Mekong River Commission

Japan International Cooperation Agency

THE STUDY ON HYDRO-METEOROLOGICAL MONITORING FOR WATER QUANTITY RULES IN MEKONG RIVER BASIN

FINAL REPORT

VOLUME III SUMMARY

March 2004

CTI Engineering International Co., Ltd.

NIPPON KOEI Co., Ltd.

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PREFACE

In response to a request from the Mekong River Commission, which was established in 1995 to promote the cooperation for the sustainable development of the Mekong River basin, the Government of Japan decided to conduct "The Study on Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin" and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched the study team headed by Mr. Kanehiro MORISHITA of CTI Engineering International Co., Ltd. consisted of CTI Engineering International Co., Ltd. and Nippon Koei Co., Ltd. to Phnom Penh, 6 times between May 2001 and January 2004. In addition, JICA set up the advisory committee headed by Messrs. Shizuo ONO (April 2001 to September 2002; Former Managing Director of the Overseas Construction Association of Japan), Minoru KURIKI (September 2002 to May 2003; Former Executive Officer for Projects Evaluation, Kinki Regional Development Bureau, Ministry of Land, Infrastructure and Transport) and Ryuzo IKUSHIMA (May 2003 to March 2004; Deputy Director of Planning and Research Administration Department, Public Works Research Institute).

The team held regional workshops and discussions with the officials concerned of the Mekong River Commission Secretariat and the riparian member countries, and conducted field surveys in the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to the promotion of the Mekong cooperation and to the enhancement of friendly relationship among the secretariat, the riparian member countries and our country.

Finally, I wish to express my sincere appreciation to the officials concerned of the Mekong River Commission and the riparian member countries for their close cooperation extended to the Team.

March 2004

Kazuhisa MATSUOKA

Vice-President

Japan International Cooperation Agency

March 2004

Mr. Kazuhisa MATSUOKA
Vice-President
Japan International Cooperation Agency
Tokyo, Japan

Sir:

LETTER OF TRANSMITTAL

We are pleased to submit herewith the Final Report on "*The Study on Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin.*"

The study was conducted by CTI Engineering International Co., Ltd. in association with Nippon Koei Co., Ltd. under contracts with Japan International Cooperation Agency (JICA) during the period from March 2001 to March 2004. In conducting the study, we have paid much attention to strengthen the existing hydrological network in the riparian countries and to assist the MRC in the process of the preparation of the water utilization rules.

We wish to take this opportunity to express our sincere gratitude to the Government of Japan, particularly, JICA, the Ministry of Foreign Affairs, and other offices concerned. We also wish to express our deep appreciation to the Mekong River Commission Secretariat, and the line agencies of the riparian member countries for their close cooperation and assistance extended to the JICA study team during the study.

Finally, we hope that this report will contribute to the further promotion of the Mekong cooperation.

Very truly yours,

Kanehiro MORISHITA
Leader, JICA Study Team
CTI Engineering International Co., Ltd.

Encl.: a/s

COMPOSITION OF FINAL REPORT

VOLUME I	**:**	**MAIN REPORT**
VOLUME II	**:**	**SUPPORTING REPORT (1/2)**
PAPER I	**:**	**IMPROVEMENT OF HYDROLOGICAL STATIONS**
PAPER II	**:**	**GAP FILLING OF RAINFALL DATA**
PAPER III	**:**	**HYDROLOGICAL MONITORING**
PAPER IV	**:**	**DEVELOPMENT OF HYDRO-HYDRAULIC MODEL FOR THE CAMBODIAN FLOODPLAINS**
PAPER V	**:**	**APPLICATION OF HYDRO-HYDRAULIC MODEL**
PAPER VI	**:**	**WATER USE IN THE LOWER MEKONG BASIN**
VOLUME II	**:**	**SUPPORTING REPORT (2/2)**
PAPER VII	**:**	**MAINTENANCE OF FLOWS ON THE MEKONG MAINSTREAM**
PAPER VIII	**:**	**INSTITUTIONAL STRENGTHENING**
PAPER IX	**:**	**WATER USE MANAGEMENT**
VOLUME III	**:**	**SUMMARY**


STUDY AREA
(LOWER MEKONG BASIN)
LEGEND
International boundary
Basin boundary
Mekong River
Upper Mekong basin
Lower Mekong basin
Major City
N
CHINA
INDIA
KUNMING
CHINA
VIETNAM
HANOI
MYANMAR
LAOS
VIENTIANE
GULF OF TONKIN
YANGON
THAILAND
BANGKOK
CAMBODIA
PHNOM PENH
HO CHI MINH
GULF OF THAILAND
SOUTH CHINA SEA
0 100 200 300 km

EXECUTIVE SUMMARY

I GENERAL INFORMATION

I-1 Introduction

1 This Report has been prepared by the JICA Study Team (hereinafter refer to as WUP-JICA Team) in accordance with the Scope of Work (S/W) for "The Study on Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin" agreed upon by and between the Mekong River Commission (MRC) and the Japan International Cooperation Agency (JICA) on December 8, 2000.

2 The Study had covered the Lower Mekong River Basin in Laos, Thailand, Cambodia and Vietnam. The study area was approximately 606,000 km^2. The Lower Mekong River Basin accounts for 76% of the entire basin, as listed below.

Catchment Area of Mekong River Basin

Country	Catchment Area (km^2)	Remarks
China	165,000 (21%)	
Myanmar	24,000 (3%)	
Laos	202,000 (25%)	Lower Mekong River Basin's Total Catchment Area: 606,000 km^2 (76% of entire basin)
Thailand	184,000 (23%)	
Cambodia	155,000 (20%)	
Vietnam	65,000 (8%)	
Total	795,000	

3 The objectives of the study were: (1) To study the flow regime of the Mekong River system; (2) To assist MRC in the processes of the preparation of the Draft MRC Rules for water quantity/utilization; and (3) To strengthen the institutional framework and capacity of the riparian members and MRCS in the course of the study.

I-2 Background

4 The "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin" (the Agreement) was signed in April 1995 by the respective plenipotentiaries of the four riparian countries: Laos, Thailand, Cambodia and Vietnam. Based on the Agreement, the Mekong River Commission (MRC) has been established.

5 At present the MRC focuses on three core programmes: (1) the Water Utilization Programme (WUP); (2) the Basin Development Plan (BDP); and (3) the Environmental Programme (EP). The WUP's objective is to assist the MRC in the establishment of mechanisms to promote and improve the coordinated and sustainable water management in the basin, including the reasonable and equitable water utilization by the riparian countries, the protection of the environment and aquatic life, and the maintenance of ecological balance. To realize this objective, the preparation of Rules for water utilization

and procedures for information exchange, notification and prior consultation is very necessary in order to comply with the Agreement.

6 Article 26 of the Agreement (Rules for Water Utilization and Inter-Basin Diversion) provides that the rules shall include but are not limited to: (a) Establishing the timeframe for wet and dry seasons; (b) Establishing the location of hydrological stations, and determining and maintaining the flow level requirements at each station; (c) Setting out the criteria for determining surplus quantities of water on the mainstream during the dry season; (d) Improving upon the mechanism to monitor intra-basin use; and (6) Setting up a mechanism to monitor inter-basin diversions from the mainstream.

7 At the unofficial donors' meetings that had been held periodically since November 1995, the Government of Japan had indicated its readiness to cooperate, under the framework of JICA's development study scheme, in the preparation of the rules for water utilization and inter-basin diversion, and in setting up the mechanism for a monitoring network as stipulated in Article 26. Meanwhile, the Mekong River Commission Secretariat (MRCS) initiated and implemented several programmes/plans/activities to support the four member countries of MRC in the implementation of the Agreement. In March 2000, the WUP, financed with funds from the Global Environmental Facility (GEF), was also started.

8 In response to the official request of the MRC on behalf of the governments of the four member countries, the Government of Japan had decided to conduct "The Study on Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin" in accordance with the relevant laws and regulations in force in Japan. The Japan International Cooperation Agency (JICA), the agency responsible for the implementation of technical cooperation programmes of the Government of Japan, was then given the task of undertaking the study in close cooperation with the authorities concerned of the MRC and its member countries.

9 In accordance with the agreed S/W, the study was commenced in March 2001 with the preparation of the draft inception report in Japan as the initial stage. Then the WUP-JICA Team was mobilised to Cambodia for the inception meeting with the MRCS in May 2001. The Team conducted the study for three years, and the three volumes of the Report cover the entire results of the Team's activities.

II HYDROLOGICAL NETWORK IMPROVEMENT, GAP FILLING AND MONITORING

10 The Team had conducted physical activities on the improvement of existing major hydrological stations. It also conducted hydrological monitoring, including discharge measurements, and some meteorological analyses for data gap filling.

II-1 Improvement of Hydrological Stations

11 Since the Mekong Committee/Interim Committee (the precursor of MRC) was established in 1957, the configuration of well-functioning hydrological networks has been the focus of activities. Improvement works had continued in cooperation with the committee and the line agencies of the riparian countries, but due to the lingering political disturbance and the differences in national economy, the physical density and observation reliability of the current network vary among the four riparian countries.

12 To solve the unequal situation of hydrological networks over the Lower Mekong Basin, the "Appropriate Hydrological Network Improvement Project" (AHNIP), supported by

AusAID, has been implemented. Under this project, eighteen (18) hydrological stations, which are major stations in the Mekong River Basin being located at the Mekong mainstream, the Tonle Sap and Bassac including two stations in China are to be upgraded into telemetry stations and their monitoring systems improved.

13 To avoid overlapping of work at the stations to be improved under the AHNIP, the WUP-JICA Team had selected the hydrological stations that are mainly located at the downstream end of the major tributaries such as Nam Mun in Thailand, Nam Ngum in Laos and so on. After examining their current situations, the Team determined the suitable improvement measures for each station. Finally the Team installed automatic water level recorders of the gas-purged type in eight stations; namely, one in Thailand, two in Laos, four in Cambodia and one in Vietnam. After the installation, the Team visited the sites to conduct on-site-training of observers/operators on the proper operation and maintenance of the recorders from time to time as required.


Improved Hydrological Stations: Neak Luong in Cambodia (Left), Ubon in Thailand (Right)

II-2 Gap Filling of Daily Rainfall Data

14 According to the WUP-PIP (WUP-Project Implementation Program), it was the task of the WUP-JICA study to fill in the data gaps and carry out technical studies to assist MRC in the formulation of the rules. This task of course conformed with the objectives of the study, but the filling of data gaps had been a much wider field than expected in the initial stage of the study. Thus the team pointed out two kinds of gaps to be filled: one was the daily rainfall data, and the other one was the complete lack of discharge data to be measured in Cambodia as described in the succeeding paragraphs.

15 One hundred twenty-six (126) stations with continuous observation data on daily rainfall since 1991, including those with some data-missing periods, had been initially selected from the MRCS hydrological database and hydrologic yearbooks. The selected stations included 52 in Thailand, 41 in Laos, 22 in Cambodia and 11 in Vietnam. Among them, 51 stations in Thailand, 25 in Laos, 3 in Cambodia and 3 in Vietnam had complete datasets without missing data.

16 For the stations with incomplete datasets of daily rainfall, the following items of work had been made to generate the missing data: (a) Estimation of yearly rainfall using regression equations between target station and high correlative stations; (b) Estimation of probability of consecutive wet and dry days by month at the target stations using available records; (c) Estimation of probability curves of daily rainfall amount in the same manner

mentioned above; and (d) Estimation of daily rainfall through generation of a random number to determine the wet events and to compute the daily rainfall amounts.

17 As a result, the daily rainfall data at 18 additional stations were made available for further study. These stations are 1 in Thailand, 4 in Laos, 11 in Cambodia and 2 in Vietnam. In total, the daily rainfalls of 100 stations in the Lower Mekong River Basin for the period of 1991 to date were used.

II-3 Hydrological Monitoring

18 Upon agreement of the four riparian countries on the Water Utilization Rules, particularly, the hydrological monitoring system, it will become necessary to establish a flow monitoring system for the proper management and maintenance of the rules because the importance of discharge data will increase. From the viewpoint of data gaps in the discharge data, there exist big gaps in the Cambodian territory due to the long-lasting political instability. However, the upgrading process by AHNIP had progressed as mentioned before. In due consideration of the above situations, the Team had selected the remaining hydrological stations located in and around the Phnom Penh area; namely, Kompong Cham, Chrui Changvar (Phnom Penh Mekong), Koh Norea and Neak Luong on the Mekong mainstream, Phnom Penh Port on the Tonle Sap, and Monivong Bridge (Chak Tomuk or Phnom Penh Bassac) on the Bassac River. The Team conducted periodical discharge measurements at the stations from July 2002 until October 2003.

19 Based on the discharge measurement results including those at Kratie (made by the DHRW, MOWRAM), rating curves had been developed for the six hydrological stations mentioned above except for Phnom Penh Port and Kratie. Using the discharge hydrograph computed through these rating curves, it has been verified that the discharge at Phnom Penh Port also could be estimated in a practical manner during the wet season. As the result, the wet-season hydrological monitoring system had been technically established from Kratie down to the Vietnam border. The issue regarding the sustainability of monitoring will however remain unsolved due to the budgetary constraint.

20 Despite the issue on sustainability mentioned above, the dry-season monitoring system had been proposed following the step-by-step approach in accordance with the study results, namely, (a) It has been verified that the rating curves at Kompong Cham could be used throughout the whole year; (b) The discharges at Chrui Changvar could be estimated by the regression equation developed between Kompong Cham and Chrui Changvar; and (c) The flow of Tonle Sap could be estimated through the developed rating curve within the conditions of normal flow until around the end of April. For bridging the limitation of the rating-curve development and establishing a whole-year-round monitoring system in the Phnom Penh area, the Team had proposed the installation of direct measurement equipment for flow current along the Tonle Sap and Bassac rivers. As a result, the hydrological monitoring system itself and the reliability of observations had been enhanced for the dry-season monitoring as well as the wet-season one in Cambodia.

21 In addition, the Team conducted two indoor trainings and one-month on-the-job training in 2002 to impart knowledge on discharge measurements using the ADCP (Acoustic Doppler Current Profiler). In 2003 on-the-job training was repeatedly conducted for one month from the beginning of the dry-season discharge measurements. Further, the joint regional workshop with the AHNIP was held for five days in July to enhance the knowledge on using the ADCP.

On-the-Job Training (left photo) and Joint Regional Workshop with the AHNIP in July 2003 (right photo)

III HYDRO-HYDRAULIC MODELLING

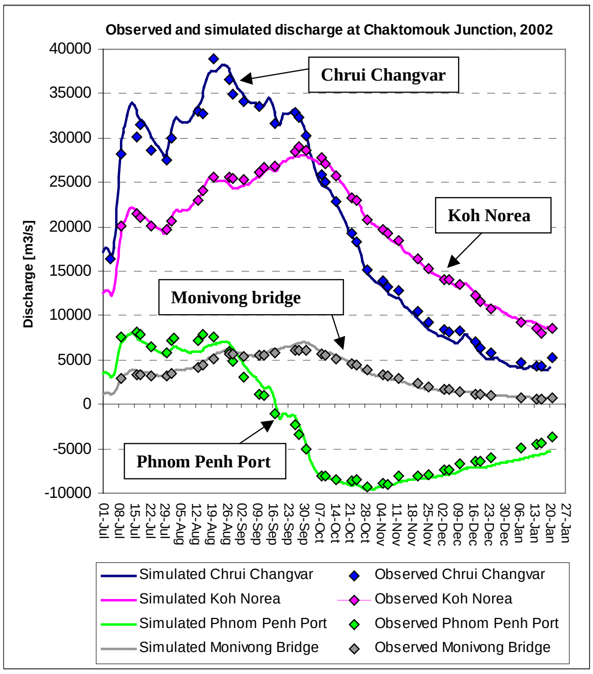
22 In succession to the Chak Tomuk Project of MRCS, the Team had continued developing the hydro-hydraulic model for utilization as the analytical tool for the WUP-JICA study. The model covers Kratie down to the Vietnam border including the Great Lake basin.

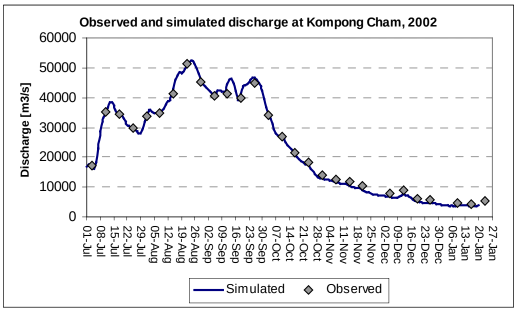
III-1 Development of Hydro-Hydraulic Model for the Cambodian Floodplains

23 The project of "Chaktomuk Area -Environment, Hydraulics, Morphology-" (Chak Tomuk Project) mentioned above was carried out under TSD-MRCS from April 2000 to July 2001 with financial assistance from the Government of Japan. A one-dimensional hydraulic model covering the major channel system of the Mekong from Kratie down to the Vietnam border was constructed in this project. The original task of this model in the Chak Tomuk Project was to provide the boundary conditions for the precise two-dimensional hydraulic model of the Chak Tomuk area.

24 The WUP-JICA Team had made modifications to the one-dimensional model prepared under the Chak Tomuk Project so as to improve and utilize it as the analytical tool for the WUP-JICA study. The improvement of the model consisted of: (a) incorporating the rainfall-runoff model of the sub-basin from Kratie down to the Vietnam border into the model; and (b) incorporating the Great Lake model and the rainfall-runoff model of its sub-basins into the model.

25 Furthermore, the flooding mechanisms over the Cambodian floodplains during the 2002 wet season had been precisely examined through the intensive discharge measurement campaign not only on the major river course but also on the floodplains, and the satellite imagery analysis in cooperation with the "Consolidation of Hydro-Meteorological Data and Multifunctional Hydrologic Roles of Tonle Sap Lake and its Vicinities" Project (TSLVP), which succeeded the Chak Tomuk Project with financial assistance from the Government of Japan. Based on the observations and analyses in the 2002 wet season, the capability and reliability of the model description had dramatically improved. The results also had been provided to the basin modelling activities under WUP-MRCS.





Model Calibration Results (in the 2002 wet season)

III-2 Application of the Model

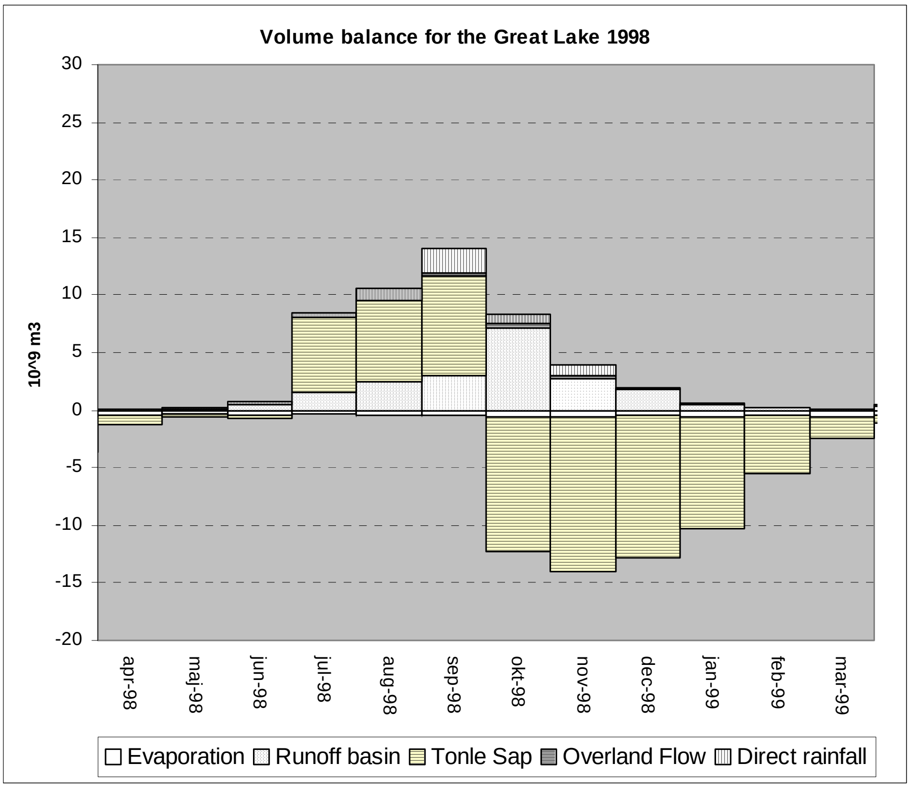
26 Investigations and assessments had been made using the developed model to assist in the relevant activities, as follows:

(a) Since water level and discharge are heavily affected by tidal fluctuation, the dry-season flow in and around Phnom Penh area shall have to be generated through hydraulic simulation. The model had been calibrated with the discharge measurement data of the 2003 dry season. Utilizing the simulation outputs of hourly discharge, which widely fluctuates in accordance with tide, the daily average flow had been calculated for investigation of the dry-season monitoring system.

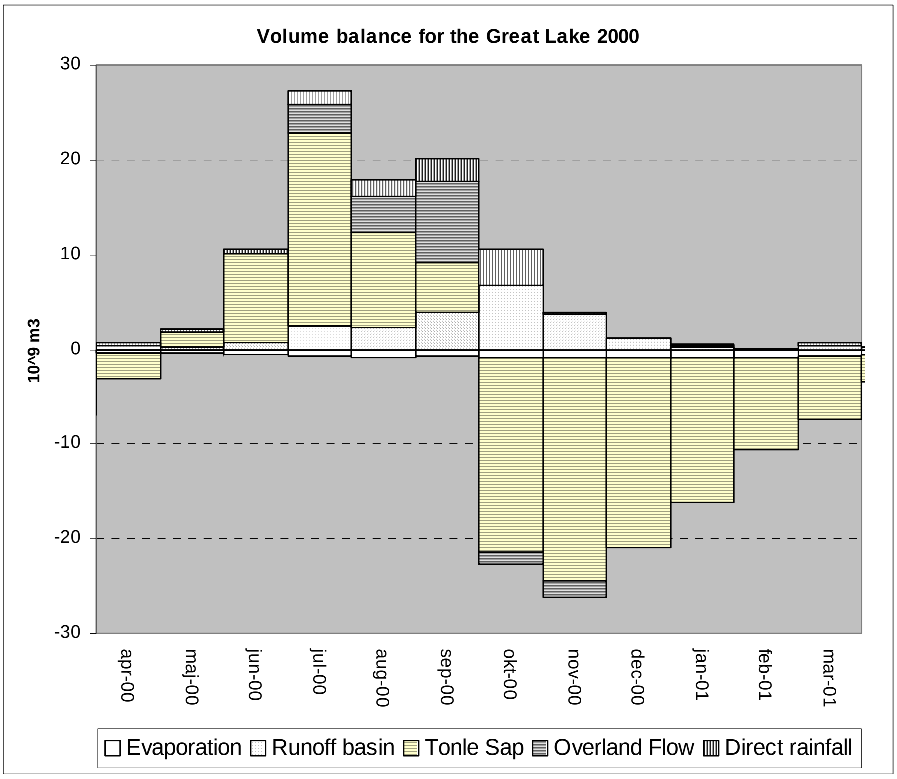
(b) The construction of road networks with embankment in the Cambodian floodplains might have historically given the largest effects to the floodplain hydrology including that of the Great Lake. The historical effects to the Great Lake and the hydrological effects of widening bridge openings had been evaluated by the simulation.

(c) Water balance of the Great Lake had been computed with the decomposition of various hydrological factors; namely, basin runoff, direct rainfall and evaporation on the lake surface, normal and reverse-flow in the Tonle Sap, and overland flow through the floodplains. The contribution rates and monthly changes had been computed from the simulation results.

27 This simulation model could be recommended as a good analytical tool for the evaluation of hydrological and hydraulic effects caused by the various development activities in the Cambodian floodplains. For this purpose it is crucial that the staffs of the responsible agencies are able to operate the model and analyse the effects by themselves in a sustainable manner. Thus the Team conducted training from December 26 to December 31, 2003, to familiarise the staffs of the DHRW with the operation and management of the model.



<u>Volume Balance of the Great Lake (Dry Year 1998)</u>



<u>Volume Balance of the Great Lake (Wet Year 2000)</u>

IV HYDROLOGY AND WATER USE IN THE LOWER MEKONG BASIN

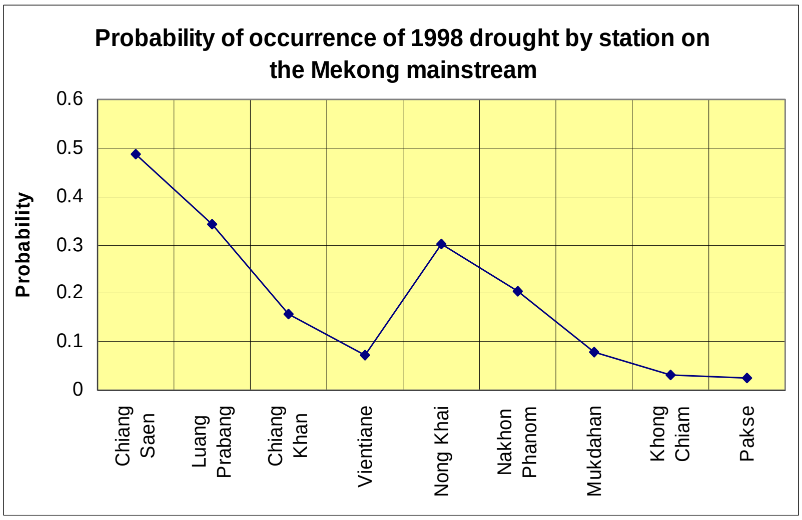
28 Data collected and results analysed in the course of the WUP-JICA study are herein summarized for better reference on the fields of hydrology and water use in the basin.

IV-1 Hydrology in the Lower Mekong Basin

29 In the course of the WUP-JICA study, various hydrological studies were made for understanding the hydrological mechanisms or in response to the requests of the WUP-MRCS and the hydrology group of the MRCS. Among the results, the following hydrological characteristics are summarised for future useful references:

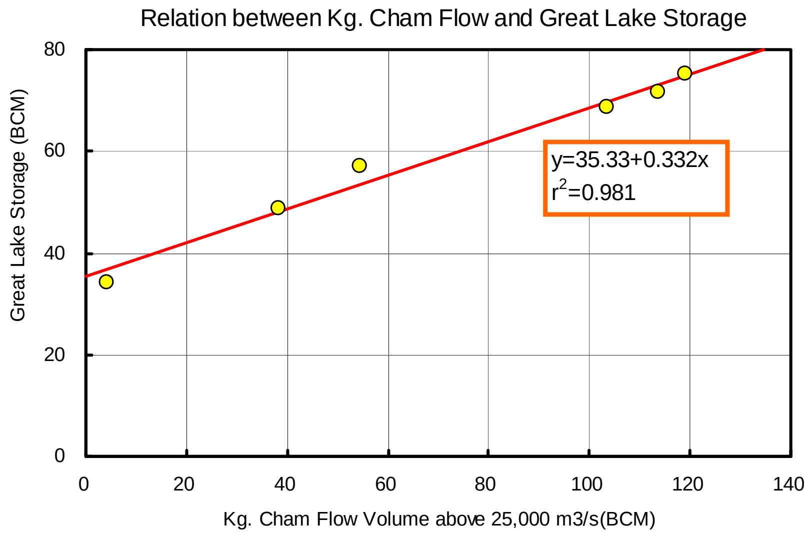
30 General features of the Mekong hydrology have been drawn out using the flow characteristics at major stations. As the noticeable flow contributions, the upstream basin of China is dominant to the dry-season flow, while the Laotian highlands are dominant to the wet-season flow.

31 Drought occurrence longitudinally varies over the lower Mekong basin due to the differences of rainfall distribution in the drought year, based on the drought analysis of historical data. The drought situation could be categorized into several types in terms of longitudinal differences of drought severities.



Comparison of Probabilities of the 1998 Drought Occurrence

32 Based on the discharge measurement campaign in the 2002 wet season and succeeding the hydraulic simulation, the flood-retarding functions of the Cambodian floodplains had been comprehensively depicted in terms of flood discharge attenuation through over-bank flooding and flood bypass on the plains. In addition, the relation between the Great Lake storage and the flood flow volume at Kompong Cham for the recent six years from 1998 to 2003 had been clarified. This relation can be used for the consideration on "natural reverse flow of Tonle Sap" stipulated in Article 6 of the 1995 Mekong Agreement.



Relation between Kg. Cham Flood Volume and Great Lake Storage

IV-2 Water Use in the Lower Mekong Basin

33 The Team had collected water use data/information through literature search and from the relevant agencies to understand the current situations of water resources development in the riparian countries.

34 The collected data/information consisted of: (a) Existing dams and reservoirs (mainly for hydropower and irrigation development) in China as well as in Thailand, Laos and Vietnam; (b) Irrigated areas and irrigation facilities in the four member countries referring to the report “Land Resources Inventory for Agricultural Development” prepared by MRC in 2002; and (c) Estimation of quantities in water use.

35 Regarding the estimation of irrigation water use, water demands had been estimated using the water requirements for irrigation and irrigated areas, because there was no data available in this field. Based on the available information related to the current dry season irrigation areas and diversion requirements, the 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.

V TECHNICAL ASSISTANCE ON WATER UTILIZATION RULES

36 For the formulation of water utilization rules, various technical assistances had been made including the technical study, technology and experience transfer, and institutional approach. Presented below are the results of the entire assistance provided by the Team.

37 There are several key terms and complex concepts regarding the water utilization rules in the 1995 Mekong Agreement to be clearly defined. For instance, the terms “natural” and “acceptable” in Article 6, Maintenance of Flows on the Mainstream, shall have to be defined clearly and unanimously agreed upon by the riparian countries as to their practical meanings.

V-1 Maintenance of Flows

38 The MRCS launched the Integrated Basin Flow Management (IBFM) Project with financial assistance from GEF at the end of year 2003. Under this project the WUP-MRC intends to submit the three types of flows stipulated in Article 6 to the Joint Committee at the end of year 2004; namely, “Acceptable Minimum Monthly Natural Flow during each month of the dry season,” “Acceptable Natural Reverse Flow of Tonle Sap to take place during the wet season,” and “Average Daily Peak Flows naturally occur on the average during the flood season.” Among the above three types of flows, the Team had focused its study on the “acceptable minimum monthly natural flow” during the dry season, since this flow will generate the most serious conflicts among the riparian countries due to the utilization of limited dry-season flow.

39 In general, the surplus water is estimated on water balance between required minimum flow and actual flow conditions starting from the downstream end. If no available surplus is found at the downstream end, it can be assumed that surplus water does not exist in the basin. In fact the Mekong Delta is the biggest water user on the mainstream and it suffers from saline water intrusion every year. Thus the required minimum flow in the Mekong Delta in the dry season is the most significant factor for determining the surplus water in the Mekong basin. The previous major water resources development schemes on the mainstream targeted increase of dry-season flow in the Delta as well as flood control in the wet season.

40 Irrigation water in the Delta is withdrawn from the canal system stretching in a finely meshed pattern in the dry season so that it is difficult to monitor water use quantity as well as to calculate the withdrawn flow directly. The only way to estimate the water use quantities is by using the water requirements of crop cultivation and their areas. Furthermore, the situations of saline water intrusion change in accordance with hydrological and water withdrawal conditions. Therefore, the countermeasures against saline water intrusion shall have to be established well balancing with water use for agriculture.

41 Monthly mean discharges of several non-exceedance probabilities had 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 the dry years of 1992 and 1998 had also been examined.

Probability of Monthly Flow in the Dry Season (Unit: m^3/s)

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

V-2 Institutional Strengthening

42 Institutional strengthening comprises assistance to the formulation of rules and the strengthening of monitoring activities after formulation of the rules.

43 Regarding assistance to the formulation of rules, the Team had conducted: (a) Collection and interpretation of 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) as an universal application; (b) Collection and interpretation of the agreements for the management of specific international rivers; and (c) Verification of the 1995 Agreement and national water resources laws in the riparian countries from the above applications and examples.

44 By reviewing the water utilization rules being formulated, the necessary measures and activities to be taken in the near future such as practical guidelines under the rules were proposed. Furthermore, current issues and future improvement on the hydrological monitoring system are to be proposed on the basis of interview survey with the line agencies of the riparian countries.

V-3 Water Use Management System in Japan

45 At the ending stage of the first field survey in August 2001, the MRCS requested the WUP-JICA Team to hold national training workshops by going around the riparian countries with the water utilization system in Japan as the main theme. After the Team had discussed the request and its reply with the JICA Headquarters in Tokyo, JICA decided to assist in the national workshops held in 2001/2002.

46 Since then the Team had prepared timely themes based on the experiences in Japan and in accordance with the impending issues at the MRCS. The following were the themes presented in the regional/national training workshops:

(a) 2001/2002: Historical background of water management processes with emphasis on the water right system, and examples of water resources development and present directions;

(b) 2002/2003: Water use monitoring procedures and activities originating from legal procedures for water right permission, and examples on monitoring system; and

(c) 2003/2004: Determination process and examples of minimum flow requirements and maintenance of flows.

VI RECOMMENDATIONS

VI-1 Hydrological Monitoring and Modelling

47 The hydrological network aims 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 the completion of formulation of the water utilization rules, the next stage of flow management will start with the full-functioning of the hydrological monitoring systems of the four riparian countries. To keep the mutual trust built 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 further improved based on guidelines/master plan to be developed where clear goals and stepwise improvement strategies of the network in parallel with institutional strengthening of the line agencies should be described in detail.

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

VI-2 Technical Assistance for Water Utilization Rules

49 Quantification of the surplus water in the entire Mekong River Basin shall be accounted for from the downstream end location of the Mekong River. Since the Mekong Delta is the starting point for the analysis of maintenance of flows on the Mekong mainstream, three key issues are 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 the 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 riparian members to agree upon the water requirements in the basin. The Team recommends reference to the supporting report that contains such data/information.

50 The existing reasonable water uses on the mainstream should be protected with certain reliability, in principle, according to the water laws of all the riparian states and of the water use rules for international rivers declared by international conferences in the past. The "acceptable minimum monthly natural flow" shall be designed to satisfy the existing water uses including off-stream, in-stream and on-stream uses with certain reliability. Surplus water shall 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.

51 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 irrigation intakes and areas is not satisfactory

River flow and water uses should be integrally monitored to manage 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. Estimation of its quantity is the most important for management of the mainstream flow. However, direct measurement of the water abstraction quantity is difficult. Hence, some indirect measurement systems acceptable to all of the riparian states should be established as early as possible.

THE STUDY
ON
HYDRO-METEOROLOGICAL MONITORING
FOR WATER QUANTITIES RULES IN MEKONG RIVER BASIN

VOLUME III

SUMMARY

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ABBREVIATIONS

ORGANIZATIONS

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
GEF	Global Environmental Facility
JICA	Japan International Cooperation Agency
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMO	World Meteorological Organization
Cambodia:	
MOWRAM	Ministry of Water Resources and Meteorology
- DHRW	Department of Hydrology and River Works
- DOM	Department of Meteorology
MPWT	Ministry of Public Works and Transport
- WD	Waterways Department
Laos:	
MAF	Ministry of Agriculture and Forestry
- DMH	Department of Meteorology and Hydrology
MCTPC	Ministry of Communication Transport Post and Construction
- WAD	Waterways Administration Division
MIH	Ministry of Industry and Handicraft
- DOE	Department of Electricity
MRC	**Mekong River Commission**
- MRCS	Mekong River Commission Secretariat
- TSD	Technical Support Division
- EP	Environment Programme
- FMM	Flood Mitigation and Management
- OPD	Operations Division
- BDP	Basin Development Plan
- WUP	Water Utilization Programme
- WG1	Working Group 1 (Basin Modelling and Knowledge Base)
- WG2	Working Group 2 (Trans-boundary and Environmental Issues)
- WG3	Working Group 3 (Rules)
- TDG	Technical Drafting Group
- TRG	Technical Review Group
- ISDIT	Information System Design and Implementation Team
- TACT	Technical Assistance and Coordination Team
NMCs	**National Mekong Committees**
- CNMC	Cambodia National Mekong Committee
- LNMC	Lao National Mekong Committee
- TNMC	Thai National Mekong Committee
- VNMC	Vietnam National Mekong Committee
Thailand:	
MNRE	Ministry of Natural Resources and Environment
-DWR	Department of Water Resouces
RID	Royal Irrigation Department
MD	Meteorological Department

Vietnam:

MSTE	Ministry of Science, Technology and Environment
- SRHMC	Southern Region Hydro-Meteorological Center
- HRHMC	Highland Region Hydro-Meteorological Canter
MARD	Ministry of Agriculture and Rural Development

Projects/Programs in MRCS

AHNIP	Appropriate Hydrological Network Improvement Project (TSD-MRC)
IBFM	Integrated Basin Flow Management
- IFP	Interim Flow Plan
LRIAD	Land Resources Inventory for Agricultural Development
TSLVP	Consolidation of Hydro-Meteorological Data and Multifunctional Hydrologic Roles of Tonle Sap Lake and its Vicinities (Tonle Sap Lake and its Vicinities Project)
WUP-A	WUP Basin Modelling and Knowledge Base Project
WUP-EP	Diagnostic Study on Water Quality
WUP-FIN	WUP Modelling of the Flow Regime and Water Quality of the Tonle Sap Project
WUP-JICA	WUP Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin

Water Utilization Rules

PDIES	Procedures for Data and Information Exchange and Sharing
PWUM	Procedure for Water Use Monitoring
PNPCA	Procedure for Notification, Prior Consultation and Agreement

Technical Terms

ADCP	Acoustic Doppler Current Profiler
ADP	Acoustic Doppler Profiler
DSF	Decision Support Framework
DTM	Digital Terrain Model
GIS	Geographic Information System
GPS	Global Positioning System

Unit of Measurement

BCM	billion cubic meters
MCM	million cubic meters
MSL	mean sea level
PPB	parts per billion
PPM	parts per million
PPT	parts per trillion

Geography

GMS	Greater Mekong Sub-region
LMRB	Lower Mekong River Basin
MRB	Mekong River Basin

CHAPTER 1 GENERAL INFORMATION

1.1 Background

The Mekong River originates in the Tibetan Plateau in the north, runs towards the southeast in Western China, cuts across Myanmar, Lao PDR, Thailand and Cambodia, and finally empties into the South China Sea in Vietnam. The catchment area of the basin is approx. 795,000 km^2, the 21st largest, and has the total annual basin runoff of 475 billion m^3, the 8th in the world. As to its length, the Mekong River is the longest river system in Southeast Asia, extending to approx. 4,880 km. The Mekong is thus ranked as the 12th longest river in the world.

The basin supports a human population of over 50 million, and it is one of the most diverse and productive freshwater ecosystems in the world. The major issues relating to water resources in the basin concern the reasonable and equitable sharing and sustainable development of natural resources. The most critical factors relate to changes in the flow regime of the river, particularly in the dry season.

The "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin" (the Agreement) was signed in April 1995 by the respective plenipotentiaries of the four riparian countries; namely, Laos, Thailand, Cambodia and Vietnam. Based on the Agreement, the Mekong River Commission (MRC) was established.

At present the MRC focuses on four core programmes, the Water Utilization Programme (WUP), the Basin Development Plan (BDP), the Environmental Programme (EP) and the Flood Management and Mitigation Programme (FMMP). Of these four core programmes, the WUP's objective is to assist the MRC in the establishment of mechanisms to promote and improve coordinated and sustainable water management in the basin, including reasonable and equitable water utilization by riparian countries, protection of the environment and aquatic life, and maintenance of ecological balance. The above situation will be achieved through the preparation of water utilization rules and procedures for information exchange, notification and prior consultation in accordance with the Agreement.

Article 26 of the Agreement (Rules for Water Utilization and Inter-Basin Diversion) provides that the rules shall include but are not limited to:

(1) Establishing the time frame for 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 criteria for determining surplus quantities of water on the mainstream during the dry season;

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

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

At the unofficial donors' meetings that had been held periodically since November 1995, the Government of Japan had indicated its readiness to cooperate, under the framework of JICA's development study scheme, in the preparation of the "rules" for water utilization and inter-basin diversion, and in setting up the mechanism for a monitoring network as stipulated in Article 26. The Mekong River Commission Secretariat (MRCS) had, meanwhile, initiated and implemented several programmes/plans/activities to support the four member countries in implementing the

Agreement. In March 2000, the WUP, financed with funds from the Global Environmental Facility (GEF), was also started.

In response to the official request of the MRC on behalf of the governments of the four member countries, the Government of Japan had decided to conduct "The Study on Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin" in accordance with the relevant laws and regulations in force in Japan. The Japan International Cooperation Agency (JICA), the agency responsible for the implementation of technical cooperation programmes of the Government of Japan, has been given the task to undertake the study in close cooperation with the authorities concerned of the MRC and its member countries.

A Preparatory Study Team was dispatched to the MRC and its member countries from December 2 to December 14, 2000 to discuss the Scope of Work for the Study. The team carried out a field survey and held a series of consultations with the officials concerned. To facilitate understanding of the performance of the study, the MRCS and JICA had finally agreed on the Scope of Work (S/W) for the Study.

In accordance with the agreed S/W, the study was commenced in March 2001 when the draft inception report was prepared in Japan at initial stage of the study. The WUP-JICA study team was mobilised to Cambodia for the inception meeting with the MRCS in May 2001. Since then, the team carried out the study for three years, and this report consisting of three volumes cover the entire results of the team activities during the study.

1.2 Objectives

The objectives of the study are:

(1) To study the flow regime of the Mekong River system;

(2) To assist MRC in the processes of the preparation of the Draft MRC Rules for water quantity/utilization; and

(3) To strengthen the institutional framework and capacity of the riparian members and MRCS in the course of the study.

1.3 Study Area

The study covers the lower Mekong River Basin in Cambodia, Lao PDR, Thailand and Vietnam. The study area is approximately 606,000 km^2, as shown in the map of the study area. The lower Mekong River Basin accounts for 76% of the entire basin, as tabulated below.

Table 1-1 Catchment Area of Mekong River Basin

Country	Catchment Area (km^2)	Remarks
China	165,000 (21%)	
Myanmar	24,000 (3%)	
Laos	202,000 (25%)	Lower Mekong River Basin's Total Catchment Area: 606,000 km^2 (76% of entire basin)
Thailand	184,000 (23%)	
Cambodia	155,000 (20%)	
Vietnam	65,000 (8%)	
Total	795,000	

1.4 Team Activities

The study had extended for thirty-six (36) months. The team had carried out field studies twice each year, in dry and wet season, to understand the hydrological situation in both seasons and for convenience in carrying out the monitoring activities.

The activities of the team are as shown below.

Fig. 1-1 Team Activities

Year	Month	Field Study	Home Office Work	Reporting (Duration of Field Study)
2001	March		□	Draft Inception Report
	April			
	May	■		
	June	■		Inception Report
	July	■		(3 months)
	August	■		Working Paper I
	September		□	
	October	■		
	November	■		
	December	■		(5 months)
2002	January	■		
	February	■		Progress Report
	March		□	
	April			
	May	■		
	June	■		
	July	■		(3.5 months)
	August	■		Working Paper II
	September		□	
	October	■		
	November	■		
	December	■		(4.5 months)
2003	January	■		Interim Report
	February		□	
	March			
	April	■		
	May	■		
	June	■		(4 months)
	July	■		Working Paper III
	August		□	
	September	■		
	October	■		
	November	■		(5 months)
	December	■		
2004	January	■		Draft Final Report
	February		□	
	March			Final Report

1.5 Organizations and Staffing

JICA had formed an organization consisting of the Advisory Committee and the Study Team. The Advisory Committee was to provide the necessary advice regarding the study to JICA, while the Study Team was to be responsible to JICA for conducting the study. The members of the Advisory Committee and the Study Team are given in Table 1-3.

Table 1-2 Members of JICA Advisory Committee and the Study Team

Name	Designation/Specialty
ADVISORY COMMITTEE	
(1) Shizuo ONO	Chairman (April 2001 to September 2002)
Minoru KURIKI	-do- (September 2002 to May 2003)
Ryuzo IKUSHIMA	-do- (May 2003 to March 2004)
(2) Hidetomi OI	River Management
(3) Kenichi MATSUI	Hydrological Monitoring
(4) Takao MASUMOTO	Water Use
STUDY TEAM	
(1) Kanehiro MORISHITA	Team Leader
(2) Norio TAKAYANAGI	Institution/Legal Frame
(3) Henrik GARSDAL	Hydro-hydraulic Modelling
(4) Minoru OUCHI	Low-flow Management
(5) Kenichiro KONDO	Watershed Management
(6) Yuichiro HAMADA	Hydrological Monitoring/Facility Design
(7) Naohito MURATA	Water Use Planning
(8) Ichiro OKUMURA	PCM Facilitator
(9) Niels-Boye KRISTENSEN	Discharge Measurement Planning
(10) Khadananda LAMSAL	Project Coordination (Hydrologist)
(11) Kazuhiro NAKAMURA	Logistic Coordinator
Akio OKAZAKI	-do-
Kazuyoshi FUJIMOTO	-do-
Ryuich YAMAZAKI	-do-

1.6 Technology Transfer

For the development of the water utilization rules, the following projects had run simultaneously with this JICA study:

(1) Development of basin modelling package and knowledge base (WUP-A), funded by the World Bank (GEF), aiming at developing the basin-wide hydrologic and hydraulic simulation model, configuring the knowledge base including database and knowledge related to the Mekong water resources, and establishing the decision support framework for assisting the decision-making of the MRCS as well as officials in the riparian governments.

(2) Modelling of the flow regime and water quality of the Tonle Sap (WUP-FIN), funded by the Finish Government, aiming at developing the hydrological and hydraulic model of the Tonle Sap Lake on water quality as well as water quantities.

(3) Diagnostic study on water quality (WUP-EP), funded by the French Government, aiming at improving the knowledge of water quality status in the Mekong River Basin.

These projects were known with the prefix "WUP" (Water Utilization Programme), so that this JICA study is also called WUP-JICA Project. In parallel with the above projects under WUP, the following two projects are also closely related to the WUP-JICA Project.

(1) Appropriate Hydrological Network Improvement Project (AHNIP), funded by the Australian Government, aiming at improving and upgrading the 18 hydrological stations as telemetry network and providing transparent and reliable hydrological data to the MRCS and the riparian countries.

(2) Consolidation of hydro-meteorological data and multi-functional hydrologic roles of Tonle Sap Lake and its Vicinities (TSLVP), funded by the Japanese Government, aiming at clarifying the flooding mechanism over the Cambodian floodplains based on the various types of field observation and deriving the hydrological functions on the floodplains and paddy fields.

Thus the occasions to transfer technical knowledge and experiences were not only the workshops held under the WUP-JICA Project but also the ones held by the related projects and activities. The WUP-JICA Project utilized the following occasions for this purpose (Table 1-4).

Table 1-3 Workshops Participated and Presented by the WUP-JICA Team

Date (Y.M.D)	Workshop Theme	Venue	Organizer	Presentation by the WUP-JICA
2001.12.13-14	Data review and modelling concept	Phnom Penh, Cambodia	WUP-A	Progress of the WUP-JICA study
2002.01.04-05	Water allocation and monitoring (National training)	Kompong Cham, Cambodia	WUP-JICA	(1) Water utilization rules in Japan (2) Interpretation of basic concept on water utilization rules in the Mekong River Basin
2002.01.07-08		Bangkok, Thailand		
2002.01.10-11		Thalat, Laos		
2002.01.14-15		Ha Long, Vietnam		
2002.01.23-25	Water allocation and monitoring	Ho Chi Minh, Vietnam	WUP-JICA	(1) National training results (2) Study Progress
2002.06.10-11	Water use monitoring	Bangkok, Thailand	WG3 of WUP	Water use monitoring in Japan
2002.09.23-24	Interim results of TSLV project	Phnom Penh, Cambodia	TSLVP of TSD	Discharge measurement on the Mekong mainstream
2002.12.03-04	Technical support for drafting process of the water use monitoring	Siem Reap, Cambodia	WG3 of WUP, and TSD	Water use monitoring in Japan and issues in the LMRB
2003.01.07-08	Integrated water management in the LMRB	Phnom Penh, Cambodia	WUP-JICA	Report on Interim Report
2003.03.04-05	Final evaluation of TSLV project	Phnom Penh, Cambodia	TSLVP of TSD	Discharge measurement results and monitoring issues
2003.07.14-18	Training of trainers on discharge measurement	Phnom Penh, Cambodia	WUP-JICA and AHNIP	Theory and practices on discharge measurement using ADCP
2003.12.15-16	Integrated water management in the LMRB	Phnom Penh, Cambodia	WUP-JICA	Report on Draft Final Report
2003.12.23-24	Maintenance of Flows on Mainstream (National Training)	Kompong Cham, Cambodia	CNMC	WUP-JICA Flow Monitoring Activities

In addition to the workshops, frequent trainings were made for familiarization on hydrological monitoring instruments and transfer of knowledge on discharge measurements. These were:

- On-site-trainings at the rehabilitated and upgraded stations for familiarization on the operation and maintenance on the installed automatic water level gauges. The on-site-trainings included data downloading and processing.

- Indoor trainings on discharge measurement were held twice in 2002, and a similar training on the development of rating curves was held in 2003. The participants were the hydrologists of the MRCS and the staffs of DHRW and MOWRAM, Cambodia.

- On-the-job trainings were held for almost one month each in 2002 and 2003. The survey expert of the WUP-JICA team participated in discharge measurement activities and trained the survey staffs of DHRW to use the Acoustic Doppler Current Profiler (ADCP) for measurement.

1.7 Composition of the Summary

This Summary report is composed of four parts covering the entire activities of the WUP-JICA team for three years with each chapter compiled in accordance with the project objectives and work fields. The components are summarized in the following table for easier reference.

Table 1-4(1/2) Composition of the Summary

Chapter	Section	Title	Remarks
2	Hydrological Network Improvement, Gap-Filling and Monitoring		This part includes the physical components of hydrological improvement and monitoring, and some meteorological analysis for data gap filling.
	1	Improvement of Hydrological Stations	After selection of hydrological stations, the team rehabilitated and upgraded the stations with installation of automatic recorders.
	2	Gap Filling of Daily Rainfall Data	To cope with shortage of available daily rainfall data, the daily rainfall data were generated through stochastic analysis.
	3	Hydrological Monitoring	To fill the gap of flow data in Cambodia, the team conducted hydrological monitoring activities covering discharge measurement up to development of rating curves.
3	Hydro-Hydraulic Modelling		Succeeding the Chak Tomuk project under MRCS, the team continuously developed the hydro-hydraulic model to utilize the analytical tool for the WUP-JICA study.
	1	Development of Hydro-Hydraulic Model in the Cambodian Floodplains	To improve the prototype of the hydraulic model, hydrological model of sub-basins, Great Lake model and elaborated floodplain model are incorporated into the model. As a result, the capability of model description is much enhanced.
	2	Application of the Model	Using the developed model, the following investigation and assessment are made for assisting the relevant activities: dry-season flow investigation, hydraulic impact of road embankment in the floodplains, water balance of the Great Lake.

Table 1-4(2/2) Composition of the Summary

Chapter	Section	Title	Remarks
4	Hydrology and water Use in the Lower Mekong Basin		Data collected and results analysed in the course of the WUP-JICA study are summarized for better reference to the fields of hydrology and water use in the basin.
	1	Hydrology in the Lower Mekong Basin	In the course of the WUP-JICA study, the various hydrological studies are made for understanding the hydrological mechanism. This chapter selected and summarised these results.
	2	Water Use in the Lower Mekong Basin	The team collected water use data/information through literature search and from the relevant agencies. These data/information of irrigation, hydropower and other sectors are compiled in this chapter.
5	Technical Assistance for Water Utilization Rules		For formulation of water utilization rules, various technical assistances are made; technical study, technology and experiences transfer and institutional approaches. This part comprises the results of the entire assistance provided by the team.
	1	Introduction of Water Utilization Rules	For easier understanding of the 1995 Mekong Agreement, this chapter provides introduction and interpretation of water utilization rules stipulated in the Agreement.
	2	Maintenance of Flows	To determine the acceptable minimum monthly natural flow in the dry season, the research work concentrated upon hydrology and water use in the Mekong Delta as the most important starting point over the basin.
	3	Institutional Strengthening	Institutional strengthening comprises wide aspects: international agreements, domestic water resources laws, and issues on related line agencies. Collection of data/information, interview survey and analytical approach were made on these aspects.
	4	Water Use Management System in Japan	In parallel with the progress of rule formulation by MRC, timely themes are provided in the national and regional workshops to transfer information on the experiences in Japan. This chapter summarizes whole topics of presentations.

CHAPTER 2 HYDROLOGICAL NETWORK IMPROVEMENT, GAP-FILLING AND MONITORING

2.1 Improvement of Hydrological Stations

2.1.1 Background and Activities

Hydrological stations in the Lower Mekong River Basin have been classified into four (4) classes according to the importance of location, channel stability and reliability of recorded data from the viewpoint of network management; namely, Key, Primary, Basic and Local network. Twenty-five (25) stations have been designated as Key network stations in the recent network study made by MRC, and fifteen (15) of them are to be improved into a telemetry system under the Appropriate Hydrological Network Improvement Project (AHNIP) with Australian assistance. The remaining ten (10) Key stations listed in the following table have been selected for further improvement under the WUP-JICA study.

Table 2-1 Selected Key Network Stations to be Improved

No.	Station (River)	Country
1	Ubon (Nam Mun)	Thailand
2	Pak Kagunung (Num Ngum)	Lao PDR
3	Ban Phonesy (Nam Cading)	
4	Ban Keng Done (Se Bang Hieng)	
5	Ban Komphoun (Se san)	Cambodia
6	Kompong Cham (Mekong)	
7	Chak Tomuk (Bassac)	
8	Neak Luong (Mekong)	
9	Can Tho (Bassac)	Vietnam
10	My Thuan (Mekong)	

Site inspections were made at the above stations from May to July 2001 to clarify the site and gauge conditions, and the necessary improvement works for each station were discussed with the line agencies. The following subsection describes the screening process for the necessary works and the actual improvement works done by the team.

2.1.2 Screening and Improvement Works

Prior to the actual improvement works, the DHRW in Cambodia had requested improvement of an additional station, the Cham Tangoy Station in Se Kong, because the station is located in one of the major international tributaries.

As for the measuring equipment, the team had determined that a gas-purged sensor should be installed at each station to be improved, following the results of discussion with the Hydrology Section of the TSD-MRCS, in view of sensor’s high-durability against heavy siltation and the well-familiarity of the staff of the line agencies with such recorders.

The progress of actual improvement of each station including the screening stages is summarised below.

(1) Thailand (DWR, former DEDP)

<u>Ubon Station in Nam Mun</u>

Ubon Station is located under the Saereprachatippatai Bridge, which strides over the Nam Mun in the town of Ubon. The station is equipped with vertical staff gauges, which have been maintained in good condition.

In addition to the staff gauges, a set of gas-purged sensor and data logger has been installed under the WUP-JICA study. For the installation of equipment, a galvanized pipe was attached along the downstream side of the bridge pier to accommodate the gas tube, and an instrument box with pole was placed on the bridge handrail.

Fig. 2-1 Location of Ubon Station and Overview of Improved Station

(2) Lao PDR (WAD and DMH)

<u>Pak Kagnung Station in Nam Ngum (DMH)</u>

Pak Kagnung Station is equipped with vertical staff gauges. There is no stairway. The improvement works consisted of the construction of both slope gauge and stairway for safer observation, and the installation of a set of gas-purged sensor and data logger. Gabion mattress and cylinder were installed at both sides of the slope gauge and stairway for protection against scouring.

Fig. 2-2 Location of Three Stations in Lao PDR and Overview of Improvement Works

Note: The photographs show the improved stations of Pak Kagnung, Ban Phonesy, and Ban Keng Done from top to bottom.

Ban Phonesy Station in Nam Cading (DMH)

A slope gauge and stairway were constructed in the late 1990s under the JICA Grassroots Project, and are still in good condition. The gas-purged sensor and its measuring tube inside a galvanized pipe had been installed along the slope gauge, and a data logger had also been accommodated in the instrument box at the bank.

Ban Keng Done Station in Se Bang Hiang (WAD)

With funds from the Government of Australia, the gas-purged sensor and data logger were installed in 1999 under the project of Improvement of the Hydro-Meteorological Network Component II. However, no stairway was constructed for the reading of slope gauge. The installation of stairway and a new slope gauge has been requested by WAD, and gabion mattress and cylinder were installed at both sides of the slope gauge and stairway for protection against scouring and bank erosion.

(3) Cambodia (DHRW)

Ban Komphoun Station in Se San

The station had been equipped with only vertical staff gauges before improvement. The slope gauge and stairway were constructed for safer observation, and a set of gas-purged sensor and data logger was accommodated in an instrument box installed at the riverbank. Gabion mattress and cylinder were also installed at both sides of the slope gauge and stairway for bank protection against scouring and erosion.

Cham Tangoy Station in Se Kong

Improvement of this station has been additionally requested by the DHRW. Site inspection and discussions were made at the same time with those of Ban Komphoun Station in Se San.

The station also has been equipped with only vertical staff gauges. The slope gauge, stairway, and gabion mattress and cylinder for bank protection were constructed, and a set of gas-purged sensor and data logger was accommodated in an instrument box installed at the riverbank.

Kompong Cham Station in Mekong

Gas-purged sensor and data logger has been installed recently at the station under an Australian assisted project. They are still functioning well, and the slope gauge and stairway are also in good condition. Thus the team had decided through the onsite discussion with the DHRW that further improvement works were not necessary.

Chak Tomuk Station in Mekong/Tonle Sap

The slope gauge and stairway, which are located on the bank at the back of the National Convention Centre in Phnom Penh, are in good condition. The measuring tube covered with a galvanized pipe was installed along the stairway, and gas-purged sensor and data logger were accommodated in an instrument box at the bank.

Fig. 2-3 Location of Four Stations in Cambodia and Overview of Improvement Works

Note: Photographs show the improved stations of Ban Komphoun and Cham Tangoy from upper left to right, and Chak Tomuk and Neak Luong from lower left to right.

Neak Luong Station in Mekong

A float type recorder in the stilling well has been installed at the station. However, the recorder and relevant facilities have much deteriorated so that restoration of the station was requested by the DHRW. In addition, gabion mattress was installed along the well, and a set of gas-purged sensor and data logger was also installed together with the old float type recorder.

(4) Vietnam (SRMHC)

Can Tho Station in Bassac

At Can Tho Station, installed were the float type recorder, gas-purged sensor and data logger, and the vertical staff gauges. The facilities and equipment were in good condition. Thus the team had decided through the onsite discussion with the SRHMC that further improvement works were not necessary.

My Thuan Station in Mekong

At present, this station is equipped with only vertical staff gauges. The SRHMC had planned to relocate the station 1 km upstream of the existing site in 2002. The new My Thuan Station was planned to be equipped with a float type recorder and staff gauges. In addition a set of gas-purged sensor and data logger is to be installed at this new station during construction.

Fig. 2-4 Location Map of Two Stations in Mekong Delta, Vietnam

2.2 Gap-Filling of Daily Rainfall Data

2.2.1 Background and Objectives

The number of rainfall stations in the three (3) riparian countries had remarkably increased in the last decade except in Thailand. In 1990, rainfall stations were 154, 70, 41 and 21, but they were 153, 143, 170 and 103 in 2000 in Thailand, Lao PDR, Cambodia and Vietnam, respectively. Basin-wide, there were 286 rainfall stations in 1990; whereas in 2000 the number reached 569. This means that the total number of rainfall stations in the basin have doubled within the decade.

At some stations in Lao PDR and Vietnam, rainfall data in the early 1990s were incomplete with missing data (data gaps). In Cambodia, most of the stations had been constructed or rehabilitated with MRC financial support during 1996-98 under Component 1 of the Improvement of Hydro-Meteorological Network Project, so that rainfall data at almost all stations before that period were also incomplete. In Thailand, however, the availability of rainfall data was good.

Rainfall data for the period 1991-2000 are considered most essential for the basin modelling activities. One of the initial tasks stated in the TOR for the study was to assist in providing a complete set of rainfall data.

2.2.2 Gap Filling Methodology

Annual Rainfall Data Gap Filling

There were rare cases where good correlation between daily rainfalls of nearby stations could be obtained. However, in the case of annual rainfall, good correlations between historical annual rainfalls of nearby stations prevail. Therefore, linear and multiple regression techniques were employed to generate the annual amount of rainfall at a desired station, using the historical annual rainfall data of nearby stations where data was missing.

The amount of annual rainfalls generated by linear and multiple regressions among stations for data missed years were verified or cross-checked with isohyetal maps. At first, the linear regression was applied to check the correlation of available historical annual rainfalls of data-missing stations with annual rainfalls of the same years at nearby stations. If correlation was found good enough (>0.8) then the simple linear regression method was applied to generate the amount of annual rainfalls at the stations. The multiple regression method was employed for generating the amount of annual rainfalls at the stations only when correlation was found low in the case of one-to-one linear regression approach.

As an example, the multiple regression relation developed for determining the annual rainfall amount during the data-missing year at Muong Nam Tha in Lao PDR using rainfall records of two nearby stations, namely, Phongsaly in Lao PDR and Chiang Khong in Thailand, is presented in Fig. 2-5.

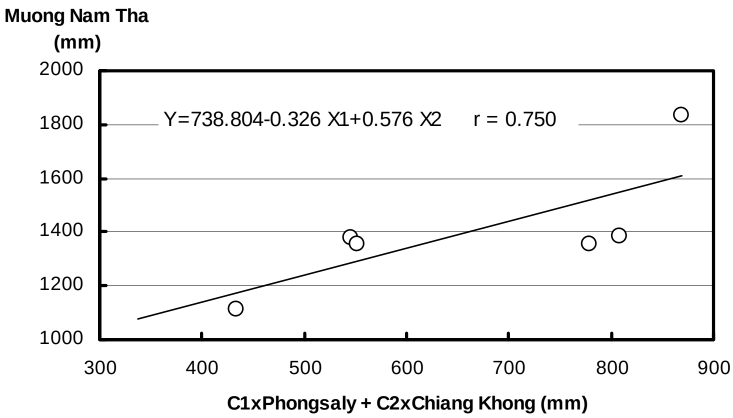


Fig. 2-5 Correlation between Annual Rainfalls of Muong Nam Tha and Nearby Stations

Daily Rainfall Data Gap-Filling

(1) Deciding Wet or Dry Days

The first work that has to be done in daily rainfall generation is deciding on whether the day is wet or dry. For this, the Markov chain phenomenon and monthly probabilities of occurrence of consecutive wet and dry days have been applied.

Using historical daily rainfall records, monthly probabilities of occurrence of consecutive wet days (wet day followed by wet day) and consecutive dry days have been determined. However, definitions of wet and dry days are essential for determining these probabilities. Therefore, the wet and dry days are defined in this study as follows:

Wet day: A day is defined as a wet day when the amount of rainfall on that day is greater than 0.5 mm.

Dry day: A day is defined as a dry day when the amount of rainfall on that day is less than or equal to 0.5 mm.

After defining the wet and dry days, the determinations of monthly probabilities of occurrence of consecutive wet and dry day became possible. For example, monthly probabilities of occurrence of consecutive wet and dry days at Muong Nam Tha Station in Lao PDR are as given in the following table.

Table 2-2 Probability of Consecutive Wet and Dry Days at Muong Nam Tha

	Month	Probability of Occurrence of Consecutive Wet Days	Probability of Occurrence of Consecutive Dry Days
1	January	0.353	0.952
2	February	0.500	0.967
3	March	0.400	0.885
4	April	0.439	0.787
5	May	0.667	0.639
6	June	0.651	0.409
7	July	0.737	0.370
8	August	0.725	0.403
9	September	0.578	0.688
10	October	0.424	0.820
11	November	0.357	0.920
12	December	0.519	0.941

The equations used for determining the consecutive wet and dry days were as follows:

Probability of consecutive wet days:

$$P_{WW} = \frac{\sum WW}{TWD}$$

Where,

P_{WW}	=	Monthly probability of occurrence of consecutive wet days
WW	=	Number of observed consecutive wet days
TWD	=	Total number of wet days

Probability of consecutive dry days:

$$P_{DD} = \frac{\sum DD}{TDD}$$

Where,

P_{DD}	=	Monthly probability of occurrence of consecutive dry days
DD	=	Number of observed consecutive dry days
TDD	=	Total number of dry days

Once the monthly probabilities of occurrence of consecutive wet (P_{WW}) and dry (P_{DD}) days were established, based on the probabilities and considering the Markov chain phenomenon (taking consideration of the condition of the $t\text{-}1^{th}$ day either wet or dry) a decision-making condition was developed to decide whether the t^{th} day will be wet or dry. For deciding whether the t^{th} day will be wet or dry, uniform random numbers from 0 to 1 were generated and then checked through the loop of decision-making condition.

(2) Stochastic Generation of Daily Rainfalls

The daily rainfalls at data-missing stations were generated by stochastic approach. For this, monthly probability curve of occurrence of different amounts of rainfalls were developed based on the available historical daily rainfall records of the same station to make the generation approach more reliable and realistic. The adopted stochastic method for daily rainfalls generation gives more realistic values of rainfalls than other methods like the Log-normal distribution method, because in the Log-normal distribution method there are many chances of generating unrealistic and extreme values that do not reflect the real situation. In the adopted daily rainfalls generation method, however, there were very little chances of generating such unrealistic extreme values due to dividing the probability curve into 3 parts to develop regression lines for fixing the amount of daily rainfalls. The procedures adopted for the development of probability curve and stochastic rainfall generation are described below.

As mentioned above, probability curves of occurrence of different amounts of daily rainfalls are developed for each month individually based on the available historical daily rainfall records of the same station at which data are missing. The probability curve is developed using the natural logarithmic values of daily rainfalls and their respective cumulative probabilities of occurrence. The observed daily rainfalls are arranged in ascending order to determine plotting positions for respective rainfall using Weibull relation. As an example, the probability curve developed for daily rainfalls generation in June at Muong Nam Tha station in Lao PDR is presented in Fig. 2-6. The Weibull relation used for plotting position determination of the i^{th} event of historical daily rainfall sorted in ascending order is as follows:

$$P_i = \frac{i}{n+1}$$

Where,

P_i	=	Plotting position for the i^{th} event of daily rainfalls
i	=	Index for events of daily rainfalls sorted in ascending order
n	=	Total number of events of daily rainfalls considered

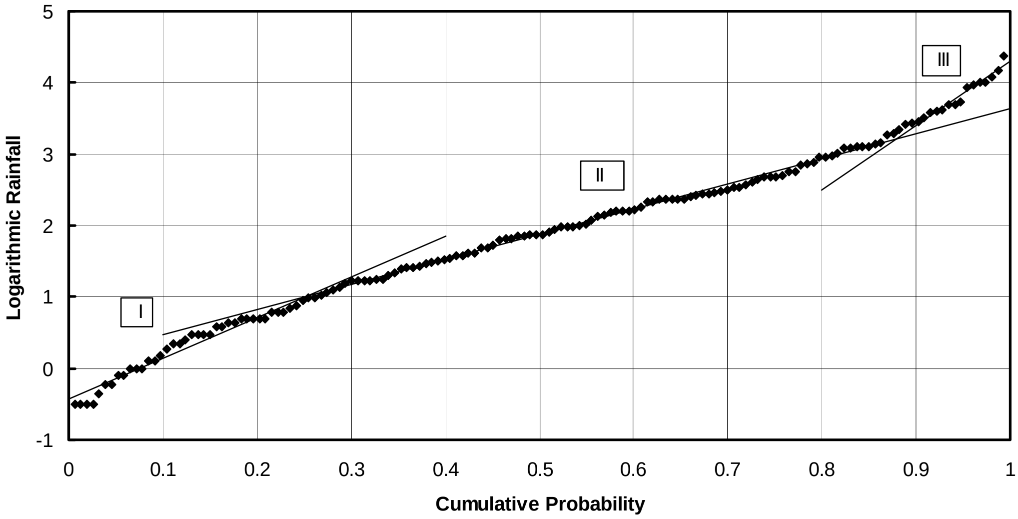


Fig. 2-6 Probability Curve and Regression Lines for Stochastic Rainfall Generation in June at Muong Nam Tha

The probability curve is divided into 3 parts for developing the best-fitted linear regression lines between the natural log value of daily rainfalls and their respective cumulative probabilities of occurrence. The daily rainfalls with cumulative probability of occurrence of between 0 – 0.3, 0.3 – 0.9 and 0.9 – 1.0 are grouped into I, II and III for developing the best-fitted regression lines for stochastic generation of the daily rainfalls (Fig. 2-6). These ranges for grouping are determined by looking at the trend in the historical daily rainfalls. For example, the values of constant (*a*), coefficient (*b*) and correlation (*r*) determined by the analysis of historical records of daily rainfalls at Muong Nam Tha in Lao PDR are as given in the following table.

Table 2-3 Parameters of Regression Lines of Probability Curves for Stochastic Generation of Daily Rainfalls at Muong Nam Tha

	Month	Cumulative Probabilities								
		0.0 - 0.3			0.3 - 0.9			0.9 - 1.0		
		a	b	r	a	b	r	a	b	r
1	January	-0.621	2.291	0.997	-0.277	2.939	0.885	-6.694	10.355	0.972
2	February	-0.171	4.494	0.951	-0.734	5.106	0.970	0.601	3.611	0.998
3	March	-0.558	4.549	0.984	-0.143	3.382	0.993	-3.638	7.383	0.955
4	April	-0.536	4.010	0.988	-0.520	4.280	0.990	-4.854	8.956	0.937
5	May	-0.423	5.960	0.988	0.533	3.088	0.986	-5.109	9.501	0.972
6	June	-0.435	5.704	0.984	0.112	3.532	0.997	-4.666	8.960	0.975
7	July	-0.533	6.944	0.993	0.464	3.343	0.999	-6.433	10.852	0.841
8	August	-0.475	7.252	0.992	0.697	3.006	0.995	-3.178	7.318	0.895
9	September	-0.435	6.811	0.975	0.154	3.808	0.998	-6.716	11.251	0.954
10	October	-0.440	3.742	0.958	-0.384	3.657	0.985	-10.419	14.693	0.915
11	November	-0.615	3.799	0.951	-1.104	5.084	0.993	-0.112	4.007	0.955
12	December	-0.827	5.269	0.873	0.000	3.393	0.974	-5.475	9.801	0.922

After developing the regression relations, uniform random numbers ranging from 0 to 1 are generated for deciding the plotting positions and generating daily rainfalls. The relations used for the stochastic generation of the daily rainfalls are as follows:

$$\log_e P_e(k) = a + b.k$$

$$Y = e^{a+b.\lambda}$$

Where,

P_e	=	Event of daily rainfall (mm/d)
a	=	Intercept of the regression line
b	=	Slope of the regression line
k	=	Cumulative probability in respect to an event of daily rainfall arranged in ascending order
Y	=	Generated daily rainfall (mm/d)
λ	=	Uniform random number between 0 to 1

Model Verification

The daily rainfalls generated by the stochastic model have been verified with the observed historical data. For verification of the model, mean monthly amount and standard deviations of daily rainfalls were compared between those of generated and observed. Student t-tests were performed to check whether or not the differences between mean monthly rainfalls and standard deviations of observed and generated rainfalls are significantly different. Tests have shown that there are no significant differences between the observed and generated mean monthly rainfalls and the standard deviations with 95% of confidence level. Moreover, correlations between the observed and generated values are also extremely high. This indicates that the developed stochastic daily rainfalls generation model is quite reliable and can generate realistic rainfalls effectively all over the year for the basin. The result of model verification test at Muong Nam Tha Station in Lao PDR, for instance, is presented in the following table.

Table 2-4 Comparison between Observed (8 years) and Generated (20 years) Rainfalls at Muong Nam Tha

	Month	Mean Monthly Rainfall		Standard Deviation of Rainfall	
		Observed	Generated	Observed	Generated
1	January	11	14	1.9	2.8
2	February	28	27	5.6	5.8
3	March	39	47	4.4	5.3
4	April	83	89	7.6	7.9
5	May	212	172	12.8	10.9
6	June	227	226	12.7	12.8
7	July	308	292	15.8	13.8
8	August	288	291	12.8	13.0
9	September	184	195	13.1	13.1
10	October	62	61	6.5	6.9
11	November	35	29	5.2	4.6
12	December	33	28	5.1	4.1
	Mean	126	123		
	Correlation	0.993		0.980	
	t-tests	Differences in both mean monthly rainfalls and standard deviations are non-significant at 95% confidence level			

Selection and Pattern Verification of Generated Rainfalls

For selection of the stochastically generated set of daily rainfalls, at first the annual amounts of rainfalls were calculated for all 20 generated daily rainfall sets. The annual amounts of all 20 generated sets were checked with the annual amounts determined by the regression using nearby stations data for the data-missing year at a station. If the annual amount of any generated rainfall set is very close or falls in the range between –5% and +5% of annual amount determined by the regression method, then the generated set of rainfall is selected. Once the set of generated daily rainfalls is selected for data gap-filling for a year, it is further checked and verified for its rainfall pattern. For this purpose, dimensionless patterns have been developed with the accumulation of historical daily rainfalls in different years for making a loop to check the daily rainfall pattern of generated rains. After the loop was developed from the historical data, the pattern of daily rainfalls of the selected set of generated rain was checked. If the daily rainfall pattern of the chosen set of the generated rain falls inside the loop, then the rainfall pattern of the selected set was also considered acceptable. If the pattern was found not acceptable, then another set of generated rain was chosen and checked for the pattern. This process was repeated until the closer set of generated rain satisfied the pattern verification criteria. When the daily rainfall pattern was also found acceptable, then the selected set of generated rain was chosen for the data gap fillings. As an example, the processes of selection of set of generated rain and rainfall pattern verification related to Muong Nam Tha Station in Lao PDR are as presented in Table 2-5 and Fig. 2-7.

Table 2-5 Selection of Sets of Generated Daily Rainfalls for Filling the Data Gaps at Muong Nam Tha, Lao PDR

	Sets of Generated Rainfalls	Annual Amount of Generated Rainfalls	Annual Rainfall fixed by Multiple Regression (MR)		Acceptable Range for Amount of Annual Rainfalls		Selection of Set of Generated Daily Rainfalls
			Data Missing Years	Annual Amount	-5% of MR fixed Amount	+5% of MR fixed Amount	
1	Set - 1	1334	1991	1076	1022	1130	Set - 6
2	Set - 2	1609	1993	1219	1158	1280	Set - 4
3	Set - 3	1292					
4	Set - 4	1232					
5	Set - 5	1532					
6	Set - 6	1118					
7	Set - 7	1376					
8	Set - 8	1634					
9	Set - 9	1649					
10	Set - 10	1627					
11	Set - 11	1805					
12	Set - 12	1286					
13	Set - 13	1551					
14	Set - 14	1520					
15	Set - 15	1277					
16	Set - 16	1518					
17	Set - 17	1448					
18	Set - 18	1367					
19	Set - 19	1682					
20	Set - 20	1576					

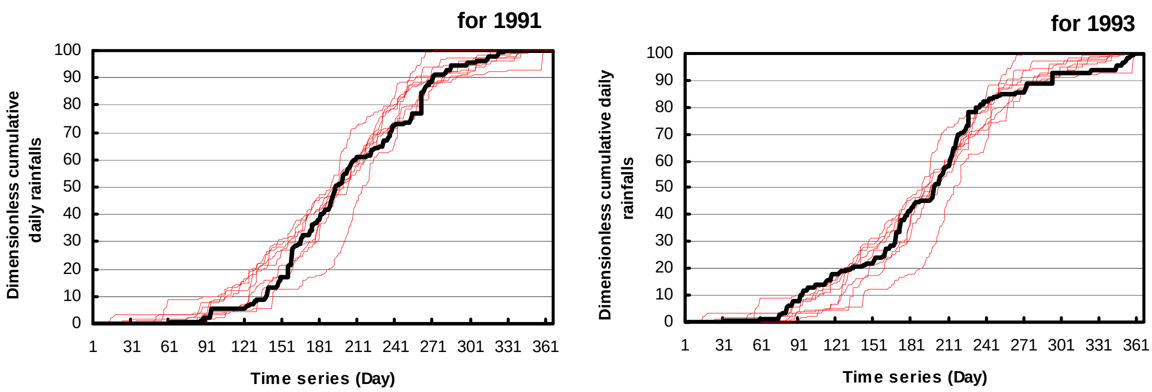


Fig. 2-7 Pattern Verification of Generated Daily Rainfalls at Moung Nam Tha

Note: Heavy lines reflect generated rainfalls and light lines reflect observed rainfalls.

2.2.3 Selected Representative Stations and Gap-Filling

Due to the very large number of stations in the basin and because it was difficult to provide rainfall data for all the stations by filling data gaps, 126 representative rainfall stations were selected considering the spatial coverage and data availability to provide rainfall data required for the basin modelling. The stations selected were 52, 41, 22 and 11 in Thailand, Lao PDR, Cambodia and Vietnam, respectively.

One of the 52 stations selected in Thailand had missing data for one year in-between the prescribed duration. In Lao PDR, out of the 41 stations selected, 16 stations had missing data for 1 to 4 years during the period so that only 4 of these 16 stations were chosen for the data gap filling considering the spatial coverage. For other stations' missing data, historical rainfall records of nearby stations in Thailand were used for the substitution, since most of them are located along the Mekong mainstream that flows near or on the national border between Laos and Thailand.

Moreover, in Cambodia, 22 stations had been selected. Data at all selected stations except three were missing for 1-9 years during the period. Out of the 19 data missing stations, gap filling has been possible for only 11 stations. Data gap filling has not been possible for the other stations because historical rainfall records were available for less than 5 years and data available years did not overlap with the records of nearby stations. The overlapping of data available years at a station with those of nearby stations is necessary to see the correlation between annual rainfalls of the station with those of nearby stations for predicting the amount of annual rainfalls in data missing years at the station. However, at a few stations, historical rainfall records were available for some years but those records did not show any correlation at all with records of the nearby stations; therefore, data gap filling could not be performed for those stations.

In Vietnam, 11 stations (7 in Mekong Delta and 4 in Central Highland) had been selected to provide rainfall data for the basin modelling purpose. Of the 7 stations in the Mekong Delta, rainfalls data were completely missing at 5 stations. Of the 4 stations in Central Highland, data were missing for one year at 2 stations, while data were completely missing at one station. In the Vietnam stations with completely missing data (5 in Mekong Delta and 1 in Central Highland), no historical rainfall records were available in all the Hydrological Yearbooks of MRC as well as in the HYMOS database. Therefore, data gap filling was not possible at those 6 selected stations.

The gap filling results are summarised in the following table. The estimated output is tabulated as the gap-filled daily rainfall as presented in Volume II, Supporting Report, Paper II.

Table 2-6 Summary of Daily Rainfall Data Gap-Filling

Country	Selected Representative Stations				Total of Stations with Available Dataset
	Total Number	Complete Dataset	Complete after Gap-Filling	Incomplete Dataset	
Thailand	52	51	1	-	52 (100%)
Lao PDR	41	25	4	12	29 (71%)
Cambodia	22	3	11	8	14 (64%)
Vietnam	11	3	2	6	5 (45%)
Total	126	82	18	26	100 (79%)

2.3 Hydrological Monitoring

2.3.1 Background and Objectives

The various line agencies have been conducting hydrological monitoring in the Lower Mekong River Basin. The status in each riparian country is as summarised below.

(1) Thailand

The condition of hydrological monitoring in Thailand is the most preferable among the four riparian countries. Monitoring has been done for a long time, and discharge data has been constantly provided.

(2) Lao PDR

Hydrological monitoring in Lao PDR may have improved in the early 1990s because a number of stations at which the responsible line agencies observe discharge had increased in the 1990s and discharge data has been constantly provided since then. According to the Hydrological Yearbook of 1998, the line agencies provided discharge data using rating curves based on an appropriate number of observed discharges at each station in 1998. The discharge measurement activities of DMH were made possible through the financial support of JICA.

(3) Cambodia

After cessation of the political disturbance in Cambodia, the line agency commenced to reconstruct the completely damaged hydrological network. The number of hydrological stations has been increasing in the 1990s due to the technical and financial support of MRCS and other donors. However, the coverage area of stations is still insufficient, and discharge measurement activities have not been made enough to develop the rating curves of the major stations.

(4) Vietnam

The line agencies have been conducting intensive hydrological monitoring, including hourly discharge measurements of the mainstream, to cope with the salinity intrusion in the dry season. As for the severe flooding, the agencies have been monitoring the flooding situation over the Mekong Delta during the flood season.

In addition to the above, the riparian line agencies have pointed out issues that need to be addressed for sustainable monitoring, as summarised below.

(1) Thailand

The line agencies intend to upgrade the present monitoring system; for instance, from manual reading of staff gauges to automatic recorders. However, the agencies have been under budgetary constraint since the economic crisis in 1997.

(2) Lao PDR

The line agencies require training of their personnel such as hydrologists and observers, as well as financial support for equipment such as vehicles and boats for field operations. In addition, they are requesting technology transfer, in particular, on the use and operation of computer software and automatic recorders introduced by MRCS-related projects.

(3) Cambodia

The Cambodian line agency is confronted with the most serious issues. These are financial constraint due to shortage of government budget and lack of opportunity for human resources training. Thus, without the assistance of donors like the MRCS, the DHRW cannot continue with its monitoring activities and cannot also improve the capability of its staff on hydrological matters.

(4) Vietnam

The Mekong Delta in Vietnam is facing various problems such as water shortage and salinity intrusion in the dry season, severe and long-lasting flooding, and water acidity. To cope with these problems, the line agencies intend to upgrade the present monitoring system, including the upgrade of recording equipment, the establishment of integrated water quality monitoring network, the introduction of latest monitoring instruments, and the improvement of data transmission system utilising e-mail.

Taking into account the situations mentioned above and the limited capacity of the WUP-JICA team to assist in the hydrological monitoring, the team had, therefore, decided to concentrate its resources on monitoring activities at the major stations within the Cambodian territory.

The hydrological monitoring under the WUP-JICA Project should concentrate on discharge measurements in Cambodia. Hence, the Team deliberately avoided overlapping and thus facilitated the collaborative works. The objectives of discharge measurement are:

(1) To develop the discharge rating curves at the major hydrological stations utilising the measured data of water level and discharge, so that hydrological balances along the Mekong River system can be easily understood for the water utilization programme throughout the entire system; and

(2) To clarify the flood retarding and succeeding water supplement functions of the floodplains including the Tonle Sap system, utilizing the discharge data simultaneously measured along the river courses, so that various related projects can utilise the water balance mechanisms of the Cambodian floodplains to evaluate the cause-effect relationships.

To achieve the former objective, continuous measurement activities were necessary at the points of major stations. Furthermore, it was indispensable to collaborate with the AHNIP by sharing the responsible stations.

To achieve the latter objective, periodical and frequent measurement activities were necessary at the selected river cross-sections following the river courses of the mainstream, the Tonle Sap, and the Bassac. It was also indispensable to collaborate with the MRC projects of the Tonle Sap and Vicinities (TSLVP).

2.3.2 Activities

The following activities were carried out in 2002/2003 and 2003/2004, in relation to hydrological monitoring:

Discharge Measurements and Development of Discharge Rating Curves

There are nine (9) major hydrological stations in Cambodia, as shown in the table below. Out of the 9 stations, 4 stations are going to be improved by AHNIP into telemetry stations. Their locations are as shown in Fig. 2-8. To avoid any unfavourable overlapping and to attain a fruitful collaboration, the WUP-JICA team selected the remaining five (5) stations to develop the discharge rating curves through intensive discharge measurement activities.

Table 2-7 Major Hydrological Stations in Cambodia

Station	River/Lake	Remarks
Stung Treng	Mekong	Being improved under AHNIP
Kratie		Being improved under AHNIP
Kompong Cham		
Churui Changvor		
Neak Luong		
Kompong Luong	Tonle Sap Lake	Being improved under AHNIP; discharge measurement not necessary
Prek Kdam	Tonle Sap	Being improved under AHNIP
Phnom Penh Port		
Chak Tomuk	Bassac	

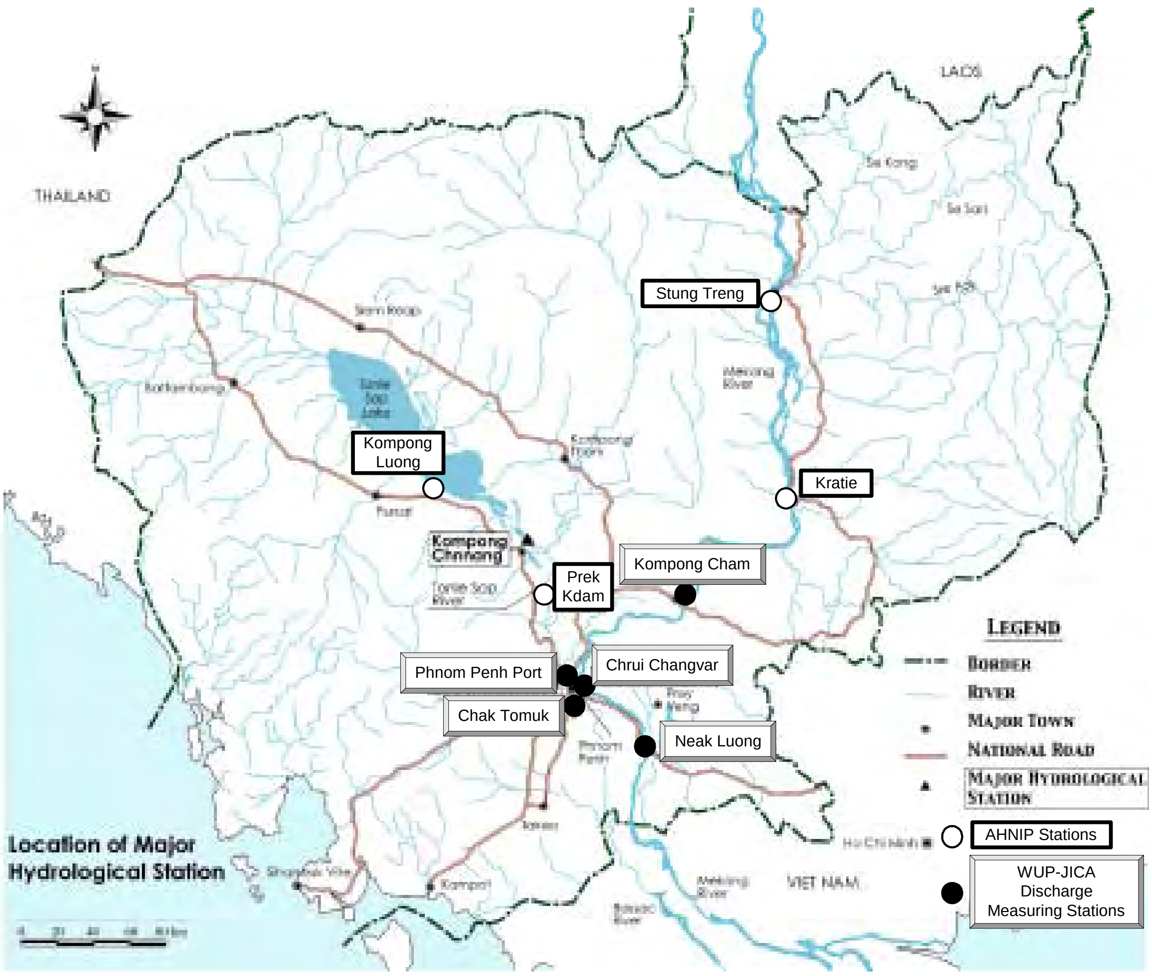


Fig. 2-8 Major Hydrological Stations in Cambodia

Using the observed hydrological data of the above 5 stations, the flow conditions in the Chak Tomuk area at the junction of the Mekong, Tonle Sap and Bassac river systems have been clarified at the minimum. Clarification of this flow distribution mechanism would be useful for future water management following the water utilization rules to be formulated.

In due consideration of international river course management, crosschecking of data from the neighbouring countries has been indispensable. Even if intensive flow measurements were made at Tan Chau, Chau Doc and Vam Nao in Vietnam, the transparently crosschecked data observed in neighbouring countries would be useful for the acknowledgement among the riparian countries, in particular, during the dry season.

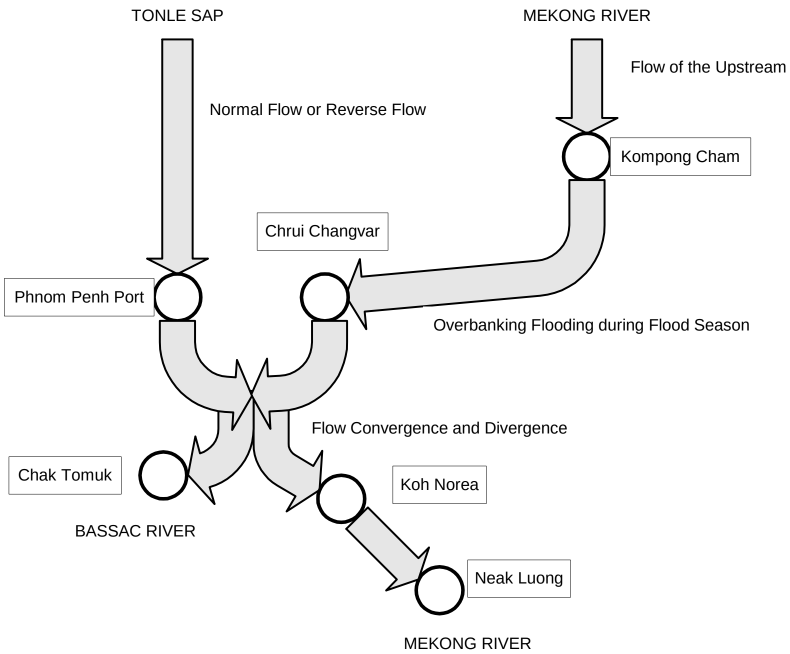


Fig. 2-9 Flow Situations and Selected Hydrological Stations/Sections

Discharge measurements were done at least once a week at each station since the beginning of July 2002 until the beginning of October 2003. The team conducted on-the-job and indoor trainings as occasions demanded in the course of the measurement activities. As a result of the activities, the Team created around 80 discharge data at each station for one year and three months.

<u>Coordinated Discharge Measurement</u>

Coordinated discharge measurements were made, in particular, together with the Tonle Sap and Vicinities Project (TSLVP). One of the major objectives of TSLVP was to clarify the hydrological mechanisms of the Cambodian floodplains. On the other hand, one of the objectives of the WUP-JICA Project was to assist in the formulation of water utilization rules among the four countries. For this purpose, flow mechanisms including the dry-season flow shall have to be clarified in the Cambodian floodplains because these are very complicated in this area. Since the floodplains widely extend and the drainage systems including the Colmatage systems complicatedly developed on them, it might be a heavy burden for the project alone to tackle the above issues and to create fruitful results. Thus, cooperative work was necessary in this field.

The work sharing between two projects was determined based on the frequent discussions with the TSLV project team. As a result of the discussion, the WUP-JICA team measured the discharges longitudinally along the river courses, while the TSLVP team made discharge measurements on the floodplains at the same time. The compiled results of the discharge measurements are also presented in Chapter 4 as the Hydrology in the Lower Mekong Basin.

2.3.3 Development of Rating Curves

Previous Efforts on the Development of Rating Curves

Regarding the development history of rating curves at major hydrological stations in Cambodia, discharge data has been recorded at Kratie Station only since 1933. Not until the early 1960s had discharge data been recorded at major stations in Cambodia based on the rating curves developed. The available discharge data ranges at the target stations of the WUP-JICA discharge measurement activities are tabulated below.

Table 2-8 Previous Discharge Records in/around Phnom Penh Area

Station	Discharge Record		Rating Range	Discharge Measurement
	Start	End		
Kompong Cham	1964	1973	Above 3m	Until 1969
Chrui Changvar	1960	1973	Above 3m	Until 1973
Chak Tomuk	1964	1973	Above 4m	Until 1973
Neak Luong	1965	1969	Above 2.5m	Until 1969

Chrui Changvar is sometimes called Phnom Penh Mekong, while Chak Tomuk is also called Phnom Penh Bassac or Monivong Bridge.

Table 2-8 indicates that discharge-rating curves were established at each station in the early 1960s. Discharge data as well as water level recording ceased in the final political disturbance. The checked measurements, however, were continued several times a year with the strong determination of the hydrologists engaged even under the worsened security conditions. Thus restoration of the monitoring system in this area should be an essential duty to be fulfilled by the succeeding hydrologists.

Results of Measurement

The actual measurement activities including the dry-season flow measurement started in July 2002 and continued until the beginning of October 2003. For the period from 04 July 2002 to 11 October 2003, the major stations had observed around eighty (80) discharge data.

Fig. 2-10 presents the relationship between the observed water level and flow discharge at 6 major stations including the Koh Norea section which is located just downstream of the Chak Tomuk junction along the Mekong. This figure implies the following facts:

- Data measured along the Mekong and Bassac show the looping ratings produced by uniformly progressing flood waves so that the discharge is greater when the water is rising than it is when the stream is falling.

- In particular, the data at Chrui Changvar show a big difference between two discharges at the same water level due to highly unsteady flow originating from the inflow or outflow of the Tonle Sap. This effect is very similar to the previous measurements made in the early 1960s.

- On the other hand, the data at Koh Norea indicate small looping at immediately downstream of the Chak Tomuk junction. In this figure, water levels of Chrui Changvar are adopted for the levels of Koh Norea because there are no gauges at the Koh Norea section.

- The flow conditions at Phnom Penh Port are extremely unsteady. The differences of water levels are much bigger compared with the differences among the discharges for the reverse and normal flow periods, while the differences of discharges are much bigger compared with the differences of water levels for the transition period from reverse flow to normal flow.

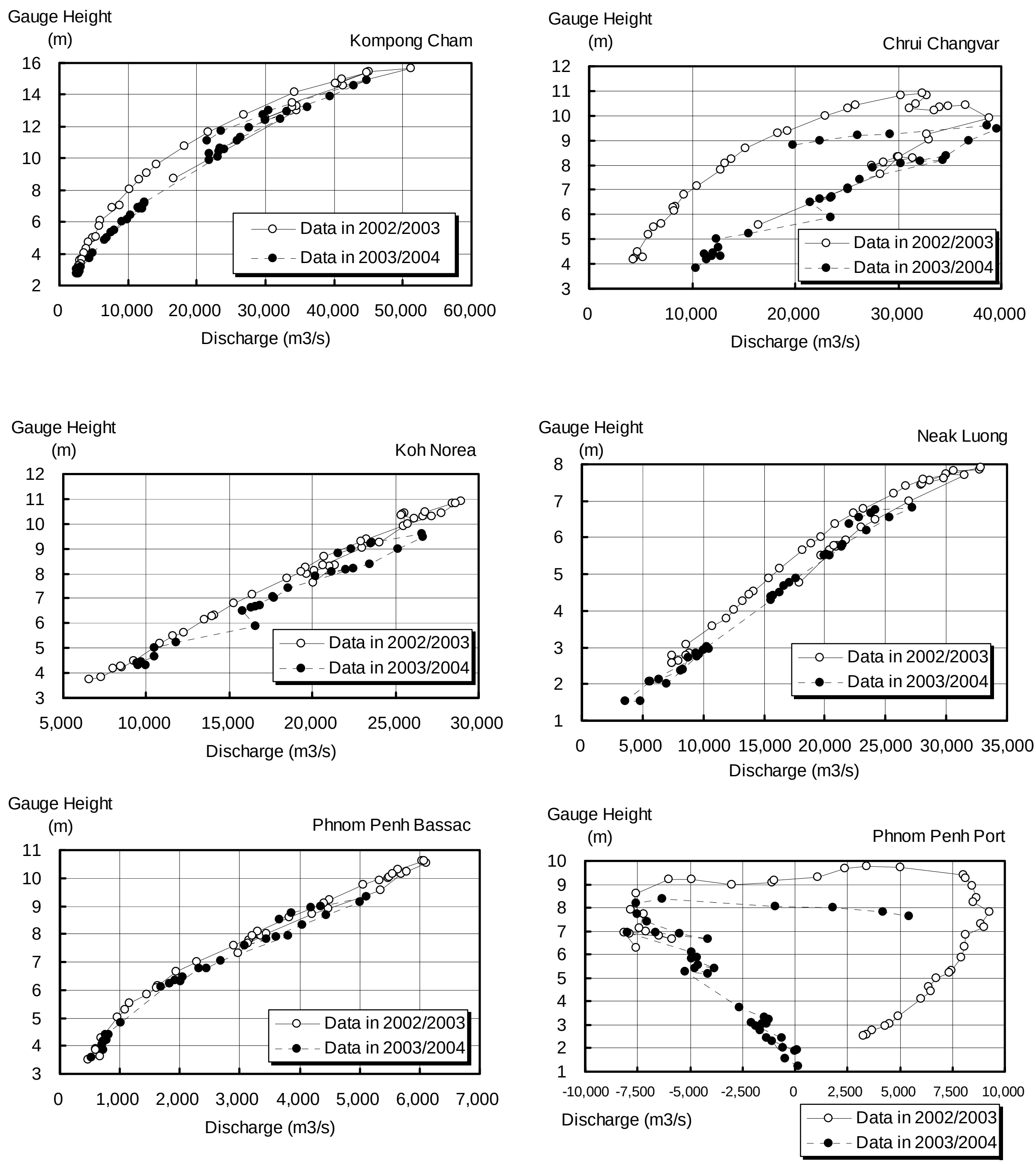


Fig. 2-10 Measured Discharge Data versus Water Level

<u>Determination of Rating Ranges</u>

According to the examination of measured discharges versus water levels as presented in Fig. 2-10, it may be very difficult to develop the rating curves at Phnom Penh Port due to the strong and complicated effects of flow convergence and divergence at the Chak Tomuk junction. Thus, except for Phnom Penh Port on the Tonle Sap, the rating curves at the remaining 5 stations had been developed using the observed data. In the process of development, the initial step had been the determination of applicable range of rating curve, since hydrological data at these stations are strongly affected by tidal fluctuation in the low-flow period.

After various comparative examinations between water levels and measured discharges, the developed rating curves were applied to the following water levels at each station. Compared with their elevations given in Table 2-9, the rating ranges of Chrui Changvar and Phnom Penh Bassac show good agreement. From the inapplicable durations of rating curves the rating range of Neak Luong, which is located at 60 km downstream of Phnom Penh, also show good agreement with both the stations of Chrui Changvar and Phnom Penh Bassac. Thus the proposed rating ranges among the 4 stations/sections can be regarded as having a harmonious balance among the lower limits of applicability.

Table 2-9 Rating Ranges and Inapplicable Durations of Rating Curves

Station/Section	Rating Range		Inapplicable Days of Rating Curves a Year (1998-2002)
	Gauge Height	Elevation	
Kompong Cham	-	-	(applicable whole-year-round)
Chrui Changvar	Above 3.5m	Above 2.42m	100-170 days
Koh Norea	Above 3.5m	Above 2.42m	100-170 days
Phnom Penh Bassac	Above 3.5m	Above 2.48m	100-170 days
Neak Luong	Above 2.5m	Above 2.17m	110-180 days

Development of Discharge Rating Curves

Under the flow conditions affected by progressing flood waves and unsteady flow, flow discharges associated with the fall of water level between two neighbouring gauges were also considered as slope of the energy gradient. Actual development work was based on the trial and error process for determination of the most suitable neighbouring gauges and of exponents of falls as the best fitting between observed and estimated values. The results of selection of suitable combinations are tabulated below. Finally, the most suitable parameters of the rating equation were determined in terms of the maximum value of correlation coefficient and minimum value of standard error.

Table 2-10 Representative Stations for Water Level Falls

Station	Water Level Falls	
	Upstream Station	Downstream Station
Kompong Cham	Kompong Cham	Chrui Changvar
Chrui Changvar	Kompong Cham	Chrui Changvar
Koh Norea	Chrui Changvar	Neak Luong
Neak Luong	Chrui Changvar	Neak Luong
Phnom Penh Bassac (Monivong Bridge)	-	-

The developed rating curves are presented in Fig. 2-11, and the equations of rating curves at the selected stations are given below. The works include development of the rating curve at Kratie utilizing the measurement results made by the DHRW, MOWRAM, Cambodia.

(1) Kratie

Rising stage: $Q = (8.158H-10.155)^{2.1}$

Falling stage: $Q = (3.300H+1.256)^{2.5}$

where Q = flow discharge, m^3/s
H = gauge height of Kratie, m

(2) Kompong Cham

$Q = (8.869H+29.811)^2 F^{0.3}$

where Q = flow discharge, m^3/s

H = gauge height (water level), m
F = falls between water levels in MSL m of the stations listed in Table 2-10, m

(3) Chrui Changvar

Rising Stage : $Q = (2.852H+54.799)^2\ F$

Falling Stage: $Q = (10.051H+30.406)^2\ F^{0.4}$

(4) Koh Norea

Water level is not observed at the Koh Norea Station (section), so that the gauge heights of Chrui Changvar were substituted for those of Koh Norea.

$Q = (5.496H+80.200)^2\ F^{0.5}$

(5) Neak Luong

$Q = (12.718H+62.250)^2\ F^{0.2}$

(6) Phnom Penh Bassac (Monivong Bridge, Chak Tomuk)

$Q = (13.943H-19.992)^{1.8}$

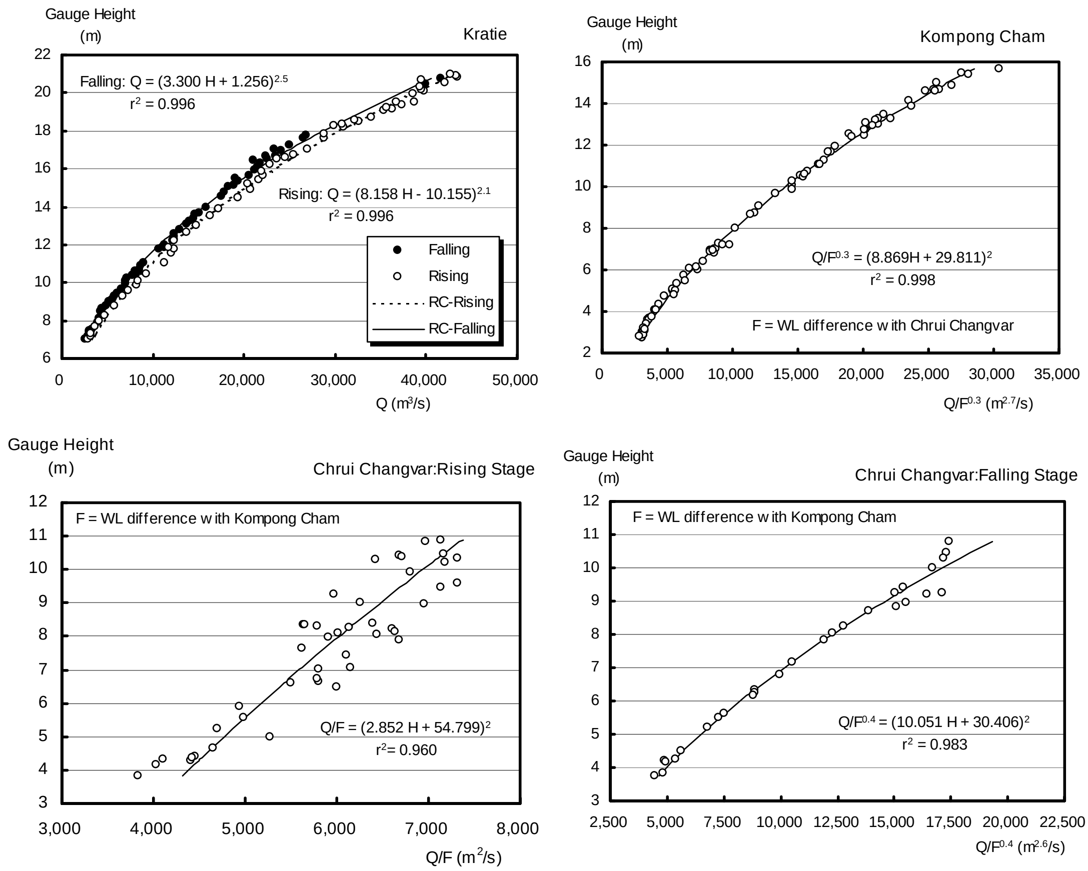


Fig. 2-11(1/2) Developed Discharge Rating Curves : Mekong Mainstream

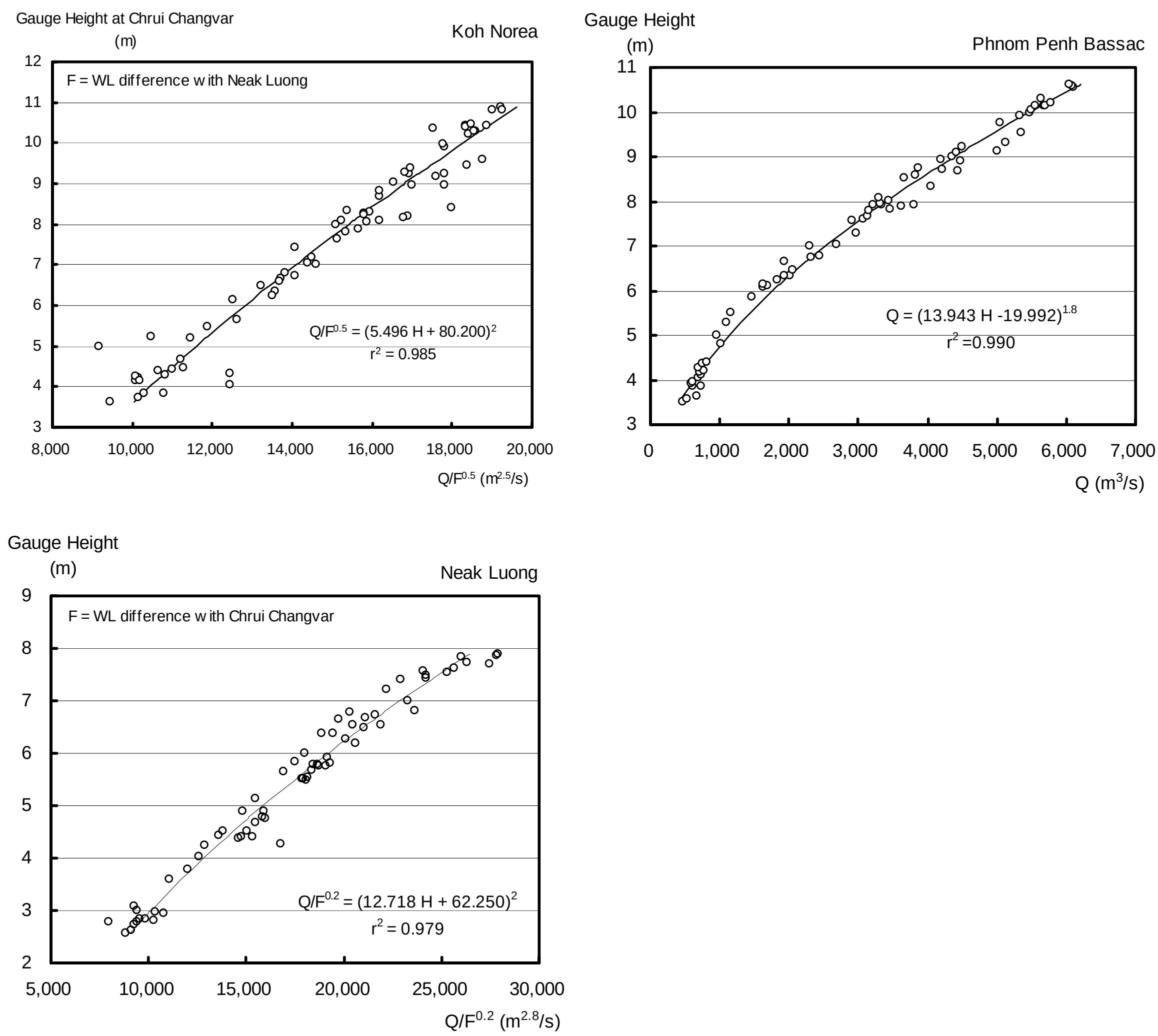


Fig. 2-11(2/2) Developed Discharge Rating Curves : Mekong Mainstream and Bassac

2.3.4 Flow Monitoring System in Cambodia

Based on the results of monitoring and analysis, practical and suitable directions for the present flow management system in and around the Phnom Penh area is deliberated in this subsection. Furthermore, the future monitoring system is also recommended from practical considerations. For easier understanding, the flow monitoring system is divided into 2 timeframes; namely, wet-season monitoring and dry-season monitoring. In terms of hydrological monitoring in Cambodia, the definition of season is closely related to the facts on whether or not tidal fluctuation strongly affects water level and flow discharges. The seasonal monitoring system has to be defined through reference to the gauge height at each station. These are summarised in Table 2-11.

As indicated in Table 2-11, the established rating curves can be applicable throughout a year at the upstream stations of Kratie and Kompong Cham, while they can be applicable in six to eight-and-a-half months (50 to 70% of the total period) in the downstream areas. For the remaining periods, some different ways of dry-season flow monitoring system shall be established.

Table 2-11 Wet Season Monitoring Periods in Cambodia

Area	Station	Threshold Gauge Height	Wet-Season Monitoring			Remarks
			Onset	End	Total Days	
Upstream	Kratie; Kg. Cham	-	-	-	-	Whole Year System
Phnom Penh	Chrui Changvar; Koh Norea; P. P. Bassac	3.5 m	Mid May to Early July	Early Jan. to Early Feb.	190 to 260 days	
Downstream	Neak Luong	2.5 m	Early May to Early July	Early Jan. to Early Feb.	180 to 250 days	

<u>Wet Season Flow Monitoring System</u>

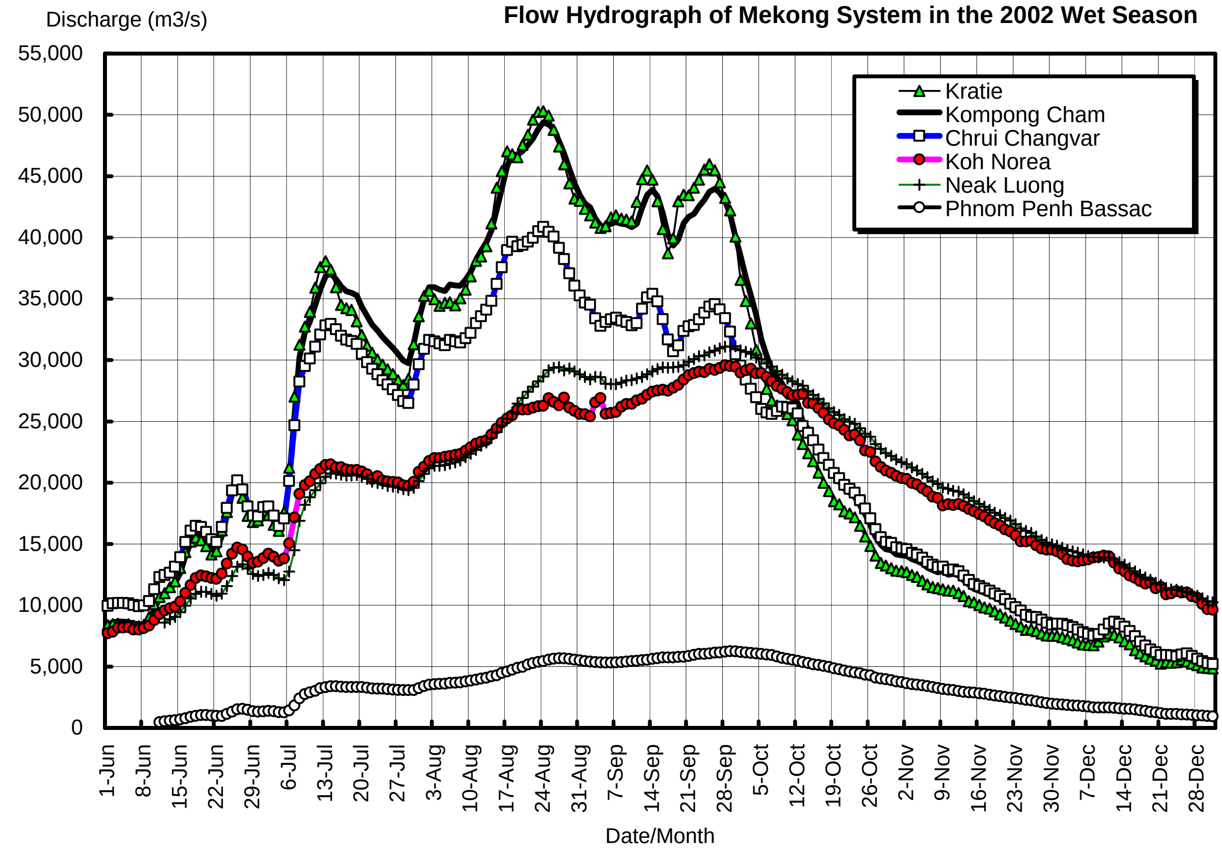
Through intensive discharge measurements and the development of rating curves, practically the wet-season flow monitoring system could be established to clarify the flow conditions in the Chak Tomuk junction. When the flow monitoring system has been established in this area, the system can provide useful information to the flood forecasting activities in connection with the flood emergency action programme over the lower Mekong Delta as well as the Cambodian floodplains.

Fig. 2-12 presents the flow hydrograph in and around the Phnom Penh area in the 2002 wet season computed by the developed rating curves as an example. The hydrographs among the stations are in good relation from the studied flooding and succeeding balanced flow conditions; for instance, the relations between Kompong Cham and Chrui Changvar, and between Koh Norea and Neak Luong.

Under these preferable conditions, the flow discharge at Phnom Penh Port was computed using the following simple water balance equation. Together with the observed data, the estimation results are also presented in Fig. 2-12.

Phnom Penh Port Q = Koh Norea Q + Monivong Bridge Q - Chrui Changvar Q

This figure implies the possibilities for establishment of the wet-season monitoring system. The computed hydrograph shows a good fit to the observed discharges during the reverse flow period as well as the transition and normal flow periods. Thus the computed flow can be practically utilized for estimation of the Tonle Sap flow in the wet season. In conclusion, the developed rating curves can be utilized for the wet-season flow monitoring system covering Kratie down to the Phnom Penh area in Cambodia, to clarify the flow rate not only at the station sites but also of divergence/convergence at the junction of the Chak Tomuk area.



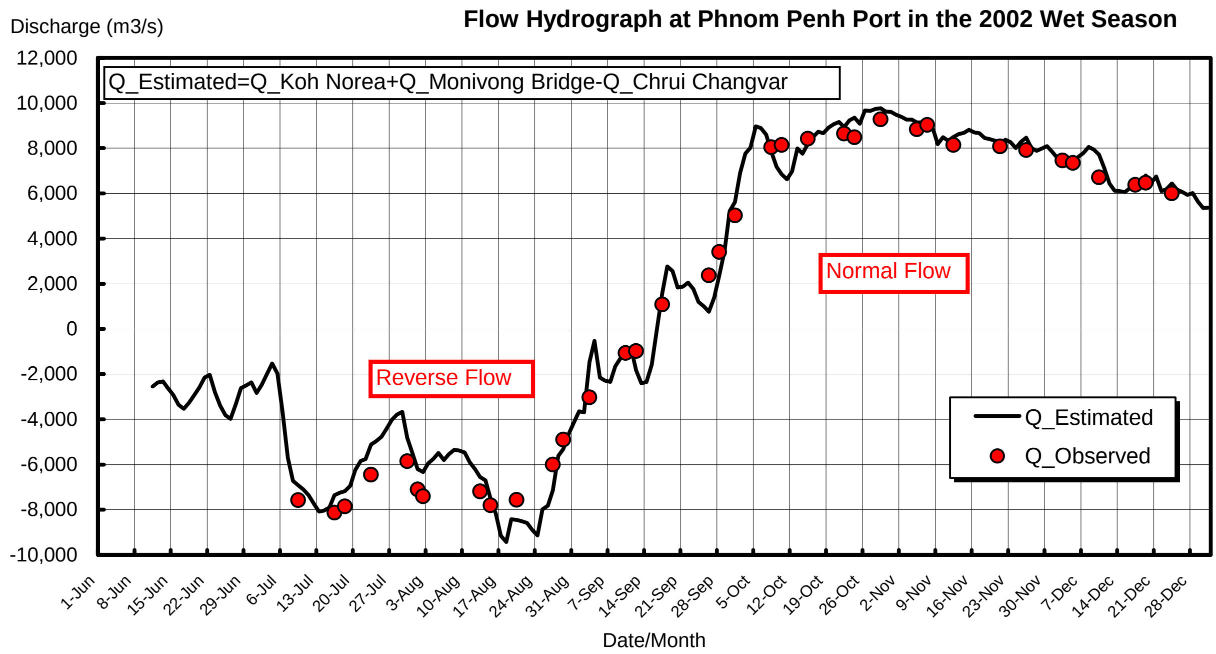


Fig. 2-12 Computed Flow Hydrographs and Comparison between Estimated and Observed Discharges at Phnom Penh Port, 2002 Wet Season

Dry Season Flow Monitoring System

The discharge measurements continued even in the dry season of 2003 at the stations of Kompong Cham, Chrui Changvar, Koh Norea, Phnom Penh Port and Phnom Penh Bassac. The area in and around Phnom Penh is geographically important for the future flow management following the Water Utilization Rules to be established in the near future, in particular, for the dry-season flow monitoring to manage the acceptable minimum monthly natural flow to the Delta. To properly and equitably manage the flow in the international watercourses, sufficient crosschecking with the downstream discharges observed at the reliable hydrological stations in Vietnam is indispensable.

From the simulation results of the 2001 dry season, the most serious dry period in 2001 was from the end of April to the beginning of May. In this period, approximate discharge fluctuations at the major stations are summarized in the following table.

Table 2-12 Effects of Tidal Fluctuation to the Dry Season Flow

Station	Average Flow (m^3/s)	Range of Fluctuation (m^3/s)	Fluctuation Rate (%)
Kompong Cham	1,600	100	6
Chrui Changvar	2,000	1,500	75
Neak Luong	3,000	3,000	100
Phnom Penh Port	1,200	500	42
Monivong Bridge	100	150	150

Fluctuation ranges due to tidal effects are very wide at all stations except for Kompong Cham. The rating curve for the dry-season flow could be developed only at Kompong Cham based on the above simulation results.

The establishment of a dry-season flow monitoring system in this area was planned following the process given below, in due consideration of the above-tabulated conditions:

(1) The rating curve developed at Kompong Cham is used for the estimation of dry-season flow as an upstream end of Phnom Penh area.

(2) Daily discharge at four stations in the Chak Tomuk junction is computed through the simulation model after the model calibration with the discharge measurement results made during the dry season.

(3) Regression equation is developed between discharges at Kompong Cham and daily average discharges at Chrui Changvar. Finally, continuous daily average discharges at Chrui Changvar are computed using the developed regression equation.

(4) Also, some hydrological relationship among upstream water levels in the Great Lake and daily average discharges at Phnom Penh Port is developed for the computation of continuous daily discharges at Phnom Penh Port.

(5) Using simulated daily average discharges at Koh Norea and Monivong Bridge, flow distribution rates into both channels in the dry season is determined.

The conceptual dry-season flow monitoring system is as schematised in Fig. 2-13.

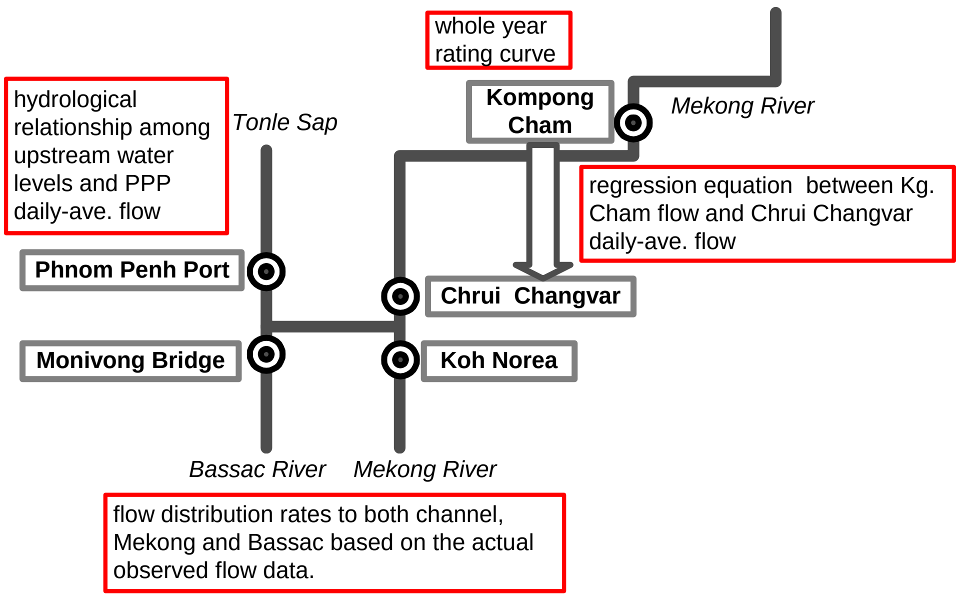


Fig. 2-13 Conceptual Dry Season Flow Monitoring System in/around Phnom Penh Area

As summarised in the study following the process mentioned above, the proposed dry-season monitoring system could be formulated in the following procedure.

(1) From the observed water level, the flow at Kompong Cham shall be computed using the rating curve equation: $Q = (8.869H+29.811)^2 F^{0.3}$, where F is fall of water level between Kompong Cham and Chrui Changvar.

(2) From the flow at Kompong Cham, the flow at Chrui Changvar shall be computed using the regression equation: $Qcc = 429 + 0.949\ Qkc$ ($r^2 = 0.984$)

(3) From the observed water level, the normal receding flow at Phnom Penh Port shall be computed using the rating curve equation: $Q = (6.608H+60.369)^2 F^{0.7}$, where F is fall of water level between Prek Kdam and Phnom Penh Port.

(4) After summation of the flows at Chrui Changvar and Phnom Penh Port, the diversion rate to the Mekong downstream shall be computed using the regression equation: $Qmd = 156 + 0.934\ Qin$ ($r^2 = 0.9998$)

For the 2003 dry season, the dry-season flow was estimated following the above procedure in order to check the applicability of this procedure and extract the problems/issues from the actual practices. Fig. 2-14 presents the monitoring practice applied for the 2003 dry season.

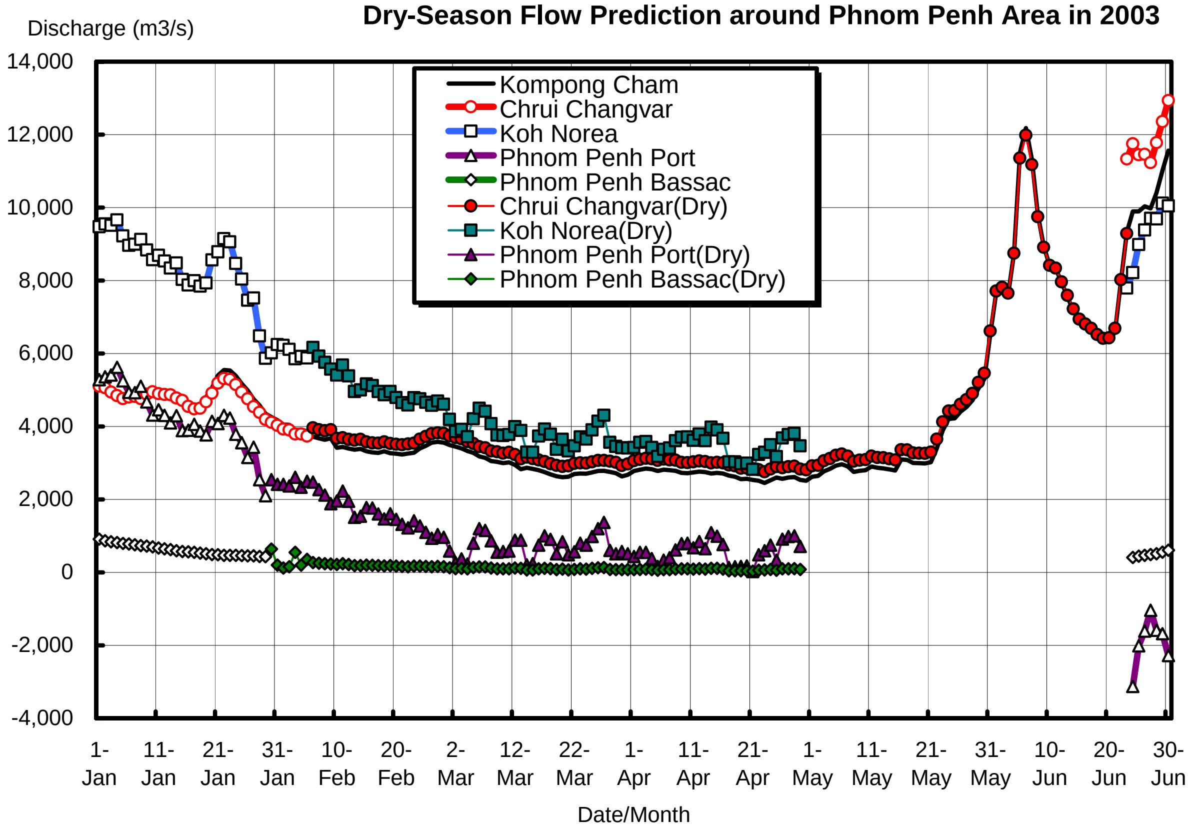


Fig. 2-14 Estimated Dry Season Flow in Phnom Penh Area

From the estimation process to prepare the above figure, the following issues and lessons were learned:

(1) The proposed dry-season flow estimation can be practically applied for the dry-season monitoring system in the Phnom Penh area.

(2) The proposed dry-season estimation can be applicable only for the normal receding flow of the Tonle Sap. After the normal flow has ceased, the proposed estimation would not be applicable. For instance, in the 2003 dry season, the inapplicable period was almost one-and-a-half months from the beginning of May to the middle of June. In the middle of June the wet-season monitoring system can be applicable.

(3) From Fig. 2-14, the flows at the Chak Tomuk junction are very sensitive in accordance with water level fluctuation, sometimes containing some errors by misreading or mistyping. Careful observation and data processing is necessary for the proper flow management as providers of the most basic and important information.

Recommendations for Future Monitoring System

Based on the process of data review and rating curve development, the future hydrological monitoring system in the Phnom Penh area, as illustrated in the following figure, could be proposed.

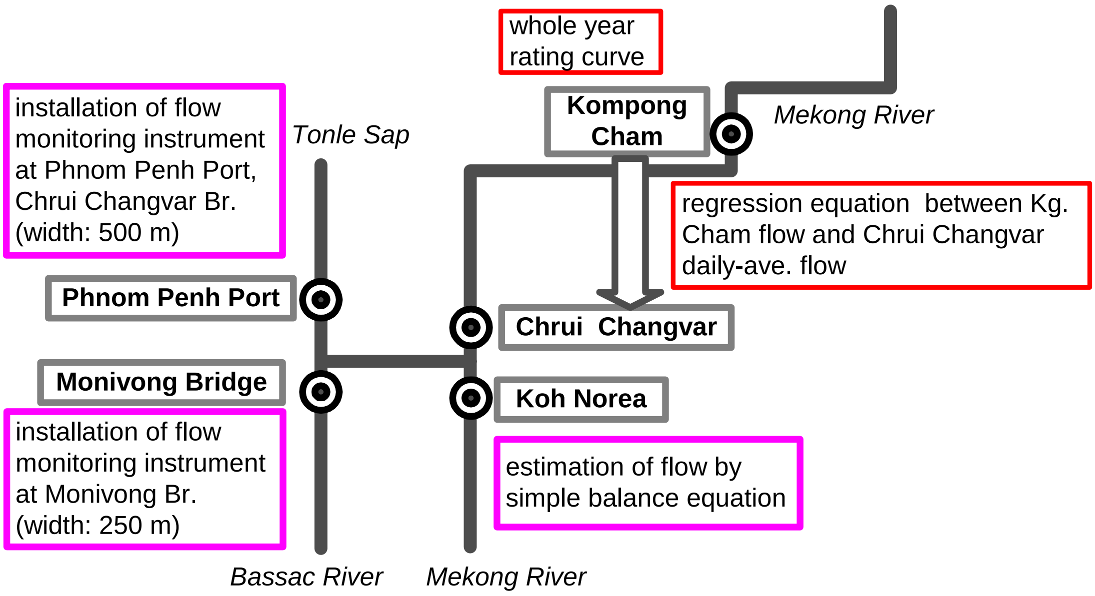


Fig. 2-15 Future Dry Season Flow Monitoring System in Phnom Penh Area

In particular, during the dry season, the Tonle Sap flow changes from normal receding flow through transition periods to the reverse flow. This full mechanism could not be depicted by the statistical equation or rating curve. The final reliable monitoring system shall be a direct measurement using new modern technology, for instance, the horizontal acoustic Doppler current meter. This kind of instrument shall have to be installed on the Tonle Sap and Bassac rivers since it is suitable for measurement at the narrow channel of both rivers.

The proposed monitoring system is also effective in the wet season along the Tonle Sap and Bassac rivers. After establishment of this monitoring system, maintaining of rating curves could be focused on Kompong Cham, Chrui Changvar and Koh Norea stations as far as listed in the above figure.