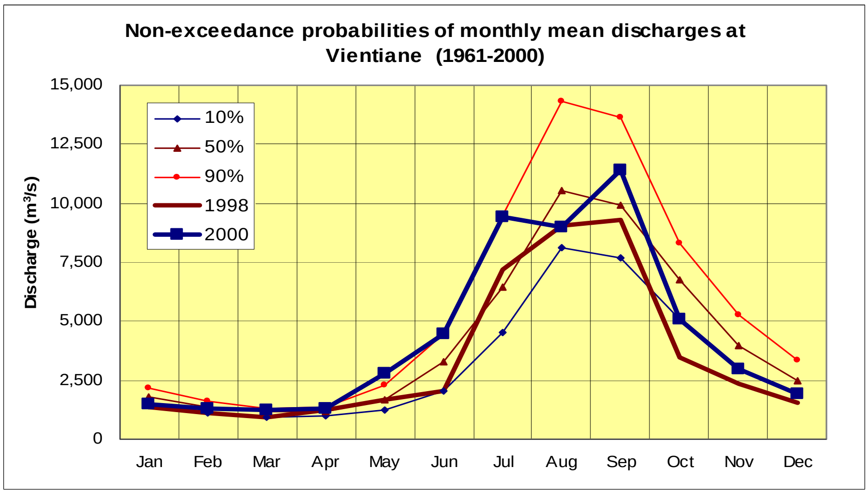


Fig. 4-4 Comparison of Monthly Mean Discharges in 1998 to Drought Discharges in April, September and November





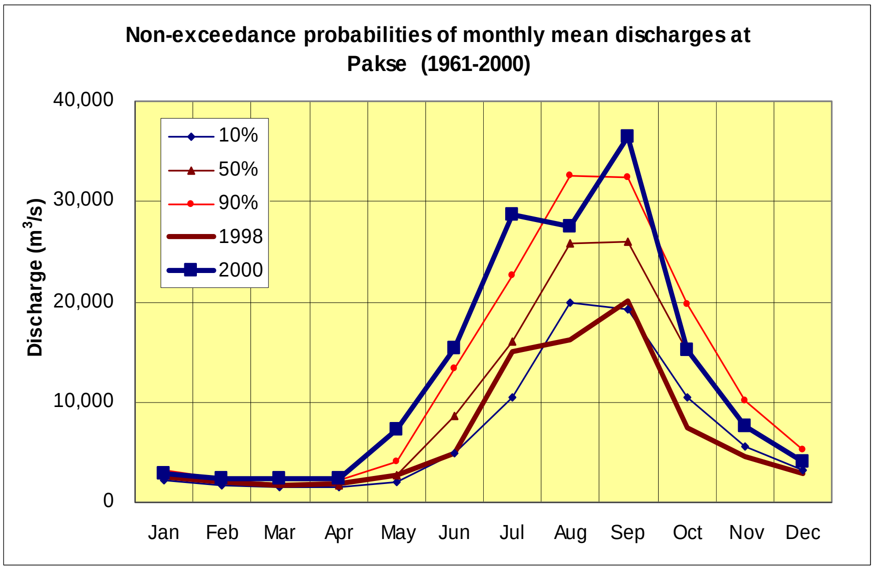


Fig. 4-5 Comparison of Monthly Mean Discharges in 1998 as Drought Year and in 2000 Water-Rich Year to Drought Discharges at Luang Prabang, Vientiane and Pakse

Categorization of Drought Events

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

From these results of probability distributions, six (6) distribution patterns of annual flow regime could be categorized for easy understanding of drought events in the basin. Out of the annual flow regimes, several typical years were selected for each pattern, as shown in the table below. Plots of probability distribution of the selected annual flow regimes are shown in Fig. 4-6.

Table 4-2 Categorization of Typical Annual Flow Regimes

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

Source: WUP-JICA Study Team

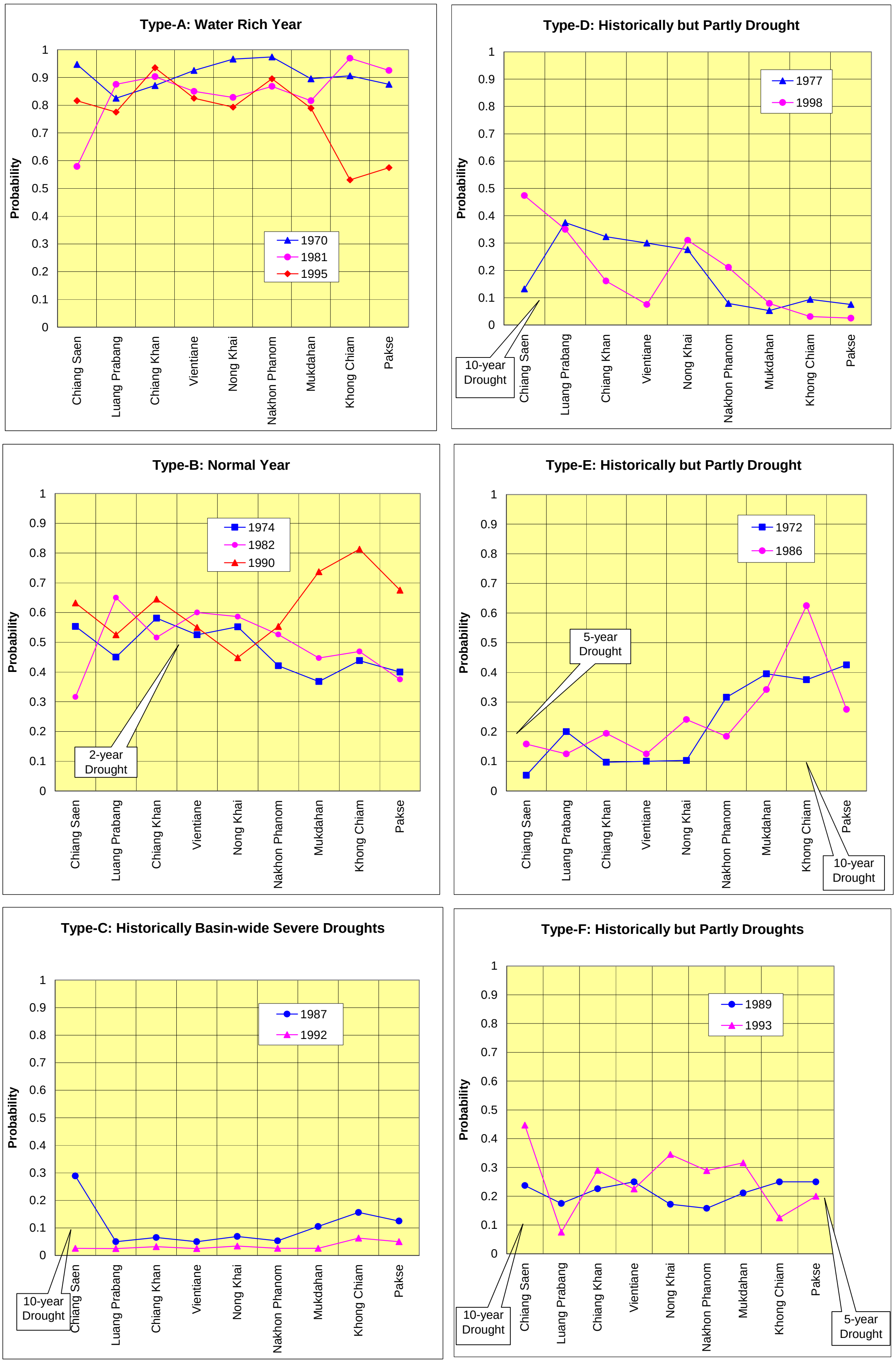


Fig. 4-6 Longitudinal Plots of Occurrence Probabilities of Categorized Annual Flows

4.1.4 Hydrological Functions of the Cambodian Floodplains

Flow Balance along 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 under the TSLVP. 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 were clarified in the hydrological functions of the Cambodian floodplains.

(1) Upstream of Kompong Cham on the Mekong

The longitudinal discharge measurements started at Kompong Cham and proceeded downward. Some significant flooding occurred in the stretch from Chhlong to Kompong Cham. A reliable rating curve was 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. 4-7.

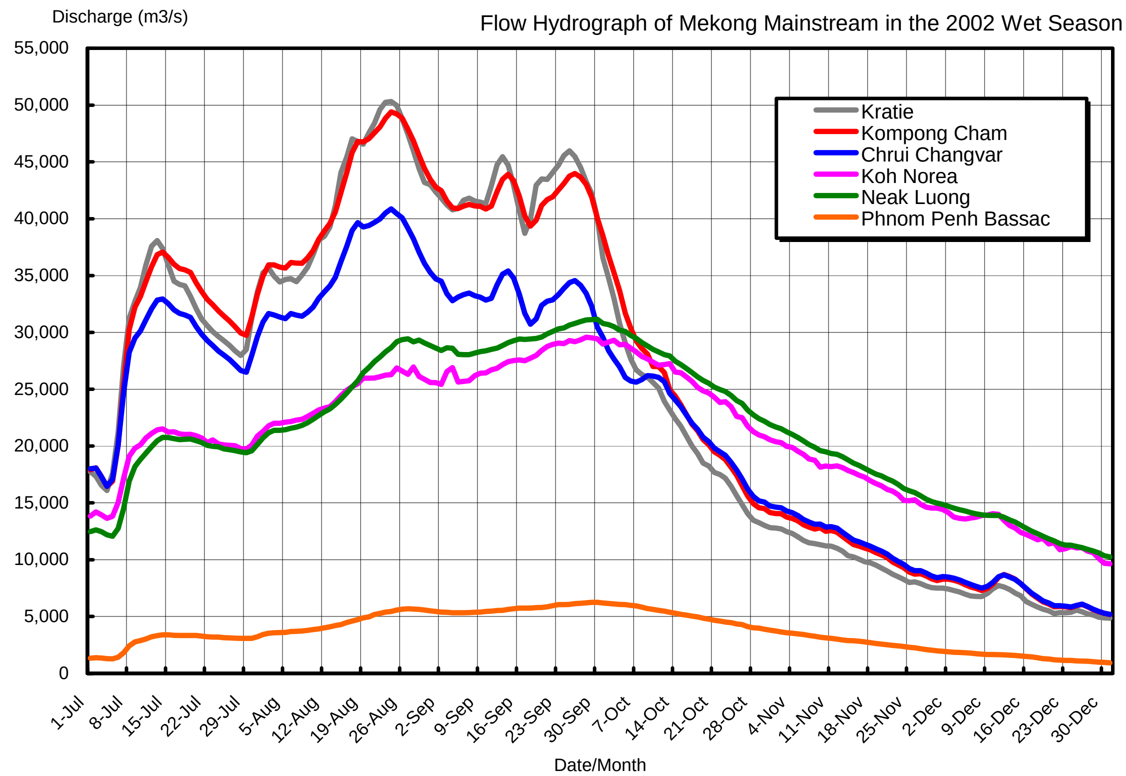


Fig. 4-7 Flood Hydrograph in Cambodian Floodplains in the 2002 Wet Season

Fig. 4-7 above shows three flood peaks in the 2002 wet season. The flooding functions of flood peak attenuation were estimated at 900 to 2,240 m^3/s. These functions are equivalent to 2 to 5% of flow discharge at Kratie.

(2) Downstream of Kompong Cham on the Mekong

In the stretch of Kompong Cham down to Neak Luong, 12 longitudinal discharge measurements were conducted from July 18, 2002. A part of the results is illustrated in Fig. 4-8.

This figure implies the following hydrological facts:

- The flood discharges of 45,100 m^3/s on August 29 and 44,800 m^3/s on September 26 are 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 overbanking flood and outflow into the flood paths. Some 25% of the discharge was reduced on the way down to Chrui Changvar.
- Fig. 4-9 depicts the relationship between 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.

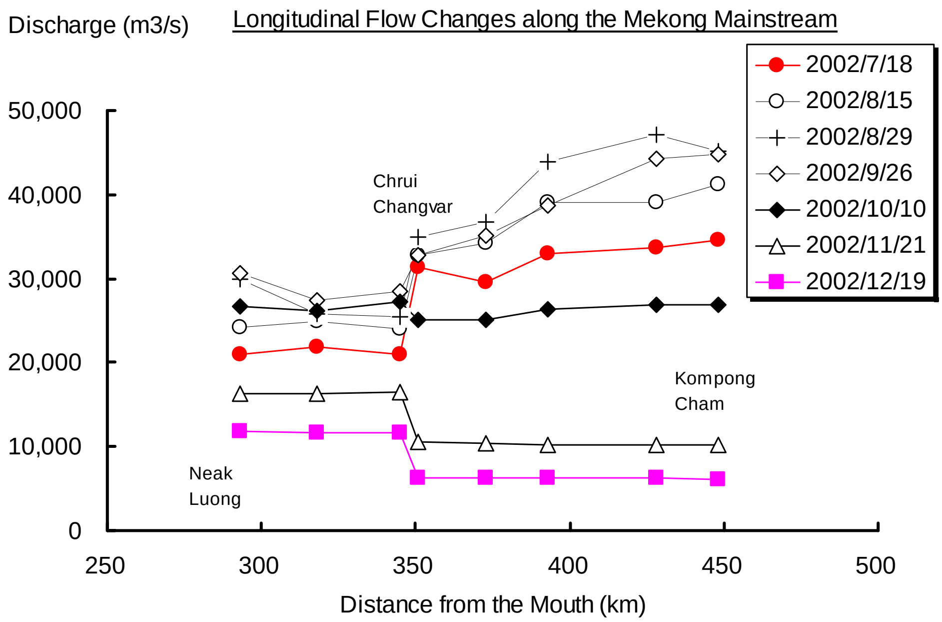


Fig. 4-8 Longitudinal Flow Changes along the Mekong Mainstream

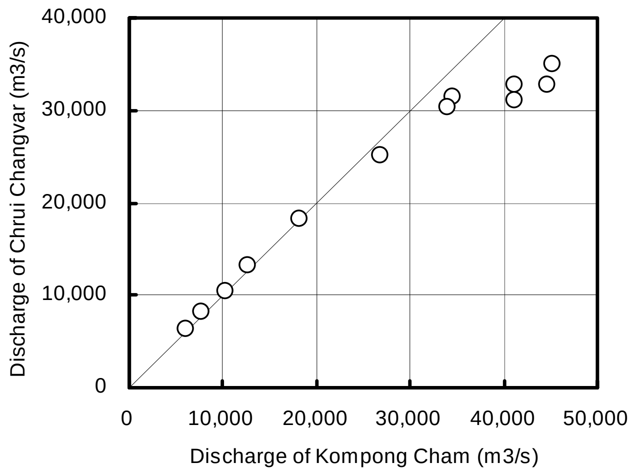


Fig. 4-9 Relationship between Flood Discharges of Kompong Cham and Chrui Changvar

(3) Tonle Sap

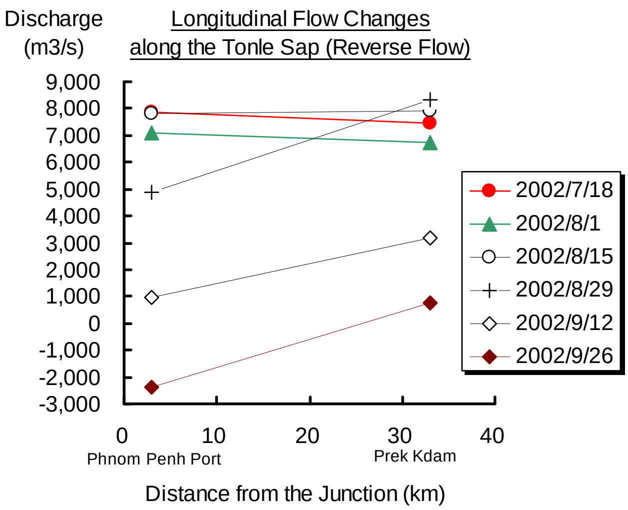
Flow balance along the Tonle Sap might be complicated since flow direction drastically changes during the flood season. The results of longitudinal measurements are illustrated in Fig. 4-10. In due consideration of the flooding process along the Mekong mainstream, the flow balance between Phnom Penh Port and Prek Kdam can be easily understood following the temporal changes of the balance.

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

- From the middle of August to the end of September, extensive flooding occurred along the Mekong mainstream. Some parts 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 starting at Chak Tomuk junction (Phnom Penh Port) increased up to Prek Kdam, receiving the floodwaters of the Mekong.

- Once the Great Lake was filled up 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.



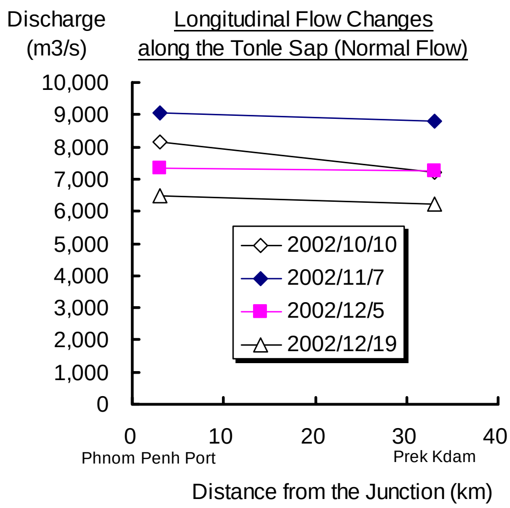


Fig. 4-10 Longitudinal Flow Changes along the Tonle Sap

(4) 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. 4-11 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 the 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.

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.

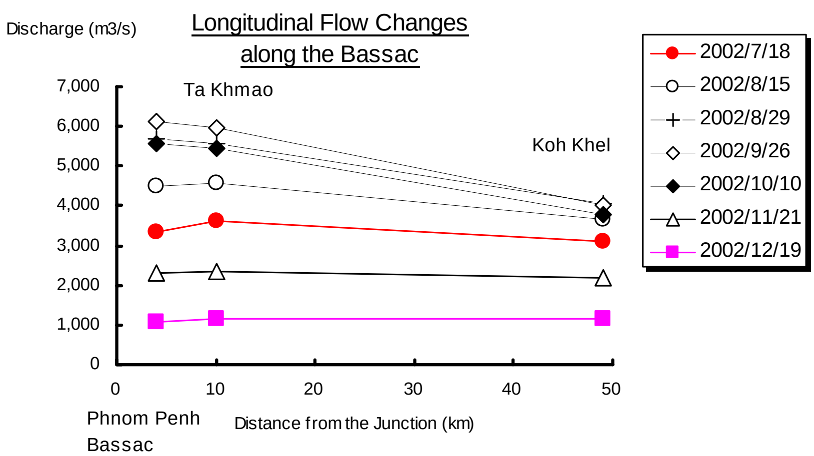


Fig. 4-11 Longitudinal Flow Changes along the Bassac River

Hydrological Functions of 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 onto 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 at 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, extensive 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.

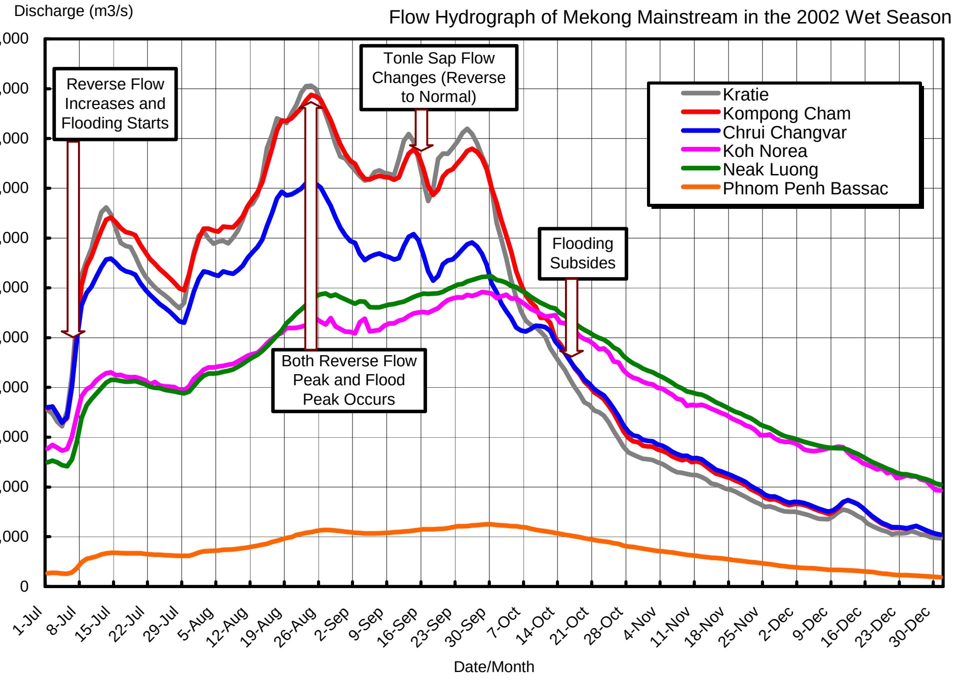


Fig. 4-12 Flooding Situations in the Cambodian Floodplains

Flood balance between Kompong Cham and Phnom Penh was computed utilizing a series of the results, such as flood hydrographs at major stations, water balance in the floodplains, and hydrodynamic simulation outputs. Fig. 4-13 summarizes the flood balance in the 2002 wet season.

From Fig. 4-13, 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 accompanying overbanking 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) Overbanking 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 shall 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.

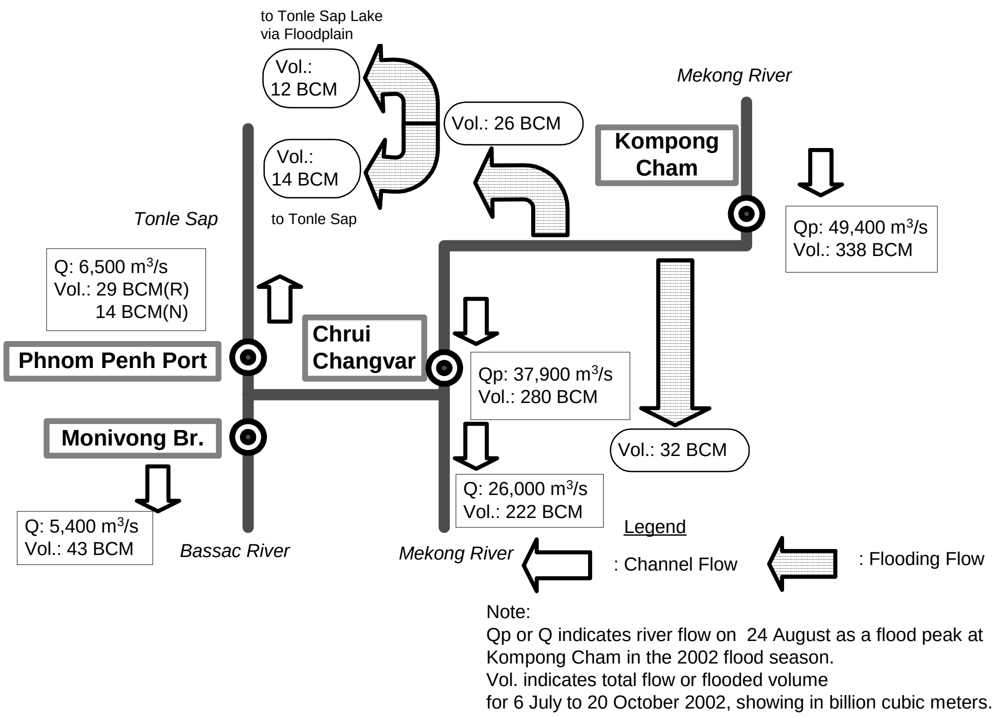


Fig. 4-13 Flood Balance between Kompong Cham and Phnom Penh in the 2002 Wet Season

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. In particular, as presented in Fig. 4-13, the flooding functions of the floodplains also play an important role towards conservation of the Great Lake as a natural retarding reservoir.

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 is to clarify the former issue.

To make the approach easier, flow data of Kompong Cham were used instead of the data of Kratie as indicated in the 1995 Agreement, 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 was made easier because the rating curve at Kratie was also developed as presented in Chapter 2 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 the 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. 4-14 illustrates the recent flood hydrographs and the threshold discharge. From the figure, differences of the flood volume in each year are easily recognized.

Flood volumes at Kompong Cham and maximum storages of the Great Lake were estimated in 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 4-3.

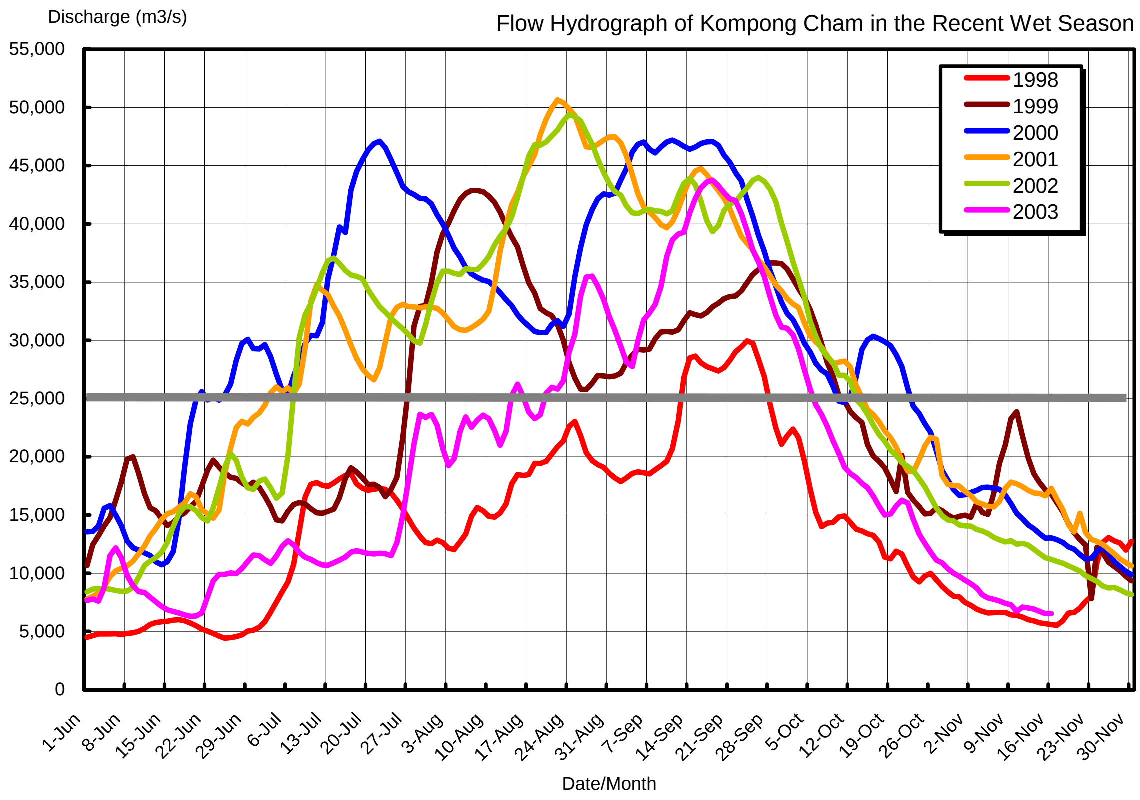


Fig. 4-14 Flood Hydrographs at Kompong Cham in Recent Years and Threshold Discharge of 25,000 m^3/s

Table 4-3 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. 4-15. The figure shows a high correlation between the two parameters.

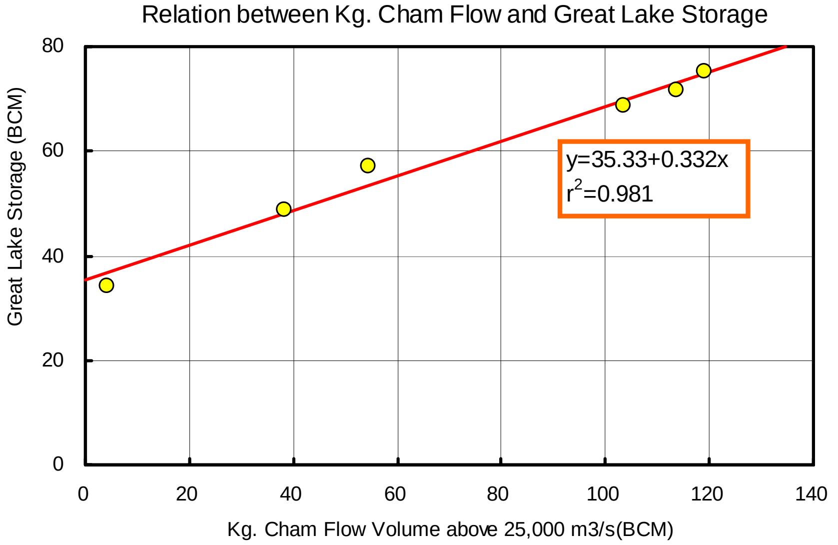


Fig. 4-15 Relation between Kg. Cham Flood Volume and Great Lake Storage

(2) Recommendation for Rule Formulation

The relation between flood volume and lake storage shows a high correlation. The stakeholders shall 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 Agreement shall be placed on some midpoint between the lowest of the 1998 event and the highest of the 2000 event. Fish catch suddenly and sharply dropped in the 1998 drought event so that the optimum level shall be higher than the level in 1998. However, the 2000 flood brought serious damages to Cambodia so that the optimum level shall be lower than the level in 2000. Thus recent year's hydrological events give better examples to consider the optimum level of the Great Lake.

4.2 Water Use in the Lower Mekong Basin

4.2.1 Introduction

The water of the Mekong River is mostly used for irrigation, hydropower generation, domestic and industrial sectors. Both peak and low flows in the river are of major concern for sustainable development of the Lower Mekong Basin (LMB). However, the low flow regime on the mainstream has been affected and altered due to enhanced water use in various sectors and development activities in the LMB. Hence, the low flow regimes, at several key hydrological stations along the mainstream, were investigated to draw attention on some pertinent issues related to a future hydrological monitoring on the Mekong mainstream in accordance with the Rules for the Maintenance of Flows on the Mainstream. The Rules are now being drafted for the approval of the MRC Council by the end 2004.

4.2.2 Existing Water Resources Facilities in the Mekong River Basin

There are many seasonal storage facilities (reservoirs) in the LMB. At present the total storage capacity of the existing large reservoirs amounts to approx. 12.1 billion m^3. The seasonal regulation rate of all of the existing reservoirs in the whole Mekong River Basin (MRB) is roughly estimated to be around 2.5%.

Table 4-4 Total Effective Storage Volume by Riparian Country

Country (Coverage of MRB)	Number 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

China

Over the Lancang River in China (22% area of the entire MRB falls in China) two hydropower development projects have already been completed, at Manwan and Dachaosan, as cascade hydropower developments on the Mekong mainstream. The effective storage capacity of both reservoirs is 498 million m^3. Although these projects are provided with large reservoirs for hydropower generation, they are operated under the mode of run-of-river basically for maintaining the maximum water level in reservoir for maximizing energy output (in principle so called "inflow = outflow" operation without seasonal regulation). It might be said that these two hydropower dams have no significant impacts on the low flow regime of the Mekong mainstream.

However, the third ongoing dam construction at Xiaowan (4200 MW) over the Lancang River, with storage capacity of 11,500 million m^3 for seasonal flow regulation, is expected to increase dry season flow by around 555 m^3/s. Further, after completion of all cascade projects, the low flow is expected to increase by around 1,230 m^3/s. Hence, it has been reported that the mean monthly flow in the Mekong downstream is expected to increase by about 28%, 27%, 27% and 17% at Chiang Saen, Luang Prabang, Vientiane and Mukdahan, respectively, in May.

Myanmar

The Mekong River forms part of the eastern border of Myanmar. In Myanmar, the Mekong River drains 28,000 km^2 (3% of the area of MRB) watershed. Water resources development activities in this watershed are quite few. Only a few mini-hydropower plants have been constructed along the tributaries of the Mekong, which do not have much impact in the flow regime at the downstream part of the mainstream.

Lao PDR

Lao PDR, which covers 25% of the area of MRB, has a large potential for hydropower development. Currently there are five hydropower projects (above 10 MW) with an installed capacity of totally 615 MW. Among these projects, three are of reservoir type hydropower projects. Those three projects are theNam Ngum and Nam Leuk hydropower projects in Nam Ngum River and the Houay Ho project in Se Kong River. The total effective storage capacity of these projects is about 5,200 million m^3. According to the historical operation records of the Nam Ngum Dam, the flow increase in terms of monthly mean discharges in the dry season (February to April) was estimated to be around 190 m^3/s. The water used for power generation at the Nam Leuk Power Station is diverted into the Nam Ngum reservoir, enhancing the power generation of Nam Ngum Power Station. The Houay Ho Hydropower Project harnesses the high water head of 765 m using the maximum plant discharge of around 24 m^3/s. The Houay Ho Hydropower Project therefore cannot expect any significant change in the low flow regime.

Thailand

In Thailand, the Mekong River has about 170,000 km^2 of watershed lying on the northeastern part of the country, which is 22% of the area of MRB. The Nam Mun-Chi River is the largest tributary with a catchment area of about 120,000 km^2. In this basin, intensive water resources development has been made from the mid-1960s to mid-1970s. At present, there are nine seasonal regulating large-scale reservoirs, which are supplying water for irrigation during the dry season. Among the nine reservoirs, four reservoirs are also used for hydropower generation as shown below. In total the reservoirs have the storage capacity of about 5,460 million m^3 and the command area for irrigation is about 240,000 ha. The seasonal regulation rate of all the reservoirs to the mean annual flow volume in the Nam Mun-Chi basin is estimated to be around 6.9%.

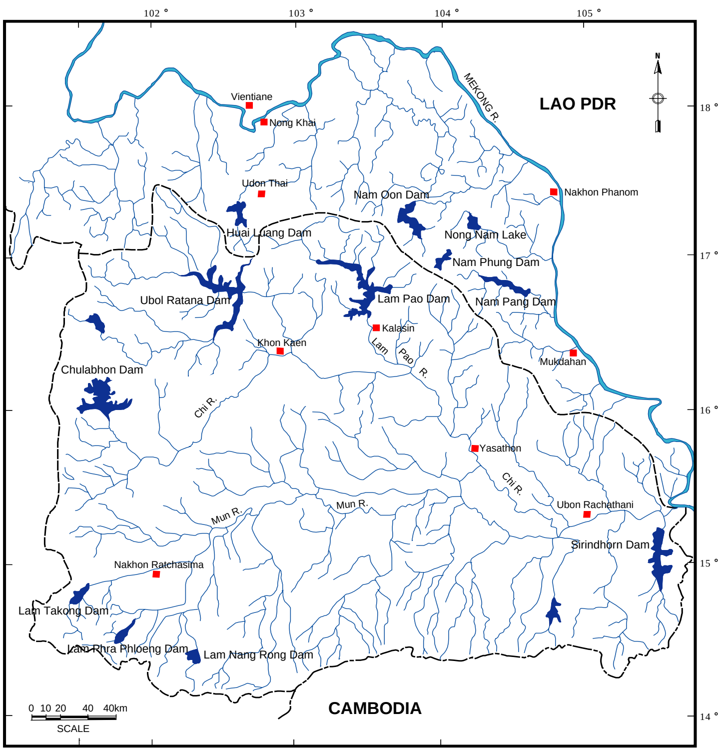


Fig. 4-16 Location Map of Major Reservoirs in Northeastern Thailand

Cambodia

In Cambodia, about 155,000 km^2 of watershed, which occupies 19% of the area of MRB and 90% of the area of the country, is drained by the Mekong River. The Tonle Sap River, which composes with largest freshwater Great Lake, is the major tributary of the Mekong River. The Great Lake, with storage capacity of about 150 billion m^3, is not only the major source of inland fishery but also vital for mitigating flood at the downstream in the Mekong Delta. There are no other reservoirs existing in Cambodia at present.

Vietnam

In Vietnam, the Mekong Basin falls on two parts of the country, namely, the Mekong Delta (39,000 km^2) and Central Highland Region (48,500 km^2). Altogether, 8% of the area of MRB falls in Vietnam. The Se San (14,800 km^2) and Sre Pok (18,200 km^2) are the major tributaries of the Mekong River in the Central Highland Region, with great potential for hydropower and irrigation development. However, the Yali (720 MW), a reservoir type of hydropower project and the first seasonal regulation reservoir in MRB with 779 million m^3 of effective storage capacity, was completed on the Se San River in 2000. Further, the Mekong Delta is the major agricultural zone, where irrigation and drainage networks have extensively developed, covering about 2.4 million hectares of land for paddy and mixed crops.

Large Reservoirs

In the Mekong River Basin, as of 2000, there were thirteen (13) hydropower plants with installed capacity greater than 10 MW. Among those hydropower plants, seven are seasonal storage (reservoir) type and six are run-of-river type, as enumerated in Table 4-5. Moreover, seasonal storage type hydropower projects have significant roles in regulating the flow in the tributaries in the dry season, because the seasonal storages (reservoirs) retain wet season river flow to generate power in the dry season; whereas, in run-of-river type hydropower projects water release and inflow rates are maintained equally so as not to have any impact on the flow regime of the river. Their locations are presented Fig. 4-17.

Table 4-5 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 related reports

Fig. 4-17 Location Map of Existing Hydropower Projects in the Mekong River Basin

Source: MRC: MRC Hydropower Development Strategy, 2001

4.2.3 Current Water Use in the Lower Mekong Basin

Domestic/Municipal Water Use

For domestic water use, about 48.3 million m^3/year was estimated for Lao PDR in 1999; however, 74% of this was for Vientiane. Further, according to ESCAP (1991), in northeastern Thailand the total domestic water use was estimated at 92.3 million m^3/year, in which urban and rural water uses were estimated at 77.3 and 15.0 million m^3/year, respectively. Similarly, in Cambodia 68 million m^3/year was estimated as urban water use for Phnom Penh in 2002. Moreover, for the Mekong Delta in Vietnam, the domestic water use was estimated at 400 million m^3/year in 2000.

This indicates that domestic water use in the Mekong Delta is far higher than in other parts of the Mekong Basin.

Irrigation Water Use

About 75% of the population of LMB is dependent on agricultural activities, which includes fisheries as well. In 1999, the contributions of agriculture on the GDP in each riparian country were 47.2%, 18.3%, 36.5% and 22.7% in Lao PDR, Thailand, Cambodia and Vietnam, respectively.

According to the LRIAD, MRC project report (2002), the total irrigated areas under LRIAD in each riparian country in the Mekong Basin were 224,232 ha, 941,425 ha, 392,117 ha, and 1,719,102 ha in Lao PDR, Thailand, Cambodia and Vietnam, respectively. However, the statistics of DOI, MOAF (2001) of Lao PDR shows that total irrigated area in Lao PDR was 152,000 ha in 1990/91. Further, the Lower Mekong Basin Water Balance Study Report (1984) shows that at that time the total irrigated area in the Mekong Basin of northeastern Thailand was 924,398 ha. Similarly, the Cambodian Agricultural Development Option Review Report (1994) states the total irrigated area in Cambodia in 1990 was 306,000 ha. Based on the study reports, it could be concluded that the irrigated area had increased considerably in Lao PDR and Cambodia during the last decade; however, expansion of the irrigated area in the Mekong Basin in Thailand was negligible during that period.

The pump irrigation system is practiced to irrigate the agricultural land in the basin as usual. In total, there are 494 pump irrigation systems in Lao PDR, which are irrigating 81,225 ha of land. Pump irrigation is a significant portion of the current irrigation systems in Lao PDR, accounting for the irrigation of around 80% of the total irrigation area. In Thailand, pump irrigation is very active along the Nam Mun-Chi River (283 systems by DEDP in 1994) as well as the Mekong mainstream (247 systems by DEDP in 1994). Although no recent data are available, according to the Lower Mekong Basin Water Balance Study Phase II Report (1984), there were 1,426 pump irrigation systems (in total for DEDP, RID and MOI) in the Mekong Basin in Thailand, which had been irrigating 924,400 ha of agricultural land. This indicates that the command areas of pump irrigation systems are quite remarkable in the basin.

The irrigation diversion requirements have been estimated for irrigating agricultural land in the riparian countries of the LMB. The diversion requirements to irrigate paddy and other field crops during wet and dry seasons have been estimated in various study reports. In the case of Vietnam, however, the diversion requirements were estimated for double paddy, triple paddy, field crops and perennial crops. The total dry season (January to April) irrigation diversion requirements are in the range of 1,423-2,495 mm (Lao PDR), 2,005-2,400 mm (Nam Chi basin in Thailand), 1,448-2,400 mm (Nam Mun basin in Thailand), 1,224-2,400 mm (Mekong tributaries in Thailand), and 1,505-2,100 mm (Cambodia). Similarly, the total dry season irrigation diversion requirements for the Mekong Delta in Vietnam are in the range of 410-1,089 mm (double paddy), 887-1,247 mm (triple paddy), 401-599 mm (field crops) and 381-535 mm (perennial crops). Currently there is no trans-basin irrigation diversion project in the Lower Mekong Basin; however, a number of trans-basin projects have been considered before.

Based on the available information related to the current dry season irrigation areas and diversion requirements, preliminary estimation of current irrigation water use in the dry season was made for each riparian country. The total dry season irrigation demand was estimated to be around 18.1 billion m^3; i.e., 3.5 billion m^3 in Thailand, 1.2 billion m^3 in Lao PDR, 1.8 billion m^3 in Cambodia, and 11.6 billion m^3 in Vietnam.

CHAPTER 5 TECHNICAL ASSISTANCE FOR WATER UTILIZATION RULES

5.1 Introduction of Water Utilization Rules

5.1.1 The 1995 Mekong Agreement and WUP-JICA Activities

On 5 April 1995, the governments of the four riparian countries in the Lower Mekong Basin; namely, Cambodia, Lao PDR, Thailand and Vietnam, signed the historic "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin," Resulting in the establishment of the Mekong River Commission (MRC). The Agreement set a new mandate for the organization "to cooperate in all fields of sustainable development, utilization, management and conservation of the water and related resources of the Mekong River Basin."

The Water Utilisation Programme (WUP) is being undertaken to help the member states of the Mekong River Commission (MRC) to implement key elements of the Agreement with regard to the cooperation required for the sustainable development of the Mekong River Basin. The WUP aims at the formulation of appropriate "Water Utilization Rules" to ensure the reasonable and equitable use of the Mekong waters and related resources that are addressed in the Agreement. The WUP aims at putting the related articles into practice, and there are at present five sets of Rules being formulated, as follows:

Table 5-1 Rule Components under Water Utilization Programme

Category	Rule
Procedural Rules	1. Procedures for Data and Information Exchange and Sharing (approved in July 2001)
	2. Procedures for Water Use Monitoring (approved in November 2003)
	3. Procedures for Notification, Prior Consultation and Agreement (approved in November 2003)
Technical Rules	4. Rules for the Maintenance of Flows on the Mainstream (to be approved by the end of 2004)
	5. Rules for Water Quality (to be approved by the end of 2005)

One of the main objectives of the WUP-JICA study was to provide the MRC with technical assistance in the process of preparation of the Draft Rules of Water Utilisation under the WUP activities. In parallel with the progress of rule formulation by the WUP, technical assistance was made by providing inputs of previous experiences in similar fields and technical analyses to support the rule formulation.

This Chapter consists of three components related to the technical assistance provided by the WUP-JICA study. These are:

(1) Maintenance of Flows

The purpose of the work was to provide technical and hydrological supplementary information to support the framework procedures of rule preparation focusing mainly on the existing hydrological behaviours of the Mekong River flow for the common understanding and agreement of riparian member countries. In the course of the study, preliminary flow regime analysis was made based on the available hydrological data. Literature review was also carried out with the maximum use of available reports and related information.

(2) Institutional Strengthening

Legal aspects and organization are the main components of institution. The team collected and reviewed the existing framework of universal application for the formulation of international agreements. Based on the interpretation of universal applications, the relevant water resources laws in the riparian countries were as well reviewed. Further focusing on the three components of organization, manpower, facility and budget, the team proposed necessary actions to properly manage rules to be formulated, through the monitoring activities.

(3) Experiences in Japan: Water Utilization Rules, Water Use Monitoring and Maintenance of Flows

In parallel with the progress of rule formulation by MRC, timely themes were provided in the national and regional workshops for the transfer of technology and experiences in Japan. These themes involve water utilization rules managed mainly by the water right system in the first year, water use monitoring system and actual monitoring activities in the second year, and maintenance system of flows based on the required minimum flow in the third year. The presentations aimed to contribute to the rule formulation as well as the transfer of knowledge to staffs of the MRCS and the NMCs.

5.1.2 Preliminary Interpretation of Water Utilization Rules

Maintenance of Flows

In the formulation of the Draft Rules for the Maintenance of Flows on the Mainstream, the best judgment is expected as to what “critical values” of the river must be protected. “Critical values” are those that the member riparian states agree should not be lost. These values are from an interpretation of what is “acceptable” with respect to Article 6, which requires the riparian states to maintain the minimum flows to form the management principles of the Mekong mainstream.

Article 6: Maintenance of Flows on the Mainstream
To cooperate in the maintenance of the flows on the mainstream from diversions, storage releases, or other actions of a permanent nature; except in cases of historically severe droughts and/or floods: A. Of not less than the acceptable minimum monthly natural flow during each month of the dry season; B. To enable the acceptable natural reverse flow of the Tonle Sap to take place during the wet season; and C. To prevent average daily peak flows greater than what naturally occur on the average during the flood season. The Joint Committee shall adopt guidelines for the locations and levels of the flows, and monitor and take action necessary for their maintenance as provided in Article 26.

Article 6 calls for the maintenance of “the acceptable minimum monthly natural flow during each month of the dry season on the mainstream” and states that wet season mainstream flows should also be sufficient to enable “the acceptable natural reverse flows of the Tonle Sap to take place.” To provide specific and social assessment of impacts to the key attributes of the basin’s resources due to changes in flow regime, the MRC had decided to follow an internationally accepted holistic approach (a holistic environmental flow methodology) to challenge the determination of such acceptable flows that will maintain the acceptable level of health or conditions of the Mekong resources.

Article 6 complements Article 26 which calls for the five specific requirements to be considered for formulating the rules. They are: (1) Establishing the time frame for the wet and dry seasons;

(2) Establishing the location of hydrological stations, and determining and maintaining the flow level requirements at each station; (3) Setting out the criteria for determining surplus quantities of water during the dry season on the mainstream; (4) Improving upon the mechanism to monitor intra-basin use;, and (5) setting up a mechanism to monitor inter-basin diversions from the mainstream.

Along this line, the "Integrated Basin Flow Management (IBFM) - Mekong Method for Setting Flows for Sustainable Development" was started in July 2003. This challenge will define what amount of flow change is socially, economically and ecologically acceptable. A key milestone of the MRC is to agree and implement the Rules for the Maintenance of Flows by the end of 2004. The IBFM Project will propose the agreed Interim Flow Plan (IFP) as the "initial" acceptable minimum monthly natural flow. The proposed IFP shall include the projected flow regime changes resulting from the selected basin development scenario. As long as an individual development project would not modify flows beyond the agreed flow limits, the acceptable minimum monthly natural flows will remain unchanged.

Major specific requirements to be highlighted together with the current progress of rule making are as follows:

Table 5-2 Key Terms in Article 26 and Current Status

No.	Key Term	Progress/Undertaken
1	To establish the timeframe for the wet and dry seasons	Approved by the MRC Council in November 2003
2	To establish the location of hydrological stations, and to determine and maintain the flow level requirements at each station	Under the IBFM Project and Technical Drafting Group (TDG) 5
3	To set out the acceptable minimum monthly natural flow during each month of the dry season	Under the IBFM Project and TDG 5
4	To set out the acceptable natural reverse flow of the Tonle Sap to take place during the wet season	Under the IBFM Project and TDG 5
5	To set out criteria for determining surplus quantities of water during the dry season	Under the IBFM Project and TDG 5
6	To improve upon the mechanism to monitor intra-basin use	Approved by the MRC Council in November 2003
7	To set up a mechanism to monitor inter-basin diversions from the mainstream	Approved by the MRC Council in November 2003

<u>Natural Flow</u>

One of the remaining of key terms to be defined is the "natural flow" in the Agreement. In general, it might be difficult to obtain pure natural flow regimes since human activities are extensive. Hence the historical water use data are very necessary to estimate the natural flow on the basis of the measured flows. The actual current river flow regimes of the Mekong River are resulting from the accumulated effects of historical basin-wide water uses. However, from the practical points of view, the actual current flow regimes are recommendable as the natural flow regimes for the drafting process of the rules taking the following characteristics peculiar to the Mekong River basin as well as facts into consideration.

The ongoing Basin Modelling Package and Knowledge Base would need to naturalize the measured hydrological flows. It is however reported that this Package has been confronted by difficulties and constraints of the serious lack of historical water usage data (mainly relating to irrigation development) and sparse information available for effective model calibration.

The Basin Development Plan (BDP) should be formulated and implemented not to infringe on the existing water uses in the entire Lower Mekong Basin. It is very natural that the four member riparian states do not wish to lose or reduce any existing water use. The highlighted acceptable limits of pattern of current flows should thus contain the existing water uses.

At the time of establishment of the Mekong Agreement in 1995, the technical term "natural" might merely mean the actual flow conditions before construction of a series of seasonal regulation large reservoirs on the Mekong mainstream. It was believed that the Mekong River was essentially unregulated and the existing low flow regimes at that time were substantially close to the natural condition.

In Lao PDR, net increase of mainstream flow in the dry season has been estimated at around 90 m^3/s by subtracting the dry season irrigation demand of around 100 m^3/s (based on the assumption that approx. 100,000 ha of dry season irrigation with a diversion requirement of 1 liter/s/ha) from the average flow increase of 190 m^3/s due to the water release of Nam Ngum reservoir. In Thailand, the dry season flow has been estimated to increase by around 45-60 m^3/s due to the supply balance of reservoirs. In Cambodia, low flow had decreased by around 68 m^3/s since the same assumption was applied to approx. 68,000 ha of dry season irrigation. The preliminary flow balance on the mainstream in the dry season implies that the existing off-stream use (irrigation use in majority) is negligibly small compared to the mean monthly flow of 2,800 m^3/s in April at the Cambodia-Vietnam national border into the Mekong Delta, when Mekong flows become the lowest.

The Xiaowan Hydropower Project, a large-scale reservoir type project with active storage capacity of 11,500 million m^3, is under construction on the Mekong mainstream in China. This project will create the first seasonal flow regulation reservoir on the mainstream. The seasonal flow regulation will drastically change the Mekong flow regime, and will also significantly increase the flow in the dry season (expectedly 550 m^3/s). The current flow regimes might be usable as the natural flow before completion of this project.

There might be no significant differences whether determination of the acceptable minimum level of flows is made on the basis of the current flow regimes or the estimated natural flow regimes. The acceptable minimum level of flows shall be practically applied to the current flow regimes. However, when some guidelines on water allocation (water sharing) among the states are established in future, evaluation of historical water usage and flow contribution by each country shall be on the basis of the estimated natural flows.

5.2 Maintenance of Flows

5.2.1 Basic Consideration on Surplus Water

The four riparian states would not wish to lose or reduce any existing water use. The surplus quantity of water is theoretically obtained subtracting the agreed acceptable minimum monthly natural flow from the observed flow. The surplus quantity of water derived at some location means not the whole available water at this location but the total available water in the entire upper reaches. The estimated surplus water at this location already includes to some extent the surplus water at the upper reaches and is already allocated to some extent at the downstream reaches. If this concept is applied to the rules, the acceptable minimum monthly natural flows will increase whenever new water users are approved (new developments in tributaries can be made only by issuing the Notification). Thus the acceptable minimum monthly natural flows or the flow level requirements shall be modified for the surplus water to decrease.

MRC has launched a new approach for setting up the acceptable monthly minimum natural flow in terms of highlighted environmental flows in the Mekong River as "Integrated Basin Flow Management (IBFM)." In this process a number of flow regimes are evaluated through a holistic multi-disciplinary approach for final selection by decision-makers. These regimes will be provided by the MRC's DSF simulation based on a range of development scenarios for different levels of water use or water abstraction and the likely ecological, social and economic consequences of each. Such development levels (options) will be subject to due consultation with the NMCs and to final selection by the Council of MRC.

In general, as mentioned earlier, the environmental flows are to be determined based on negotiations on the acceptable balance (trade-offs) between development and protection of river conditions reflecting different engineering, economic, ecological and social implications. Such negotiations will be made on the flow regimes that will allow sustainable development, utilization, conservation and management of the Mekong River Basin water and its resources (1995 Mekong Agreement). The negotiated acceptable minimum monthly natural flow will already include future water uses (both consumptive and non-consumptive or in-stream use). In this respect, the surplus water estimated will be a temporal usage. Moreover, as far as individual development projects will not modify flows beyond the agreed flow limits, the acceptable minimum monthly natural flows will remain unchanged.

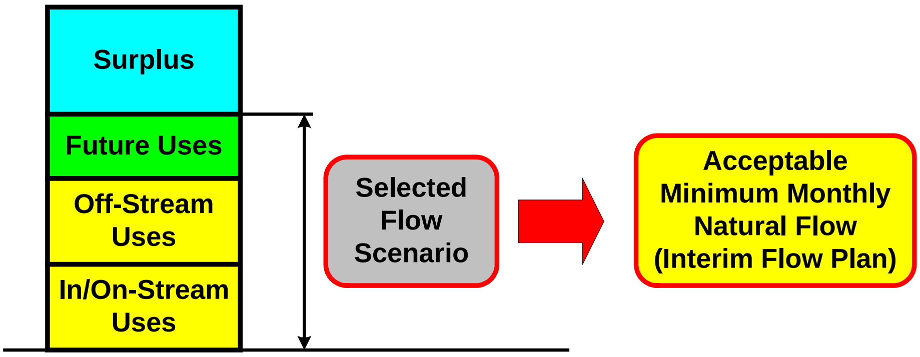


Fig. 5-1 Simplified Definition of Surplus Water under IBFM Approach

Low Flow Conditions on the Mekong Mainstream

From March to April, the Mekong flows become the lowest. Specific discharges in March and April at hydrologic stations from Chiang Saen (189,000 km^2 in watershed area) to Kratie (646,000 km^2) on the Mekong mainstream vary within a smaller range of 3 to 5 liters/s/km^2, corresponding to 0.3 to 0.5 m^3/s per 100 km^2, or 30 to 50 m^3/s per 10,000 km^2. From Kratie in Cambodia, an extensive floodplain area in the lower part of the Mekong is formed up to the Mekong Delta.

The Tonle Sap joins the Mekong River at Phnom Penh in Cambodia. In the dry season the stored water in the Great Lake is gradually and naturally released into the Mekong mainstream through the Tonle Sap. At Chak Tomuk junction of the confluence of the Tonle Sap, the Mekong River bifurcates into two rivers; the Mekong mainstream and the Bassac River. These two rivers enter the Mekong Delta in Vietnam. At present, water level and discharge are monitored at Tan Chau on the Mekong and at Chau Doc on the Bassac. These stations are located at about 10 km downstream from the Cambodia--Vietnam border and at about 200 km inland from the South China Sea.

Dry season flows into the Mekong Delta are partly dependent on the amount of wet season mainstream flows stored in the Great Lake. Specific discharges at the Mekong Delta inflow (combined flows at Tan Chau and Chau Doc, 756,000 km^2) in March and April are 5.4 and 4.2 liters/s/km^2, showing higher values than those at the upstream stations on the Mekong. Flow contributions from the Great Lake into the Delta are estimated to be 2.8 and 1.6 liter/s/km^2, respectively.

Observed hourly water level and discharge records at Tan Chau and Chau Doc are available for the period 1997-2001. The total mean annual inflow into the Mekong Delta (sum of discharges both at Tan Chau and Chau Doc) is 13,200 m^3/s. The total mean monthly inflow varies from 2,800 m^3/s in April to 26,300 m^3/s in September. Flow distribution between Tan Chau and Chau Doc is almost constant in the dry season. The Mekong River (at Tan Chau) delivers the flow volume of around 82% of the total inflow into Vietnam.

Saline Water Intrusion in the Mekong Delta

Total inflow into the Mekong Delta in Vietnam is monitored at Tan Chau on the Mekong mainstream and at Chau Doc on the Bassac River. Magnitude of the dry season flows into the Mekong Delta in relation to salinity intrusion length is the most important factor to flow management. Tidal effects are very significant at both stations. The tidal range is greatest over the dry season period from March to May when flows are the lowest. Accurate and reliable monitoring of flows at both stations is difficult to make because of quick hourly changes of water level and velocity due to strong effects of tides. During the dry season, flow reversal occurs at both stations.

The following table shows that the tidal conditions between the South China Sea and the Gulf of Thailand are extremely different, with the tidal amplitude and highest tide level being substantially higher in the South China Sea than in the Gulf of Thailand. In addition, the South China Sea is somewhat more saline than the Gulf of Thailand. The tidal amplitude varies during the spring tide and neap tide cycle.

Table 5-4 Characteristics of Tide in the Mekong Delta

Item	South China Sea (at My Thuan)	Gulf of Thailand (at Rach Gia)
Tidal Amplitude	3.0 m	0.7 m
Salinity	33 ppt	25 ppt
Highest Tide Level	+1.6 m	+0.5 m

Source: Mekong Delta Water Resources Development Project, Feasibility Study Update, Environmental Impact Assessment and Environmental Action Plan, Annex 1, August 1998

During the dry season saline water from the South China Sea and the Gulf of Thailand move upstream along the rivers and canals of the Mekong Delta. The salinity intrusion into the Mekong Delta is very complicated. The highest salinity is usually observed in April. Currently 1.7 million ha of delta lands are affected by saltwater intrusion, which not only affects irrigation development but also domestic water supply. Salinity worsens water quality and damages crop-lands. The most severe situations occur during the low flow season when there is not enough flow to prevent seawater intrusion. Strong tidal waters encroach up to 50-70 km. The existing engineering interventions would be inadequate for coping with salinity intrusion, if water abstraction increases in the delta. The area affected by salinity is expected to increase to 2.2 million ha, if preventive measures are not taken up. Fig. 5-2 presents the area affected by saltwater intrusion in the Mekong Delta.

Generally, the water with salinity higher than 4 g/l could not be used for irrigation. Penetration of 4 g/l isohaline from the sea may reach up to 29.4 km in the Co Chien branch, 26.4 km in the Ham Luong branch, 26.2 km in the Cua Dai branch, 43.2 km in the Cua Tieu branch, and 25.6 km in the Bassac. Salinity intrusion impacts are different for each year, depending on not only hydro-meteorological conditions, but also on the water abstraction from the river that can cause the decrease of flow to make deeper salinity intrusion. Thus, increase of water use in the dry season means lowering of the Mekong flow that coincides with the increase of salinity intrusion impacts. This is a conflict between development and protection of water resources.

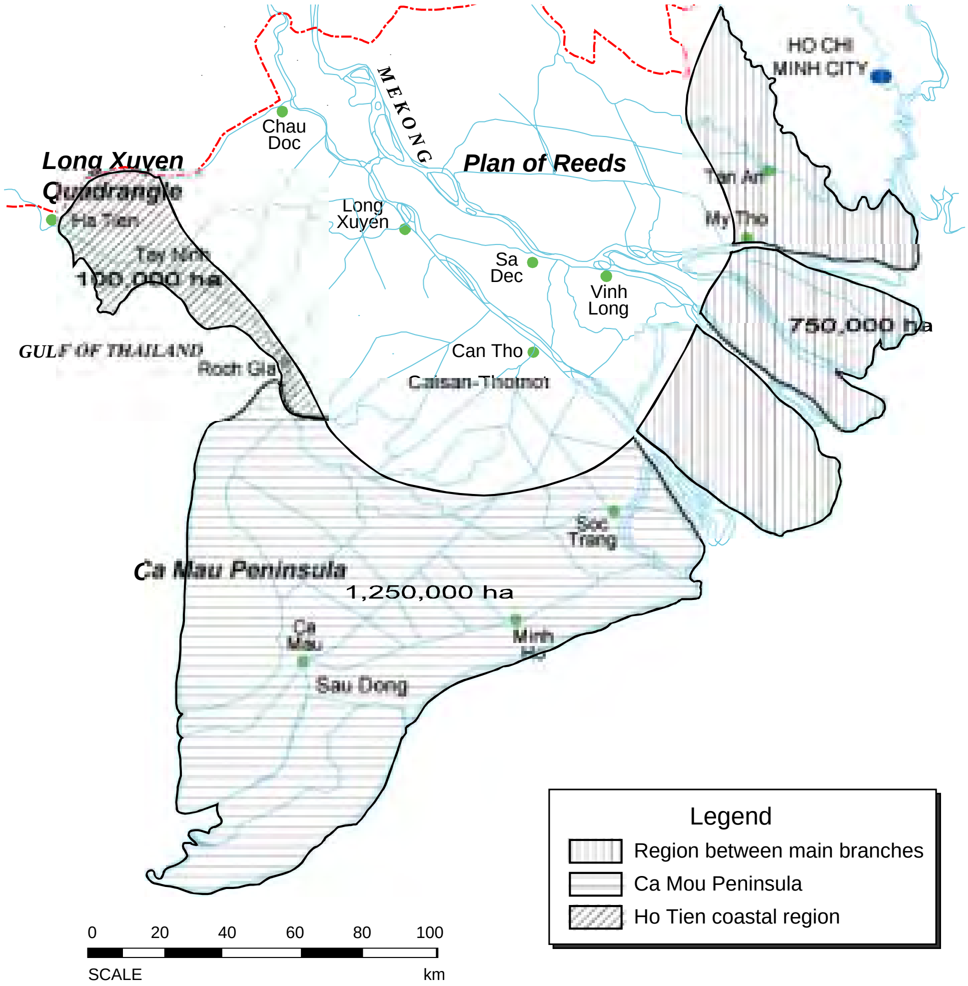


Fig. 5-2 Area Affected by Saline Water Intrusion in the Mekong Delta
Source: Summary Report of the Project Manager, Programme of Mekong Delta Salinity Intrusion Studies, Phase III, 1992

Key Issues on Water Resources Management in the Mekong Delta

Three key issues are highlighted from the aspect of current water use as well as water resources management in the Mekong Delta. They are: (1) water shortage in the dry season, (2) seawater intrusion in the dry season, and (3) acidification. Among them, issues (1) and (2) are key factors in view of the determination of maintenance of flows on the Mekong mainstream. These issues are likely to intensify in the near future by impacts of various water resources development in upstream riparian countries.

Due to decrease of the Mekong flows in the dry season, seawater intrudes further upstream in the delta. The salinity intrusion into the delta is very complicated. The highest salinity is usually observed in April. Currently 1.7 million ha of the delta lands are affected by saltwater intrusion, which not only affects irrigation management but also domestic water supply. The problem is most severe in April when the Mekong flows become the lowest. It is said that 4 g/l saline level penetrates 30-40 km upstream.

Salinity intrusion impacts are different for each year, depending on not only hydrological conditions, but also on the irrigation water abstractions from the rivers that cause the decrease of flow to make deeper salinity intrusion. Thus increase of water use in the dry season leads to decrease the Mekong delta flows resulting in an increase of salinity intrusion. This would be a conflict between development and protection of water resources in the Mekong delta.

Under the Programme of Salinity Intrusion Studies, measurement campaign was carried out in two dry seasons in 1989 and 1990. The study results indicate that the maximum salinity often occurs in April, when the tide varies most strongly and the Mekong discharge becomes lowest. Salinity variations in the dry season were measured at major stations under the measurement campaign in 1990, as summarized below.

Table 5-5 15-Day Average Salinity in the Mekong Delta in the 1990 Dry Season

Period	Total Discharge	Salinity (g/l)				
		My Tho	Xuan Hoa	My Hoa	Tra Vinh	Dai Ngai
Feb 1st	4,100	0.16	0.59	0.78	2.03	0.36
Feb 2nd	3,170	0.21	0.71	1.22	2.86	0.68
Mar 1st	2,550	0.75	2.09	1.11	2.83	2.64
Mar 2nd	2,070	0.50	1.47	1.54	3.57	3.51
Apr 1st	1,930	0.65	1.74	1.65	4.56	2.89
Apr 2nd	1,570	1.49	2.86	3.13	5.57	2.96
May 1st	2,340	1.95	3.87	2.24	5.48	3.48
May 2nd	3,600	0.47	1.31	0.88	2.83	1.38

Source: Some Fundamental Hydrodynamic Characteristics of the Mekong Delta Water System during the Dry Season, Programme of Salinity Intrusion Studies in the Mekong Delta Phase III, SIWRPM, 1992

The variation of salinity above is illustrated in Fig. 5-3. As seen, due to decrease of the Mekong flow in the dry season, seawater intrudes further upstream of the Mekong branches.

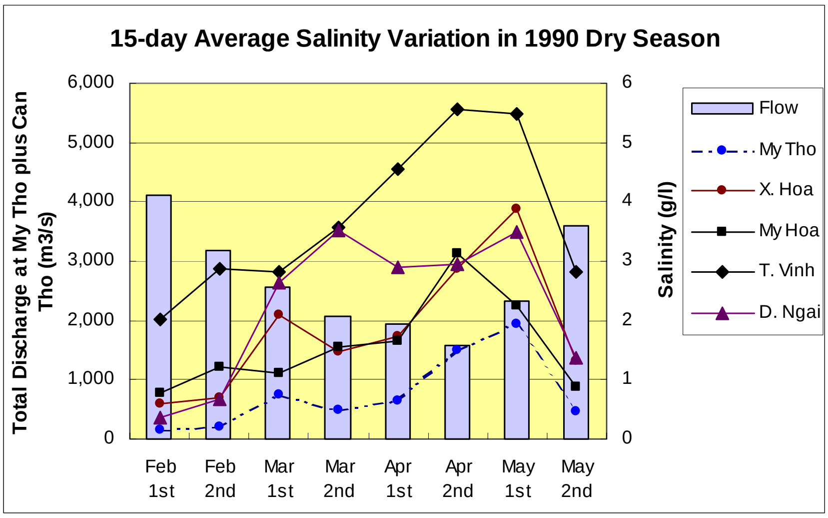


Fig. 5-3 15-Day Average Salinity in Mekong Delta in the 1990 Dry Season

5.2.3 Hydrological Flow Requirements in the Mekong Delta

Extreme Drought in 1998/99 and Impacts Occurred

The year 1998 was a dry year bringing an extreme drought readily understood by a wider range of local people engaging in agriculture and fishery. The maximum water level at Kratie, located on the Mekong mainstream, was considerably below the water levels in normal years, as depicted in Fig. 5-4. Water levels at both Tan Chau and Chau Doc showed the lowest variations, being around 1.5 m lower than in normal years as presented in Fig. 5-5. In the Mekong Delta, impacts of the drought appeared in the dry season in 1999 as the considerably decreased inflows into the delta. The mean monthly inflows were 1,850 m^3/s in March and 2,200 m^3/s in April. They were the lowest compared to the mean monthly flows of 3,200 m^3/s in March and 2,800 m^3/s in April.

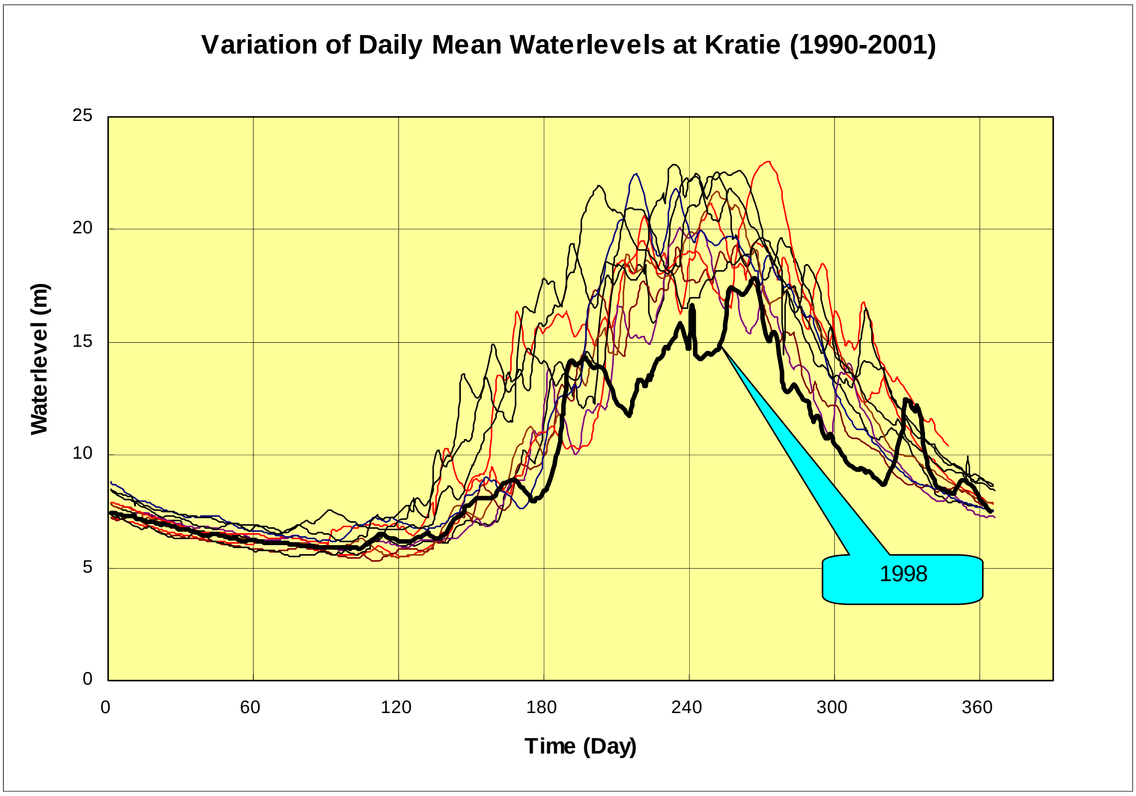
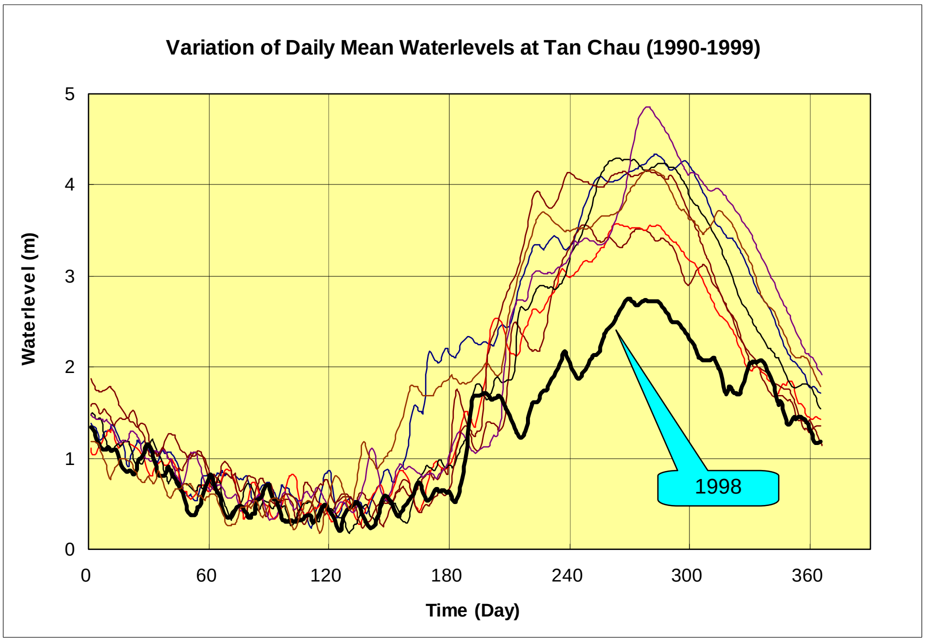


Fig. 5-4 Daily Water Level at Kratie on the Mekong Mainstream (1990-2001)



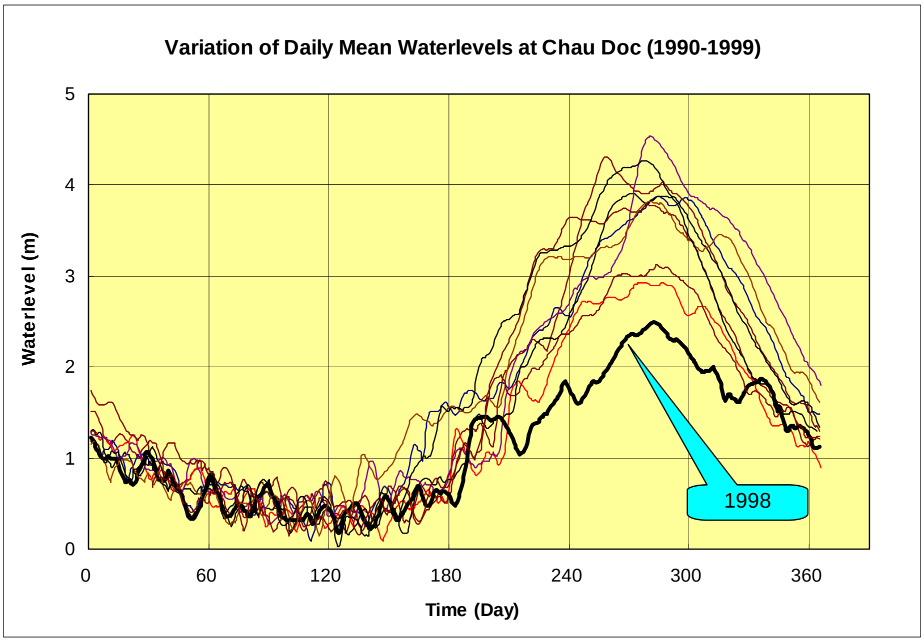
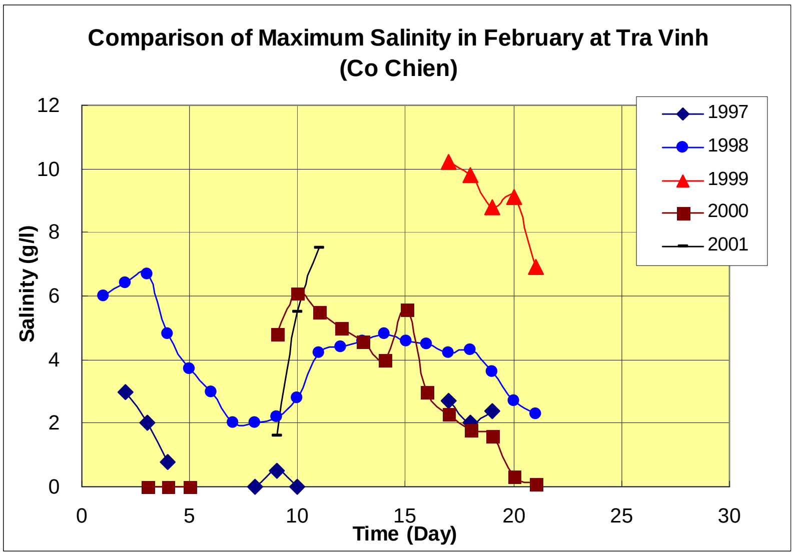


Fig. 5-5 Daily Water Levels at Tan Chau and Chau Doc (1990-1999)

Significant issues arose from the environmental impacts of the flow regime changes in the dry year 1998. Drastic decrease of maximum water level occurred in the Great Lake. The estimated maximum water level and volume of the Lake were around 6 m and 28 billion m^3 in 1998 and 9.5 m and 65 billion m^3 in 2000 in normal years. The lake inundation areas were significantly different from around 8,500 km^2 in 1998 to 13,000 km^2 in 2000. The floodplains in Cambodia are very productive for growing and migration of young fishes and thus fish productivity has a close relation with the extent and duration of floodplain inundation. Due to the drastic reduction of inundation area, a drastic decrease of fish catch in 1998/99 in Cambodia occurred from the environmental consequences. Since inland fishery is of great economic and social importance in Cambodia, associated socio-economic impacts are very significant.

The decreased dry season flows in the Mekong delta in 1999 allowed salty seawater to intrude further upstream than in normal years. Salinity concentrations drastically increased. At Tra Vinh on the Mekong, the maximum salinity was recorded at more than 10 g/l, where usually less than 6 g/l. At Dai Ngai on the Bassac, the salinity increase was more significant as it increased to around 10 g/l from less than 4 g/l in most years. These conditions on salinity intrusion in the 1999 dry season are illustrated in Fig. 5-6. No information is however available on the impacts to agriculture in the delta.



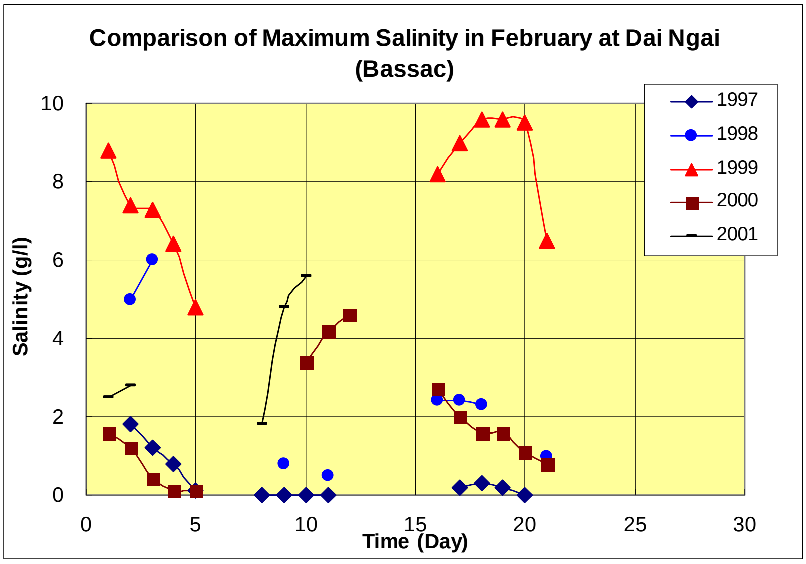


Fig. 5-6 Comparison of Maximum Salinity in February of 1997 to 2001 in the Mekong and Bassac Rivers

The floodplain inundation in terms of fisheries activities and fish dynamics, and salinity intrusion in terms of agricultural activities in the delta are key attributes for the determination of environmental flows under the IBFM project.

<u>Drought Analysis on the Mekong Mainstream</u>

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 undestandable in terms of difference of occurrence probabilities of a hydrological event. There are great varieties of dry year events like the basin-wide dry year in 1992 and the partially basin-wide dry year in 1998.

The probability of occurrence of the dry year in 1998 has been evaluated at nine stations from Chiang Saen to Pakse on the Mekong mainstream by means of the total seasonal flow volume in the wet season (from June to November). The estimated probabilities were different from station to station varying from 0.5 (to occur once in 2 years) at Chiang Saen to 0.025 (once in 40 years) at Pakse. Considering lower probabilities from Mukdahan to Pakse, it implies that severe drought occurred in a wider range of the contributing left bank tributaries in Lao PDR and Vietnam; namely, the Se Bang Hien, Se Sang, Se Kong and Sre Pok rivers. 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 dominantly influence the incidence and severity of drought in the Mekong Delta.

Flow Regime Analysis on the Mekong Mainstream

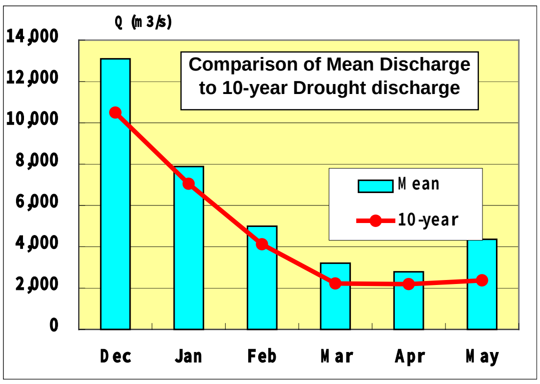
Monthly mean discharges of several non-exceedance probabilities have been estimated for the ten stations on the Mekong mainstream from Chiang Saen to Pakse based on the monthly mean discharge data. The estimated drought discharges compared to the monthly mean discharges in dry years in 1992 and 1998 are as follows:

Table 5-6 Probability of Monthly Flow in the Dry Season

Station	Drainage Area (km2)	Mar					Apr				
		Mean	10-year	5-year	1992/93	1998/99	Mean	10-year	5-year	1992/93	1998/99
Chiang Saen	189,000	835	660	730	801	702	915	700	820	824	645
Lua. Prabang	268,000	1,065	890	920	1,025	673	1,112	900	990	1,011	625
Chiang Khan	292,000	1,043	870	910	962	969	1,056	890	920	881	943
Vientiane	299,000	1,167	960	1030	1,046	755	1,194	970	1030	974	766
Nong Khai	302,000	1,176	1,020	1,090	1,214	971	1,215	1,030	1,100	1,110	991
Na. Phanom	373,000	1,548	1,230	1,310	1,224	1,454	1,526	1,160	1,230	1,108	1,692
Mukdahan	391,000	1,600	1,300	1,450	1,548	1,343	1,569	1,290	1,430	1,453	1,514
Khon Chiam	419,000	1,903	1,520	1,640	1,845	1,616	1,839	1,520	1,610	1,775	1,789
Pakse	545,000	1,852	1,490	1,650	1,575	1,502	1,819	1,520	1,600	1,449	1,778
Delta Inflow	756,000	4,120	2,230	3,450	4,024	1,852	3,204	2,200	2,440	2,856	2,191

Preliminary Quantification of Surplus Water on the Mekong Mainstream

Preliminary quantification of the surplus water has been made at the national border entering the Mekong Delta (combination of Tan Chau and Chau Doc) using the 10-year drought discharges, which were assumed to be the acceptable minimum monthly natural flows. The applied monthly discharges at both stations were the observed ones in 1997-2001. It should be noted that the surplus quantity of water is still variable and stochastic. Hence, the flow regime may vary from season to season, from year to year and from station to station.



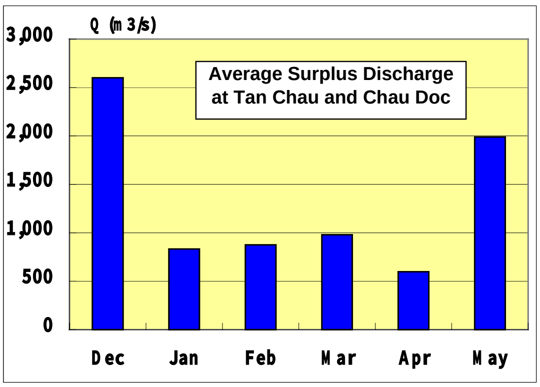


Fig. 5-7 Preliminary Estimation of Surplus Water Exceeding the 10-Year Drought Discharge

Monitoring Simulation of Mainstream Flows

Maintaining dry season flows on the Mekong mainstream is one of the most important management activities confronting the MRC. Mainstream monitoring simulation has been made using the past representative flow regimes together with the assumed minimum flow requirements, the monthly 10-year (10% of non-exceedance probability) and the 5-year (20%) drought discharges at the respective hydrological stations from Chiang Saen to Tan Chau and Chau Doc on the Mekong Delta. An example of monitoring at the entry point into the Mekong Delta is shown below.

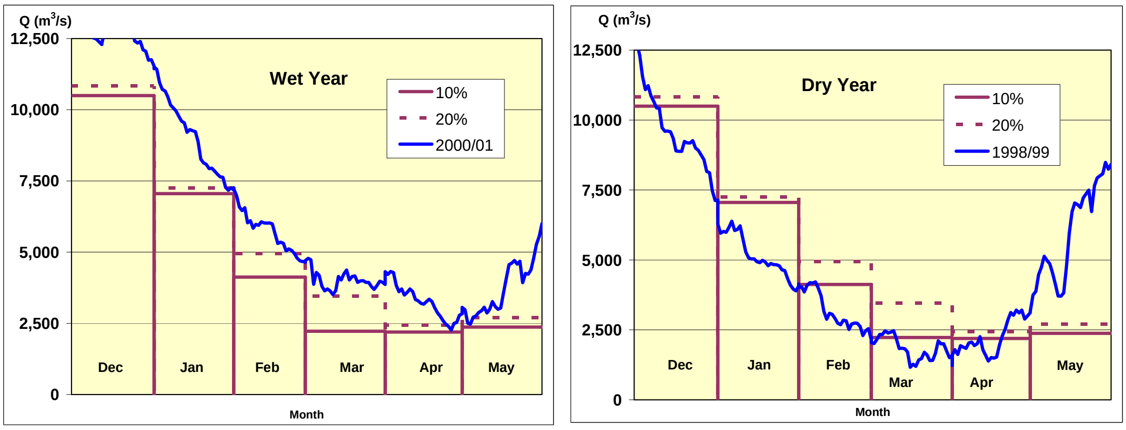


Fig. 5-8 Comparison between Probable Monthly Drought Flows and Daily Flow Series in Wet and Dry Years

5.3 Institutional Strengthening

5.3.1 General

The Council had decided to formulate five Rules in its 6th meeting in 1999. The MRC under its Water Utilization Program (WUP) has been preparing the Rules together with the Technical Drafting Group participated by the delegations from each member country, and have successfully formulated the three procedural rules by the end of December 2003 as scheduled.

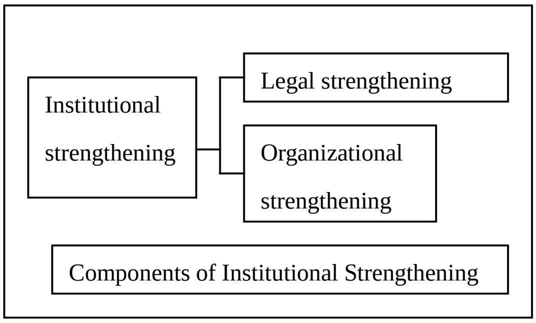


Fig. 5-9 Structure of Institutional Strengthening

Institution comprises legal and organizational aspects as its main components. Hence, the Institutional Strengthening by the WUP-JICA Project comprises legal strengthening and organizational strengthening. The strengthening has been duly specified to provide suggestions to the MRCS in legal and organizational aspects with regard to the Rules and hydro-meteorological monitoring.

The legal aspects are mainly the formulation and implementation of the five procedural rules and procedures being formulated by the MRC through the activity of the WUP. On the other hand, the highlights of the organizational aspects studied were the hydro-meteorological monitoring systems of member countries and the MRC.

As a result, the legal strengthening focussed on the strengthening for rule preparation and the strengthening for rule implementation. On the other hand, the organizational strengthening focussed on the strengthening for the organization of hydro-meteorological monitoring, as follows:

(1) Legal Strengthening : Strengthening for rule preparation and Strengthening for rule implementation

(2) Organizational Strengthening : Strengthening for the organization of hydro-meteorological monitoring

The substantial works conducted for the strengthening for rule preparation were: (1) Definition of the important concepts and principles to be adopted in the preparation rules; (2) Technical interpretations of the abstracted and defined concepts and principles for proper application to the Rules; and (3) Confirmation of the consistency of each domestic water related law to the concepts and principles so that the Rules prepared will be implemented smoothly without causing a significant conflict with the domestic law.

The main works conducted for the strengthening for rule implementation were: (1) Identification of functions of the Rules, (2) Assumption of scenario to implement the Rules; and (3) Observation on the Rules in view of operation.

On the other hand, the works conducted for the organizational strengthening are: (1) Surveys on the existing hydro-meteorological monitoring systems; and (2) Assessment of the existing monitoring systems in view of implementation of the Rules.

5.3.2 Strengthening for Rule Preparation

Existing Agreements for the Management of Shared Watercourses

The WUP-JICA team had collected the existing agreements for the management of international river basins as references for the Rule preparation. The collected agreements were 3 general agreements and 15 specific agreements including multi-lateral and bi-lateral agreements or protocols in various areas in the world. Some of them were forged in the older times when social and political situations and requirements were different from the ones presently prevailing.

The general agreements collected were the Helsinki Rule, 1970; the Draft Articles on the Law of Non-Navigational Uses of International River Course, Geneva in 1980; and the Resolution of the General Assembly of the UN: the Agreement of Convention on the Law of the Non-Navigational Uses of International Watercourse (21 May 1997, New York). Those are recognized as the frameworks of a rule of universal application on the utilization of international river basin.

The collected agreements for the management of specific rivers are listed as follows:

(1) Amazon Cooperation Treaty

(2) Agreement on the Utilization of Water in the Boden Lake

(3) The Columbia Treaty

(4) Convention regarding the Regime of Navigation on the Danube

(5) Agreement between the Government of the Republic of Austria and the Government of the Federal Republic of Germany and of the Free State of Bavaria concerning the Danube Power Pla and Jochenstein Stock Company

(6) Protocol regarding Water Regulation of the Tigris and the Euphrates (The first annex to the Treaty for Friendship and Good Neighbour)

(7) Agreement between His Majesty's Government of Nepal and the Government of India on the Gandak Irrigation and Power Project

(8) Agreement between the Government of the Peoples' Republic of Bangladesh and the Government of the Republic of India on Sharing of the Ganges Water at Farrakka and on Augmenting its Flows

(9) Agreement between the Government of the Union of Soviet Socialist Republics, the Government of Norway and The Government of Finland concerning the Regulation of Lake Inari by means of the Kaitakoski Hydroelectric Power Station and Dam

(10) The Indus Waters Treaty concluded between India and Pakistan

(11) Treaty of Peace between the State of Israel and the Hashemite Kingdom of Jordan (Article 6; Water)

(12) Agreement for the Full Utilization of the Nile Waters

(13) Treaty between Austria and Liechtenstein regarding the Regulation of the Rhine and Tributary Waters

(14) Protocol on Shared Watercourses in the Southern African Development Community

(15) Agreement between the Republic of Syria and the Hashemite Kingdom of Jordan concerning the Utilization of the Yarmuk Waters

The Team had compiled the collected existing frameworks and agreements together with the observation thereon in another volume entitled “Existing Agreement for Water Utilization” that was issued in March 2002.

Concepts and Principles in Frameworks of Universal Application

The selected frameworks advocate similar concepts and principles as those to be adopted in the agreement for the management of international rivers to achieve reasonable and equitable use and to maintain good and peaceful relationship among the riparian countries. The team had abstracted commonly adopted concepts and principles from the provisions of the frameworks, as follows:

(1) Concept of river basin

(2) Principle of common property

(3) Principle of reasonable water use

(4) Principle of equitable use

(5) Principle of sustainable development

(6) Principle of risk management

(7) Principle of exchange of data and information

(8) Principle not causing harmful effect to others

(9) Principle of cooperation

(10) Principle of compensation

The team had elaborated the technical interpretations of the abstracted concepts and principles to facilitate reflecting them in the provisions of the Rules being prepared.

Examination on Consistency of Domestic Laws to the Concept and Principles

The concepts and principles discussed above should overrule in the formulation of the Water Utilization Rules. Besides, all of the provisions of the Rules should be consistent with both the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin and the laws enforced in the countries concerned to secure the smooth formulation and implementation thereof. In this connection, the consistency of the concepts and principles with the domestic laws have been preliminarily assessed to confirm the amicability of the Rules to each domestic law. Further, the responses of the domestic laws against international agreements are crucial to implement the Rules in each country. The assessed and studied laws are as follows.

Table 5-7 Reviewed Laws Related to Water Resources in Riparian Countries

Country	Name of Law
Cambodia	Draft Law on Water Resources Management of the Kingdom of Cambodia (Submitted to the Council of Ministers on March 5, 2001)
Laos	The Water and Water Resources Law (Resolved at the National Assembly on November 10, 1996)
Thailand	Water Resources Act (Unofficial translation: Note on principle and reasons)
Vietnam	The Law on Water Resource (Resolved at the National Assembly on May 20, 1998)

The results of Article by Article examination attested that all the domestic laws are consistent to the concepts and principles and no legal conflict is foreseeable. The examination confirmed that all the domestic laws are formulated on the same foundation as the Water Utilization Rules in principle.

The domestic laws of Cambodia, Laos and Vietnam enunciate the responses of laws to international agreements in their articles. Although there is no prescription about the international agreement in the Act of Thailand drafted before the end of 2002, no difficulty is foreseeable to implement the Rules because no inconsistent act can be formulated if the Rules are agreed in advance.

5.3.3 Strengthening for Rule Implementation

Operational Implementation of Water Utilization Rule

The reasonable use of water aims at the maximum or optimum utilization of the water resources taking account of the mobility and probabilistic uncertainty of water. Maximum utilization is to minimize the ineffective release of water to the sea under the condition of maintaining the required flows or balances of demands and supplies at the selected stations by means of taking appropriate actions on the basis of the monitored information.

The supply capacity or the potential of water resources varies from time to time and from place to place. The water demand fluctuates from time to time as well due to various causes. The effective rainfall for agricultural cultivation, which is decisive to define the diversion requirement, depends on variable precipitation. In case the water availability in the upstream reach area is just enough and the downstream reach area is suffering shortage, appropriate controls of demands in both areas may ensure an equivalent use. In case of the contrary, the upstream reach may use the water to the maximum extent consuming even the water that otherwise be released to the downstream reach in normal situation. Agriculture with by far the largest demand has flexibility against water demand to some extent within a certain period. Accordingly, a water supply corresponding to the controlled demand may not affect seriously only if the shortage due to the control is made up within a few days.

In this consequence, daily monitoring and daily balance forecasting are required to realize a reasonable water use by means of adaptable actions to cope with the hydro-meteorological fluctuation. Eventually, implementation of the Rules of PDIES and PWUM are on daily basis. Along this line, daily implementation of maintenance of flows and water quality, or taking action, are technically feasible although actual operation may be a 10-day interval taking account of the costs to be incurred by operation.

The Rules are mostly frameworks and further guidelines, standards and detailed procedures are necessary to implement them effectively in the actual fields. The implementation becomes more concrete when such guidelines are formulated.

Water Utilization Rules and Observations in View of Operation

(1) Procedures for Data and Information Exchange and Sharing (PDIES)

The Procedures mandate custodianship of the data and information on the MRCS in its fifth article. The article stipulates the responsibility of MRCS to report the data to the Joint Committee and the Council annually. The MRCS has responded to this mandate and organized the Mekong River Commission Information System Design and Implementation Team (ISDIT). The functions of the ISDIT have been duly transferred to the Technical Assistance and Coordination Team (TACT) with broader and integrated functions to implement the Procedural Rules.

The data and information exchange is to be so designed as to contribute to ensure Reasonable and Equitable water utilization for sustainable development of the Mekong River Basin in a mutually beneficial manner. The Procedures are appropriate for the purpose of forming the frameworks of the Rules. However, some reinforcements thereof are necessary in order to ensure effective operation, as follows:

- Standards for the collection of data and information are required together with the standards for data access or retrieval.
- The interval of transfer of data and information to the MRCS should be such that afford the management of water uses as implemented for the flood forecasting.
- Modern forecasting method should be established and be agreed upon by the member countries to afford optimum use of water observing the Rules for Maintenance of Flows.
- The standard for data transmission to the Management Agency of water use is required to facilitate smooth and effective operation.
- Establishment of a Special Rule is necessary to compensate for the extra expenditures incurred by line agencies in the observation and transmission of data to comply with the Procedures.

(2) Procedures for Notification, Prior Consultation and Agreement (PNPCA)

The definition of “Wet and Dry Season” is a significant issue to define the necessity of prior consultation for a water utilization project. The approved Procedures define the timeframe for the seasons with ranges of around one month for both start and end of a season taking account of the probabilistic uncertainty of hydrology along the river stretches. The Procedures stipulate further that the Joint Committee shall decide on the actual dates of the start and end of a season to ensure the reasonable water utilization principle.

The Procedures categorise a natural bifurcation channel as a tributary. Accordingly, the branches in the delta including the Bassac River are classified as tributary. The development of an off-take or inter-basin diversion from a branch is a matter to be notified although the water in question is a part of the mainstream water.

The third article defines the principles of equitable and reasonable utilization adopted in the Procedures. The policy of socio-economic development may vary from country to country, and nobody can infringe on the policy pursuant to another adopted principle of sovereign equality. A country aiming at rapid socio-economic development may have a larger water demand at present than one aiming at a slow and steady development.

However, the water demand of the latter will surely increase towards the distant future. The principle should encompass equitable utilization in the future.

The scope of Notification, form, institutional mechanism, process, timing and absence of Notification are the subjects provided in the fourth article. Development of water resources at once is a discrete but important basic concept of the Notification. However, procedures for filing the comments to be raised by other riparian countries should be established to reinforce the implementation of the Rules, because water use within the river basin affects more or less the flow of the mainstream that should be maintained pursuant to other Rules. The principle of not causing harmful effect to others supersedes these Procedures because the principle is adopted in the 1995 Mekong Agreement, and the filed comments might be reflected in the operational stage of development.

(3) Procedures for Water Use Monitoring (PWUM)

The second article specifies the objective of the Procedures to provide comprehensive and adaptive frameworks and process to support effective implementation of water use monitoring. The provision enunciates that the Procedures are frameworks and the detailed method to implement the Procedures is yet to be established.

The fourth article specifies three components of the Monitoring System and mandates a technical support team to determine the details thereof.

Institutional arrangement is another subject of the article. It specifies that the establishment of the Monitoring System is the role of the MRC Joint Committee and the NMCs. They will decide on the target of monitoring, sites, and methods of monitoring. On the other hand, the institutional arrangement mandates the MRCS to assist the NMCs on financial and technical strengthening regarding this monitoring.

Since the technical support team is to determine the details of the system component, the establishment of the team is an urgent matter to be settled. The MRC Joint Committee and the NMCs should establish the monitoring system as soon as possible. The MRCS should find financial sources and establish the procedure for financial assistance of the line agencies to be affected by the implementation of the Procedures through the NMCs.

5.3.4 Strengthening for Organization of Hydro-Meteorological Monitoring

Surveys on Existing Organization of Hydro-Meteorological Monitoring

The WUP-JICA team had conducted the survey on the existing hydro-meteorological monitoring system to assess the adaptability thereof to the required functions applicable to the implementation of the Rules. All NMCs cooperated with the team and coordinated with the line agencies that are mandated to monitor hydro-meteorological conditions in each territory. The team had conducted investigation surveys on the MRCS as a recipient and custodian of the data and information as well. So far the role of the MRCS in this respect is the custodianship, which is presently the terminal stage of the monitoring. The MRC may entrust the MRCS with the conduct of such data processing for the implementation of the Rules through its Technical Assistance and Coordination Team (TACT).

The survey focused on the data being monitored, capability of monitoring with regard to human resources aspect, facilities availed and budget allocated to the monitoring. The team distributed a questionnaire to the line agencies through the NMCs in advance. Each NMC held a meeting with the team with the participation of the representing staff from agencies concerned on the occasion of the visit to collect the answer to the questionnaire. The answers to the questionnaire and the discussions in the meeting have furnished the team with effective information on the existing monitoring system. In addition, the team had conducted investigation surveys on the MRCS through interviews with the related staffs to assess the necessary enhancement to the monitoring system to implement the Rules.

Observations and Assessment of Existing Hydro-Meteorological Monitoring System

(1) Human Resources for Hydro-Meteorological Monitoring

The line agencies of the member countries have contracts with local residents for the observation at substantial gauging stations located in isolated remote areas. The location of gauging station is usually remote even from the residences of the local people. The accesses are poor especially in the wet season. Staffs of branch offices of the agencies are mandated to measure most of the synoptic gauging stations. The incentives of these people are allowances for the observation. However, almost all of the observers feel that the allowances they receive are too small for their efforts to observe and send the data to the regional offices. Consequently, they quit observations rather easily if they encounter difficulties in access.

Special seminars for observers have not been contemplated. The chances to participate in orientations or seminars on hydro-meteorological monitoring are seldom for these observers. Therefore, in most cases, they have less concern about the importance of monitoring.

Mechanical and electrical engineers or technicians for the maintenance of monitoring equipment are limited. Once they have obtained such technology, they readily transfer to enterprises that pay better salaries. Accordingly, the technologies are not accumulated and the transfer of knowledge is difficult. The closed promotion system is another reason for them to move to the private sector.

As for the management level in the regional offices or central government, scientific interest and betterment of water resources management has become the incentive for monitoring. However, the mobility of the experienced specialist is an impediment to the enhancement of monitoring. The reasons of mobility are the salary and the working environment. Some experienced engineer in charge of monitoring iterated that he likes to actually experience or realize the important roles of monitoring and pointed out that the monitoring itself is not always the objective but may sometimes be an incentive to take action so that the monitoring would fulfil its intended purpose.

Human resources development programs to reconfirm the mission of the hydro-meteorological monitoring and to foster the mind of cooperation are necessary for all levels of staff in the line agencies of the member countries.

The Procedures for Data and Information Exchange and Sharing has provided MRC with Guidelines on Custodianship and Management of the MRC-IS in its attachment. While the Guidelines entrusted the Custodianship to the MRCS, it prescribes the establishment of the MRC-IS to support the activities of the MRC through the dissemination of information. The Guidelines provides further the establishment of the ISDIT to manage the MRC-IS, inviting participants from the member countries and the MRCS.

The MRCS has been playing the role as custodian of the data received from the NMCs with staffs of the Technical Support Division (TSD). The implementation of the Procedures and Rules would surely increase the task of the MRCS significantly. The employment of an additional number of staff including a database administrator might be necessary to cope with the increased workload.

(2) Facilities for Precipitation Gauging

Most of the precipitation gauges have the tipping-bucket type of sensors. Roll Paper logging are dominant but recording on a magnetic card has recently become popular. Manual measurement by a measuring cylinder is common in a comprehensive meteorological station to collate the records of automatic gauges. Telemetering systems are installed where real-time data are necessary for the operation of facilities such as the hydroelectric power station.

Most of the countries adopt the equipment and location of gauging station in accordance with their own standards or the standards proposed by the WMO. The actual experience in usage is one of the most important conditions to select the type of equipment considering maintenance and repair. On the other hand, the condition of access is an important factor to select the location of a gauging station site. This is quite natural taking account of the manual data collection and the maintenance work on the equipment.

The MRCS had registered about 700 gauges in total. A number of gauges are distributed in the territory of each member country rather evenly. The MRCS had received the data observed at 231 stations in 1997, which is almost 30% of the stations, and compiled the data in the Lower Mekong Hydrologic Yearbook.

(3) Facilities for Water Level Gauging and Discharge Measurement

Most water level gauges have pressure sensors or float sensors. Roll Paper logging are dominant but recording on a magnetic card has recently become popular. Manual observation by measuring staff gauge is adopted for backup at important gauging stations. Telemetering systems are installed where the real-time data are necessary for the operation of facilities such as the hydroelectric power station.

Most of the countries adopt the equipment and location of gauging station in accordance with their own standards. The actual experience in usage is one of the most important conditions to select the type of equipment considering maintenance and repair. The sedimentation and scouring at the gauge site are matters to be deliberated in the selection of location in the case of the Mekong River Basin. Further, the condition of access is an important factor to select the location of a gauging station as well. This is quite natural taking account of the manual data collection and the maintenance work on the equipment.

The MRCS had registered more than 200 gauges in total. A number of gauges are distributed in the territory of each member country rather evenly. The MRCS had received the data observed at 125 stations in 1997, which is almost 60% of the stations, and compiled the data in the Lower Mekong Hydrologic Yearbook. The number of data is supposed to be sufficient to make the estimations and the forecasts adaptive to the actual figures. Monitoring at borders might be necessary for the water utilization management.

Discharge measurements are carried out at the vicinity of the selected stations therefrom. In most cases, current meters are used to measure the flow velocity at the sites. On the other hand, the GPS system, levelling surveys and the theodolite with echo-sounder are common equipment for measuring river cross-sections. Trucks haul the equipment to the site and boats are used for the underwater works. There are sites where wires are provided to fix the boat. There is a difficulty to settle the current meter at the intended depth even at such wired sites.

(4) Facilities for Sediment and Water Quality Analysis

The line agencies of the member countries have carried out sediment analysis with frequencies of once a month to 4 times a month. The used equipment is mostly the internationally accepted sampler for suspended sediment sampling. Samples are sent to the laboratory and the concentrations thereof are estimated. Most of the agencies do not carry out sampling of bed load.

The line agencies of the member countries have carried out water quality analysis mostly with frequencies of once a month. The used equipment is mostly the internationally accepted sampler for water sampling. Samples are sent to the laboratory and the concentrations thereof are estimated using mainly the pH-meter, conductivity meter, DO-meter and spectrometer.

(5) Facility for Communication and Data Transmission

<u>Precipitation Data</u>

More than 60% of the daily precipitation data are sent to the monitoring center within 24 hours. The remaining data are sent in phases of once in every 2 days, monthly or once in a year. The means availed to send the data are by post or by hand (50%), telephone or fax (30%), E-mail (10%), and SSB exclusive radio (10%). The daily transmission of the 60% mentioned above exceeds the total of telephone or fax, E-mail and SSB of 59%. This indicates that at least 10% of the records are brought to the monitoring center by hand within 24 hours.

The monitoring center transmits 10% of observed data to NMCs daily including the data for flood forecasting. The NMCs receive about 50% once a year to prepare the yearbook. E-mail is the substantial measure, transmitting about 45% of data to NMCs. Accordingly there might be the possibility that the NMCs could receive 60% of data daily without significant additional input by availing of the E-mail some more.

<u>Stream Flow Data</u>

More than 50% of the daily water level data are sent to the monitoring center within 24 hours. The remaining data are sent in phases of once in every 2 days, monthly or once in a year. The means availed to send the data are by post or by hand (45%), telephone or fax (35%), E-mail (10%) and SSB exclusive radio (10%). The daily transmission of the 50% mentioned above is slightly lower than the total of telephone or fax, E-mail and SSB of 55%.

The monitoring center transmits 30% of observed data to the NMCs daily including the data for flood forecasting. The NMCs receive the remaining 70% once a year to prepare the yearbook. E-mail is the substantial measure, transmitting about 50% of data to NMCs. Accordingly there might be the possibility that the NMCs could receive 50% of data daily without additional significant input by availing of the E-mail some more.

<u>Water Quality Data</u>

More than 20% of the water quality data are sent to the monitoring center within 24 hours. The remaining data are sent in phases of once in every 2 days and monthly. The measures availed to send the data are by post or by hand (70%), telephone or fax (10%), E-mail (10%) and SSB exclusive radio (10%).

The monitoring center transmits 10% of observed data to NMCs within a day. The NMCs receive the remaining 90% once in a year to prepare the yearbook. E-mail is the substantial measure, transmitting about 55% of data to the NMCs.

The NMCs send digital data to the MRCS monthly or yearly by E-mail or by hand, except for the data related with flood forecasting. Daily transmission is, however, vital for the implementation of the Procedures and Rules.

(6) Budgetary Constraints and Other Issues

Data on the exact amount of annual budget to be allocated to hydro-meteorological monitoring were not available because an accountable and reasonable segregation of the gross amount to the specific works requires a complicated study. However, the annual amounts are assumed to be in a range between 50,000 USD and 200,000 USD. The assumed amounts are not sufficient even for the maintenance only. Enhancement or extension of the existing system is not affordable. Actually, the survey results indicate that budgetary constraints are the most significant impediments to both observation and data transmission.

5.4 Water Use Management System in Japan

5.4.1 Introduction

The water use management system for the Lower Mekong Basin (LMB) should be established based on the 1995 Mekong Agreement (the Agreement). The following three (3) Articles of the Agreement are technically considered as the most important ones for establishing the management system.

(1) Article 5: Reasonable and Equitable Utilization

(2) Article 6: Maintenance of Flows on the Mainstream

(3) Article 26: Rules for Water Utilization and Inter-Basin Diversions

In these Articles, there are many technical issues to be resolved. Among them, the following three (3) issues are considered to be the most basic ones:

(1) Establishment of the acceptable minimum monthly natural flow on the mainstream;

(2) Agreement on the proposed intra-basin use during the dry season and the inter-basin diversion on the mainstream; and

(3) Management of the mainstream flow especially in severe drought, including the establishment of the water use monitoring system.

The team provided the policies and experiences on water use management in Japan cited to give some materials, guidelines or suggestions necessary or useful for developing the discussions on the above issues as required for presentation in the workshops for three years of 2001 to 2003.

5.4.2 Issues on Determination of Acceptable Minimum Monthly Natural Flow

Article 6 of the Agreement prescribes cooperation in the maintenance of flows on the mainstream from diversion, storage release, or other actions of a permanent nature except in the cases of historically severe droughts and/or floods. In the dry season the flow on the mainstream shall not be less than the “acceptable minimum monthly natural flow (AMMNF)” during each month except in the cases of historically severe droughts.

Then, for what purpose shall the AMMNF be set? Firstly, the objectives of setting the AMMNF should be clarified before proceeding to the identification of technical issues to be discussed.

(1) Article 5 prescribes the necessary procedures of only the proposed (new) water uses but does not mention anything on the existing water uses. A number of intra-basin water uses already exist on the mainstream so that prior consultation for them has no meaning.

(2) The proposed water uses of the tributaries shall be subject to only notification to the Joint Committee. This may mean that the proposed water uses will be managed independently under the water law of each riparian state.

(3) Hence, Article 5 should be interpreted to mean that prior consultation with and agreement of the Joint Committee on the proposed water uses on the mainstream is stipulated to coordinate the following possible conflicts:

   (a) <u>Conflicts between the existing and proposed water uses on the mainstream</u>. If a proposed water use is too large, it may affect the existing water uses in the downstream. Hence the conflicts should be coordinated through prior consultation with and agreement of the Joint Committee on the proposed water use.

(b) Conflicts among the riparian states in the allocation of available water resources on the mainstream. Available surplus water on the mainstream is limited during the dry season. If the total proposed water use of the riparian states exceeds the amount of surplus water, allocation of the surplus water to the riparian states should be coordinated through prior consultation with and agreement of the Joint Committee on the proposed water use.

(4) A certain criterion is necessary to coordinate the conflicts between the existing and proposed water uses and to evaluate the surplus water that can be allocated for the proposed water uses. The AMMNF in Article 6 is considered to be the criterion for the above conflict coordination and surplus water evaluation.

However, the following technical issues should be clarified to determine the AMMNF:

(1) Protection of the Existing Water Uses

In the Agreement, it is not mentioned clearly whether or not the existing water uses will be protected by the AMMNF. This is still controversial.

(2) Probability of the AMMNF

According to Article 6, the AMMNF shall be maintained except in cases of historically severe drought. What is the historically severe drought? Hydrological probability of the AMMNF must be determined to evaluate the reliability of the existing water use and surplus water.

(3) Definition of Natural Flow

The technical term “natural flow” of the AMMNF is not clearly defined in the Agreement, so that it must be defined clearly to obtain the hydrological database necessary for setting the AMMNF. The actual flow data at principal stations of the mainstream are those affected by water use developments in the past. Is it necessary to reproduce a purely imaginary natural flow regime?

Judging from the above discussions, the concept of AMMNF is considered similar to or the same as the one of “Required Minimum Flow” in Japan. Reference to the flow management system of Japan may be useful to develop the discussions on the above technical issues, so that the management systems in Japan relevant to the above issues are summarised in the following subsection.

5.4.3 Flow Management System in Japan

General

River water is designated as public property according to the River Law, which was firstly enacted in 1896 and thereafter, revised in 1964 and 1997. The River Administrator based on the water right system integrally controls all the river water abstractions in a basin.

The river systems in Japan are legally categorized into two (2) classes; Class I and Class II river systems. The Class I River is important for the economy, social welfare and environment of the country and the drainage basin covers the land of more than two (2) prefectures in principle. The basin of the Class II River is located within only one (1) prefecture.

The Class I River is administered by the Central Government [River Administrator: Minister, Ministry of Land, Infrastructure and Transport (MLIT)]. On the other hand, the Local Government (River Administrator: Governor of Concerned Prefecture) administer the Class II Rivers. The river administrator manages and controls the river flow, river water use, river course, river environments, river structures, etc.

Any person who intends to abstract the river water for such off-stream uses as domestic, irrigation, industrial, hydropower, and other purposes shall obtain the permission (water right) of the river administrator. The granted water right is protected from new water uses. However, a number of river water uses (mostly for agricultural purpose) had been conducted even before the River Law was firstly enacted. Those water uses are all regarded as granted water right (called customary water right), which has the same legal status as the legally permitted water right.

River water for such in/on-stream uses as preservation of aquatic life, fishery, scenic view, preservation of water quality, navigation, prevention of salinity intrusion, prevention of estuary clogging, maintenance of groundwater table, etc., is maintained by establishing the river environmental flow (usually called "maintenance flow" in Japan) at principal stations. The river administrator is responsible for maintenance of the minimum flow required for the existing off-stream and in/on-stream uses.

Water Use Management by Water Right

(1) Principles of Granting Water Right

A water user who intends to obtain a new water right shall submit necessary application documents to the river administrator. A new water use is permitted as far as its application satisfies the conditions enumerated below. However, a user cannot reserve a water right for only a potential water use in the future because the available river water is limited.

(a) Definitely the water use applied for shall be implemented in the immediate future.

(b) The water use applied for shall not affect the existing water uses (both off-stream and in/on-stream uses) in the downstream.

(c) The water use applied for shall be within the surplus natural river flow rate at a design drought. [Permissible new water use ≤ design low flow – required minimum flow for downstream (including existing off-stream and in/on-stream water uses)]. (See, Fig. 5-10, Case I.)

(d) Such a structure as storage dam shall be provided to increase the design low flow in case that the water use applied for exceeds the surplus natural river flow. (See, Fig. 5-10, Case II.)

(e) The proposed structures for the water use applied for shall not worsen the flooding situation or cause adverse effects on river environments.

The river administrator will grant the applicant a water right with the following water use conditions: (1) location of water abstraction, (2) water abstraction quantity, (3) operation rule of storage dam and barrage, and (4) conditions for water abstraction from intake and water storage in dam.

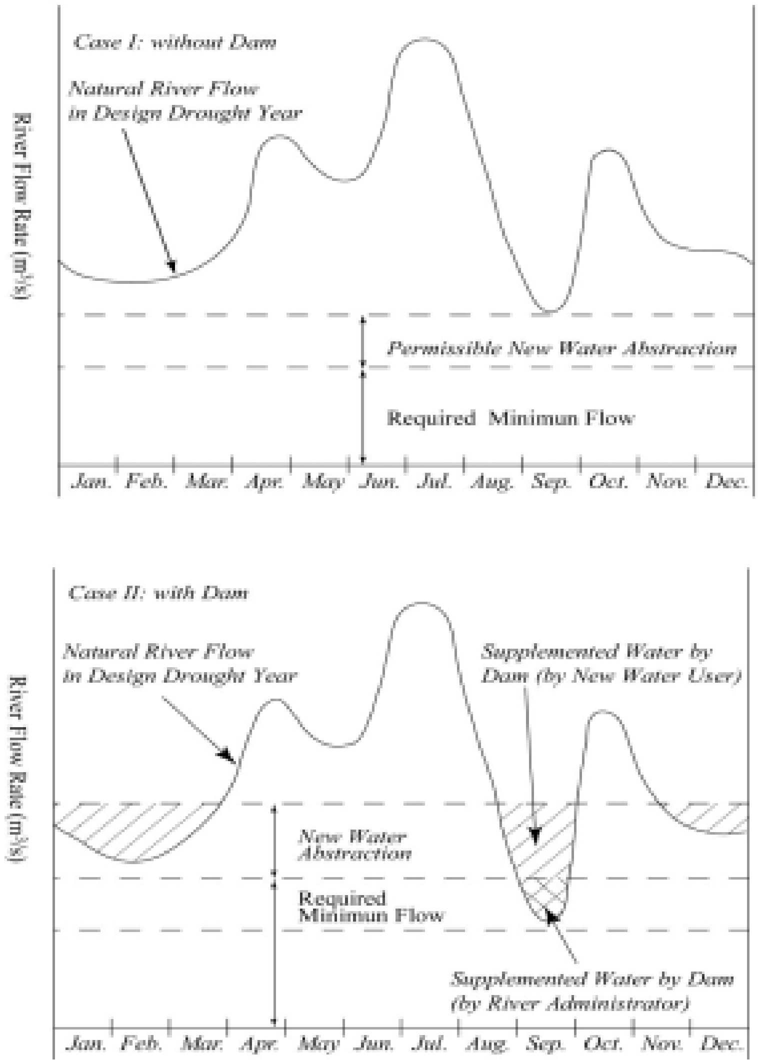


Fig. 5-10 River Water Utilization in Japan

(2) Necessary Consultation and Coordination prior to Granting Water Right

For Class I rivers, the river administrator (Minister of the Ministry of Labour, Infrastructure and Transport or MLIT) shall in principle consult with the ministers of concerned ministries for domestic, agricultural, industrial and hydropower water uses, and the governors of concerned prefectures when he intends to give permission for a new water use. For Class II rivers, the river administrator (Governor of Concerned Prefecture) shall in principle consult with the heads of concerned municipalities and obtain the agreement of the Minister of MLIT when he intends to give permission for a new water use. The Minister of MLIT shall consult with the ministers of concerned ministries prior to the above agreement.

Further, the river administrator shall issue a notification to the existing water users in the downstream when he has received an application for new water use. The existing water users may submit a statement of protest against the new water use to the river administrator, making clear the incurred loss due to the new water use, when they consider that their existing water uses may be affected by the new water use. The river administrator shall not in principle grant permission when the existing water uses are affected by the new water use.

(3) Priority Order

It is generally recognized that higher priority is given to an old water right than a new water right (first in time, first in right) according to the instruction of the river administrator on the above-mentioned water use conditions. Domestic water is not always given the top priority.

(4) Term of Validity

The water right is usually valid for approximately 30 years for hydropower use and about 10 years for other water uses. The original water use quantity, pattern and location may change in the future according to the socio-economic development of the river basin and hence, the contents of the water right need to be reviewed in every certain period. However, the term of validity is renewed in every 10 or 30 years in principle as far as the water use is necessary and active and no vital change occurs in the original water use plan.

Design Flow for Water Use Management

Technically the water use management is performed, assuming the natural flow; design low flow and required minimum flow for the downstream. Definition, criteria, contents and estimation method of these river flows are described below.

(1) Natural Flow

The river water has continuously been developed since the olden days to meet the increasing water requirement of the river basin. Hence, the river flow regime has historically changed according to the water use development.

Even in the past, new water uses (including storage/release of dam and abstraction from river) were planned based on the actual flow regime at that time. The proposed new water uses were implemented by coordinating them with the water uses that had already existed.

At present, the existing water uses are managed based on the current flow regime. New water uses are planned and implemented not to infringe upon the existing water uses. Hence, it is considered impractical or unnecessary to reproduce the imaginary natural flow regime in the past days by removing the existing water uses when a new water use plan is prepared.

From the above considerations, the river flow under the existing water use conditions (including water abstraction and water storage/release of dam) should be defined as natural flow when a new water development is discussed unless the existing water uses are revised.

Usually, the flow records during a certain period in the past are necessary for planning a new water use. However, they are employed for the analysis of flow characteristics, assessment of hydrological probability and preparation of the operation rule of the new water use. Accordingly, the imaginary natural flow needs to be reproduced only when the flow regime has been largely disturbed by the water use development in the past. If the disturbance is not significant, the flow records in the past can be used as the natural flow under the existing water use conditions.

In most of the rivers in Japan, the natural flow is almost all abstracted at drought time ever since the olden days. However, the regulation of river flow by large storage dams was never made before World War II (1945). The large-scale water resources development of major river basins (including large-scale storage dam and water diversion) started only around 1955-1960. The water resources development plans before 1955-1960 were prepared based on the observed flow regime during a certain period because the flow records were scarcely disturbed during the above period.

(2) Design Low Flow

The design low flow is determined to evaluate the available surplus natural flow. It is defined as the minimum rate of the natural flow regime (hydrograph) in the design drought. However, it is determined for each season when the water use seasonally varies.

Probability of Design Low Flow

The design low flow varies depending on its hydrological probability. If the design probability (safety factor) is set lower, a larger design low flow may be estimated and, as a result, more new water abstraction can be permitted. In this case, however, the reliability of water use becomes lower. In the inverse case, the permissible new water use is limited and more river water will be wasted to the sea although the reliability of water use becomes higher.

In Japan, the design low flow is determined for the natural flow regime of a 10-year drought probability. All the water uses in any category are ensured to the extent of a 10-year drought. This design reliability of water use is considered higher than that in the Southeast Asian region. It is because:

(a) A large quantity of river water is used for domestic and industrial purposes in the urban areas; and

(b) A high reliability is required for such water uses because lack of water supply may cause vital damage on the urban and industrial activities in the country.

Design Flow Pattern

The river flow widely fluctuates throughout the year, and wet and dry seasons are not distinct in Japan. For example, the flow of Tone River, the largest and most important river in Japan, has varied from the minimum (6 m^3/s) to the maximum (11,444 m^3/s) with an average (252 m^3/s) at the principal station of Kurihashi (drainage area: 8,588 km^2) during the recent approximately 60 years.

Usually, the flow regime (flow hydrograph) of the typical drought year with a 10-year probability is assumed as the design flow regime based on the actual flow records in the past. For this design flow regime, the water balance at the principal stations is calculated and the required water supply from dam is estimated. This simple static approach is employed for the planning of new water development for practical purposes. It is because:

(a) A number of people, communities, central/local governments, NGOs, water users, relevant experts and others are involved in the planning of new water development.

(b) Many people/organizations may benefit from the proposed development; however, some people/organizations may be affected by it.

(c) In Japan, a large cost is required to develop 1.0 m^3/s of new water use because of the dense population of land uses. Usually, the cost is borne by the central/local government, municipalities and water users (citizens, farmers and private enterprises).

(d) If the planning criteria are not fixed and have a certain range, the exploitable water quantity will sometimes vary to a considerable extent. It will cause many severe trade-off conflicts among the concerned people and organizations.

(e) Hence, the proposed plan must be well understood and accepted by all the concerned people and organizations. The planning methodology must be simple, practical and easy to understand as far as technically/scientifically allowable.

Required Minimum Flow

(1) Objectives and Functions of the Flow

The river administrator must establish the minimum flow required for the maintenance of desirable river water functions in each river section according to the River Law. This flow is usually called "maintenance flow of normal river water function" in Japan; however, it is called "required minimum flow" in this Report to avoid misunderstanding of the technical term. This flow is considered to be similar to or the same as the "acceptable minimum monthly natural flow" in the 1995 Mekong Agreement. Any new water use must be developed in an appropriate manner that does not infringe on the required minimum flow.

The required minimum flow is designed to satisfy both existing reasonable off-stream and in/on-stream uses in each river section. The off-stream use includes domestic, agricultural, industrial, hydropower and other off-stream uses. The in/on-stream water use covers preservation of aquatic life, fishery, scenic view, preservation of water quality, navigation, prevention of salinity intrusion, prevention of estuary clogging, maintenance of groundwater table, etc. The flow required for in/on-stream uses is usually called "river maintenance flow" in Japan; however, it is called "environmental flow" in this Report to avoid misunderstanding of the technical term.

(2) Seasonal Variation of the Flow

In Japan, the domestic and industrial water uses are nearly constant throughout the year. The agricultural water is mostly used for the irrigation of paddy. Paddy is cropped once a year during the summer season (May to September) and hence, the target irrigation area is fixed. The agricultural water use seasonally varies in pattern and is roughly divided into three (3) seasons: puddling season (May), growing season (June to September) and non-irrigation season (for miscellaneous uses).

The in/on-stream water uses also vary in time, according to the seasonal variation of their requirements. Hence, the required minimum flow is determined by season.

(3) Reliability of the Flow

The reliability of all the off-stream water uses in Japan is determined to meet a 10-year drought probability. Theoretically, however, the reliability of in/on-stream water use should be different according to purpose and river section.

Nevertheless, the same reliability is applied for both off-stream and in/on-stream water uses from the viewpoint of practical water management at present. Hence, the required minimum flow shall in principle be maintained throughout the year with a 10-year probability.

Establishment of Required Minimum Flow

(1) General

The required minimum flow has been proposed in nearly 50% of the total 109 Class I rivers since 1964 when its establishment was stipulated in the River Law (the existing New River Law was enacted in 1964). The proposed required minimum flow fully covers the off-stream uses in every river because the water right quantity of all the existing off-stream uses are registered in the office of the river administrator. However, coverage of the environmental flow in these rivers is not always satisfactory since estimation of the environmental flow has been difficult.

In 1997, the Government revised the River Law to include the preservation/recovery of river environment in addition to the conventional management of river including water use control, flood/drought control, and river space/course/structure management. The river administrator must prepare the environmental improvement plan to preserve/recover/improve the river environment and implement the plan in cooperation with the concerned governmental and non-governmental organizations, disciplinary experts, and citizens.

In these circumstances, the River Bureau under the MLIT had surveyed the existing ecological conditions of the river and riverside area of all the Class I rivers. The survey was called the "national river ecology census." The objective ecologies include riverside plants, aquatic plants, fishes, birds, animals, insects, benthos and others.

Further, the MLIT had developed the technical guidelines for establishing the required minimum flow including environmental flow. Based on the guidelines, the required minimum flow of all the Class I rivers have been studied. Among them, the required minimum flow including environmental flow of approximately 20 rivers has already been authorized, while those of the remaining rivers are still under discussion.

The procedure to establish the required minimum flow is described below according to the technical guidelines proposed by the MLIT.

(2) Basic Assumption

The river environment, especially ecological environment, varies throughout the year corresponding to the flow variation of river. Theoretically, the environmental flow should be dynamically determined to meet the varying environmental requirement corresponding to the variation of river flow. However, this dynamic approach is not yet applied due to the reasons given below. The required minimum environmental flow is statistically determined so that it can meet the in/on-stream uses at the design drought (usually, 10-year drought) in the same way as off-stream uses for practical purposes.

(a) Impacts of the flow variation on ecology are not yet clear.

(b) Adoption of different reliabilities between off-stream and in/on-stream uses will make the water use management more complicated and difficult. For example, if design environmental flow yearly changes, operation (especially water storage) of upstream storage dams may be restricted for ecological uses in the downstream even at water abundant time. It may reduce the benefits of the storage dam.

(c) In Japan, the wet and dry seasons are not distinct. The river flow fluctuates to a large extent throughout the year. A spell of drought is severe in quantity but not so long in time. Hence, river flow of nearly natural pattern is usually expected except in drought time unless a large regulating reservoir is provided on the mainstream. At present, the flow regulation capacity of the existing storage dams is limited because they are mostly installed in the uppermost reaches.

Generally, the controlled river flow regime of the mainstream in the major rivers is not so much different from the natural pattern except in drought time and except in some specific locations.

(3) Methodology

Division of River Course

The river course is divided into several river segments. The required minimum flow is set to satisfy all the permitted off-stream uses and required environmental flow in every river segment. The division is made in due consideration to the following factors:

(a) Inflow of tributary: Divided at a location immediately upstream of the confluence of major tributaries.

(b) Topographic conditions: Divided so that topographic conditions of river course (slope, width, etc.) may not largely change within a river segment.

(c) Environmental conditions: Divided so that environmental conditions (aquatic life, water quality, etc.) may not largely change within a river segment.

(d) Water balance: River flow changes in longitudinal direction due to water abstraction, return and tributary inflow. The river is divided in consideration of the water balance.

(e) Tidal reach: Tidal reach (especially, brackish water zone) is separated from the upstream fresh water reach since the relationships between environmental characteristics and hydrological indexes are different.

Estimation of Off-stream Uses

The objective off-stream uses are those registered in the office of the river administrator. The registered water rights are in principle employed to estimate the off-stream water uses. Sometimes, however, the water right quantity is larger than the actual use. They are checked and revised based on a field survey as required.

The agricultural water use seasonally changes. It is set according to the season, at least, into irrigation and non-irrigation periods.

Finally, water intake location and quantity of all the off-stream uses is set according to the season.

Estimation of Environmental Flow

The environmental flow is set to satisfy all the existing in/on-stream uses in each river segment. The environmental flow is also set according to season to meet the seasonal change of the in/on-stream use requirement.

The major elements of environmental flow are to fulfil the requirement of (1) aquatic life and fishery, (2) scenic view, (3) preservation of water quality, (4) navigation, and (5) prevention of salinity intrusion.

Estimation of Water Balance

Intake quantity of the off-stream uses is estimated as described above. However, a considerable portion of the abstracted water returns to the downstream of the river through the drainage channels. Usually, the return flow of agricultural water use is significant and it cannot be neglected. This return flow quantity and location is estimated based on the result of a field survey.

Further, the river receives inflow of tributaries at many locations. The tributary inflow at the design drought is estimated.

Finally, water balance among the intake quantity, return flow and tributary inflow is calculated to estimate the net off-stream use requirement to be supplied from the mainstream. This water balance is calculated along the mainstream from upstream to downstream.

Establishment of Required Minimum Flow

The required minimum flow to satisfy both off-stream uses and environmental flow is estimated for each river segment and season. This flow shall be maintained at the upper end of each river segment.

Actually, the required minimum flow shall be established at one to several principal river stations selected since it is too complicated to establish the required minimum flow at the upper boundary of each river segment. Each selected principal station will govern several river segments in the downstream.

The required minimum flow at each principal station shall be determined to satisfy all the required minimum flows in the governed river segments.

5.4.4 Water Use Monitoring

Issues to be solved in the Lower Mekong Basin

Article 6 prescribes that the Joint Committee shall adopt guidelines for the location and level of flows, and monitor and take action necessary for their maintenance as provided in Article 26. The above "take action necessary for their maintenance" may include water use coordination in a severe drought time.

According to Article 26 of the Agreement, the Joint Committee shall prepare rules for water utilization and inter-basin diversion including:

(1) Improving upon the mechanism to monitor intra-basin use; and

(2) Setting up a mechanism to monitor inter-basin diversions from the mainstream.

Apart from the Agreement, all the riparian states shall monitor water uses within their territories according to their respective water laws. The monitoring may be necessary: (a) to estimate the existing water uses; (b) to check the compliance of the proposed water uses with water right conditions; and (c) to coordinate the water uses in severe droughts.

Also on the regional level, the water use monitoring may be necessary: (a) to share data of the existing water uses in the basin with one another; (b) to check the compliance of the proposed water uses in the basin with the notification/agreement to/by the Joint Committee: and (c) to coordinate the water uses on the mainstream in severe droughts.

Sharing of the water use data with sufficient transparency is essentially necessary for cooperation in the water use management of the LMB.

There are a large number of water uses including irrigation, urban, hydropower and other off-stream uses in the LMB. However, the existing water uses have scarcely been monitored except the operation data of large storage dams.

The existing irrigation areas are widely distributed over the riparian countries, respectively. The total irrigation area in the LMB covers more than 3.0 million ha as shown in Table 5-8 even if the irrigation projects smaller than 100 ha are cut off. However, the intake systems are old and complicated. Even, the available inventory of the existing irrigation intakes and areas is not satisfactory.

Table 5-8 Existing Irrigation Areas in the Lower Mekong Basin

Item	Laos	Thailand	Cambodia	Vietnam (Delta)	Total
No. of Projects	703	1,426	386	85 [1)]	
Whole Area (ha)	165,328	924,398	269,642	1,683,094 [2)]	3,042,462
Dry Season Area (ha)	113,080	No data	138,466	1,417,549 [2)]	

Note: 1): Number of irrigation blocks that are further divided into many small projects.
2): Gross area including settlements, fishponds, uplands, roads and water channels.
Source: Land Resources Inventory for Agricultural Development, Feb. 2002, MRC.

Further, there are a number of large and small storage dams for hydropower and irrigation purposes. Inventories are available for only limited large storage dams. No data is available for the others.

In these circumstances, the following issues should be solved to establish a technically and financially feasible monitoring system:

(1) The kind of water use to be monitored;

(2) The procedure to monitor water use including dam operation;

(3) The procedure to maintain transparency of water uses, especially, inter-basin diversion; and

(4) The procedure to coordinate the water uses in severe droughts.

Reference to the monitoring system of Japan may be useful to develop the discussions on the above technical issues. The monitoring system including river flow, dam operation and water abstraction, and the water use coordination system in drought time in Japan are presented below.

<u>Water Use Restriction in Drought Time</u>

Water right is ensured for the design low flow with a certain probability (generally, 10-year drought). The water uses shall be partly cut when the river flow lowers than the design one. According to the River Law, such water use reduction shall in principle be determined through the coordination among the concerned water users. The river administrator shall provide necessary data for the coordination and can arbitrate among the users when requested.

For this purpose, ninety-nine (99) drought coordination committees have been established in the 68 river basins among the 109 Class I river basins until 1999. A committee consists of the river administrator, water users, concerned ministries of the central government and the concerned local governments.

Water use is usually restricted through the following processes in a severe drought time for each river basin:

(1) Step I: Start of Drought Management

Drought management shall start when:

(a) River flow lowers to a certain level;

(b) Remaining water storages in dams lower to a certain levels; and

(c) It is forecast that the water right may not be satisfied in the near future.

(2) Step II: Holding of Drought Coordination Committee

In the drought coordination committee, the river administrator and water users (mostly represented by the concerned divisions of local government) shall provide or exchange the information shown in Table 5-9.

Table 5-9 Data/Information Exchange in Drought Coordination Committee

Concerned Person	Information
River Administrator	• River flow quantity, water storage in dam and river water quality • Necessary rate of water use restriction based on the forecasting of future river flow and dam storage
Water Users	• Expected damages due to water use restriction • Dissemination of necessity of water use saving

(3) Step III: Decision on Water Use Restriction

The water use restriction program (restriction rate of each water use and date of commencement) shall be determined through coordination among the water users.

(4) Step IV: Performance of Water Use Restriction

During the period of water use restriction, the river administrator and water users shall perform the activities shown in Table 5-10.

Table 5-10 Activities in Water Use Restriction

Concerned Person	Activities
River Administrator	• Dam operation based on the water use restriction program • River flow monitoring and forecasting
Water Users	• Performance of water use restriction • Monitoring of damages

<u>Water Use Monitoring System</u>

(1) Necessity of Water Use Monitoring

River water is abstracted at a number of locations along the river course from the upstream to the river mouth. Excessive water abstraction by the upstream users may cause water shortage to the downstream users. For the prevention of water use conflicts, all water users shall comply with the water use conditions attached to their water rights.

Registered water right shows the maximum quantity of water abstraction. However, actual water use seasonally varies within the limit of the water right quantity. Daily management of river water shall be done based on actual water abstraction.

In Japan, there is no surplus natural flow in most of the rivers during the dry season. Water shortage is supplemented from the upstream storage dams. For effective dam operation, actual water use in the downstream should be monitored.

In a severe drought time, water users shall partly cut their water abstraction. For rational coordination of the water use restriction, the actual water abstraction shouldbe monitored and reported by the water users.

(2) Water Use Monitoring System

According to the River Law, every water user shall monitor his water abstraction at intake and report the data to the river administrator. When water users own storage dams, they shall also monitor the dam operation (water level, inflow discharge, water abstraction and water release) and report the data to the river administrator. The standard monitoring and reporting rules are as given in Table 5-11.

Table 5-11 Standard Monitoring and Reporting Rules in Japan

Monitoring Item	Monitoring Interval	Monitoring Measures	Data Reporting Time to River Administrator
Intake			
Abstracted Quantity	Everyday	Automatic Water Gauge	End of Year (or Month)
Storage Dam			
Water Level	Everyday	Automatic Water Gauge	End of Year (or Month)
Inflow Discharge	Everyday	Automatic Water Gauge	End of Year (or Month)
Abstracted Quantity	Everyday	Automatic Water Gauge	End of Year (or Month)
Released Discharge	Each Time	Automatic Water Gauge	End of Year (or Month)

The water use monitoring shall be done at the cost of water user. The river administrator shall evaluate the reported data and file them. The river administrator shall inspect the structural and operational conditions of river water intake facilities and storage dam once a year. At the time of inspection, the river administrator shall also check the monitoring system and equipment.

The river administrator himself has a number of multipurpose dams, and rain and water gauging stations for river water management. He also monitors rainfall, river water level (discharge), and dam operation (water level, inflow discharge, water abstraction and water release) everyday.

The monitoring of river water quality as well as river water quantity is important for the management of river water use. River administrators, local governments and domestic water users are mainly responsible for the monitoring of river water quality. A river water pollution monitoring committee consisting of the river administrator and local governments has been established in each of the Class I river basins to promote water quality monitoring, to exchange information on water pollution, to cope with accidental water pollution, etc.

The data on rainfall, river water level (discharge), river water quality, river water abstraction and dam operation filed by the river administrator shall be open to any concerned water user and organization for mutual understanding on water use and for smooth coordination of water conflicts in drought time. The data shall be open also to the public according to the Information Publicity Law when requested.

The river administrator publishes annual reports on rainfall, river water discharge and river water quality, and the dam operation data at all the monitoring stations and dams under his jurisdiction. The Ministry of Environment also publishes annual report of the water quality in public water bodies. The major water users publish annual report on their river water abstraction.

The following real time data in all the Class I rivers are accessible through the Internet as listed in Table 5-12.

Table 5-12 Nationwide River Information System through Internet in Japan

Item	Real Time Data
Rainfall	Rainfall at Principal Station, Radar Rainfall
River Water	Water Level and Water Quality at Principal Station
Storage Dam	Storage Volume, Inflow Discharge, Outflow Discharge, Notice/Alarm of Flood Water Release
Drought Management	Remaining Dam Storage Volume, Cut of Water Abstraction
Flood Management	Flood Forecasting/Warning

RECOMMENDATIONS

1. HYDROLOGICAL MONITORING AND MODELLING

Hydrological Monitoring

The aim of the hydrological network is to provide timely, sufficient and reliable hydrological data/information to the agencies and activities concerned. In the course of the WUP-JICA study, the team had recognized existence of discharge data gaps on the Cambodian monitoring network comparing among the riparian countries. Thus the team focused the measurement activities upon establishment of rating curves at the major hydrological stations in Cambodia. After completion of the formulation work on the water utilization rules, the next stage of flow management should start with the full-functioning of the hydrological monitoring systems of the four riparian countries. To keep the mutual trust built up for a long time as the "Mekong Spirit," the line agencies should make efforts to provide timely, sufficient and reliable data to each member country and the MRC. In particular the hydrological network in Cambodia should be improved further based on guidelines/master plan to be developed, in which clear goals and stepwise improvement strategy of the network in parallel with institutional strengthening of the line agencies should be described in detail.

Hydro-Hydraulic Modelling

The hydro-hydraulic simulation model developed is able to simulate the dynamics of flows and water levels in the river system in both wet and dry seasons, the water levels and inundation on would be very useful for a variety of studies such as: flood analysis, flood impact studies, water balance studies, and dry-season flow investigations. Furthermore, the model is flexible to the extension of area for future expansion such as the flood forecasting system. The team had recommended model utilization as the management tool for flood forecasting system with some expansion, as part of flood management in low-lying areas in the MRC. In the meantime, the Cambodian line agencies could utilize the model as the planning and evaluating tool for the development and environmental conservation schemes in the Cambodian floodplains.

2. TECHNICAL ASSISTANCE ON WATER UTILIZATION RULES

Maintenance of Flows

Quantification of the surplus water in the entire Mekong River Basin should be accounted for at the downstream end location of the Mekong River. The Mekong Delta is the starting point for analysis of the maintenance of flows on the Mekong mainstream. Three key issues have been highlighted from the aspect of current water use as well as water resources management in the Mekong Delta. They are: (i) water shortage in the dry season, (ii) seawater intrusion in the dry season, and (iii) acidification. Among them, issues (i) and (ii) are key factors in view of the determination of maintenance of flows on the Mekong mainstream. These issues are likely to intensify in the near future by the impact of various water resources development in upstream riparian countries. In parallel with the progress of the Integrated Basin Flow management (IBFM) Project, a detailed situation of data/information in the Delta will surely be necessary for the riparian members to agree upon the water requirements in the basin. The team recommends reference to the supporting report that contains such data/information.

Acceptable Minimum Monthly Natural Flow

The existing reasonable water uses on the mainstream should be protected with a certain reliability in principle according to the water laws of all the riparian states and principles of the water use

5.2.2 Natural Conditions and Water Resources Issues in the Mekong Delta

Importance of the Mekong Delta as a Starting Point for Estimation of Surplus Water

Quantification of the surplus water in the entire Mekong River Basin shall be accounted for at the downstream end location of the Mekong River, preferably, at both the hydrologic stations of Tan Chau on the Mekong mainstream and Chau Doc on the Bassac River where the total inflow into the Mekong Delta in Vietnam could be measured and monitored. The Mekong Delta shall be the starting point for the analysis of maintenance flows on the Mekong mainstream.

It is generally said that the Mekong Delta covers an area of 45,000 km^2, of which 39,000 km^2 or 87% of the whole delta lies within the borders of Vietnam. Mekong Delta hereinafter refers to the delta in Vietnam. The Mekong Delta is 12% of the total land area of Vietnam. About 16 million Vietnamese, or one in every five, live in the delta. The delta covers 4.9% of the entire Mekong River Basin (795,000 km2) or 6.4% of the Lower Mekong River Basin (606,000 km^2).

The Mekong Delta is where the economy has responded quickly to the government's "open door (doi moi)" reform policy. The economy of the delta, the major agricultural production area of Vietnam, is oriented towards the primary sector. The delta shares 27% to the total GDP of Vietnam, some 40% of agricultural production, and half of rice production in the country. Paddy production is at 11 million tons, nearly 740 kg/capita (despite the high population density of nearly 400 persons/km^2), making the Mekong Delta the largest producer compared to other river basins in Vietnam. Rice and fishery products contribute significantly to the nation's export earnings. The delta contributes approximately 85% of the rice for export.

The lowlands, particularly the areas of recent alluvium, have historically been the most densely populated and productive agricultural part of the Lower Mekong Basin. Although large tracts of land in the delta, particularly, the Plain of Reeds, the Long Xuyen – Hatien quadrangle and the interior of the Ca Mau Peninsula, consist of acid-sulphate soils, it is thought that with ample supply of water and proper land water management these soils can be made productive. In general, the delta has much potential for water resources development for agriculture. The Mekong Delta covers 12 provinces. The population distribution of the Mekong Delta in 1998 is given in the following table.

Table 5-3 Population and Density of Mekong Delta in 1998

Province	Area (ha)	Population	Density (person/km^2)
Long An	444,885	1,306,202	294
Tien Giang	232,694	1,605,147	699
Ben Tre	228,191	1,296,914	568
Dong Thap	323,530	1,564,977	484
Vinh Long	147,370	1,010,486	686
Tra Vinh	236,694	965,712	408
Can Tho	296,300	1,811,140	611
Soc Trang	320,027	1,173,820	367
An Giang	340,623	2,049,039	602
Kien Giang	625,564	1,494,433	239
Bac Lieu	248,925	736,325	296
Ca Mau	521,511	1,117,829	214
Total	3,965,314	16,132,024	407

Source: MRC and KOICA; Flood Control Planning for Development of the Mekong Delta (Basin-wide), September 2000 rules of international rivers declared by international conferences in the past. The "acceptable minimum monthly natural flow" should be designed to satisfy the existing water uses including off-stream, in-stream and on-stream uses with a certain reliability. Surplus water should be estimated by using the "acceptable minimum monthly natural flow" as the basis of estimation. Early quantification of the "acceptable minimum monthly natural flow" is awaited.

Water Use Monitoring

The major objectives of water use monitoring by MRC are: (i) to share data on the existing water uses in the basin with one another; (ii) to check compliance with the proposed water uses in the basin through notification/prior consultation/specific agreement to/by the Joint Committee; and (iii) to coordinate the water uses on the mainstream in severe droughts. The existing major water uses in the LMB are irrigation and hydropower. However, irrigation uses have scarcely been monitored except the operation of large storage dams. Even the available inventory of the irrigation intakes and areas is not satisfactory.

River flow and water uses should be integrally monitored to manage the low flow of the mainstream, especially, to coordinate the water uses on the mainstream in severe droughts. For this purpose, monitoring with sufficient accuracy should be performed for the mainstream flow at the principal stations, the inflow of major tributaries at the outlets, and the off-stream uses on the mainstream at the intakes. The existing largest off-stream use on the mainstream is irrigation use on the Mekong Delta. The estimation of its quantity is the most important for the management of mainstream flow. However, direct measurement of the water abstraction quantity is difficult. Hence, some indirect measurement system acceptable to all of the riparian states should be established as early as possible.