No.

Mekong River Commission

Japan International Cooperation Agency

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

FINAL REPORT

VOLUME I MAIN REPORT

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**


N
STUDY AREA
(LOWER MEKONG BASIN)
LEGEND
International boundary
Basin boundary
Mekong River
Upper Mekong basin
Lower Mekong basin
Major City
CHINA
INDIA
KUNMING
CHINA
MYANMAR
VIETNAM
HANOI
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

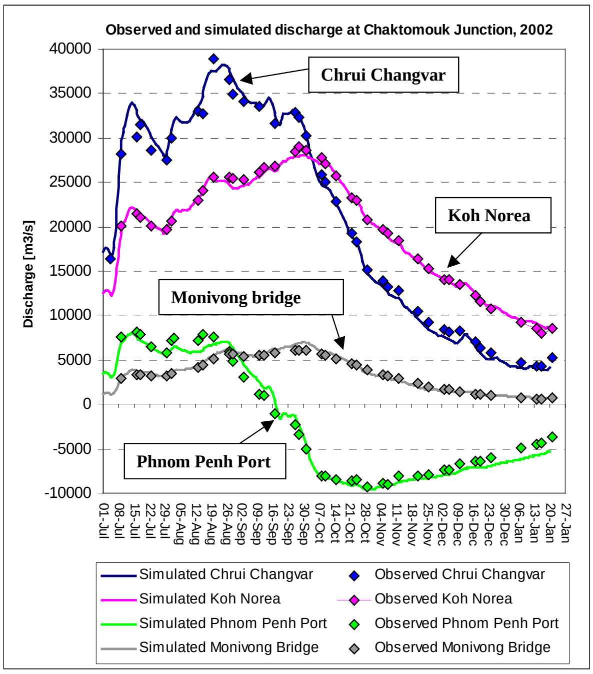
22 In succession to the Chak Tomuk Project of MRCS, the Team had continued developing the hydro-hydraulic model for utilization as the analytical tool for the WUP-JICA study. The model covers Kratie down to the Vietnam border including the Great Lake basin.

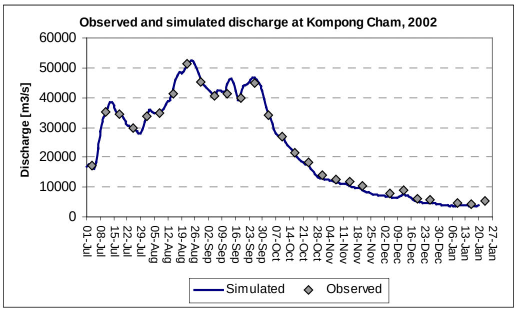
III-1 Development of Hydro-Hydraulic Model for the Cambodian Floodplains

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

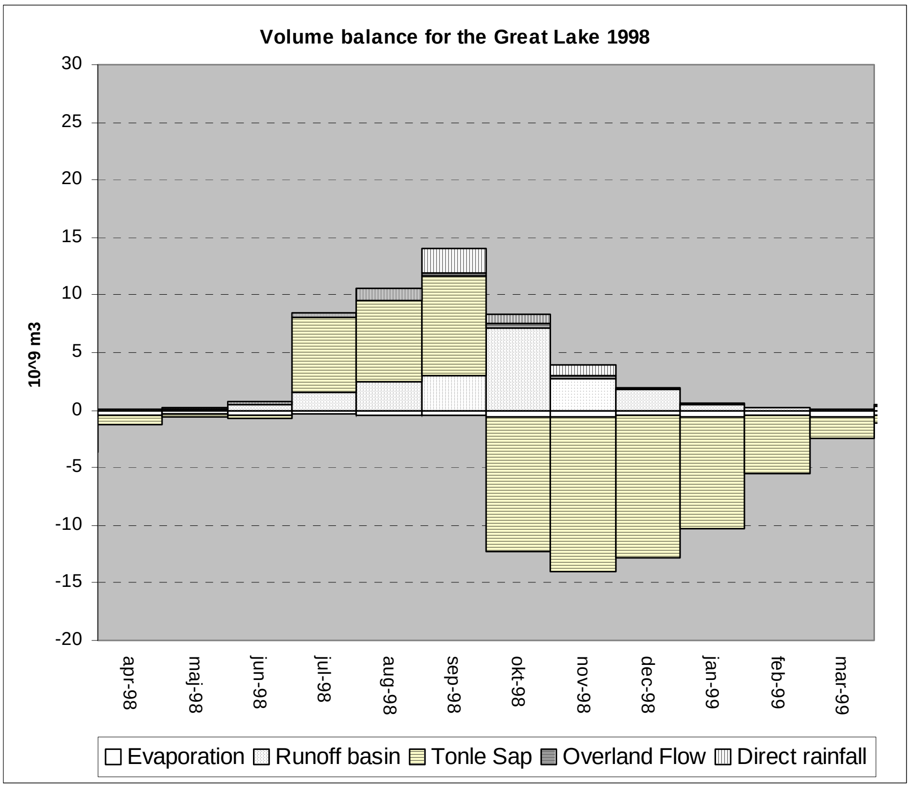
26 Investigations and assessments had been made using the developed model to assist in the relevant activities, as follows:

(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.

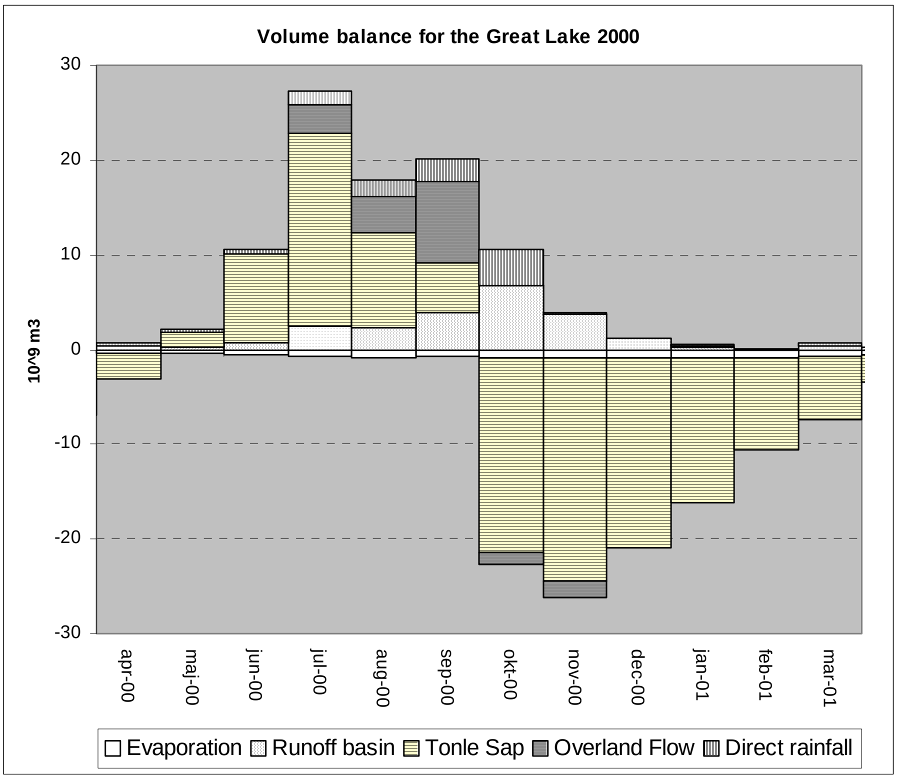
(b) The construction of road networks with embankment in the Cambodian floodplains might have historically given the largest effects to the floodplain hydrology including that of the Great Lake. The historical effects to the Great Lake and the hydrological effects of widening bridge openings had been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

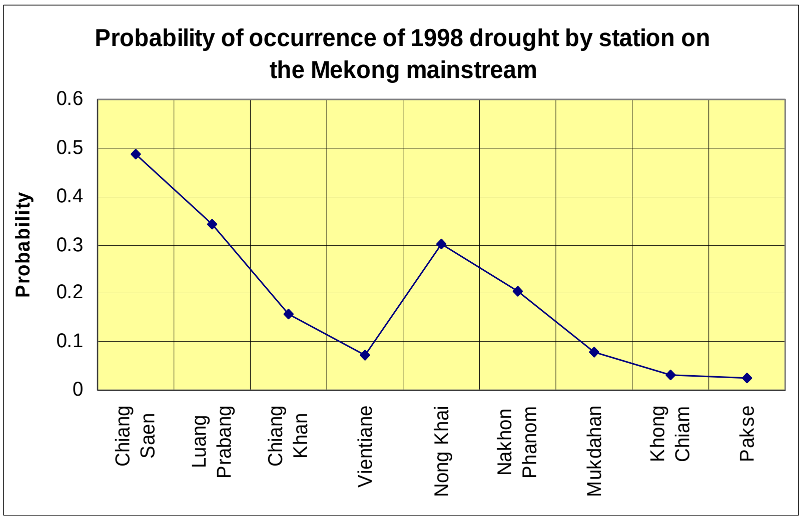
28 Data collected and results analysed in the course of the WUP-JICA study are herein summarized for better reference on the fields of hydrology and water use in the basin.

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:

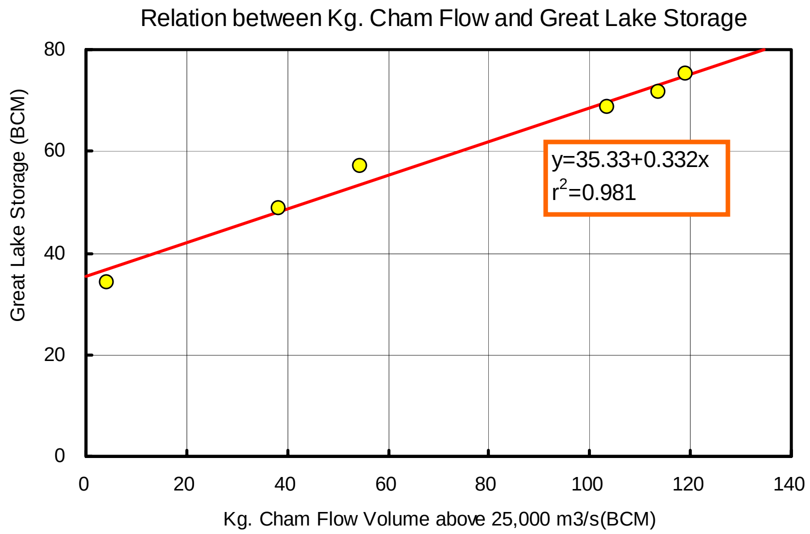
30 General features of the Mekong hydrology have been drawn out using the flow characteristics at major stations. As the noticeable flow contributions, the upstream basin of China is dominant to the dry-season flow, while the Laotian highlands are dominant to the wet-season flow.

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.



<u>Comparison of Probabilities of the 1998 Drought Occurrence</u>

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 I

MAIN REPORT

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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

PART I

GENERAL INFORMATION

PART I GENERAL INFORMATION

1.1 Background

The Mekong River originates in the Tibetan Plateau in the North, runs South-East 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 length, the Mekong River is the 12th longest river in the world and is the longest river system in Southeast Asia extending to approx. 4,880 km.

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 in the basin concern the reasonable and equitable sharing of water resources, and the 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 the four, the WUP has the objective to assist the MRC in establishing the mechanisms to promote and improve a coordinated and sustainable water management in the basin, including the reasonable and equitable water utilization by the riparian countries, the protection of environment and aquatic life, and the maintenance of ecological balance. The above situation could be achieved through the establishment of rules for water utilization and procedures for information exchange, notification and 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 of wet and dry seasons;

(2) Establishing the location of hydrological stations, and determining and maintaining the flow level requirement at each station;

(3) Setting out the 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 the mechanism to monitor inter-basin diversions from the mainstream.

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

Agreement. In March 2000, the WUP, 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" (the Study) in accordance with the relevant laws and regulations of Japan. The Japan International Cooperation Agency (JICA), the agency responsible for the implementation of technical cooperation programmes of the Government of Japan, undertook the study in close cooperation with the authorities concerned in the MRC and its member countries.

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

In accordance with the agreed S/W, the Study was commenced in March 2001. The draft inception report was prepared in Japan as the initial stage and, in May 2001, the JICA study team was mobilised to Cambodia to discuss it in the inception meeting with the MRCS. The Study was conducted for 36 months and this report consisting of three volumes contains all the results of the entire activities of the team.

1.2 Objectives

The objectives of the Study are:

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

(2) To assist the MRC in the processes of 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 shall cover 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 study area map. The lower Mekong River Basin accounts for 76% of the entire basin, as tabulated below.

Table I-1-1 Catchment Area of Mekong River Basin

<table>
<tr><th>Country</th><th>Catchment Area (km²)</th><th>Remarks</th></tr>
<tr><td>China</td><td>165,000 (21%)</td><td></td></tr>
<tr><td>Myanmar</td><td>24,000 (3%)</td><td></td></tr>
<tr><td>Laos</td><td>202,000 (25%)</td><td rowspan="4">Lower Mekong River Basin's
Total Catchment Area =
606,000 km² (76% of entire basin)</td></tr>
<tr><td>Thailand</td><td>184,000 (23%)</td></tr>
<tr><td>Cambodia</td><td>155,000 (20%)</td></tr>
<tr><td>Vietnam</td><td>65,000 (8%)</td></tr>
<tr><td>Total</td><td>795,000</td><td></td></tr>
</table>

1.4 Team Activities

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

The activities of the team are as reflected in the figure below.

Fig. I-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 Organization and Staffing

JICA had formed an organization consisting of the Advisory Committee and the Study Team. The Advisory Committee is to provide the necessary advice regarding the study to JICA, while the Study

Team is to be responsible to JICA for conducting the study. The members of the Advisory Committee and the Study Team are given in Table I-1-2 below.

Table I-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	-ditto- (September 2002 to May 2003)
Ryuzo IKUSHIMA	-ditto- (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	-ditto-
Kazuyoshi FUJIMOTO	-ditto-
Ryuich YAMAZAKI	-ditto-

1.6 Technology Transfer

For development of the water utilization rules, the following projects ran 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 in 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.

Since the above projects were known with “WUP” (Water Utilization Programme) affixed to the name of the respective organizations/countries providing assistance, this JICA study was also called as the WUP-JICA Project. In parallel with the above projects under the WUP, the following two projects were also closely related to the WUP-JICA study.

(1) Appropriate Hydrological Network Improvement Project (AHNIP), funded by the Australian Government, aiming at improving and upgrading 18 hydrological stations into a

telemetry network and at providing transparent and reliable hydrological data to the MRCS and the riparian countries.

(2) Consolidation of Hydro-Meteorological Data and Multifunctional 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 of the floodplains and paddy fields.

Thus the occasions to transfer technical knowledge and experiences were not only the workshops held by WUP-JICA but also the ones held by the related projects and activities. WUP-JICA utilized the following occasions for this purpose.

Table I-1-3 Workshops Participated and/or Organized 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 with the hydrological monitoring instruments and transfer of knowledge on discharge measurements. These are:

- On-site-training at the rehabilitated and upgraded stations for familiarization with the operation and maintenance of the installed automatic water level gauge. This on-site-training included data downloading and processing.
- Indoor training on discharge measurement (held two times in 2002), and similar training on the development of rating curves (held in 2003). The participants were the hydrologists of the MRCS and the staffs of DHRW, MOWRAM, Cambodia.
- On-the-job training held for almost one month each in 2002 and 2003. The survey expert of the WUP-JICA team participated in the discharge measurement activities and trained the survey staffs of DHRW in using the Acoustic Doppler Current Profiler (ADCP) for measurement.

1.7 Composition of the Main Report

The Main Report is composed of four parts covering the entire activity of the WUP-JICA team for 36 months with each part being compiled in accordance with the project objectives and work fields. Except Part I, the other components of the Main Report are summarized in the following table for easier reference.

Table I-1-4(1/2) Composition of the Main Report

Part	Chapter	Title	Remarks
Part II	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 the 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 measurements up to the development of rating curves.
Part III	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, the hydrological model of sub-basins, the Great Lake model and the elaborated floodplain model were incorporated into the model. As a result, the capability of model description was much enhanced.
	2	Application of the Model	Using the developed model, investigation and assessment were made for assisting the relevant activities; namely, dry-season flow investigation, hydraulic impact of road embankment in the floodplains, water balance of the Great Lake.

Table I-1-4(2/2) Composition of the Main Report

Part	Chapter	Title	Remarks
Part IV	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 were 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. Data/information on irrigation, hydropower and other sectors are compiled in this chapter.
Part V	Technical Assistance for Water Utilization Rules		For the formulation of water utilization rules, various technical assistances were provided; namely, technical study, technology and experience 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 were provided in the national and regional workshops to transfer information on the experiences in Japan. This chapter summarizes whole topics of presentations.

PART II

HYDROLOGICAL NETWORK IMPROVEMENT, GAP-FILLING, AND MONITORING

PART II HYDROLOGICAL NETWORK IMPROVEMENT, GAP-FILLING AND MONITORING

1. IMPROVEMENT OF HYDROLOGICAL STATIONS

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 networks. Twenty-five (25) stations have been designated as Key network stations in the recent network study made by the MRC[(1)], and fifteen (15) of them were scheduled for improvement into a telemetry system with Australian assistance under the Appropriate Hydrological Network Improvement Project (AHNIP). The remaining ten (10) Key stations listed in the following table were selected for further improvement under the WUP-JICA Study.

Table II-1-1 Key Network Stations Selected for Improvement under WUP-JICA Study

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 concerned. After the site inspections and discussions, the following actions were taken with the mutual understanding between the WUP-JICA team and the line agency concerned:

(1) Selection of stations to be improved, including stations newly proposed by the agencies;

(2) Determination of rehabilitation and upgrading works needed for the selected stations;

(3) Selection of suitable type of automatic recorder;

(4) Preparation of design drawings for the improvement of monitoring stations;

(5) Rehabilitation and upgrading of monitoring stations constructed by local contractors of each riparian country; and

(6) On-site training on maintenance and operation of recorders installed in each country to familiarise the staff of the line agencies concerned.

1.2 Screening and Improvement Works

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

Following the results of discussion with the Hydrology Section of the MRCS, the Team had determined that a gas-purged sensor should be installed at each station to be improved in view of the sensor's high-durability against heavy siltation and the well-familiarity of the staffs of the line agencies with such kind of recorders.

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

(1) Thailand (DWR, formerly DEDP)

Ubon Station in Nam Mun

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 are maintained in good condition.

In addition to the staff gauges, a set of gas-purged sensor and data logger was 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. II-1-1 Location of Ubon Station and Overview of Improved Station

(2) Lao PDR (WAD and DMH)

Pak Kagnung Station in Nam Ngum (DMH)

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 the stairway for protection against scouring.

Fig. II-1-2 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 (Top to Bottom).

Ban Phonesy Station in Nam Cading (DMH)

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

Ban Keng Done Station in Se Bang Hiang (WAD)

Gas-purged sensor and a data logger were installed in 1999 under Component II of the Improvement of the Hydro-Meteorological Network Project, which was funded by the Government of Australia. However, no stairway was constructed for the reading of slope gauge. The installation of stairway and a new slope gauge was requested by WAD, so that gabion mattress and cylinder were installed at both sides of the slope gauge and the stairway for protection against scouring and bank erosion.

(3) Cambodia (DHRW)

Ban Komphoun Station in Se San

The station was 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 the stairway for bank protection against scouring and erosion.

Cham Tangoy Station in Se Kong

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

The station also was equipped with only vertical staff gauges before improvement. The slope gauge, stairway, and gabion mattress and cylinder for bank protection were thus 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 recently installed 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 has determined through the onsite discussion with the DHRW that further improvement works are 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 is installed along the stairway, and the gas-purged sensor and data logger were accommodated in an instrument box at the bank.

Fig. II-1-3 Locations of Four Stations in Cambodia and Overview of Improvement Works

Note: Photographs show the improved station 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 to the restoration work, 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 are the float type recorder, gas-purged sensor and data logger, and the vertical staff gauges. The facilities and equipment are in good condition. Thus the team has determined through the onsite discussion with the SRHMC that further improvement works are not necessary.

My Thuan Station in Mekong

At present, this station is equipped with only vertical staff gauges. The SRHMC planned to relocate the station at 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 will be installed at this new station.

Fig. II-1-4 Location Map of Two Stations in Mekong Delta, Vietnam

1.3 Improvement Process and Onsite Training

The rehabilitation and upgrading works, which are mainly composed of civil works, were implemented in the dry season, from the beginning of year 2002. The installation of equipment was made in the wet season of 2002. The following figure summarises these activities.

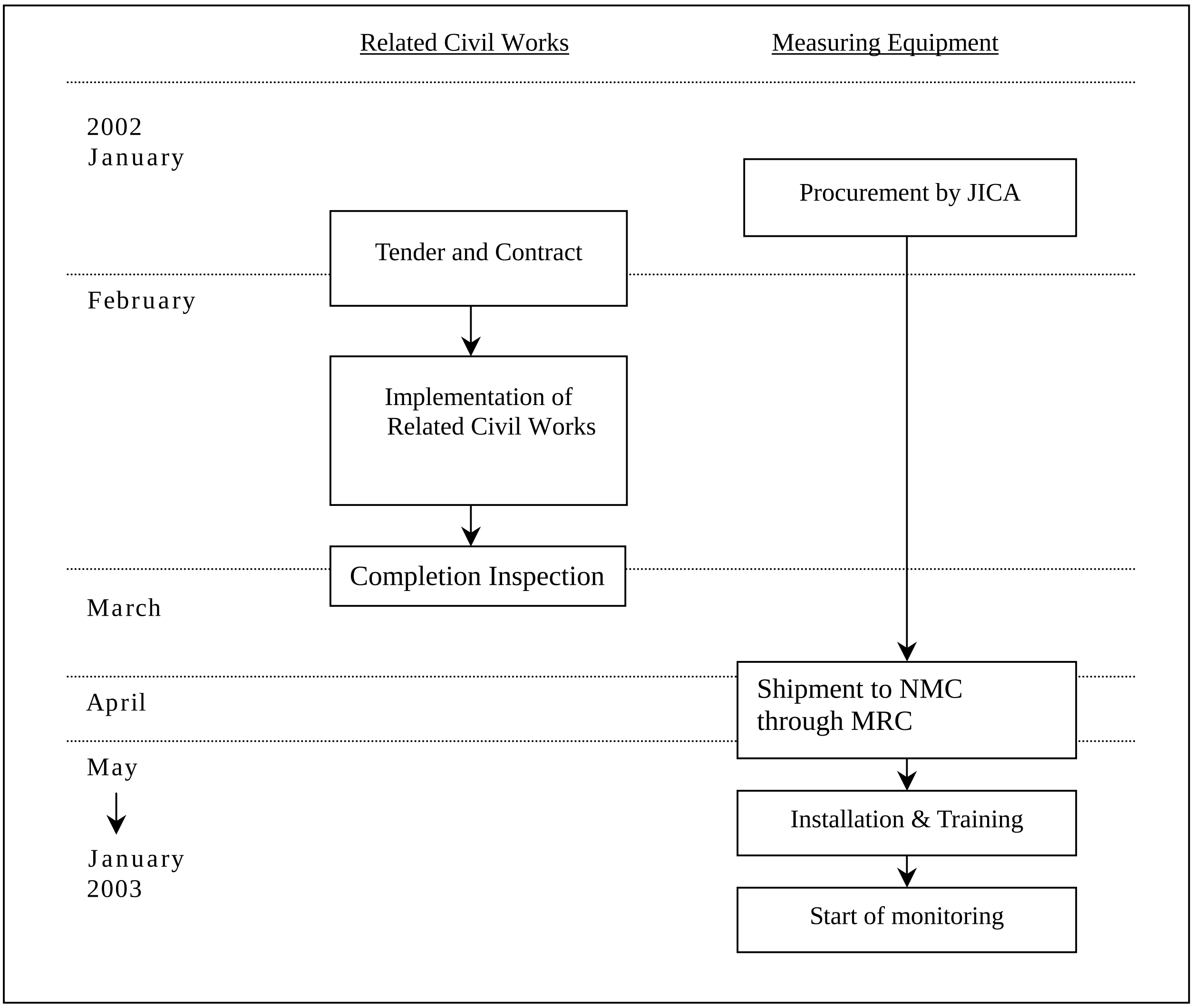


Fig. II-1-5 Implementation Process of Hydrological Station Improvement Works

After the completion of improvement works, training with the following contents was made onsite in each riparian country:

- Principles of measurement mechanism;
- Procedure of operation and maintenance of Nimbus, which is installed as a set of gas-purged sensor and data logger; and
- Procedure of communication to Nimbus using HYDRAS 3 software, which is attached to the hardware.

As for Vietnam, the schedule of relocation of My Thuan Station was delayed so that the SRMHC in Ho Chi Minh City is keeping the equipment until the new My Thuan Station is constructed.

2. GAP-FILLING OF DAILY RAINFALL DATA

2.1 Background and Objectives

The number of rainfall stations in the three (3) riparian countries has 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 are incomplete with missing data (data gaps). In Cambodia, most of the stations were newly constructed and rehabilitated by the MRC 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.

One of the initial tasks stated in the TOR for the Study is for the WUP-JICA Team to assist in providing a complete set of rainfall data. Rainfall data for the period 1991-2000 were considered most essential for the basin modelling activities.

2.2 Gap Filling Methodology

2.2.1 Annual Rainfall Data Gap Filling

There were rare cases where good correlation between daily rainfalls of nearby stations can be obtained. However, in the case of annual rainfall, good correlations between historical annual rainfalls of nearby stations prevailed. 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 regression 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. The relations used for generating the amount of annual rainfalls at stations are as follows:

Linear Regression:

$$Y = a + bX \qquad (1)$$

Where,

Y	=	Predicted annual rainfall at a data missing station
X	=	Annual rainfall at a nearby station
a	=	Intercept of the regression line
b	=	Slope of the regression line

Multiple Regression:

$$Y = a + \sum_{i=1}^{n} b_i X_i \qquad (2)$$

Where,

Y	=	Predicted annual rainfall at a data missing station
X_i	=	Annual rainfall amount at i^{th} nearby station
a	=	Intercept of the regression line
b_i	=	Coefficients
i	=	Index for nearby stations
n	=	Numbers of nearby stations considered

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. II-2-1 below. This figure shows an example analysed by multiple regression due to low correlation coefficient less than 0.8 in linear regression analysis.

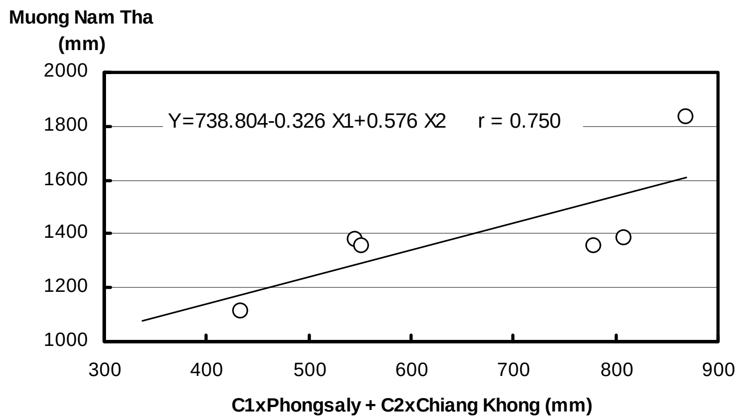


Fig. II-2-1 Correlation between Annual Rainfalls of Muong Nam Tha and Nearby Stations

2.2.2 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 were applied.

<u>Markov Chain</u>

Gabriel and Neumann(2) developed the Markov chain model for the occurrence of wet and dry days in daily rainfalls. After that, many others used the Markov chain for modelling rainfall processes. According to the Markov chain, the foregoing probability is expressed as follows:

$$P\left[X(t) = x_t \mid X(t-1) = x_{t-1}\right] \qquad (3)$$

The above relation indicates that the outcome of a process at time *t* can be defined by using the outcome of the process at time *t-1*. This is the property of the simple Markov chain.

Probabilities of Occurrence of Consecutive Wet and Dry Days

Using historical daily rainfall records, monthly probabilities of occurrence of consecutive wet days (wet day followed by wet day) and consecutive dry days were determined. However, the definition of wet and dry days is 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 amount of rainfall in that day is greater than 0.5 mm.

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

After defining the wet and dry days, determination of monthly probabilities of occurrence of consecutive wet and dry days become possible. As examples, monthly probabilities of occurrence of consecutive wet and dry days at Muong Nam Tha Station in Lao PDR are given in the following table.

Table II-2-1 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 relations used for determining the consecutive wet and dry days, as reported by Lamsal et al[3], are as follows:

Probability of consecutive wet days:

$$P_{WW} = \frac{\sum WW}{TWD} \tag{4}$$

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:

$$P_{DD} = \frac{\sum DD}{TDD} \quad (5)$$

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 are 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 is 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 are 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 curves 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 are 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 development of probability curve and stochastic rainfalls generation are described below.

Probability Curve

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 the plotting positions for respective rainfalls using the 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. II-2-2. The Weibull relation used for plotting position determination of the i^{th} event of historical daily rainfall sorted in ascending order is as follows:

$$P_i = \frac{i}{n+1} \quad (6)$$

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

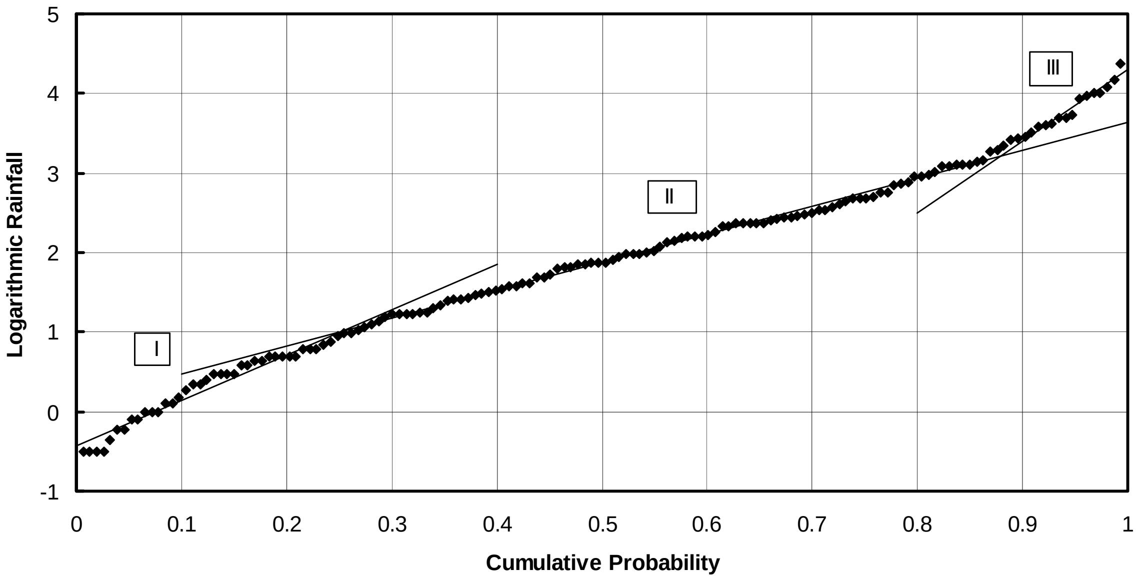


Fig. II-2-2 Probability Curve and Regression Lines for Stochastic Rainfall Generation at Muong Nam Tha in June

Rainfall Generation

The probability curve is divided into 3 parts for developing the best-fitted linear regressions 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. II-2-2). 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 II-2-2 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 daily rainfalls are as follows:

$$\log_e P_e(k) = a + b.k \qquad (7)$$

$$Y = e^{a+b.\lambda} \qquad (8)$$

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

2.2.3 Model Verification

The daily rainfalls generated by the stochastic model were 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 the differences between mean monthly rainfalls and standard deviations of observed and generated rainfalls were significantly different or not. Tests have shown that there were no significant differences between the observed and generated mean monthly rainfalls and the standard deviations were at the 95% confidence level. Moreover, correlations between the observed and generated values were also extremely high. This indicates that the developed stochastic daily rainfalls generation model were 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 II-2-3 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			

2.2.4 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 amount determined by the regression using nearby stations data for a data-missing year at a station. If the annual amount of any generated rainfall set was very close or fell in the range of ±5% of annual amount determined by the regression method, then the generated set of rainfall was selected. Once the set of generated daily rainfalls was selected for data gap-filling for a year, it was further checked and verified for its rainfall pattern. For this purpose, dimensionless patterns were 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 the 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 satisfies the pattern verification criteria. When the daily rainfall pattern was also found acceptable, then the selected set of generated rain was chosen for 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 presented in Table II-2-4 and Fig. II-2-3.

Table II-2-4 Selection of Sets of Generated Daily Rainfalls for Filling the Data Gaps at Muong Nam Tha

	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					

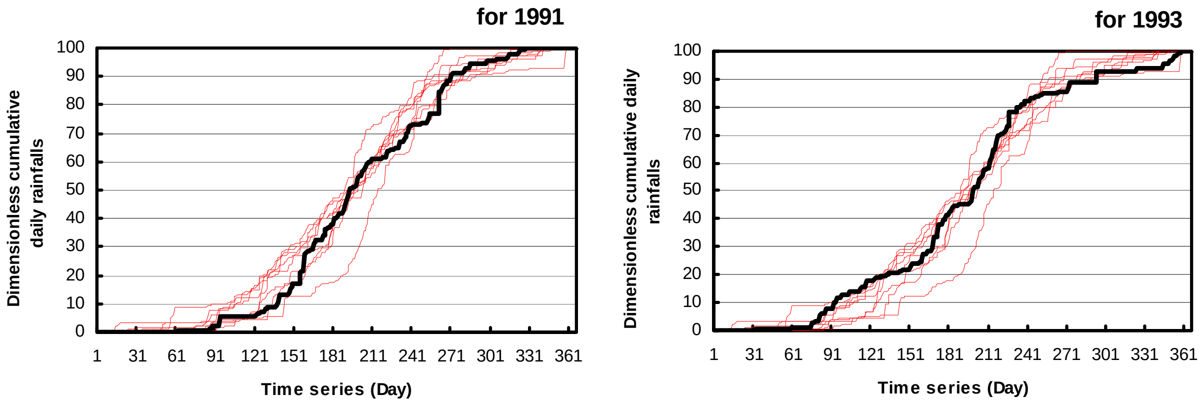


Fig. II-2-3 Pattern Verification of Generated Daily Rainfalls at Moung Nam Tha
Note: Bold line shows generated rainfalls, while light lines show observed rainfalls.

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.

Among the 52 stations selected in Thailand, one station has 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 in 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 were 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 was possible for only 11 stations. Data gap filling was not 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 was 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 in those stations.

In Vietnam, 11 stations (7 in Mekong Delta and 4 in Central Highland) were 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 missing completely 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 list of selected representative rainfall stations and their evaluation results, as well as their locations and spatial distribution are given respectively in Table II-2-5 to 8 and in Fig. II-2-4 to II-2-7. These are shown in the order from the upstream countries; namely, Thailand, Lao PDR, Cambodia and Vietnam.

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

Table II-2-9 Summary of Daily Rainfall Data Gap-Filling

Country	Selected Representative Stations				Total of Stations with Available Datasets
	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%)

Table II-2-5 Selected Representative Rainfall Stations and Data Availability in Thailand

	Yearbook Code	Hymos Code	Station Name	Data Evaluation	91	92	93	94	95	96	97	98	99	00
1	438	150403	AMNAT CHAROEN	Complete	H	H	H	Y	H	Y	H	H		
2	539	130204	ARANYAPRATHET	Complete	H	H	Y	Y	H	Y	H	H		
3	346	170406	BAN PHAENG	Complete	H	H	H	Y	Y	Y	H	H		
4	362	170105	CHIANG KHAN	Complete	H	H	H	Y	Y	H	H	H		
5	303	200001	CHIANG KHONG	Complete	H	H	H	Y	H	H	H	H		
6	302	200002	CHIANG SAEN	Complete	H	H	H	H	H	H	H	H		
7	572	140202	CHOK CHAI	Complete	H	H	Y	Y	Y	Y	H	H		
8	405	160207	CHUM PHAE	Complete	H	H	H	Y	Y	Y	H	H		
9	365	170104	DAN SAI	Complete	H	H	H	Y	Y	Y	H	H		
10	317	199901	FANG	Complete	H	H	H	H	H	H	H	H		
11	580	160503	KHEMARAT	Complete	H	H	H	Y	Y	Y	H	H		
12	411	160202	KHON KAEN	Complete	H	H	H	Y	Y	Y	H	H		
13	525	140205	KORAT	Complete	H	H	Y	Y	Y	H	H	H		
14	413	160309	KOSUM PHISAI	Complete	H	H	H	Y	Y	Y	H	H		
15	424	160407	KUCHINARAI	Complete	H	H	H	Y	Y	Y	H	H		
16	363	170101	LOEI	Complete	H	H	H	Y	Y	Y	H	H		
17	428	160401	MUKDAHAN	Complete	H	H	H	Y	Y	Y	H	H		
18	343	170403	NAKHON PHANOM	Complete	H	H	H	H	Y	H	H	H		
19	357	170206	NONG KHAI	Complete	H	H	H	H	H	H	H	H		
20	458	150202	PHON	Complete	H	H	H	Y	Y	Y	H	H		
21	354	180301	PHON PHISAI	Complete	H	H	H	Y	Y	H	H	H		
22	403	160106	PHU KRADUNG	Complete	H	H	H	Y	Y	Y	H	H		
23	443	150407	RASI SALAI	Complete	H	H	H	Y	Y	Y	H	H		
24	347	170401	SAKON NAKHON	Complete	H	H	H	Y	Y	Y	H	H		
25	351	170305	SAWANG DAEN DIN	Complete	H	H	H	Y	Y	Y	H	H		
26	533	140302	SURIN	Complete	H	H	H	Y	Y	Y	H	H		
27	358	170201	THA BO	Complete	H	H	H	Y	Y	Y	H	H		
28	429	160403	THAT PHANOM	Complete	H	H	H	Y	Y	Y	H	H		
29	453	150308	THA TUM	Complete	H	H	H	H	Y	H	H	H		
30	435	150401	UBON	Complete	H	H	H	Y	Y	Y	H	H		
31	356	170202	UDON THANI	Complete	H	H	H	Y	Y	Y	H	H		
32	361	170102	WANG SAPHUNG	Complete	H	H	H	Y	Y	Y	H	H		
33	465		CHAIYAPHUM	Complete	Y	Y	Y	Y	Y	Y	Y	Y		
34	466		CHATTURAT	Complete	Y	Y	Y	Y	Y	Y	Y	Y		
35	528		NANG RONG	Complete	Y	Y	Y	Y	Y	Y	Y	Y		
36	307	190002	CHIANG KHAM	Complete	H	H	H	Y	H	H	H	H		
37	309	199904	PHAYAYO	Complete	H	H	H	Y	H	H	H	H		
38	407	160201	PHU WIANG	Complete	H	H	H	Y	Y	Y	H	H		
39	408	160208	NONG SANG	Complete	H	H	H	Y	Y	H	H	H		
40	412	160204	UBOLRATANA DAM	Complete	H	H	H	Y	Y	Y	H	H		
41	455	150311	SATUK	Complete	H	H	H	Y	Y	Y	H	H		
42	527	150205	LAM PLAI MAT	Complete	H	H	H	Y	Y	Y	H	H		
43	416	160308	KANTHARAWICHAI	Complete	H	H	H	Y	Y	Y	H	H		
44	418	160307	YANG TALAT	Complete	H	H	H	Y	Y	Y	H	H		
45	582	160313	THAWATCHABURI	Complete	H	H	H	Y	Y	Y	H	H		
46	431	150503	KHONG CHIAM	Complete	H	H	H	Y	Y	Y	H	H		
47	433	150501	PHIBUN MANGSAHAN	Complete	H	H	H	Y	Y	Y	H	H		
48	604	199913	MAE SUAI DAM SITE	Complete	H	H	H	H	H	H	H	H		
49	526	140204	KHON BURI	Complete	H	H	H	Y	Y	Y	H	H		
50	522	150104	SIKHIU	Complete	H	H	H	Y	Y	Y	H	H		
51	442	150402	YASOTHON	Complete	H	H	H	Y	Y	Y	H	H		
52	342	180302	BUNG KAN	Gap-Filling	H	H	M	Y	Y	Y	H	H		

H = Data in Hymos   Y = Data in Yearbook   M = Missing data

Data Evaluation   Complete: Complete daily data,   Gap-Filling: Complete daily data by partial gap-filling,
Incomplete: Incomplete daily data due to unsuitableness for gap-filling

Fig. II-2-4 Location of Selected Rainfall Stations in Thailand and their Data Evaluation

Table II-2-6 Selected Representative Rainfall Stations and Data Availability in Lao PDR

	Yearbook Code	Hymos Code	Station Name	Data Evaluation	91	92	93	94	95	96	97	98	99	00
1	250	210201	Phong Saly (I)	Complete	H	H	H	H	H	H	H	H	H	H
2	206	190202	Luang Prabang at Airport(I)	Complete	H	H	H	Y	H	H	H	H	H	H
3	236	180207	Vang Vieng (II)	Complete	H	H	H	H	H	H	H	H	H	H
4	215	170203	Vientiane at DMH(I)	Complete	H	H	H	H	H	H	H	H	H	H
5	232	180205	Ban Hin Heup(II)	Complete	H	H	H	H	H	H	H	H	H	H
6	227	150602	Saravanne (I)	Complete	H	H	H	H	H	H	H	H	H	H
7	225	150504	Pakse (I)	Complete	H	H	H	H	H	H	H	H	H	H
8	230	140501	Muang Khong (II)	Complete	H	H	H	H	H	H	H	H	H	H
9	222	190101	Senkhalok	Complete	H	H	H	H	H	H	H	H	H	H
10	235	180206	Muong Kasy	Complete	H	H	H	H	H	H	H	H	H	H
11	254	180307	Muong Borikhane (Kao)	Complete	H	H	H	H	H	H	H	H	H	H
12	253	180308	Muong Mai	Complete	H	H	H	H	H	H	H	H	H	H
13	220	160505	Keng Kok	Complete	H	H	H	H	H	H	H	H	H	H
14	260	150605	Nong Hine	Complete	H	H	H	H	H	H	H	H	H	H
15	229	140504	Moulapamok	Complete	H	H	H	H	H	H	H	H	H	H
16	259	140507	Champasak	Complete	H	H	H	H	H	H	H	H	H	H
17	261	190301	Ban Naluang	Complete	H	H	H	H	H	H	H	H	H	H
18	268	170502	Muong Mahaxay	Complete	H	H	H	H	H	H	H	H	H	H
19	265	160601	Muong Tchepon	Complete	H	H	H	H	H	H	H	H	H	H
20	209	180306	Ban Thouei (Tha Bok)	Complete	H	H	Y	H	H	H	H	H	H	H
21	219	160504	Dong Hene	Complete	H	H	H	H	Y	H	H	H	H	H
22	273	200204	Oudomxay	Complete	H	Y	H	H	H	H	H	H	H	H
23	272	160602	Muong Nong	Complete	Y	Y	H	H	H	Y	H	H	H	H
24	283	160603	Ban Dong	Complete	H	H	H	H	Y	H	H	H	H	H*
25	266	140705	Attapeu	Complete	H	H	H	H	H	H	H	Y	H	H*
26	285	180501	Nape	Gap-Filling	Y	Y	H	H	M	H	H	H	H	H
27	208	180303	Paksane (I)	Incomplete	H	M	H	H	H	H	H	H	H	H
28	218	170404	Thakhek (I)	Incomplete	H	H	M	H	H	H	H	H	H	H*
29	223	160405	Savannakhet(I)	Incomplete	H	H	M	H	H	H	H	H	H	H
30	224	150506	Khong Sedone (II)	Incomplete	H	H	H	M	H	H	H	H	H	H
31	256	140506	Soukhouma(II)	Incomplete	H	H	M	Y	H	H	H	H	H	H
32	243	190205	Xieng Ngeun	Incomplete	H	H	H	M	H	H	H	H	H	H
33	216	180203	Ban Maknao (Nasone)	Incomplete	H	H	H	H	H	H	H	H	M	H
34	242	150508	Selabam	Incomplete	H	M	H	H	H	H	H	H	H	H
35	264	190302	Xieng Khouang	Gap-Filling	H	H	M	H	H	H	H	H	H	H
36	270	150604	Ban Lao Ngam	Gap-Filling	H	H	Y	M	H	Y	H	H	H	H
37	255	140505	Pathoumphone	Incomplete	M	M	H	H	H	H	H	H	H	H
38	252	200101	Moung Nam Tha	Gap-Filling	M	H	M	H	H	H	H	H	H	H
39	276	160508	Ban Senouane	Incomplete	H	H	H	H	M	M	H	H	H	H*
40	251	200201	Moung Ngoy	Incomplete	M	Y	M	M	M	H	H	H	H	H
41	204	190108	Sayaboury (I)	Incomplete	M	H	H	M	M	H	H	H	H	H

H = Data in Hymos Y = Data in Yearbook M = Missing data * Partial data

<u>Data Evaluation</u> Complete: Complete daily data, Gap-Filling: Complete daily data by partial gap-filling,
Incomplete: Incomplete daily data due to unsuitableness for gap-filling

Fig. II-2-5 Location of Selected Rainfall Stations in Lao PDR and their Data Evaluation

Table II-2-7 Selected Representative Rainfall Stations and Data Availability (Cambodia)

	Yearbook Code	Hymos Code	Station Name	Data Evaluation	91	92	93	94	95	96	97	98	99	00
1	7	130603	Lomphat	Incomplete	M	M	M	M	M	M	M	M		H*
2	8	140602	Voeun Sai	Incomplete	M	M	M	M	M	M	M	M		H*
3	33	120202	Pailin	Incomplete	M	M	M	M	M	M	M	M		H
4	84	120606	Snuol	Incomplete	M	M	M	M	M	M	H	M		H*
5	10	130501	Stung Treng	Gap-Filling	Y	H	M	H	Y	M	M	M	H	H
6	78	120603	Kratie	Gap-Filling	M	Y	H	H	M	H	H	H	H	H
7	71	120504	Kompong Cham	Incomplete	H	H	H	H	Y	M	M	M		
8	162	110425	Pochentong	Gap-Filling	H	H	H	H	M	M	M	M		
9	26	130305	Battambang	Gap-Filling	H	M	H	H	H	Y	M	M		
10	156	110514	Prey Veng	Incomplete	H	H	H	H	M	M	M	M		
11	137	100401	Kampot	Gap-Filling	H	H	H	H	M	M	M	M		
12	147	100408	Takeo (Ville)	Incomplete	H*	Y	Y	M	M	M	M	M		
13	91	110503	Svay Rieng	Incomplete	M	Y	Y	H	M	M	M	M		
14	29	130202	Sisophon (Kang Var)	Gap-Filling	H*	H	H	H*	M	H	M	M	M	H*
15	15	130405	Kompong Kdei	Gap-Filling	M	H*	M	M	M	H	H	Y	H	
16	64	120404	Kompong Thom	Complete	H	H	Y	H	H	H	H	H	H	H
17	117	110404	Kompong Speu	Gap-Filling	H	H	H	H	Y	H	M	M		H
18	60	120401	Kompong Chhnang	Gap-Filling	H	H	M	H	Y	H	H	H	H	H
19		110405	Kampong Tralach	Gap-Filling	M	M	M	H*	M	H	H	H	H	H
20		120303	Maung Russey	Gap-Filling	M	M	H	H	H	H	H	H	H	H
21		130306	Siem Reap	Complete	H	H	H	H	H	H	H	H	H	
22		120302	Pursat	Complete	H	H	H	H	H	H	H	H	H	H

H = Data in Hymos Y = Data in Yearbook M = Missing data * Partial data
Data Evaluation Complete: Complete daily data, Gap-Filling: Complete daily data by partial gap-filling,
Incomplete: Incomplete daily data due to unsuitableness for gap-filling

Fig. II-2-6 Location of Selected Rainfall Stations in Cambodia and their Data Evaluation

Table II-2-8 Selected Representative Rainfall Stations and Data Availability in Vietnam

	Local Code	Hymos Code	Station Name	Data Evaluation	91	92	93	94	95	96	97	98	99	00
			Lower Mekong Delta											
1	90107	100605	My Tho	Incomplete	M	M	M	M	M					
2	101107	100506	Vinh Long	Incomplete	M	M	M	M	M					
3	120107	100509	Can Tho	Complete	H	H	H	H	H	H	H	H	H	
4	130107	90501	Soc Trang (Khanh Hung)	Incomplete	M	M	M	M	M					
5	150206	100505	Chau Doc	Complete	H	H	H	H	H	H	H	H	H	
6	170107	100504	Rach Gia	Incomplete	M	M	M	M	M					
7	150307	100507	Long Xuyen	Incomplete	M	M	M	M	M					
			Central Highland Area											
8		140704	Kon Tum (Lasan)	Gap-Filling	M	H	H	H	H	H	H	H	H	
9		140703	Pleiku	Complete	H	H	H	H	H	H	H	H	H	
10		120801	Buon Me Thuat	Gap-Filling	M	H	H	H	H	H	H	H	H	
11			Dakmil	Incomplete	M	M	M	M	M					

H = Data in Hymos Y = Data in Yearbook M = Missing data * Partial data

Data Evaluation Complete: Complete daily data, Gap-Filling: Complete daily data by partial gap-filling,
Incomplete: Incomplete daily data due to unsuitableness for gap-filling

Fig. II-2-7 Location of Selected Rainfall Stations in Vietnam and their Data Evaluation

3. HYDROLOGICAL MONITORING

3.1 Background, Issues and Objectives

3.1.1 Background

The major line agencies in charge of hydrological monitoring in the four riparian countries located in the Lower Mekong River Basin (LMRB) are:

Thailand	:	DWR (Department of Water Resources)
Lao PDR	:	WAD (Waterway Administration Division)
		DMH (Department of Meteorology and Hydrology)
Cambodia	:	DHRW (Department of Hydrology and River Works)
Vietnam	:	SRHMC (Southern Region Hydro-Meteorological Centre)
		HRHMC (Highland Region Hydro-Meteorological Centre)

So far, the DWR in Thailand and the WAD in Lao PDR have been jointly conducting discharge measurements at the major stations in the mainstream where the national boundary runs along the Mekong river course, and have developed discharge-rating curves based on these field measurements. The SRHMC of Vietnam has also been conducting intensive measurements of discharge, because it has to cope with both salinity intrusion during the dry season and severe flooding during the flood season, for the protection of residents and agricultural products in the Mekong Delta.

On the other hand, the condition of hydrological data in Cambodia has been recognised as much more unfavourable due to lack of discharge data at the major stations. In general, Cambodia is located in the most important and sensitive area of the Lower Mekong River Basin with respect to water conveyance to the Delta during the dry season and flood-retarding over the widely extending floodplains during the flood season.

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 the cessation of 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 limited, and discharge measurement activities were not sufficient to develop the rating curves at the major stations.

(4) Vietnam

The line agencies have been conducting intensive hydrological monitoring, including hourly discharge measurements on 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 agency intends to upgrade the present monitoring system; for instance, from manual reading of staff gauges to automatic recorders. However, the agency has 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 land vehicles and boats for field operations. In addition, they need technology transfer, in particular, on the use and operation of the 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 the electronic mail (e-mail).

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

3.1.2 Issues on Hydrological Monitoring

The issues to be addressed with regard to hydrological monitoring in Cambodia may be divided into three areas. These are:

(1) Physical Issues

The density of hydrological network in Cambodia is inadequate compared to the other riparian countries. Furthermore, the existing hydrological stations are decrepit, and the periodical renewal and repair of manual-reading gauges has not been completely made.

In the near future, various development projects such as irrigation improvement, hydropower generation, and bridge and road construction/improvement may be implemented to uplift the Cambodian economy and the people's living standard. Hence, hydrological information/data will be needed for the proper design and evaluation of such development projects.

However, it could be expected that these development projects will change the hydrological conditions of flooding as well as the low flow regimes, so that the abundant water-related resources including inland fishery, wetlands with rich biodiversity, and flood receding agriculture would be affected. To evaluate these effects, the appropriate hydrological observation network should be established all over the country as early as possible and, for this purpose, a master plan of hydrological network development, which will include classification and the phased development schemes of the network, should be formulated.

Regarding the hydrological data itself, the DHRW has been observing and providing water level data at its managing stations. The crucial issue is, however, the absolute lack of discharge data, because only the Stung Treng Station is continuously providing discharge data.

In connection with the lack of data mentioned above, it should be noted that Cambodia is situated in an important location in the Lower Mekong River Basin in geopolitical terms. It receives the excess water of the upper reaches in the wet season and flooding starts at Kratie towards the lower reaches of the floodplains during floods. In the dry season, the water detained in the floodplains as well as the Tonle Sap Lake supplements the water for the Delta where the biggest water users on the mainstream live and utilize water. Thus, measuring and providing discharge data in the Cambodian territory is a crucial issue for the successful water management in the Lower Mekong River Basin.

(2) Institutional and Technical Issues

Technically, human resources development is indispensable for the sound operation and maintenance of the network. The issue related to this area may be subdivided into:

- Shortage of skilled staff including observers;
- Lack of opportunity for practical training; and
- Lack of budget to sustain the above activities.

There is no institution in Cambodia that could provide well-trained and experienced hydrologists and related technicians, as reported by the DHRW. In spite of this situation, practical training could partially make up for the shortage of skills and experiences. Thus, capacity building through practical training could be one of the solutions to these issues.

Strengthening the institutions in water-related fields was unfortunately beyond the scope of the Study.

The financial/budgetary issues are as discussed below.

(3) Financial Issues

The lack of budget for network operation and maintenance has been a critical issue to be addressed. For a short certain period, the project-basis support may be possible to sustain the monitoring activities. However, the problem is the uncertainty on when the government can consolidate its budgetary self-support system to sustain the monitoring activities. This might be a time-taking process and will depend on the economic growth of Cambodia.

For the time being, the related projects shall have to supplement the shortage of budget through the project-basis support. The projects shall have to enhance the technical knowledge and skill of the DHRW staff through various kinds of training and workshop.

3.1.3 Related Projects and Possible Cooperative Activities

In a similar field of hydrological monitoring in Cambodia, two (2) projects have been implemented by the MRCS in parallel with this WUP-JICA Study (hereinafter called the WUP-JICA Project). The two projects, which are closely related to the WUP-JICA Project, are: (1) the “Appropriate Hydrological Network Improvement Project (AHNIP);” and (2) “The Consolidation of Hydro-Meteorological Data and Multi-Functional Hydrologic Roles of Tonle Sap Lake and its Vicinities (TSLVP).”

(1) AHNIP

AHNIP was started in April 2001 and is scheduled for completion in five years. The project involves the line agencies concerned in hydro-meteorological monitoring. The project aims to collect real-time water level and discharge data, and to handle, manage and share the data among the riparian countries and China together with the improvement of 18 hydrological stations located mainly along the Lancang-Mekong mainstream. In Cambodia, the target telemetry stations under AHNIP are:

- Stung Treng on the Mekong
- Kratie on the Mekong
- Kompong Luong in the Tonle Sap Lake
- Prek Kdam on the Tonle Sap

The project emphasizes strengthening of the capacity of MRCS and the line agencies in dealing with real time data to implement the rules to be established for water sharing, environmental protection and damage mitigation. AHNIP has periodically held training and workshops as initially planned. The activities cover related subjects such as selection of equipment, train-the-trainer training and so on.

(2) TSLVP

TSLVP (Phase I) substantially started in February 2002 and was completed in March 2003. The project area covered the Tonle Sap Lake and the drainage basins of its tributaries, as well as the floodplains of the Mekong mainstream extending from Kompong Cham down to Tan Chau and Chau Doc of the downstream ends along the Mekong and the Bassac, respectively. The major objectives of the project were:

- To evaluate the multifunctional hydrologic roles of the Tonle Sap Lake and vicinities through improvement of hydro-meteorological and related topographic data/information; and

- To provide MRC projects and programmes, as well as the line agencies, with more accurate and updated hydrological data/information about the project area.

Under the TSLVP, twenty (20) hydrological stations have been installed in the floodplains to record floodwater rising and falling situations. All the gauges are automatic recorders with data loggers. Some of them started observation in 2001. All of the gauges have recorded water level fluctuations from the beginning of the wet season in 2002 until the driest period in 2003.

The TSLVP also measured discharges at passages of floodwaters toward the Tonle Sap Lake and the lower reaches of the project area. However, the discharge measurement activities excluded mainstream flow and were limited to the floodplain areas. Thus, some cooperative activities of a related project were needed to accomplish the objective of clarifying the hydrological mechanism in the Cambodian floodplains throughout the year.

3.1.4 Objectives of the Discharge Measurement

As mentioned before, the hydrological monitoring under the WUP-JICA Project should concentrate on discharge measurements in Cambodia due to its limited resources. Hence, the Team deliberately avoided overlapping and thus facilitate the collaborative works. The objectives of the discharge measurement were:

(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 major stations. Furthermore, it was indispensable to collaborate with the AHNIP by sharing the responsible stations with that project.

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).

3.2 Activities of the Hydrological Monitoring

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

(1) 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 as telemetry stations by AHNIP. Their locations are as shown in Fig. II-3-1. To avoid any unfavourable overlapping and to attain a fruitful collaboration, the WUP-JICA Team had selected the remaining five (5) stations to develop the discharge rating curves through intensive discharge measurement activities.

Table II-3-1 Major Hydrological Stations in Cambodia

Station	River/Lake	Remarks
Stung Treng	Mekong	Improvement under AHNIP
Kratie		Improvement under AHNIP
Kompong Cham		
Churui Changvor		
Neak Luong		
Kompong Luong	Tonle Sap Lake	Improvement under AHNIP; unnecessary to measure discharge
Prek Kdam	Tonle Sap	Improvement under AHNIP
Phnom Penh Port		
Chak Tomuk	Bassac	

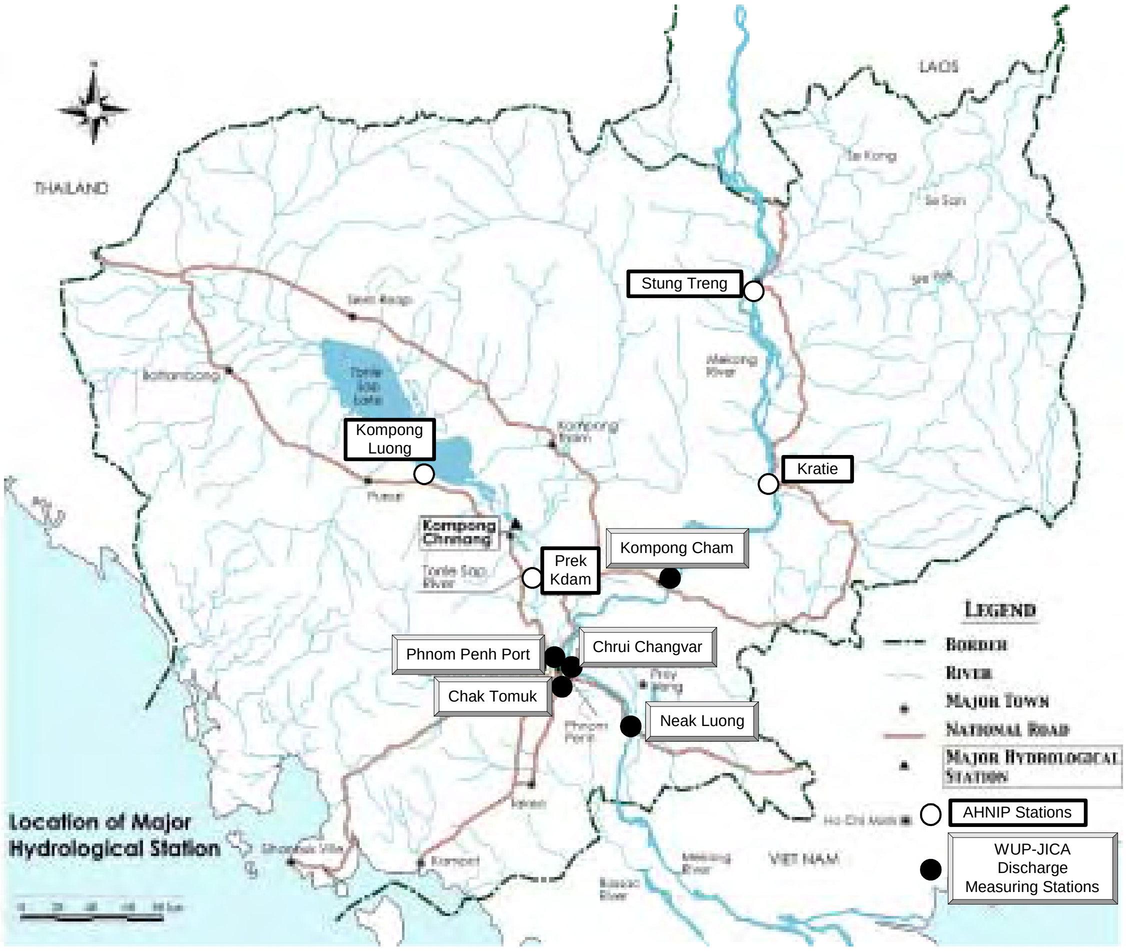


Fig. II-3-1 Major Hydrological Stations in Cambodia

Using the hydrological data observed by the above 5 stations, the flow conditions in the Chak Tomuk area at the junction of the Mekong, Tonle Sap and Bassac river systems were clarified to be minimum. Clarification of this flow distribution mechanism would be useful for the 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 the neighbouring countries would be useful for the acknowledgement of the riparian countries, in particular, during the dry season.

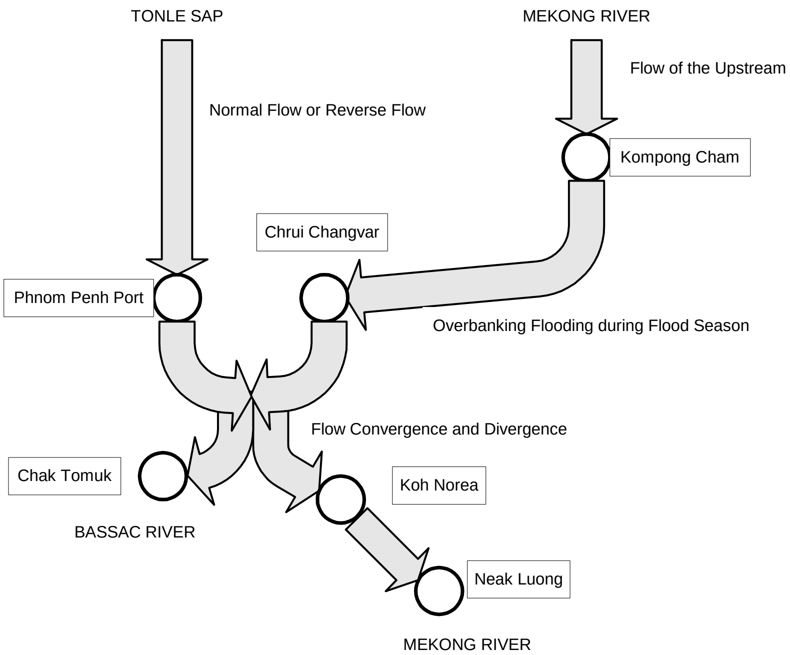


Fig. II-3-2 Flow Situations and Selected Hydrological Stations/Sections

Discharge measurements had been done at least once a week at each station since the beginning of July 2002 until the beginning of October 2003. The WUP-JICA Team conducted on-the-job and indoor trainings as occasions demanded in the course of the measurement activities. As a result of the activities for one year and three months, the Team created around 80 discharge data for each station. The following figure shows the frequency of discharge measurements at Kompong Cham as an example.

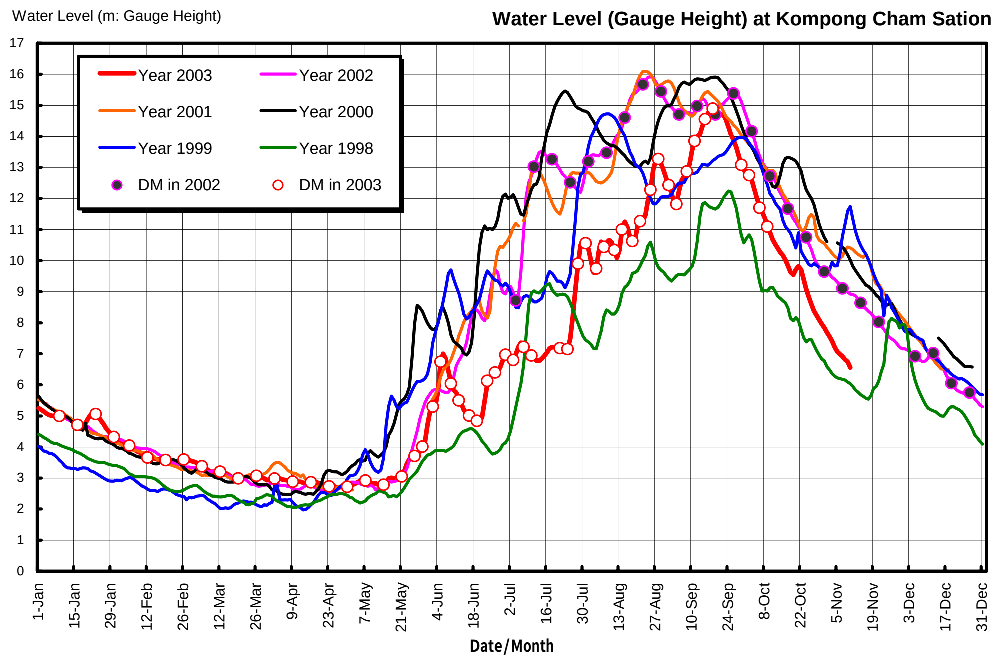


Fig. II-3-3 Discharge Measurement Activities at Kompong Cham

(2) Coordinated Discharge Measurements

One of the major objectives of the TSLVP has been 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 formulating the water utilization rules among the four countries. For these purposes, flow mechanisms including the dry-season flow in the Cambodian floodplains shall have to be clarified 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 one project alone to tackle them and to create fruitful results. Thus, cooperative work was necessary in this field.

Coordinated discharge measurements had been made, in particular, together with the Tonle Sap and Vicinities Project (TSLVP). The work sharing between the two projects was determined based on the frequent discussions with the TSLV project team. As a result of the discussions, it was decided that the WUP-JICA Team will measure the discharges longitudinally along the river courses, while the TSLVP team will make discharge measurements on the floodplains at the same time. The compiled results of the discharge measurements are presented in PART IV-1, Hydrology in the Lower Mekong River Basin.

3.3 Development of Rating Curves

3.3.1 Previous Efforts on the Development of Rating Curves

Regarding the development history of rating curves at the 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 measurements are tabulated below.

Table II-3-2 Previous Discharge Records in/around Phnom Penh Area

Station	Discharge Records		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 II-3-2 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 measurement, however, continued even under the worsened security conditions several times a year by the strong determination of the hydrologists engaged. Thus restoration of the monitoring system in this area should be an essential duty to be fulfilled by the succeeding hydrologists.

3.3.2 Results of Measurement

The actual measurement activities including the dry-season flow measurements started in July 2002 and continued until the beginning of October 2003. Thus the discharge measurements started in the middle of the rising limbs of the wet season, as presented in Fig. II-3-3. For the period from 04 July 2002 to 11 October 2003, the number of discharge data observed at the major stations is as listed below. The raw data and typical cross-sections at each station measured by ADCP are given in the Databook.

Kompong Cham	:	81
Chrui Changvar	:	80
Neak Luong	:	79
Chak Tomuk (Phnom Penh Bassac)	:	78
Phnom Penh Port	:	79

Fig. II-3-4 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 levels 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 were adopted for the levels of Koh Norea because there were 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.

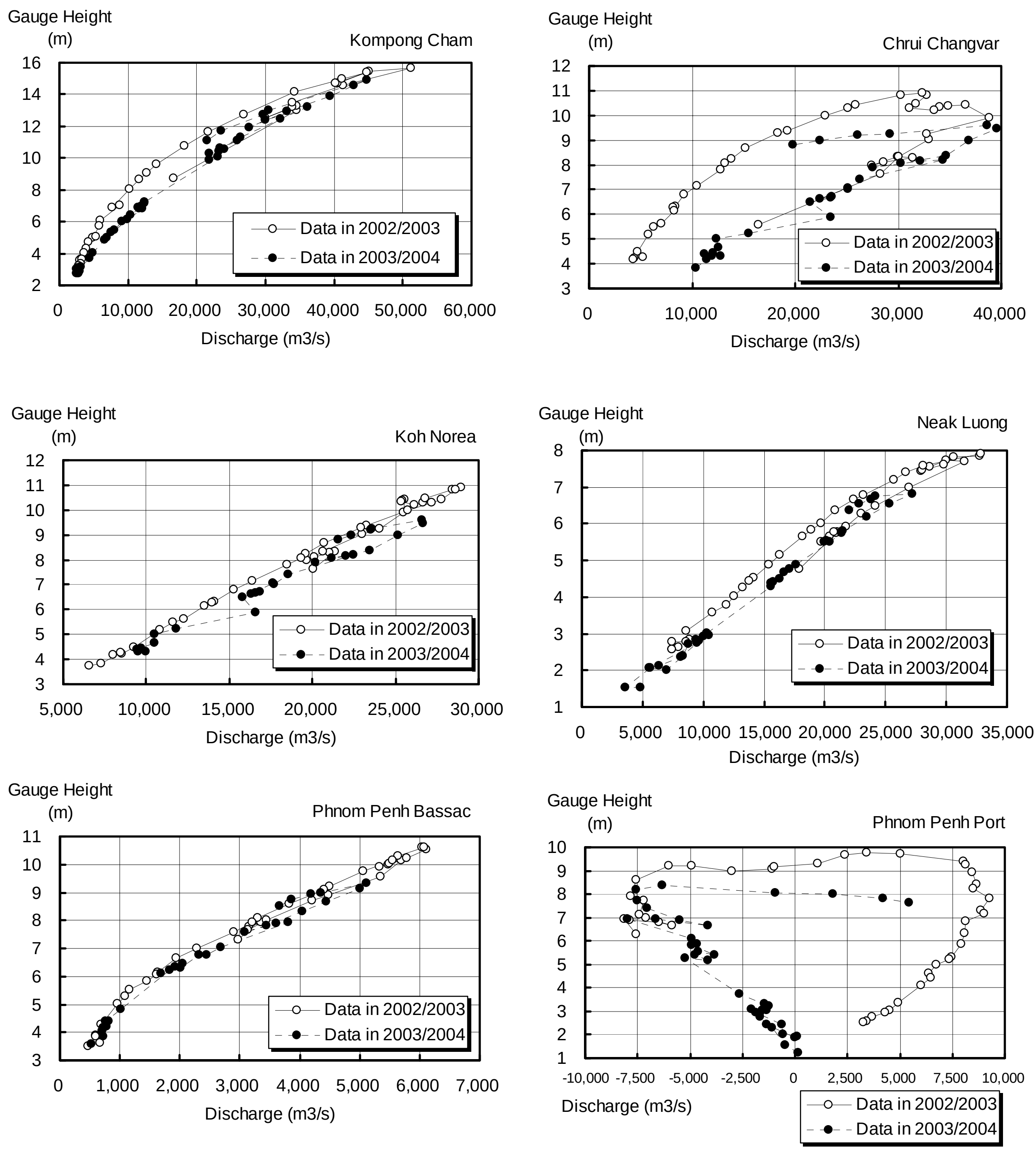


Fig. II-3-4 Measured Discharge Data versus Water Level

3.3.3 Determination of Rating Ranges

An examination of the measured discharges versus water levels in Fig. II-3-4 will show that it was 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 were developed using the observed data. In the process of development, the initial step was to determine the applicable range of rating curve, because hydrological data at these stations are strongly affected by the tidal fluctuation in the low-flow period.

Tidal effects and fluctuation ranges using the simulation results at 4 stations are shown as the first examination in Fig. II-3-5 and described in Part III of this Main Report. The discharge fluctuations in parallel with the tidal ones are considerably large and not negligible at the stations in Phnom Penh downward, while they are negligibly small at Kompong Cham. These facts imply that there is a possibility to develop rating curves covering an entire year at Kompong Cham. On the other hand, the applicable and practicable ranges of rating curves shall have to be checked at the downstream stations.

At the Chrui Changvar, Koh Norea and Phnom Penh Bassac stations, the Team conducted the dry-season discharge measurement three times a day once a week to clarify the tidal fluctuations. The observation results are presented in Fig. II-3-6.

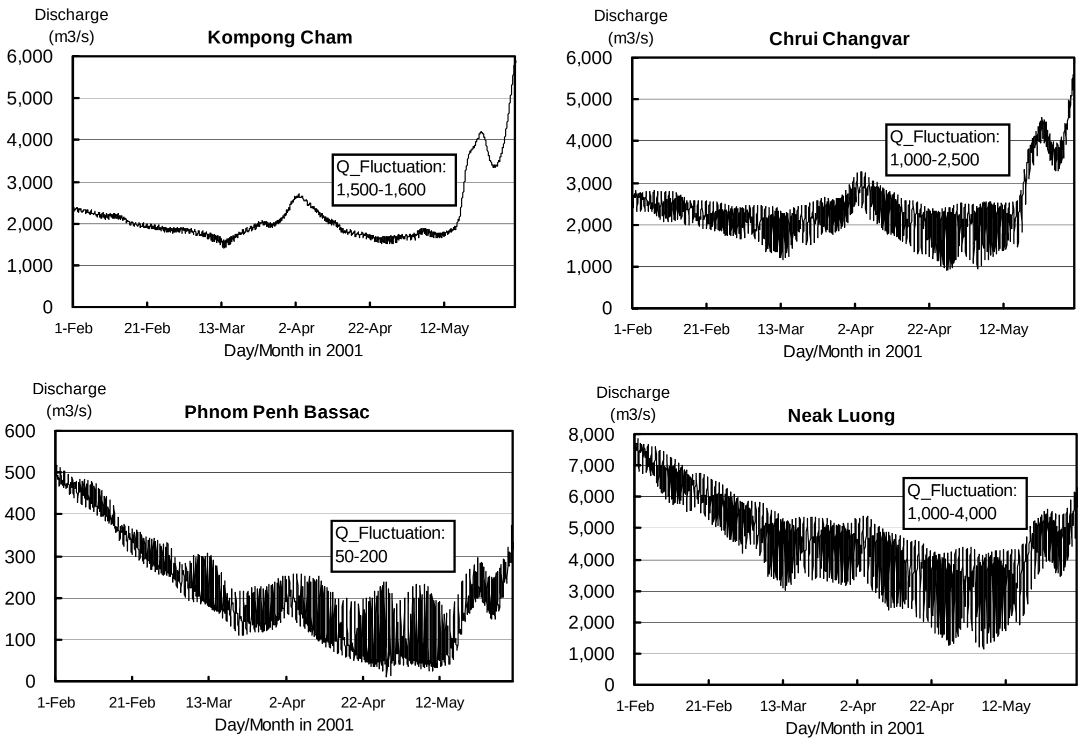


Fig. II-3-5 Tidal Effects in the Dry Season at Selected Stations

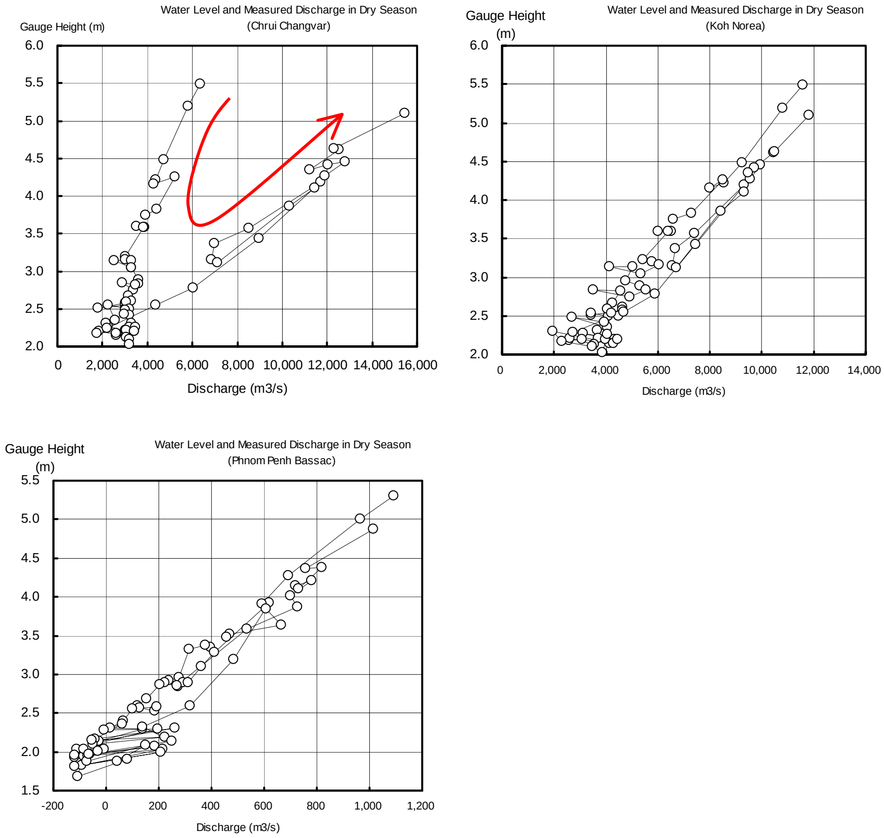


Fig. II-3-6 Measured Discharge in the Dry Season in Phnom Penh Area

As reflected in Fig. II-3-6, both effects of looping and tidal fluctuation are recognizable in the dry-season flow at the Phnom Penh area. To further clarify the tidal fluctuations, the figures below were delineated as the relationship between measured discharge fluctuations and daily water level. The figures indicate the ranges of discharge fluctuations due to tidal effects. At all stations, wider fluctuations of discharge appear at water levels lower than 3.5 m. Thus the rating curve was applied to the water levels (gauge height) higher than 3.5 m at the 3 stations.

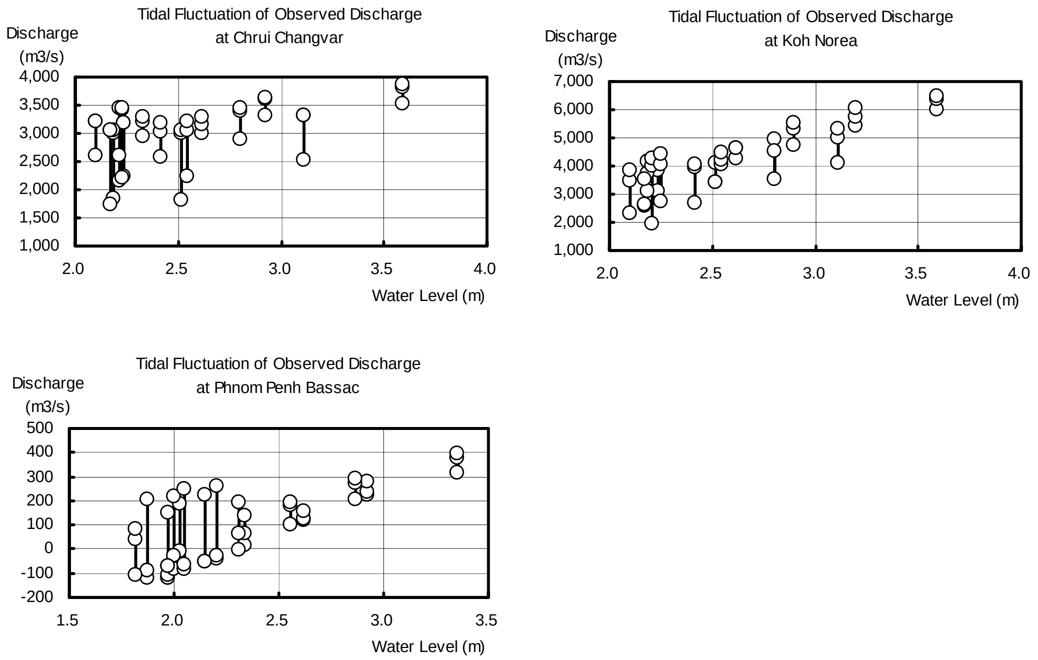


Fig. II-3-7   Measured Discharge in the Dry Season versus Daily Water Level

Regarding the remaining station of Neak Luong, the relation between measured discharge and gauge height is shown in the following figure. This relation also shows both effects of looping and tidal fluctuation. The tidal effects might be predominant when the water level is lower than 2.5 m.

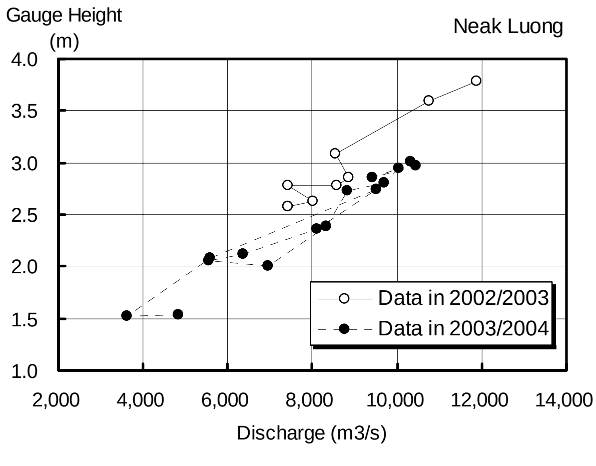


Fig. II-3-8   Measured Discharge in the Dry Season at Neak Luong

To summarise this section, the developed rating curves have been applied to the following water levels at each station. Compared with their elevations given in Table II-3-3, 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 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/section can be regarded as having a harmonious balance among the lower limits of applicability.

Table II-3-3 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	-	-	-
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

3.3.4 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 are also considered as the 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 II-3-4 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. II-3-9, 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

The DHRW had continuously measured the discharge at Kratie Station with financial support from the MRC since the middle of October 2002. The total number of measurements was 119 times within almost one year, i.e., 64 times in the falling stage and 55 times in the rising stage. Through examination of plotting between measured discharge and gauge height, the following two rating curves of the rising and falling stages are considered suitable.

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

Using the eighty-one (81) discharge data observed throughout the wet and dry seasons from 04 July 2002 to 09 October 2003, the following single rating curve has been developed:

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

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 III-3-4, m

(3) Chrui Changvar

The rating curve presentation was divided into two stages, rising and falling limbs, due to the big looping. For the rising stage, the number of data was relatively small to develop the rating curve because the measurements started only in the beginning of July 2002. The total number of measurements was 72 times until 11 October 2003, i.e., 28 times in the falling stage and 44 times in the rising stage. These data were extracted under the limitation of gauge height above 3.5 m due to the elimination of tidal effects as examined in Subsection 3.3.3.

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

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

(4) Koh Norea

The flow at Koh Norea becomes obviously steady after divergence from the Tonle Sap or convergence into it, compared with the flow at Chrui Changvar. Thus separation work into rising and falling parts may not be necessary for the rating curve development. The developed rating curve shows a good fit to the observed data. As already described, 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.

Total number of measurements was 72 times made at the same time as those for Chrui Changvar. These data were extracted under the limitation of gauge height above 3.5 m due to elimination of tidal effects, as examined in Subsection 3.3.3.

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

(5) Neak Luong

The developed rating curve at Neak Luong fits well with the observed data. Total number of measurements was 68 times for the period from July 2002 to 10 October 2003. These data were extracted under the limitation of gauge height above 2.5 m due to elimination of tidal effects, as examined in Subsection 3.3.3.

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

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

The rating curve at Monivong Bridge was developed as a quite simple equation without falls. Total number of measurements was 70 times for the period from 09 July 2002 to

11 October 2003. These data were extracted under the limitation of gauge height above 3.5 m due to elimination of tidal effects, as examined in Subsection 3.3.3.

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

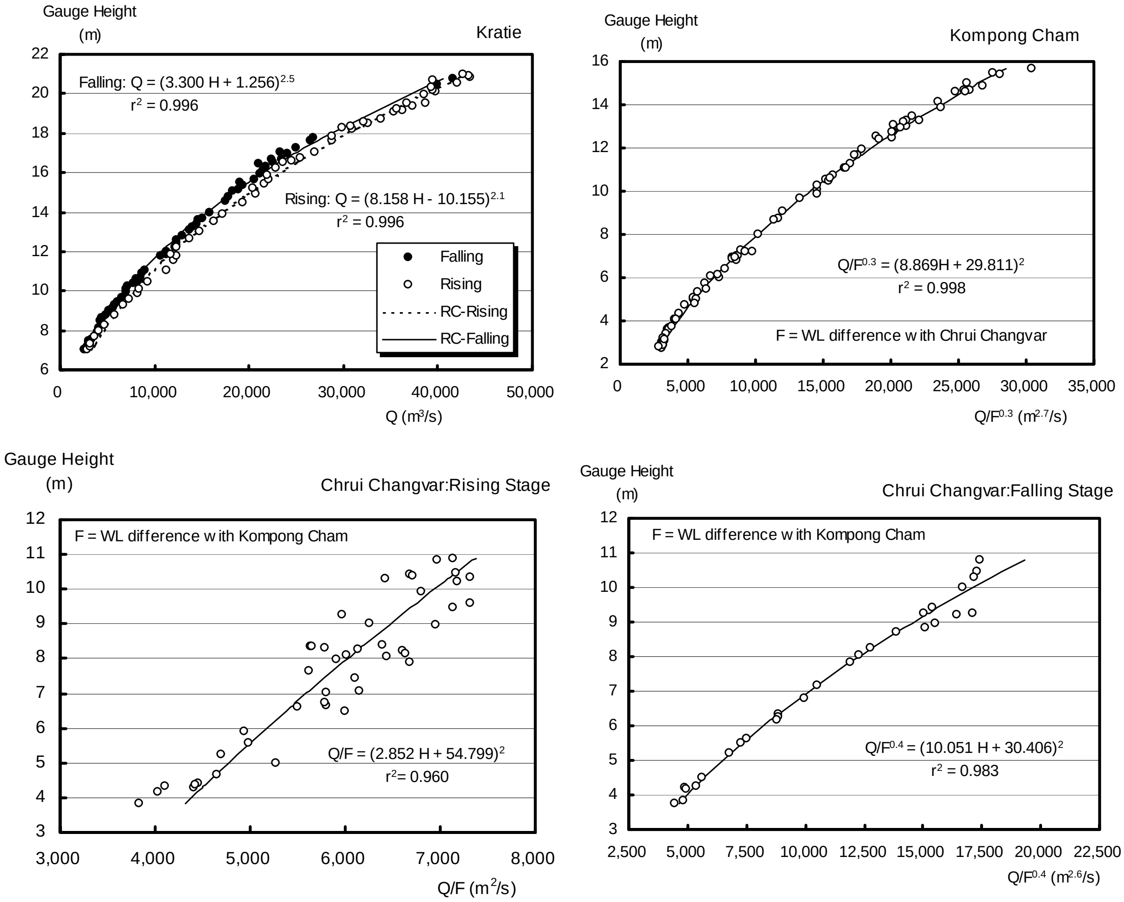


Fig. II-3-9(1/2) Developed Discharge Rating Curves : Mekong Mainstream

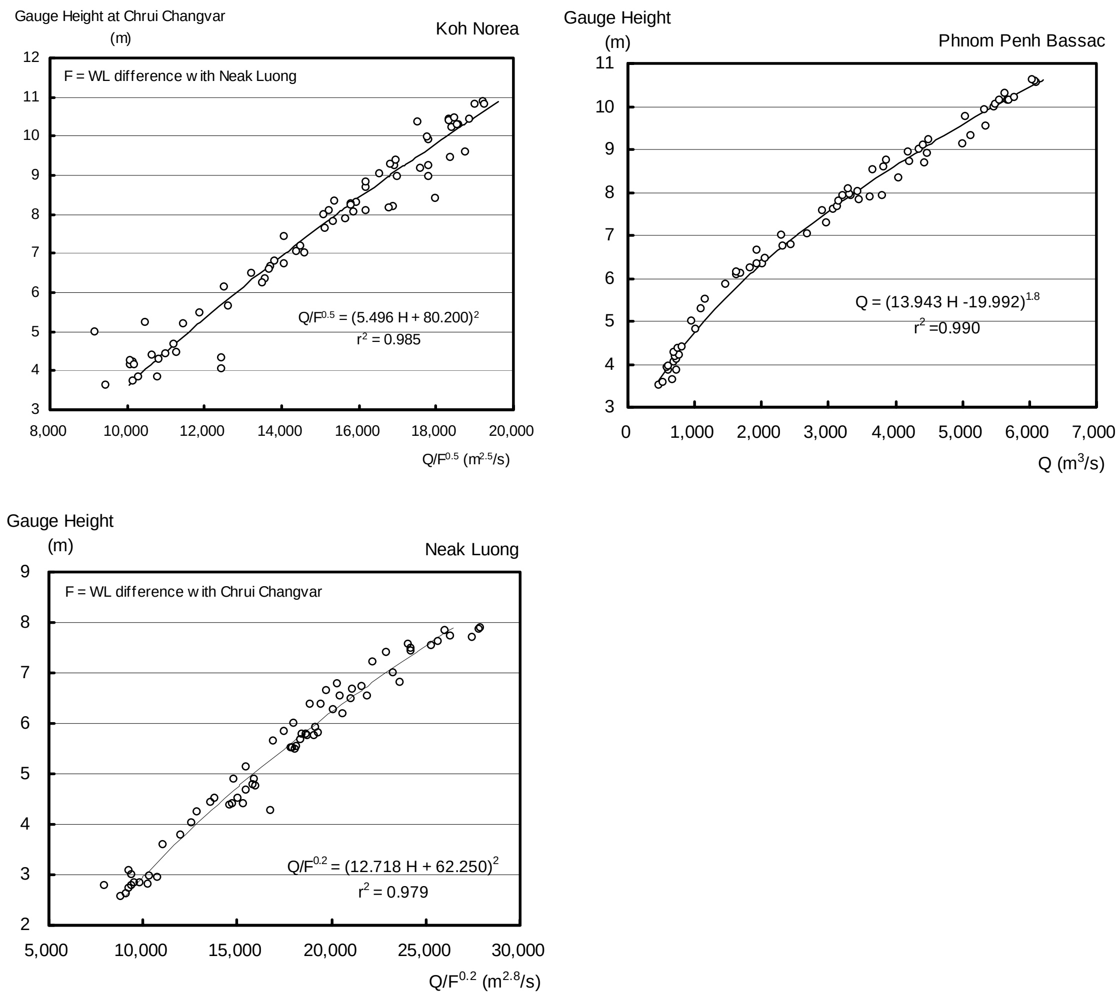


Fig. II-3-9(2/2) Developed Discharge Rating Curves : Mekong Mainstream and Bassac

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 section. Furthermore, the future monitoring system is also recommended from practical considerations. For easier understanding, the flow monitoring system is divided into 2 time frames; 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. Thus, as examined under the applicable rating ranges in Subsection 3.3.3, the seasonal monitoring system shall be defined through reference to the gauge height at each station. These are summarised in the following table.

Table II-3-5 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	

As indicated in Table II-3-5, the established rating curves can be applicable throughout a year at the upstream stations of Kratie and Kompong Cham; whereas, 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. The dry-season monitoring system is discussed in Subsection 3.4.2.

3.4.1 Wet-Season Flow Monitoring System

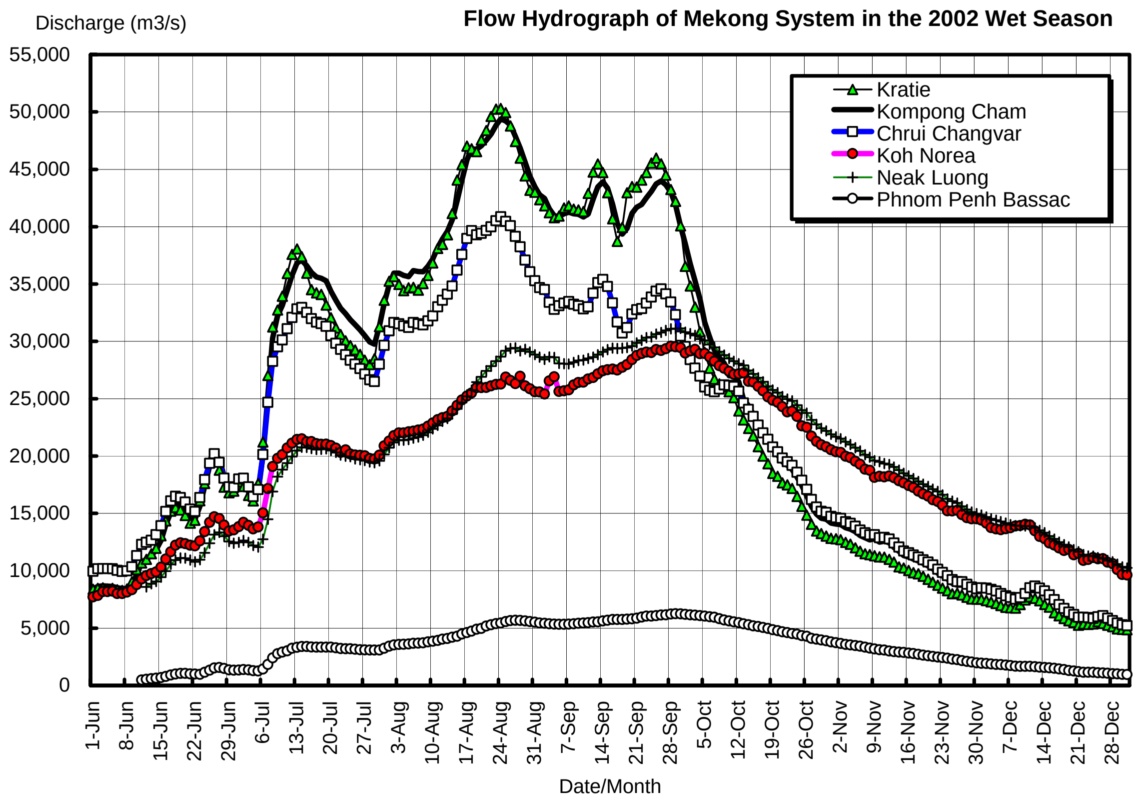
For the period from July 2002 to October 2003, the WUP-JICA Team had continuously conducted discharge measurements in and around the Phnom Penh area. Based on the discharge measurement results, the rating curves, except for Phnom Penh Port Station, were developed as accurately as possible. Thus the wet-season flow monitoring system could be established to clarify the flow conditions in the Chak Tomuk junction in a practical manner. If the flow monitoring system is 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. II-3-10 presents the flow hydrograph in and around the Phnom Penh area in the 2002 wet season and the 2003 wet season up to the data computed by the developed rating curves. The hydrographs among the stations are in good relation according to 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. II-3-10.

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. Computed hydrograph at Phnom Penh Port 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 from Kratie down to 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.



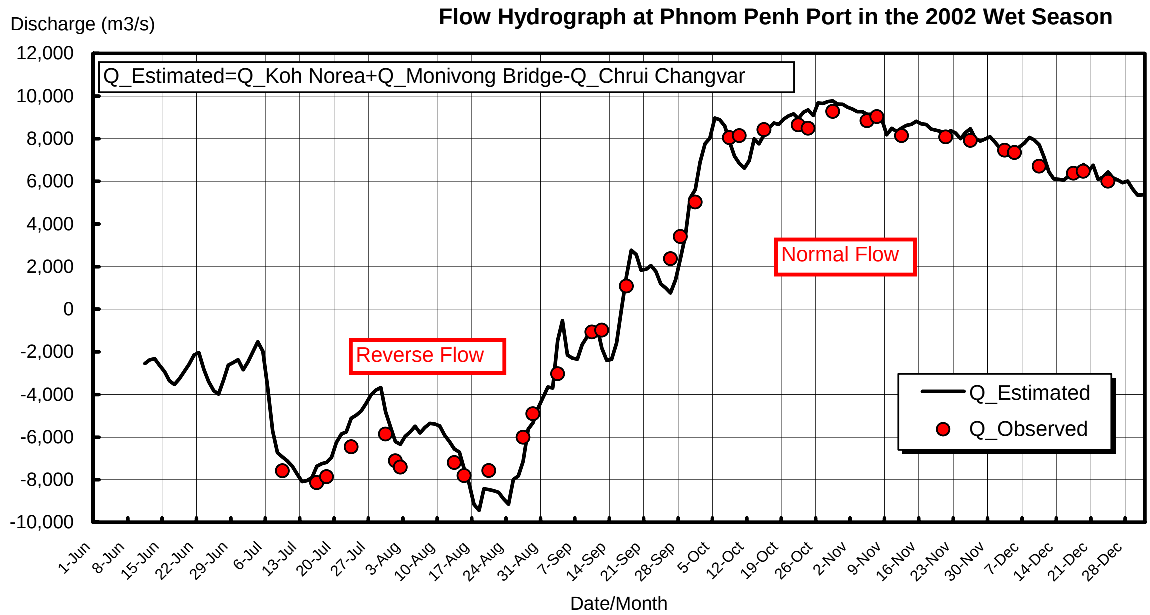
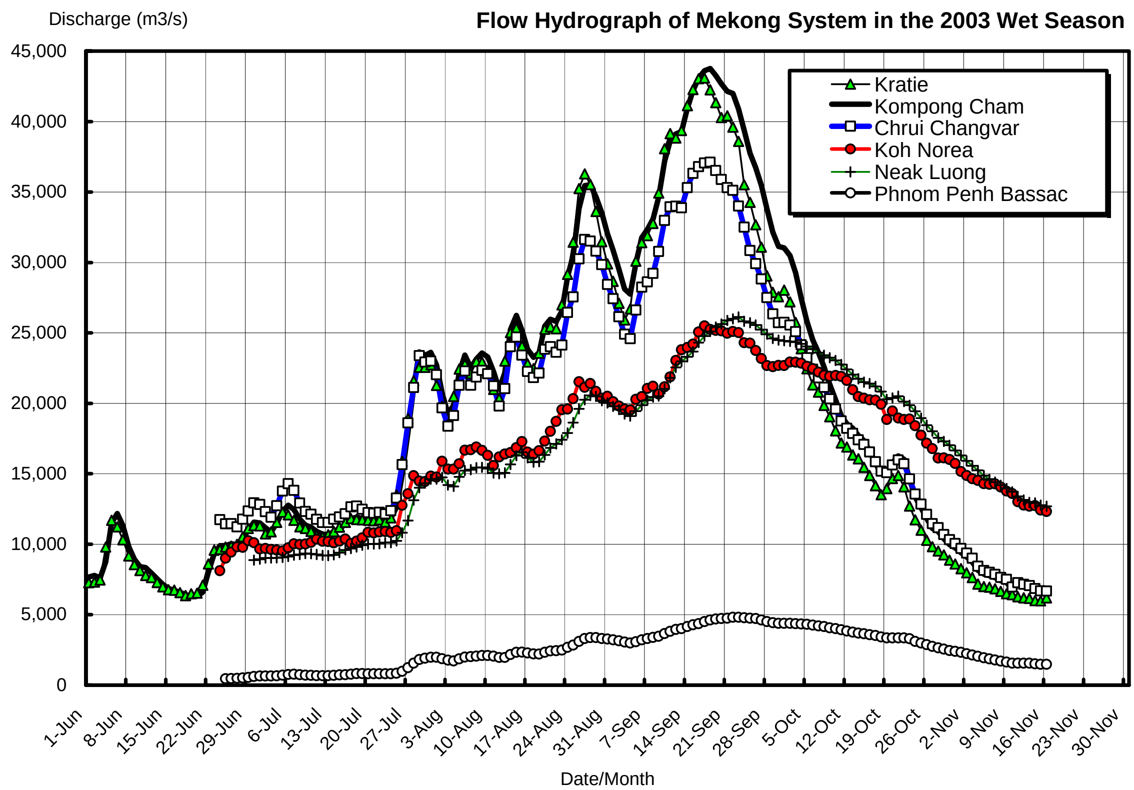


Fig. II-3-10(1/2) Computed Flow Hydrographs and Comparison between Estimated and Observed Discharges at Phnom Penh Port, 2002 Wet Season



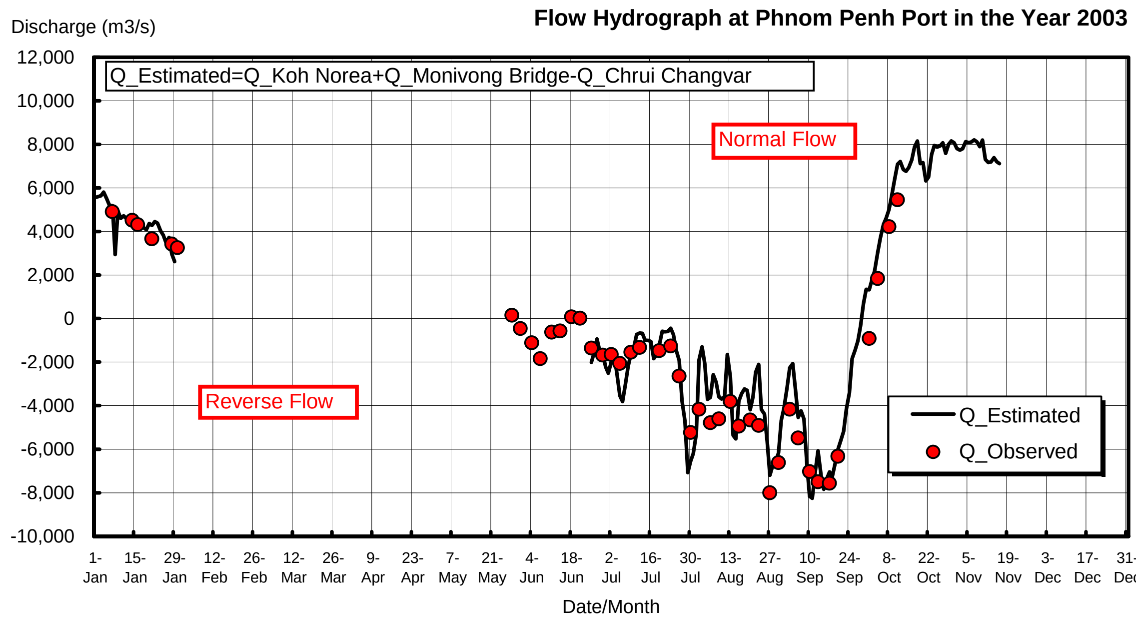


Fig. II-3-10(2/2) Computed Flow Hydrographs and Comparison between Estimated and Observed Discharges at Phnom Penh Port, Year 2003

3.4.2 Dry-Season Flow Monitoring System

The discharge measurements continued at the stations of Kompong Cham, Chrui Changvar, Koh Norea, Phnom Penh Port and Phnom Penh Bassac even in the dry season of 2003. 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. In order to properly and equitably manage the flow in the international watercourses, sufficient crosschecking to the downstream discharge observed in Vietnam is indispensable at the reliable hydrological stations.

Unfortunately the dry-season flows in the Cambodian floodplains are strongly affected by tidal fluctuation. Figs. II-3-5 to II-3-8 had already presented the hourly fluctuation of discharges in the dry season in 2001 to 2003 through the hydraulic simulation and actual measurements. In Fig. II-3-5, 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 II-3-6 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 thus be developed only at Kompong Cham based on the above simulation results.

Prior to entrance of the 2003 dry season, the establishment of a dry-season flow monitoring system in this area was planned in accordance with the following procedure and in due consideration of the above-tabulated conditions:

(1) Discharge measurement activities shall be continued at Kompong Cham in the same manner as the 2002 wet season. Then the rating curve applicable for the whole year shall be developed.

(2) At four stations in the Chak Tomuk junction, frequent discharge measurements shall be conducted within a day so as to estimate the daily average discharges.

(3) Regression equation shall be developed between discharges at Kompong Cham and daily average discharges at Chrui Changvar. Finally, continuous daily average discharges at Chrui Changvar shall be 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 shall be developed for the computation of continuous daily discharges at Phnom Penh Port.

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

Based on the above procedure, the conceptual dry-season flow monitoring system is as schematised in Fig. II-3-11.

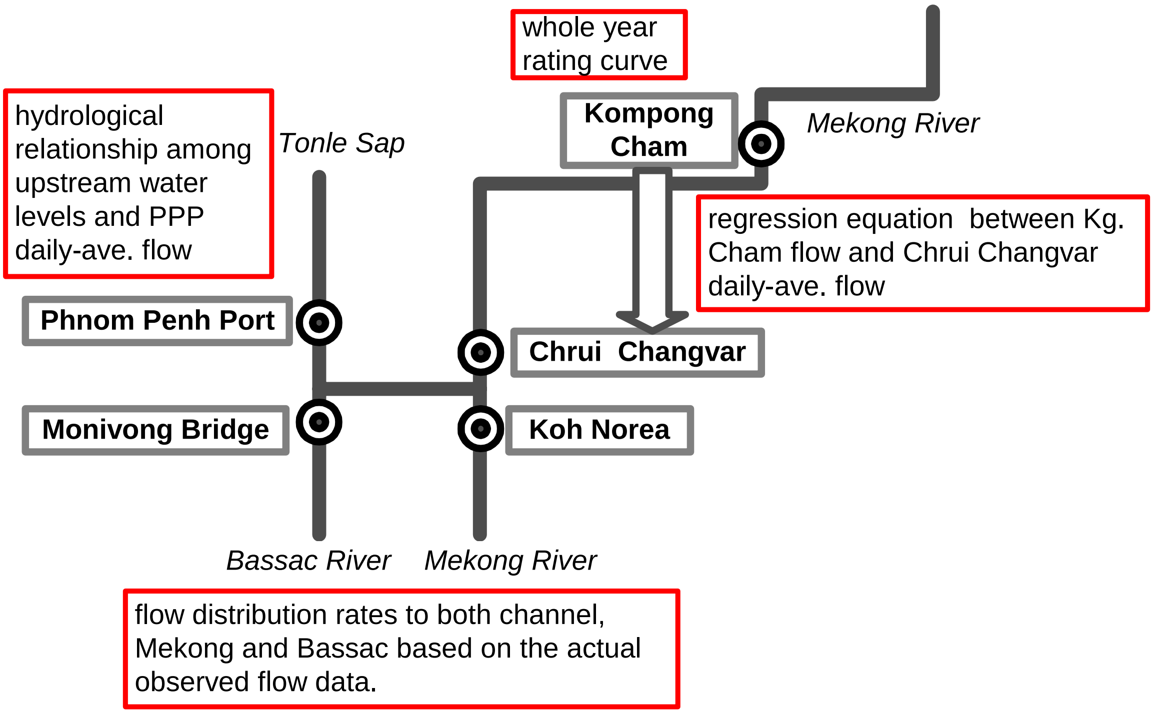


Fig. II-3-11 Conceptual Dry-Season Flow Monitoring System in/around the Phnom Penh Area

Based on the paper framework mentioned above, the following are the trial results for the establishment of the dry-season flow monitoring system in Cambodia. A comparison between Kratie and Kompong Cham has been included in the examination process.

(1) Comparison of Dry-Season Flow between Kratie and Kompong Cham

As one of the most important key stations in Cambodia, Kratie Station has been providing hydrological information on water level and flow discharge for a long time since 1933. In the 1960s the dry-season flow discharges at Phnom Penh on the Mekong (Chrui Changvar) had been estimated from the flow discharges at Kratie. Furthermore, the seasonal flooding of the Mekong has been starting from the downstream plains of Kratie. Thus, Kratie is also one of the important control points in the Lower Mekong River Basin.

In addition, the 1995 Mekong Agreement stipulated the importance of Kratie as follows: "Acceptable natural reverse flow: The wet season flow level in the Mekong River at Kratie that allows the reverse flow of the Tonle Sap to an agreed upon optimum level of the Lake."

As mentioned above, Kratie Station is important in geographical and hydrological terms, but the station is located at some remote area from Phnom Penh City, the capital of Cambodia. If Kompong Cham Station can be utilised instead of Kratie Station, maintenance and operation will be much easier and less costly. In this context, comparison of dry-season flow between Kratie and Kompong Cham has been examined. Flood flow discharges between the two stations are more or less at the same level, as shown in Fig. II-3-10.

Fig. II-3-12 depicts the 2003 dry season hydrographs at Kratie and Kompong Cham using the newly developed rating curves, as described in Subsection 3.3.4, while Fig. II-3-13 plots the flow discharges between the two stations. Both figures show good agreement of the simultaneous flow discharges at both stations.

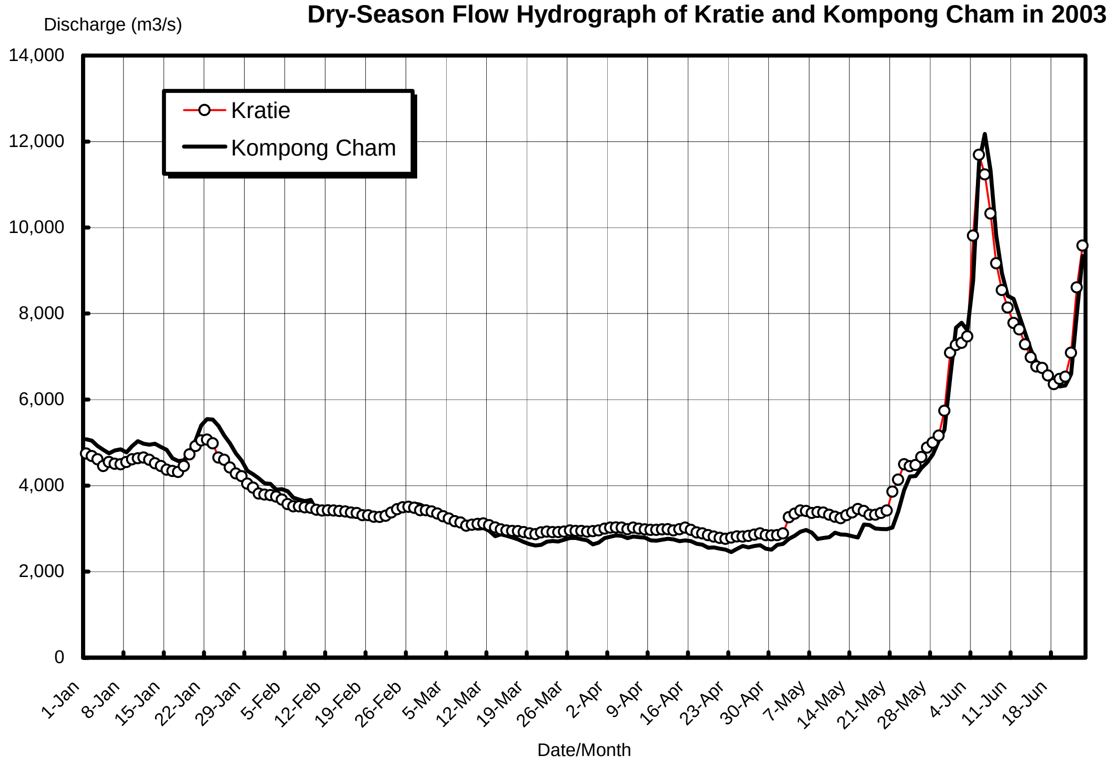


Fig. II-3-12 Flow Hydrograph of Kratie and Kompong Cham in the 2003 Dry Season

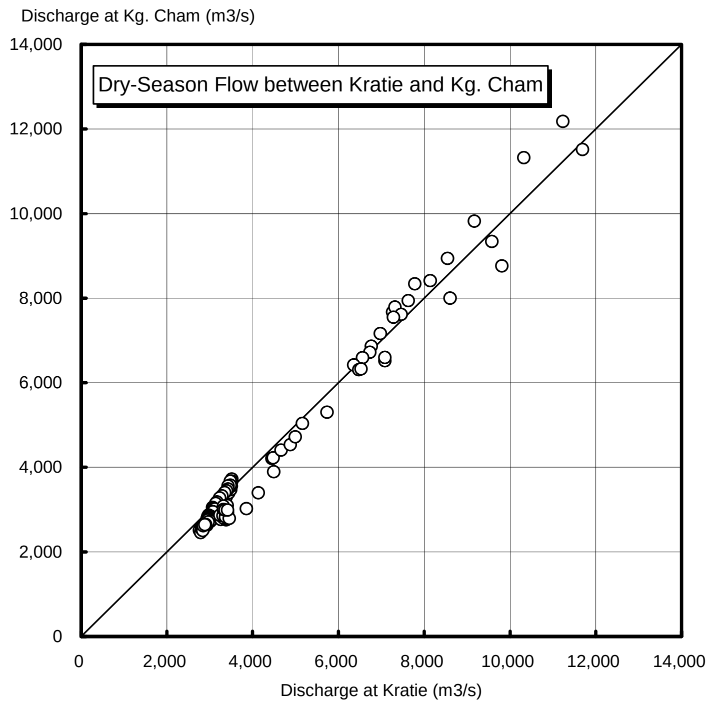


Fig. II-3-13 Comparison of Flow Discharges of Kratie and Kompong Cham in the 2003 Dry Season

In conclusion, the dry-season flows at Kompong Cham can be practically utilized as representative flows down to the Cambodian floodplains instead of the flows at Kratie, even though the flows at Kompong Cham are slightly affected by tidal fluctuations.

(2) Relationship of Dry-Season Flow between Kompong Cham and Chrui Changvar

Based on the discharge measurement conducted in the 2003 dry season, the hydraulic model calibration was made to adjust the dry-season flow in the Phnom Penh area. Fig. II-3-14 presents the calibration results on the flows at Phnom Penh Port as an example. Discharge measurements were conducted three times a day once a week in the Phnom Penh area during the 2003 dry season. The detailed calibration works are described in Chapter 2 (Application of the Model) of Part III (Hydro-Hydraulic Modelling) of this Main Report.

The hydraulic model well represents the flow recession curves and tidal fluctuations. The generated hourly/daily flow as an output of the model could be useful in the succeeding works.

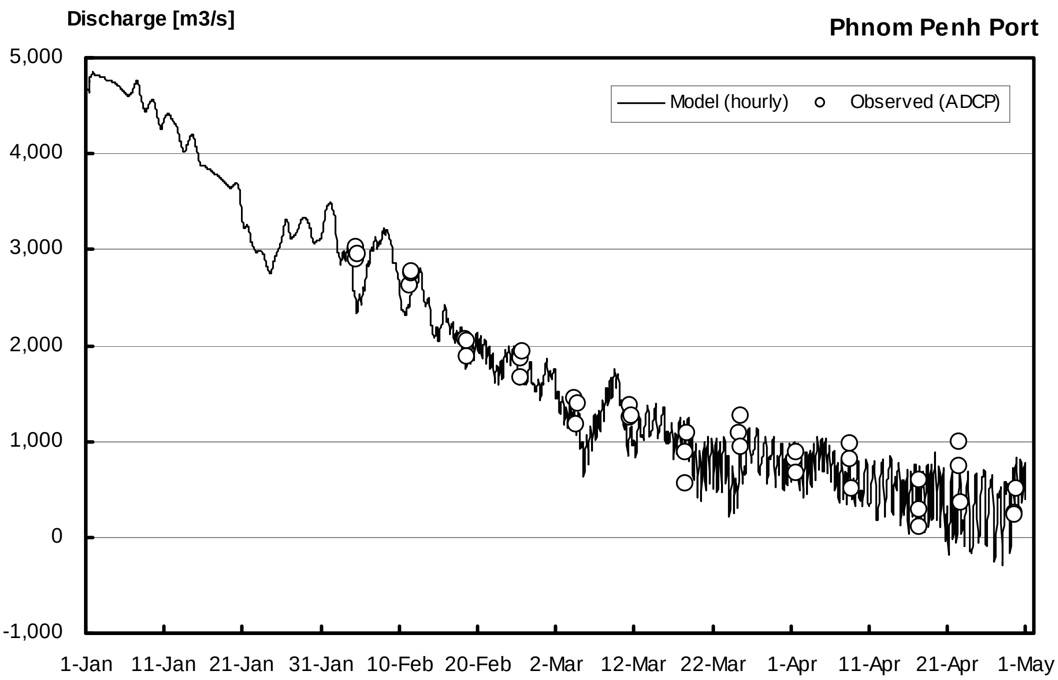


Fig. II-3-14 Hydraulic Model Calibration Results at Phnom Penh Port for the 2003 Dry Season

From the hourly flow discharges of the simulation results, the daily average flows were estimated for the 4 stations at the Chak Tomuk junction: Chrui Changvar, Koh Norea, Phnom Penh Port and Phnom Penh Bassac. The following comparison study was made to establish the relation of dry-season flows between Kompong Cham and Chrui Changvar:

- Daily flow at Kompong Cham: Estimation using rating curve and recorded water levels; and
- Daily flow at Chrui Changvar: Estimation averaging the hourly outputs of the simulation results.

Fig. II-3-15 presents the results of regression analysis on the said daily flows between the two stations. Since the two stations show a high correlation coefficient, the following regression equation can be used for the estimation of dry-season flow discharges at Chrui Changvar:

Qcc = 429 + 0.949 Qkc

Where; Qcc = dry-season flow discharge at Chrui Changvar, m^3/s
Qkc = dry-season flow discharge at Kompong Cham, m^3/s

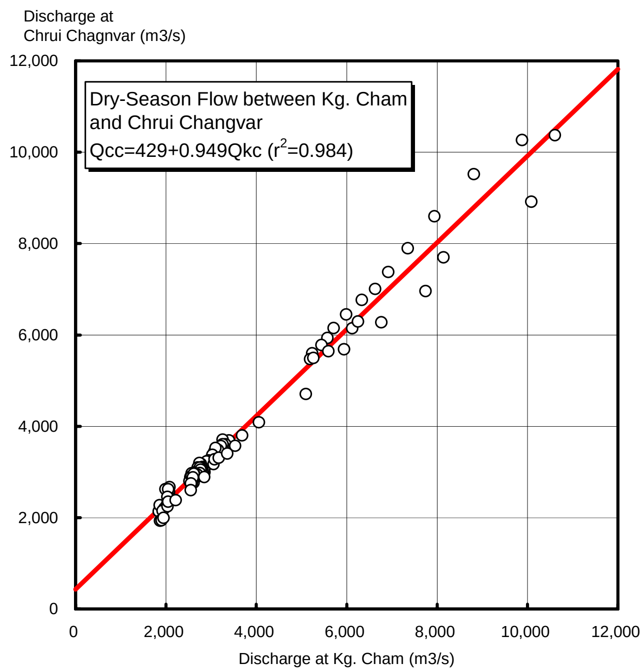


Fig. II-3-15 Relation of Dry-Season Flows between Kompong Cham and Chrui Changvar (Phnom Penh Mekong)

(3) Establishment of Dry-Season Flow Rating Curve at Phnom Penh Port

As presented in Fig. II-3-4, the relation between water level and discharge at Phnom Penh Port shows a large loop striding over the normal and reverse flow directions. Since the stream flow of the Tonle Sap is the normal receding flow in the dry season, its hydraulic conditions may be relatively stable compared with the reverse flow in the rising limb of the Mekong mainstream and the flow in some transition period of flow directions from reverse to normal generally occurring in September to October. Thus there might be possibilities to develop the rating curve applicable to the normal recessing period of the Tonle Sap during the dry season.

Fig. II-3-16 shows the simulated hourly and daily average dry-season flows at Phnom Penh Port. It implies that the receding flow of Tonle Sap is stable in the dry season. Fig. II-3-17 depicts the relation between daily average flow and gauge height at Phnom Penh Port. It shows good one-to-one relationship between them.

Finally, the following rating curve was developed additionally using the water levels of Prek Kdam as the reference station.

$Q = (6.608H+60.369)^2 F^{0.7}$

Where; Q = flow discharge at Phnom Penh Port, m^3/s
H = gauge height (water level) at Phnom Penh Port, m
F = falls between water levels in MSL m of the stations, Phnom Penh Port and Prek Kdam, m

Fig. II-3-18 presents the comparison of daily average flows computed by the model and estimated by the above rating curve. It shows good correlation.

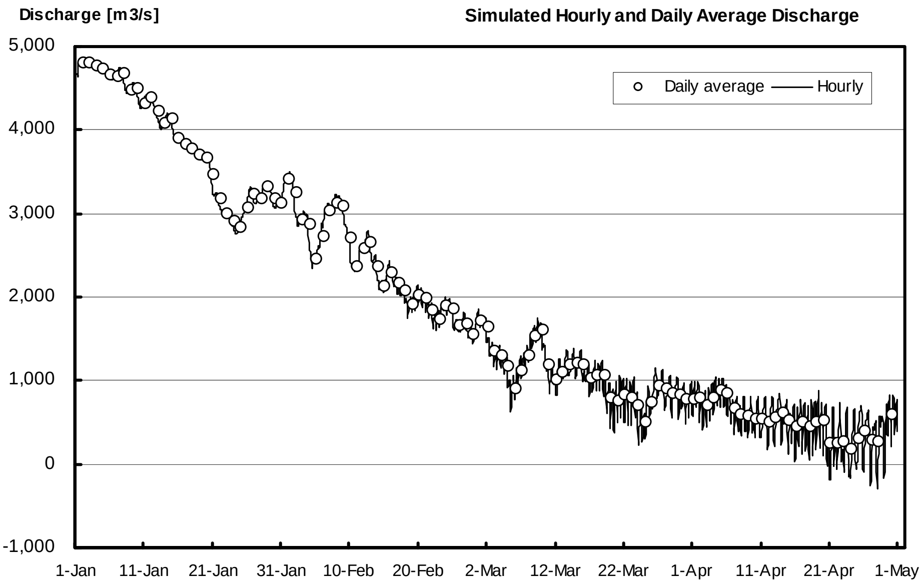


Fig. II-3-16 Simulated Hourly and Daily Average Dry-Season Flows at Phnom Penh Port

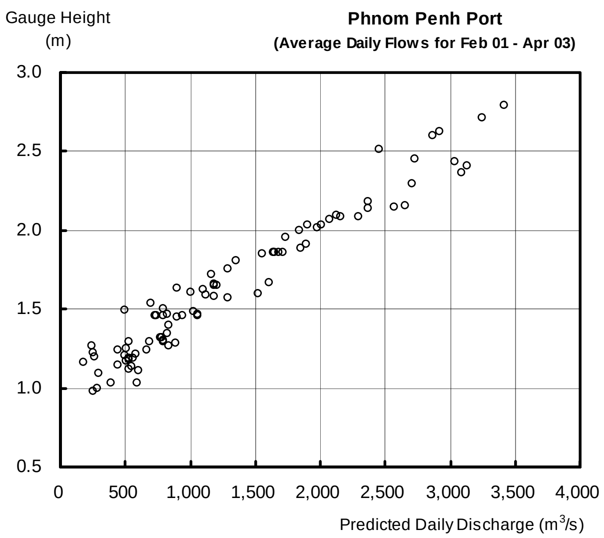


Fig. II-3-17 Relation between Daily Average Dry-Season Flow and Gauge Height at Phnom Penh Port

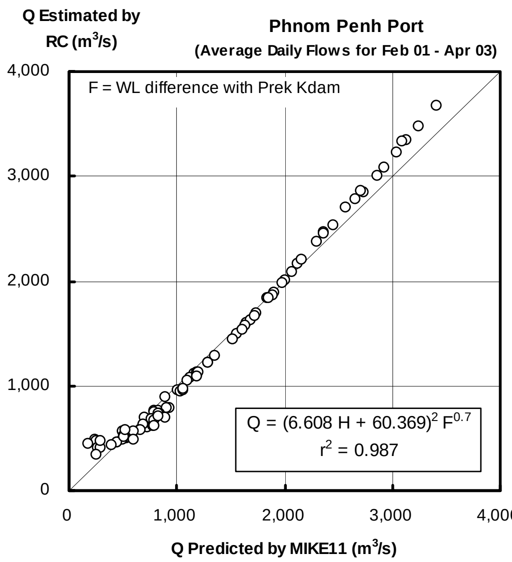


Fig. II-3-18 Comparison of Daily Average Dry-Season Flows Computed by the Hydraulic Model and Estimated by the Rating Curve at Phnom Penh Port

(4) Flow Diversion Rate to Downstream of Chak Tomuk

In the same manner as the estimation of rating curve at Phnom Penh Port, statistical analysis was made to compute the diversion rate to the lower reaches of the Mekong and Bassac at the Chak Tomuk junction using simulated daily average flow. Fig. II-3-19 shows the relation between the inflow, which sums up flows at Chrui Changvar and Phnom Penh Port, and the outflow to the Mekong downstream after divergence from the Bassac. The figure presents a high correlation between them since the diverted flows going into the two branches, Mekong and Bassac, are in different order of magnitude. Thus the diversion rate can be practically applied to estimate the diverted flow from the summation of inflows at the junction.

$$Qmd = 156 + 0.934\ Qin \qquad (r^2=0.9998)$$

Where; Qmd = outflow to be diverted at Chak Tomuk junction to the Mekong downstream, m^3/s
Qin = inflow at Chak Tomuk junction summed up the flows at Chrui Changvar and Phnom Penh Port, m^3/s

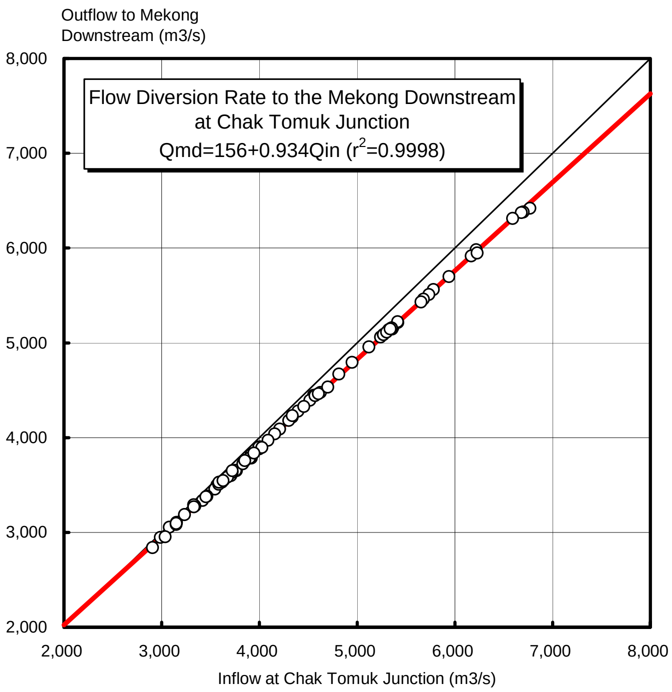


Fig. II-3-19 Estimated Diversion Rate to the Mekong Downstream at the Chak Tomuk Junction

(5) Summary of the Dry-Season Monitoring System

As summarised in the above study, the dry-season monitoring system can be proposed in the following procedure.

(a) From the observed water level, the flow at Kompong Cham will 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.

(b) From the flow at Kompong Cham, the flow at Chrui Changvar will be computed using the regression equation: $Qcc = 429 + 0.949\ Qkc$.

(c) From the observed water level, the normal receding flow at Phnom Penh Port will 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.

(d) After summation of the flows at Chrui Changvar and Phnom Penh Port, the diversion rate to the Mekong downstream will be computed using the regression equation: Qmd = 156 + 0.934 Qin.

For the 2003 dry season, the dry-season flow was estimated by following the above procedure in order to check the applicability of this procedure and extract the problems/issues from the actual practices. Fig. II-3-20 presents the monitoring practice applied in the 2003 dry season.

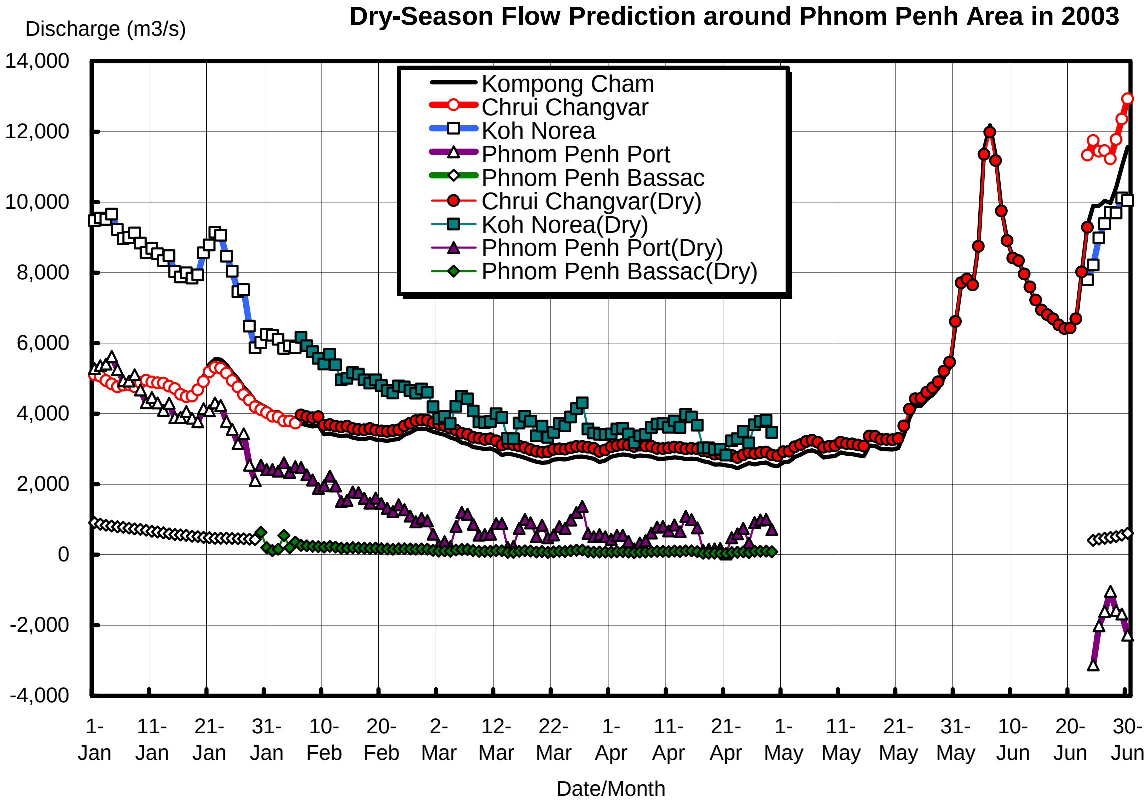


Fig. II-3-20 Estimated Dry-Season Flow in Phnom Penh Area

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

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

(b) 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.

(c) From Fig. II-3-20, 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.

3.4.3 Recommendations for the Future Monitoring System

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

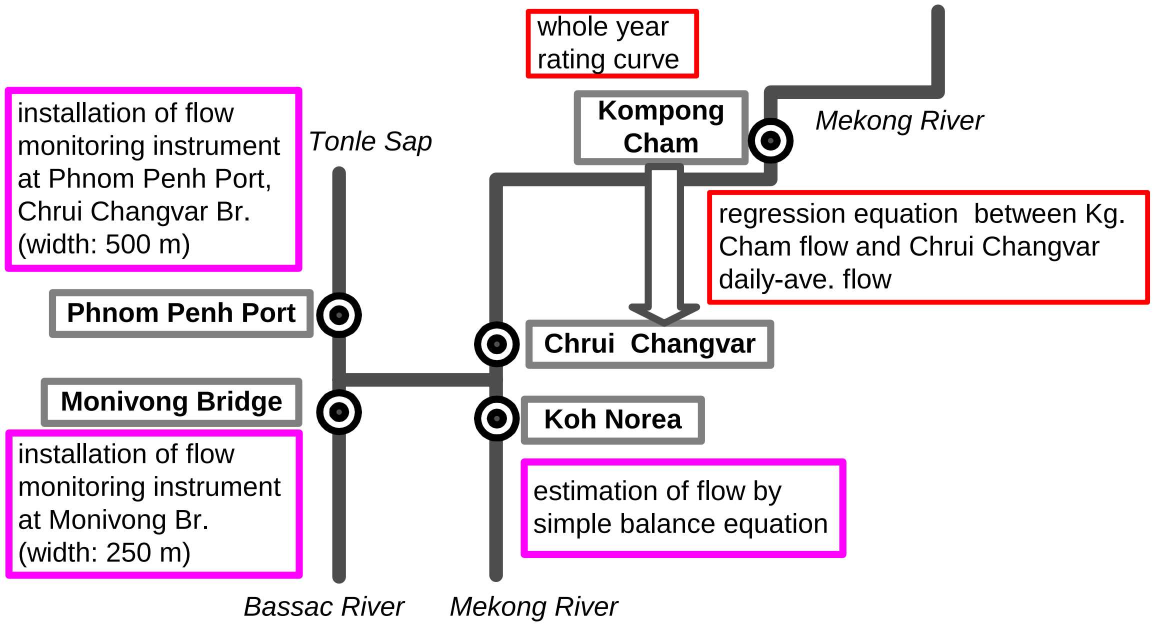


Fig. II-3-21 Future Dry-Season Flow Monitoring System in Phnom Penh Area

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 cannot be depicted by the statistical equation or rating curve. The final reliable monitoring system shall be a direct measurement using a new, modern technology, for instance, the horizontal acoustic Doppler current meter. This kind of instrument should be installed on the Tonle Sap and Bassac rivers because it is suitable for the measurement at the narrow channels of these 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, maintenance of rating curves could be focused on the Kompong Cham, Chrui Changvar and Koh Norea stations as far as listed in the above figure.