VOLUME II

PAPER V

APPLICATION OF
HYDRO-HYDRAULIC MODEL

<u>FINAL REPORT</u>

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WUP-JICA TEAM

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1. INTRODUCTION

This Paper V, Application of Hydro-Haydraulic Model, describes the various applications made with the hydro-hydraulic model. The applications comprise:

- Dry season flow investigations
- Hydraulic Impact of Road Embankments
- Effect of increased bridge openings on flood plain inundation
- Water balance for Tonle Sap Lake

The purpose of the dry season flow investigation has been to support the WUP-JICA study in the establishment of a dry season flow management system .The dry season flow investigations makes use of the discharge and water level data which have been collected at the Chaktomouk junction during the 2003 dry season period. The dry season data are used for model calibration as well as for application to support the work on dry season flow management system.

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

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

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

2. DRY SEASON FLOW INVESTIGATIONS

2.1 Introduction

The established MIKE 11 model has been used to model the dry season conditions during 2003. During the 2003 dry season, discharges have been measured in the four branches of the Chaktomouk junction every week. During the weekly measurements, each of the branches was measured three times a day. Because the junction is highly affected by tide during the dry season, the discharge measurements within a day show significant variation. The three measurements per day are not sufficient to resolve the complete tidal variation in the discharge.

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

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

2.2 Available Data

The data available for model calibration for the dry season 2003 are:

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

The period for which the above-mentioned data are available is January 1 to May 31, 2003, except for the water levels at Tan Chau and Chau Doc, which only cover February to April 2003. In the month of January, daily water levels were therefore used from these two stations. The data listed above are presented in Fig. 2.1 to 2.10 and Table 1.

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

The water level data are somewhat questionable. The difference between the observed water levels at Chrui Changvar and Chaktomouk is shown in Fig. 2.11. It appears that the average difference is almost 25 cm, which is not believed to reflect the reality. At the time of writing the report it has not been possible to check whether the benchmarks used from the two stations were correct. However, the relative levels from the two stations seem to be all right.

The wind data stem from only one station, namely Pochentong. The data are daily average velocity and direction (see Table 1). It is obvious that one station cannot represent the wind field of the entire model area, and also that daily average values of wind velocity and direction will not catch the extreme and important events. However, since the wind field is an important force during the dry season, data from one station will still be valuable to use, and will give a more correct result (on hourly basis) than if it is omitted.

For the dry season simulations of 1997-2001, hourly water levels at Tan Chau and Chau Doc were applied as downstream boundary conditions. Daily water level at Kratie has been used as upstream boundary condition for those years. The rainfall data used are described in ref. /2/. The means of model verification for the years 1997-2001 are the hourly discharges, which are observed at Tan Chau and Chau Doc.

2.3 Model Simulations - Dry Season 2003

The MIKE 11 model used for the dry season simulations has been setup during the study, and is thoroughly described and reported in ref. /1/ and /2/.

<u>Simulation period</u>

The model has been run from January 1 to May 31, 2003. The driving forces in the model are the water level boundaries at Kratie, Tan Chau and Chau Doc, the local rainfall and the wind force. The latter two are included as distributed input, whereas the water levels are inputs in single points. The water level boundary condition at Kratie is seen in Fig. 2.12 whereas the conditions at Tan Chau and Chau Doc are seen in Figs. 2.1 and 2.2.

<u>Roughness coefficients</u>

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

<u>Wind</u>

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

2.4 Model Results - Dry Season 2003

<u>Main Results</u>

The model simulations revealed that it is possible to simulate the dry season discharges with a reasonable accuracy. The best prediction was obtained for Koh Norea; for the other stations, some discrepancy occurred in parts of the simulated period. The model predicts the phase and amplitude of the tidal levels relatively well. However, there seems to be some consistent error related to the absolute water levels at Chaktomouk, either associated with the model or with the observed data.

Results from model tests with changed cross section configuration appeared to be rather insensitive to the change. At present the uncertainty is, therefore, thought as related to the data. A thorough investigation of this issue remains. The accurate prediction of the hourly water levels is on the other hand not very important. The main output, which will be used from the modelling, is the predicted daily discharge.

The predicted average daily discharge during the 2003 dry season is shown in Figs. 2.18 to 2.22 and presented in Table 2. One conclusion is that the daily average discharge based on observations and model results respectively, can be quite different.

An interesting result of the analysis is that the observed daily average discharge in Tonle Sap correlates with the daily water level observed at Chaktomouk. This relation is shown in Fig. 2.30a. It should be recognised, however, that the number of observations is limited and that the water level range is limited to 0.76 m to 2.34 m MSL. Such a relation was not anticipated, and could be the coincidental result of the actual data set and timing of measurements.

A step further was made to produce a relation between the flow at Phnom Penh Port and the water level at both Phnom Penh Port and Prek Kdam. A relation of this type is consistent with the principles of rating curve derivation at backwater-affected stations. The flow relation is shown together with the produced discharges in Fig. 2.30b and 2.30c. It was concluded that a relation (rating curve) between the flow at Phnom Penh Port and the water levels at Prek Kdam and Phnom Penh Port could be established.

Detailed Results - Discharges

Figs. 2.12 to 2.15 show the simulated and observed discharges at Chrui Changvar, Koh Norea, Phnom Penh Port and at Monivong Bridge for the entire simulation period.

The simulated and observed discharge at Koh Norea match quite well. There are various examples in Figs. 2.12b to 2.12g, which show that the model picks up the rising and falling part of a tidal cycle. One reason why the model predicts fairly well at this location is that the section has a downstream control.

The agreement between simulated and observed discharges is acceptable for Chrui Changvar (see Figs. 2.13a to 2.13g), although it is less good compared to Koh Norea. This is partly because the station has no downstream control, but is dependent on the conditions in the three other branches at Chaktomouk. However, the model picks up the daily discharge variation.

The simulated discharge in Tonle Sap River at Phnom Penh Port is also acceptable (see Fig. 2.14a(1/2), (2/2) to 2.14g). Results in Figs. 2.14a(1/2), 2.14b to 2.14g include wind action, although these are given as daily averaged wind direction and velocity. For comparison with Fig. 2.14a(1/2), the results at Phnom Penh Port from a simulation with no wind included are shown in Fig. 2.14a(2/2). It is seen that the variation in hourly discharges is not obtained if the wind is omitted. Reverting to Fig. 2.14a(1/2) -including wind- it is on the other hand seen that the model does not pick up some of the discharges. The reason for this is likely to be due to more extreme wind conditions which are not included in the available wind data, since these are daily averages. Even a few hours with large changes in wind velocity will change the discharge significantly. It is also likely that there is a spatial variation of the wind field, which is not obtained by only one available station. For the mentioned reasons there has been no further attempt to achieve better results, since the input to the model would rely on many assumptions.

The simulated and observed discharges at Monivong Bridge are seen in Figs. 2.15a to 2.15g. Discharge in the Bassac river is low in the dry season, and even return flow occurs. The return flow is believed to be associated with wind from the south. In the month of April there are frequent return flows in the Bassac River (see Fig. 2.10). Exactly the model picks none of these up, although the model simulates a few situations with return flow in March/April. The reason for this is probably a combination of lack of extreme wind data, and also inaccuracy of the topographical data. Especially at the entrance to the Bassac River it is important to have accurate topographical data. The present cross sections in the model at this location stem from the hydrographic surveys in 1998 and the configuration of the riverbed at the entrance has most likely changed since then.

Detailed Results - Water Levels

The simulated and observed water levels at Chrui Changvar and at Chaktomouk are seen in Figs. 2.16 and 2.17. From the detailed plots in Figs. 2.16b to 2.16g, it is seen that the general level at Chrui Changvar is represented by the model, so is the tidal phase. However the amplitudes are larger in the measurements than in the simulations. In actual fact the measurements reflect water surface disturbances due to wind action on top of the tidal amplitude. These small-scale water level disturbances are not represented in the model.

The simulated and observed water levels at Chaktomouk (Figs. 2.17a to 2.17g) show almost a constant water level difference. This difference is approximately 20 cm. Various test simulations have been carried out with changed channel roughness and also cross section geometry. Since the model is rather insensitive to these changes, it is concluded that the observed water levels may have a datum error associated. However, the simulated phase and amplitude of the tide is well in accordance with observations. The tidal variation at Chaktomouk is driven by the water level variation at Chau Doc and Tan Chau. Since the tidal phase as well as the various single and double peaks at Chaktomouk is well represented by the model, an additional conclusion arises: the water level observations at Chau Doc/Tan Chau and Chaktomouk are consistent. The issue, which remains to be checked, is the zero gauge datum at Chaktomouk.

Detailed Results - Daily Average Discharge

One of the purposes of the dry season modelling is to support the discharge-monitoring programme, which has collected three measurements per day in each of the four river branches. Ideally the measurements would provide sufficient data for model calibration, and in return the model would provide hourly results, upon which daily averages or other data extractions could be made.

Initially a comparison of the daily average discharge from the model (based on 24 hourly values) and the average discharge using the collected data (based on 3 measurements per day) was made. Fig. 2.18 shows the daily average discharge from the model simulations at the four river branches. These daily average discharges are also presented in Table 2. In Figs. 2.19 to 2.22 the daily average discharge for each station is plotted together with the daily average discharge derived from the monitoring campaign. As expected, the two averaged discharges vary on some days and at other times they are close to each other. It is somewhat surprising that the daily average discharge (model and measurements) at Phnom Penh Port is relatively close to each other.

Detailed Results - Discharge Relations

At the Chaktomouk junction, the flow splits into: (1) the lower Mekong branch; (2) the Bassac; and (3) the Tonle Sap River. At rising flood the flow in these branches becomes dependent on the flow in the Mekong upstream of Chaktomouk. In the receding flood, the flow in Tonle Sap is towards the Chaktomouk junction. Therefore the flows in Mekong downstream of the junction and in the Bassac become a function of the total flows upstream of the Chaktomouk junction.

If there is any relation between the flows at the four stations around the Chaktomouk junction (Chrui Changvar, Koh Norea, Phnom Penh Port and Monivong Bridge), the relation will be most clear during the rising flood. During the falling period, it could not be expected that there is any relation between the flows in the Tonle Sap River and the other branches at Chaktomouk. This is observed in Figs 2.23 to 2.25 in which the daily average discharge at Chrui Changvar is plotted against the daily average discharges at Koh Norea, Phnom Penh Port and Monivong Bridge and from it is seen that especially the measurements show quite some scatter.

If the flows upstream of the junction (Chrui Changvar plus Phnom Penh Port) are added, then the relations to downstream flows become more clear. This is seen from Figs. 2.26 and 2.27. Assuming a linear trend in the model predictions (Fig. 2.26), the result is that 93% of the upstream flows is found in the Mekong downstream of the Chaktomouk junction. Correspondingly 7% is found in the Bassac River. This distribution can be assumed to be valid in the recession period from February to April.

It is likely that the discharge at Chrui Changvar can be assessed by either a rating curve or by some relations between the flow at Kompong Cham and the flow at Chrui Changvar. The remaining flow component for downstream flow prediction is the flow in Tonle Sap at Phnom Penh Port. During the recession period a relation between the discharge in the Mekong and the discharge in the Tonle Sap could not be set. Hence one is left with the only option being a rating curve for Phnom Penh Port.

Detailed Results - Discharge Rating Curve

A discharge-rating curve could not be set for Phnom Penh Port for hourly data in the dry season. This is clear from Fig. 2.28 showing simulated hourly discharge versus hourly water level at Phnom Penh Port. The reason is that the station is tidally affected. This is also confirmed by plotting the observed discharges versus the observed water level (instantaneous) from the dry season 2003 against each other (see Fig. 2.29).

A daily average discharge can be established by averaging the hourly discharge values in a 24-hour time frame. The problem is to assess the corresponding water level for this discharge. The corresponding water level is NOT the daily averaged water level. The corresponding water level is also NOT the water level taken at a specific time, say e.g. 7 o'lock.

However, one may take a practical approach and obtain as much as possible from the data collected. The average discharge of the measurements during the dry season is plotted against the 7 o'clock water level at Chaktomouk in Fig. 2.30a. The water level at Chaktomouk is directly accessible and can be obtained for a good number of years back in time. It appears from Fig. 2.30a that a linear relation between the average discharge and the 7 o'clock water level at Chaktomouk can be established. Obviously this relation can only be assumed within the water level range observed in the dry season 2003, which is 0.76 m to 2.34 m MSL. The surprising thing is that the discharge can be related to the water level at only one station (there is backwater in Tonle Sap River) and also at a fixed time (7 o'clock). The relative good fit in the relation may also be due to the limited number of data sets.

Instead of the above-mentioned relation it would be more correct to relate the discharge at Phnom Penh Port to the water level at both Phnom Penh Port and Prek Kdam. Such a relation was consistent with the principles of rating curve derivation at backwater-affected stations. The relation was made on basis of model results. The outcome is seen in Fig. 2.30b and 2.30c. It was concluded that a relation (rating curve) between the flow at Phnom Penh Port and the water levels at Prek Kdam and Phnom Penh Port could be established.

2.5 Model Simulations - Dry Seasons in 1997-2001

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

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

2.6 Model Results - Dry Seasons in 1997-2001

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

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

Hourly discharge

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

Figs. 2.36 and 2.37 show an example of simulated and observed hourly discharge at Tan Chau. The conclusion from the figures is that the model is able to predict the tidal dynamics at Tan Chau.

Daily average discharge

The observed daily average discharge at Tan Chau is simply obtained by averaging the 24 hourly values of each day. The same averaging is applied on the model results, which are stored for each hour. Figs. 2.31 to 2.35 show the observed and simulated daily average discharge at Tan Chau for each of the dry season periods of the years 1997-2001.

Figs. 2.31 to 2.35 present the main conclusion that the model is able to predict the measured discharge at Tan Chau during the dry season. This verifies that the model has the correct roughness distribution in Bassac/Mekong branches downstream of Chaktomouk, and also that the discharge contribution from the Great Lake and upstream Mekong are well estimated.

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

The daily average discharges at Chrui Changvar, Koh Norea, Phnom Penh Port and Monivong Bridge during the dry seasons of the five years are presented in Tables 3 to 7.

2.7 Conclusion

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

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

The model results were used to derive a possible relation between the discharges in the Mekong and Bassac downstream of the junction as a function of upstream flows. Within the range of dry season flows simulated, a linear relation could produce this flow relation. Data substantiated the derived flow relation.

Further, the observed average daily discharge (based on only 3 values per day) in Tonle Sap River at Phnom Penh Port showed to be fairly well-correlated with the observed daily (7 o'clock) water level at Chaktomouk. Such a relation was not anticipated, and could be the coincidental result of the actual data set and timing of measurements. Hence a relation was produced (based on model results) which accounted for the water level at both Phnom Penh Port and Prek Kdam. Such a relation was consistent with the principles of rating curve derivation at backwater-affected stations. It was concluded that a relation (rating curve) between the flow at Phnom Penh Port and the water levels at Prek Kdam and Phnom Penh Port could be established.

3. HYDRAULIC IMPACT OF ROAD EMBANKMENTS

3.1 Introduction

The established model has been used to determine the changes in the discharge hydrograph in the river system as a result of the construction of the major road embankments between the Mekong and Tonle Sap rivers during the last century.

The following major periods representing the different stages in the embankment construction can be identified:

- Prior to 1920s: there were no significant road embankment
- Between late 1920s and 1940s: embankment on Road 61 and Road 6
- Between 1940s and 1960s: embankment on Road 61, Road 6, and Road 7
- After 1960s: embankment on Road 61, Road 6, Road 6A and Road 7

The different roads with embankment locations are shown in Fig. 3.1.

The simulations carried out used the existing model setup and topography as a basis. Therefore, the simulations do not represent the true physical conditions in the periods mentioned above, but rather the present day situation if the embankments are removed. In order to represent the situations of the above periods correctly, it is necessary to obtain river and floodplain topography, discharge and water level hydrographs as well as rainfall from the different periods in time. Not all of these data are available; hence the adopted approach was the closest representation of the historical periods specified. Given this, it has not been attempted to use hydraulic data from these periods. Instead the hydrograph from years 2000, 2001 and 2002 have been used in the simulations. The existing river model setup has been modified to represent the embankment condition in the four periods mentioned.

3.2 Model Setups

<u>After 1960s</u>

After 1960 all embankments of Roads 61, 6, 6A and 7 existed, with the embankment of Road 6A being the latest one built. Obviously there has been changes to the embankment height as well as the number and size of the bridges along Road 6 and Road 6A in recent years and all of these are reflected in the existing model setup. Since the purpose of the modelling was to determine the overall effect of embankment or no embankment, there has been no attempt to change the bridge and embankment layout for the period between 1960 and the present day. Hence the model setup used for the period after 1960 was identical to the present day model. A close-up of the model branch layout between the Mekong and Tonle Sap rivers is seen in Fig. 3.2, top.

<u>1940s to 1960s</u>

Before 1960 the road embankment of Road 6A did not exist. The schematisation of bridges along this road was therefore removed from the existing model, and two additional link channels were introduced between the Mekong and the floodplains on the southern end of Chrui Changvar. The latter was made to provide for over-bank flows at multiple locations. The road embankments of Road 61, 6 and 7 did however exist and are part of the model schematisation. The model layout for this situation is shown in Fig. 3.2, middle.

<u>1920s to 1940s</u>

During the late 1920s, Roads 61 and 6 were constructed. Hence the schematisations of these road embankments from the existing model setup were kept unchanged. However, at this time the embankment of Roads 6A and 7 did not exist. The only implication the latter has in the model relates to Moat Khmun Bridge and the road embankment from Kompong Cham to the bridge. Thus the bridge and embankment schematisation at this location was taken out of the existing setup to provide a setup that represents the situation between 1920s and 1940s. The model branch layout is identical to the one for 1940s to 1960s, since it is only the cross section at the moat of Khmun bridge that has been changed.

<u>Prior to 1920</u>

There were no major embankments constructed prior to 1920. All embankment and bridge schematisations between the Mekong and the Tonle Sap rivers have therefore been taken out of the existing model setup. Besides this it was necessary to introduce two additional floodplain channels, which join the northern and southern portions of the floodplain that was later intersected by Road 61. The model layout for this situation is shown in Fig. 3.2, bottom.

3.3 Model Results

<u>Effect on discharges</u>

The simulated discharge at Chrui Changvar is seen in Fig. 3.3, top. It is seen that the discharge for the “prior to 1920” situation is significantly lower during peak flood than the other model setups. The discharge is reduced because a large portion of the flow has spilled into the flood plains towards the Great Lake between Kompong Cham and Chrui Changvar. The three other setups show almost identical discharges at Chrui Changvar.

Similarly the simulated discharge at Prek Kdam (see Fig. 3.4) is significantly different from the other set-ups, which are almost identical. It can be concluded from the plots on Fig. 3.3 and 3.4 that the setups describing the 1920-1940, 1940-1960 and the 1960-present periods give almost identical model results.

On this background it is only the present model setup (described from 1960 up to present day) and the setup prior to the 1920s that are compared and analysed in the following.

As mentioned the discharge at Chrui Changvar is significantly reduced if there are no embankments at all between the Mekong and Tonle Sap rivers (see Fig. 3.3, top). The discharge is instead diverted to the floodplains between the Mekong and Tonle Sap rivers, and flows towards the Great Lake. With no embankments, a larger part of the Mekong discharge flows to the Great Lake via the floodplains and, consequently, the peak discharge at Prek Kdam is reduced compared to the present situation with embankments (see Fig. 3.3, bottom). Since the route to the Great Lake is shorter via the floodplains than via the river system, the lake fills up faster if no embankment is present. This has the consequence that the flow in Tonle Sap River reverses towards Phnom Penh two weeks earlier than with the present system of road embankments. This phenomena could be seen from Fig. 3.3, bottom.

It can also be seen from Fig. 3.3 that: (1) the peak outflow from the lake is only slightly reduced, (2) the total outflow volumes from the lake are larger (whereas the inflow volumes are significantly reduced), and (3) that the low flows by the end of the dry season have increased. The reason for the latter is that the lake receives more water in total if no embankment is present. With the resulting higher water levels in the Great Lake, the dry season flows are enhanced.

The simulated discharge at Koh Norea is shown in Fig. 3.4, top. The increased peak discharge at Koh Norea is mainly caused by a shift in flow proportions between the Mekong and the Bassac rivers. Hence the increase in discharge (during peak) is balanced by a decrease in the discharge in Bassac (see Fig. 3.4, bottom). Another important feature is that the low flow discharges at Koh Norea increase by about 1000 m^3/s if there is no embankment present.

Water Balance

A total water balance has been made for the river and floodplain system for each of the three years simulated. The period for which the balance was calculated was June 1 to November 1.

The result of the water balance is seen in Figs. 3.5, 3.6 and 3.7, which show the balance for each of the years simulated. Each figure shows the balance for two situations: (1) with the existing embankment situation (right), and (2) without any embankment (left).

There is not a major difference between the water balances derived from the simulations using the different hydrographs of 2000, 2001 and 2002. The reason is that all three years are similar in magnitude.

However, there are significant differences between the water balances of the present embanked situation and the situation with no embankment (see each individual set of Figs. 3.5, 3.6 and 3.7). The main difference relates to the total loss between Kompong Cham to Chrui Changvar as well as to the distribution of floodplain flows to either side along this reach. Thus the total loss is about 12-14% (of Kompong Cham flow volumes) for the embanked situation, and 20-23% for the situation with no embankment. Of this loss, roughly 50% flows to each side in the embanked situation, whereas 60% flows into the right bank floodplains in the non-embanked situation.

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

Downstream of the Chaktomouk junction there is a difference in the distribution of flow volumes between the Bassac and Mekong rivers. In the embanked situation the volumes are larger in the Bassac River than in the non-embanked situation.

3.4 Conclusions

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

- The major change in the floodplain and river flow pattern occurred when the road embankments of Road 6 and Road 61 were constructed.

- The various embankment constructions between the Mekong and Tonle Sap rivers since the embankments of Road 6 and Road 61 were made have had little impact on the flow distribution in and between rivers and floodplains. Thus the embankment of Road 6A has not modified the flow exchange between the Mekong and Tonle Sap rivers significantly.

- With no embankment between the Mekong and Tonle Sap rivers, the overland flow on the floodplains towards the Great Lake will increase. As a consequence, less flow occurs at Chrui Changvar and the inflow to the lake through the Tonle Sap river decreases.

- In contrast to this, the outflow volume from the Great Lake as well as low flow levels in the Tonle Sap River increases if no embankment is present. This is so because the lake receives more water (in total) if embankments are not present.

- The flow reversal (from inflow to outflow) in the Tonle Sap River occurs about 2 weeks earlier if embankments are not present. The reason for this is the shorter overland flow route, which causes the lake to fill faster and thus reach its maximum water level earlier.

4. EFFECT OF INCREASED BRIDGE OPENINGS ON FLOODPLAIN INUNDATION

4.1 Introduction

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

As an application example, the model has been used to simulate the effect of increased bridge openings along Road 1 east of Neak Luong. The increase in bridge span was arbitrarily selected. The location of the embankment and Road 1 is shown in Fig. 4.1.

4.2 Model Tests

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

Fig. 4.1 shows a longitudinal profile of water level (at peak flood, year 2002) from upstream to downstream of the existing bridge located on Stung Sloat. It is seen that a significant gradient in the water level exists. There is almost a one meter difference from up- to downstream of the bridge. Part of this is a difference if naturally due to the head loss which the bridges along Road 1 create.

In the test simulation, the bridge openings have been increased by a factor of 3, and the 2002 simulation was repeated. Fig. 4.2 shows the effect of the increased opening on the water levels up and downstream of the bridge as well as the effect on the discharge. The water levels on the upstream side decreases with approximately 0.5 m, and on the downstream side (only vicinity of bridge) the levels increase by 0.2 m. The effect on the discharge is an increase of 500 m^3/s from the original 3,000 m^3/s.

The effect on the water level is felt over a long distance. This is seen from Fig. 4.3, which contain flood maps for the existing and the test situation, as well as a water level difference map. The latter shows that the upstream effect reaches more than 30 km upstream.

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

4.3 Conclusions

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

- The presence of road embankments in the Cambodian floodplains significantly impedes the flows across the plains.

- The large water level gradients which results from the presence of the road embankments creates large flow velocities and potential scour at existing bridge sites.

- Increased bridge spans on the road embankments can lead to a significant reduction of the hydraulic gradient and thereby eroding power.

- The reduction in water level on the upstream side of road embankments (due to increased bridge spans) is felt over long distances, in the example, over 30 km.

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

5. WATER BALANCE OF THE TONLE SAP LAKE

5.1 Introduction

The present chapter describes the outcome of a water balance study of the Tonle Sap Lake. The bases for the water balance assessment are the model results from 1998-2002.

5.2 Water Balance Assessment

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

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

- Runoff from the Tonle Sap Lake Basin (sub-catchments around the Lake)

- Direct rainfall on the lake

- Evaporation from the lake

- Inflow from Tonle Sap River

- Overland flow from Mekong

The model obtained all of these elements. The monthly contribution from each of the elements were calculated and added together to give a total monthly volume change in the lake. This total monthly volume change of the lake has been compared with the observed monthly volume change. The observed monthly volume change was determined by use of the observed water level at Kompong Luong and a relation between lake level and lake volume.

(1) Volume change based on inflows/outflows

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

(a) Runoff from the Tonle Sap Lake Basin

The rainfall-runoff model is applied to provide the inflows from the tributaries around the lake. The runoff results mentioned in Subsection 3.1.6 and shown in Fig. 3.86 to 3.97 (of the accompanying Paper 4: Development of Hydro-Hydraulic Model for the Cambodian Floodplains) are used for this contribution. However, for the water balance assessment the total catchment runoff was reduced for the direct rainfall on the part of the sub-catchments that gradually become inundated during the wet season.

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

(b) Direct Rainfall on the Lake

The direct rainfall on the dry season lake is shown in Fig. 3.102 (of the accompanying Paper 4: Development of Hydro-Hydraulic Model for the Cambodian Floodplains). Rainfall is the average of 4 to 7 stations scattered around the lake, the number being dependent on each years availability. This rainfall is scaled to account for the changed surface area of the lake. The surface area is obtained from the level-area relation, which has been derived for the lake, and the observed monthly averaged water level at Kompong Luong. The level-area curve for the lake is shown in Fig. 3.115 (of the accompanying Paper 4: Development of Hydro-Hydraulic Model for the Cambodian Floodplains). For water levels above 2 m, the lake area can be determined by the following relation:

$$\text{Lake Area} = 1197.7 * \text{WaterLevel} + 1215.7$$

The lake area is in km^2 and the water level is that of Kompong Luong and given in meters.

The direct rainfall on the lake is converted into volume.

(c) Evaporation of the Lake

The monthly evaporation rates shown in Table 3.3 (of the accompanying Paper 4: Development of Hydro-Hydraulic Model for the Cambodian Floodplains) are applied to the changing lake area and converted into volume. The determination of the lake area is described above.

(d) Inflow from Tonle Sap River

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

(e) Overland flow from the Mekong

The same explanation as for Tonle Sap River inflow applies.

(2) Volume change based on observations

The observed volume change in the lake was determined by use of the recorded water level at Kompong Luong in the Great Lake and the established relation between the water level and the lake volume.

The relation between water level and volume is shown in Fig. 3.105 (of the accompanying Paper 4: Development of Hydro-Hydraulic Model for the Cambodian Floodplains). The observed water level at Kompong Luong is seen as part of Fig. 3.122, top, (of the accompanying Paper 4: Development of Hydro-Hydraulic Model for the Cambodian Floodplains). By taking the average water level in one month and determining the corresponding volume, it is possible to calculate the actual lake volume as well as the monthly volume change.

(3) Results of water balance assessment

The results of the volume change based on inflows/outflows are seen in Fig. 5.1 to 5.7. Fig. 5.1 shows the results from 1962-63 (reprinted from ref. /3/), and is included for historical reference. Fig. 5.2 shows the results for all of the years 1998-2002, whereas Fig. 5.3 to 5.7 shows the results from each of the years.

The figures show the monthly volume change for five contributions: (1) Evaporation of the lake, (2) Runoff from the Tonle Sap Lake Basin, (3) Inflow from Tonle Sap river, (4) Overland flow from Mekong, and (5) Direct rainfall on the lake. Positive values mean an increase of the lake volume and a negative value is correspondingly interpreted as a decrease in lake volume. By this notation the runoff from the lake basin is always positive or zero, the evaporation is always negative, and the flow from/to the Tonle Sap River is positive during the rising monsoon and negative in the falling part when the flow reverses.

The figures show some important features. First of all the contributions to volume change have the following ranking (most significant first, sign disregarded): (1) flow from Tonle Sap, (2) runoff from Tonle Sap Basin, (3) overland flow from Mekong, (4) direct rainfall on the lake, and (5) evaporation of the lake. This is concluded when all years are considered and accumulated values taken. The ranking is however changing with years (compare, e.g., 1998 with 2001) and also on a monthly basis.

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

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

One important observation is that the local runoff from the Tonle Sap Basin does not change proportionally to the magnitude of the flood (i.e., 1998 was a dry year, 2000 was a wet year). So, the results reflect also the regional variation of rainfall pattern.

The results of volume change based on observations are seen in Fig. 5.8 and 5.9. The absolute volumes have been determined by a combination of the observed water levels at Kompong Luong and a relation between level and volume for the lake.

Fig. 5.8 show the absolute lake volumes in each month from 1998-2001 as well as the monthly volume change. The latter is determined as the difference between the absolute monthly volumes.

The observed monthly volume change is compared with the volume change based on inflows/outflows. This comparison is shown in Fig. 5.9. The figure shows that there is a relatively good match, considering all the uncertainties and assumptions in the modelling of inflows/outflows. The month of October always shows a discrepancy: the inflow/outflow assessment predicts a negative volume change, whereas the observations suggest a positive change. The reason for the inflow/outflow assessment to be negative is that the outflow through Tonle Sap is larger than the direct rainfall and basin runoff in October (see Fig. 5.2). It should be mentioned that this balance is sensitive to both assessments of inflows and outflows, with the net difference being maximum 8×10^9 $m^{3,}$ or approximately 10% of the lake volume in October.

5.3 Conclusions

The water balance analysis of the Great Lake has been made for the years 1998 to 2002. The water balance has been made on a monthly basis using model results. The seasonal dynamics of all the elements in the balance (Tonle Sap river flow, overland flow, basin runoff, direct rainfall, evaporation) is consistent from year to year, and proportionally and also in absolute terms comparable to the findings from 1962/63, ref. /3/, which was based on observations.

Detailed conclusions of the analysis include:

- The contributions to the lake have the following ranking (largest contributor first): (1) Flow from Tonle Sap, (2) Runoff from Tonle Sap Basin, (3) Overland flow from Mekong, (4) Direct rainfall on the lake, and (5) Evaporation from the lake.

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

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

- The year of 1998 had almost no overland flow.

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

6. CONCLUSIONS

The mathematical model established as part of the WUP-JICA study has been applied for a number of applications. These include: (1) Dry season modelling, (2) Hydraulic impact of road embankments, (3) Effect of increased bridge openings, and (4) Water balance assessment for the Great Lake. The detailed conclusions from each of these applications are found at the end of each paragraph in this paper.

The following are general conclusions and information:

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

- The model has been used in a parallel study (Tonle Sap Lake & Vicinities Project, ref./4/) for detailed assessment of the functional role of the floodplain compartments, exchange of flows between rivers and floodplains, and detailed water balance assessment for the flood plains. The combined data sets provided by the WUP-ICA and TSLV studies have been essential for the model verification.

- The model is at a stage where it can be used for detailed hydrologic studies, whether these are concerning wet or dry seasons. The applications, which have been made so far, are mainly concerned with the wet season (impact of road embankments and bridges). The dry season application has given support to the WUP-JICA work on establishment of a dry season flow management system.

- MRC staff used the model system during the 2003 monsoon to provide daily and forecasted flood maps on a daily basis. The flood maps were published to the MRC Flood Information Webpage.

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

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

REFERENCES

/1/ WUP-JICA, Progress Report: Hydrometeorological Monitoring for Water Quantity Rules in the Mekong Basin, February 2002

/2/ WUP-JICA, Interim Report: Hydrometeorological Monitoring for Water Quantity Rules in the Mekong Basin, March 2003

/3/ J.P Carbonnel and J. Guiscafre, Ministiere des Affaires Etrangeres Gouvernement Royal du Cambodge Grand Lac du Cambodge: Sedimentologie et Hydrologie, 1962-63

/4/ CTI Engineering International Co., Ltd. and DHI-Water & Environment, Main Report: Consolidation of Hydro-Meteorological Data and Multi-functional Hydrologic Roles of Tonle Sap Lake and its Vicinities (Basinwide), August 2003

Table 1 Wind Data from Pochentong Airport, 2003

(Daily Average of wind direction and velocity taken at 10 m altitude)

Date	Jan		Feb		Mar		Apr		May	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
1	NE	4	N	4	SE	4	NE	4	NE	4
2	NE	3	SE	3	SE	5	S	5	S	4
3	NE	7	NE	4	SE	5	SE	3	S	3
4	NE	5	SE	7	SE	5	NE	4	S	6
5	NE	6	E	7	SE	6	SE	3	S	4
6	NE	3	NE	4	SE	5	SE	4	SW	3
7	N	4	NE	3	SE	5	SE	4	S	4
8	NE	4	W	3	S	4	SE	4	SE	4
9	N	4	S	3	NW	3	SE	4	SE	9
10	NE	5	SE	5	SE	5	SE	4	S	4
11	N	4	S	4	SE	5	SE	4	NE	4
12	N	4	NE	3	S	5	S	5	SE	3
13	NE	4	S	4	S	5	S	4	S	5
14	N	4	SE	5	S	5	SE	4	W	4
15	NE	5	S	4	SE	4	SE	4	W	5
16	NE	4	S	5	SE	5	S	4	SW	6
17	NE	4	SE	4	SE	4	SE	4	SW	5
18	NE	3	SE	5	S	4	S	4	W	16
19	NE	4	SE	4	SE	5	SW	6	S	4
20	N	3	SE	4	SE	5	SE	5	SW	2
21	S	3	S	5	E	4	S	6	SW	5
22	SE	4	SE	5	S	5	SE	4	NW	4
23	SE	4	SE	4	SE	4	SE	5	SW	4
24	SE	5	SE	4	SE	6	SE	5	SW	4
25	SE	4	SE	5	SE	4	SE	3	W	8
26	NE	4	SE	4	E	3	SE	5	SW	10
27	SE	3	SE	5	SE	4	SE	5	SW	8
28	NE	3	S	4	SE	4	NE	7	SW	10
29	NE	4			SE	4	NW	3	SW	8
30	SE	2			SE	4	SE	5	SW	8
31	N	4			SE	4			SW	6

Table 2 Simulated Daily Average Discharges, Dry Season 2003

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
01-Feb-03	4175	7267	3493	407
02-Feb-03	4098	6779	3036	358
03-Feb-03	3990	6670	3053	374
04-Feb-03	4029	6331	2603	304
05-Feb-03	3965	6349	2711	330
06-Feb-03	3689	6421	3079	347
07-Feb-03	3613	6381	3084	318
08-Feb-03	3608	6375	3070	305
09-Feb-03	3644	6312	2944	279
10-Feb-03	3706	5982	2509	237
11-Feb-03	3548	5916	2620	252
12-Feb-03	3438	5949	2791	279
13-Feb-03	3377	5700	2562	239
14-Feb-03	3523	5562	2255	219
15-Feb-03	3369	5509	2365	225
16-Feb-03	3365	5460	2312	218
17-Feb-03	3444	5432	2209	223
18-Feb-03	3400	5214	2015	203
19-Feb-03	3287	5144	2070	214
20-Feb-03	3261	5161	2103	205
21-Feb-03	3254	5061	1985	179
22-Feb-03	3442	5087	1826	183
23-Feb-03	3403	5153	1942	194
24-Feb-03	3421	5222	1992	193
25-Feb-03	3546	5139	1778	184
26-Feb-03	3571	5158	1784	195
27-Feb-03	3608	5086	1660	183
28-Feb-03	3549	5113	1754	190
01-Mar-03	3560	5147	1778	193
02-Mar-03	3607	4956	1511	165
03-Mar-03	3568	4794	1378	154
04-Mar-03	3483	4670	1327	143
05-Mar-03	3528	4447	1024	109
06-Mar-03	3373	4393	1143	124
07-Mar-03	3250	4443	1319	127
08-Mar-03	3092	4476	1533	148
09-Mar-03	2996	4533	1706	166
10-Mar-03	3194	4464	1407	139
11-Mar-03	3230	4216	1105	121
12-Mar-03	3058	4091	1150	115
13-Mar-03	3043	4181	1258	119
14-Mar-03	3114	4279	1282	118
15-Mar-03	3179	4328	1274	128
16-Mar-03	3197	4231	1136	107

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
17-Mar-03	3043	4040	1113	117
18-Mar-03	2924	3972	1163	117
19-Mar-03	2948	3822	965	93
20-Mar-03	2939	3630	783	96
21-Mar-03	2863	3652	901	114
22-Mar-03	2767	3550	868	85
23-Mar-03	2901	3654	855	103
24-Mar-03	3021	3500	543	66
25-Mar-03	3016	3599	692	109
26-Mar-03	2967	3785	951	132
27-Mar-03	2983	3881	1016	117
28-Mar-03	3079	3903	926	103
29-Mar-03	3102	3898	891	97
30-Mar-03	3015	3757	839	98
31-Mar-03	3017	3724	812	107
01-Apr-03	3026	3786	881	122
02-Apr-03	2977	3642	741	79
03-Apr-03	3107	3785	790	114
04-Apr-03	3099	3896	924	129
05-Apr-03	3024	3836	920	109
06-Apr-03	3081	3757	769	94
07-Apr-03	3085	3632	636	90
08-Apr-03	3061	3584	611	89
09-Apr-03	3031	3528	585	88
10-Apr-03	2978	3457	569	88
11-Apr-03	3012	3508	571	76
12-Apr-03	3038	3530	546	56
13-Apr-03	3095	3651	626	72
14-Apr-03	3048	3545	580	83
15-Apr-03	2978	3381	486	82
16-Apr-03	2912	3338	508	81
17-Apr-03	2947	3375	506	79
18-Apr-03	2854	3278	483	62
19-Apr-03	2768	3287	567	48
20-Apr-03	2981	3291	343	37
21-Apr-03	2888	3055	187	24
22-Apr-03	2875	3085	273	64
23-Apr-03	2802	2946	184	41
24-Apr-03	2947	3106	203	46
25-Apr-03	2975	3270	353	60
26-Apr-03	2906	3188	327	45
27-Apr-03	2962	3095	187	54
28-Apr-03	2879	2840	26	67
29-Apr-03	2748	2953	289	84

Table 3 Simulated Daily Average Discharges, Dry Season 1997

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
04-Jan-97	5473	9996	5272	757
05-Jan-97	4812	9421	5286	682
06-Jan-97	4577	9137	5216	659
07-Jan-97	4427	8921	5129	637
08-Jan-97	4290	8711	5037	619
09-Jan-97	4165	8515	4949	601
10-Jan-97	4034	8312	4860	585
11-Jan-97	3926	8130	4772	571
12-Jan-97	3832	7963	4686	557
13-Jan-97	3760	7838	4615	539
14-Jan-97	3678	7740	4547	486
15-Jan-97	3636	7682	4481	438
16-Jan-97	3618	7625	4425	419
17-Jan-97	3584	7554	4382	413
18-Jan-97	3534	7468	4343	411
19-Jan-97	3466	7370	4311	410
20-Jan-97	3364	7227	4272	410
21-Jan-97	3295	7115	4226	409
22-Jan-97	3245	7025	4181	404
23-Jan-97	3166	6897	4130	401
24-Jan-97	3122	6812	4083	394
25-Jan-97	3070	6727	4041	386
26-Jan-97	2990	6599	3989	382
27-Jan-97	2926	6467	3921	381
28-Jan-97	2912	6397	3860	375
29-Jan-97	2890	6336	3809	364
30-Jan-97	2850	6267	3766	350
31-Jan-97	2846	6250	3735	334
01-Feb-97	2823	6217	3711	319
02-Feb-97	2749	6118	3677	310
03-Feb-97	2702	6033	3633	303
04-Feb-97	2674	5960	3584	299
05-Feb-97	2668	5902	3528	296
06-Feb-97	2609	5770	3458	296
07-Feb-97	2577	5663	3380	294
08-Feb-97	2567	5571	3297	293
09-Feb-97	2575	5494	3212	293
10-Feb-97	2608	5452	3135	291
11-Feb-97	2651	5433	3069	288
12-Feb-97	2660	5386	3009	284
13-Feb-97	2690	5368	2955	278
14-Feb-97	2735	5378	2914	272
15-Feb-97	2748	5359	2875	265
16-Feb-97	2745	5329	2840	258
17-Feb-97	2662	5216	2802	251
18-Feb-97	2563	5084	2761	242
19-Feb-97	2500	4990	2720	231
20-Feb-97	2440	4895	2675	222
21-Feb-97	2356	4750	2610	218
22-Feb-97	2335	4695	2567	208
23-Feb-97	2243	4557	2513	200

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
24-Feb-97	2175	4445	2459	191
25-Feb-97	2127	4353	2409	185
26-Feb-97	2078	4261	2360	179
27-Feb-97	2041	4179	2309	173
28-Feb-97	2033	4137	2268	167
01-Mar-97	2049	4128	2236	160
02-Mar-97	2061	4118	2207	153
03-Mar-97	2020	4040	2169	150
04-Mar-97	2000	3971	2118	148
05-Mar-97	1979	3904	2066	143
06-Mar-97	1943	3828	2022	139
07-Mar-97	1874	3696	1957	136
08-Mar-97	1784	3517	1868	135
09-Mar-97	1759	3417	1789	132
10-Mar-97	1775	3380	1732	129
11-Mar-97	1811	3392	1702	123
12-Mar-97	1830	3399	1686	119
13-Mar-97	1844	3401	1668	115
14-Mar-97	1859	3407	1651	106
15-Mar-97	1845	3374	1626	101
16-Mar-97	1857	3366	1600	94
17-Mar-97	1877	3367	1573	87
18-Mar-97	1839	3288	1531	85
19-Mar-97	1765	3168	1488	86
20-Mar-97	1799	3213	1481	68
21-Mar-97	1751	3160	1463	56
22-Mar-97	1697	3043	1397	51
23-Mar-97	1665	2904	1291	52
24-Mar-97	1657	2808	1204	54
25-Mar-97	1609	2678	1126	59
26-Mar-97	1534	2514	1047	67
27-Mar-97	1552	2485	1004	71
28-Mar-97	1582	2490	977	71
29-Mar-97	1592	2497	969	67
30-Mar-97	1607	2517	968	61
31-Mar-97	1561	2433	934	64
01-Apr-97	1585	2413	891	64
02-Apr-97	1631	2447	870	57
03-Apr-97	1720	2563	887	48
04-Apr-97	1708	2546	883	48
05-Apr-97	1590	2344	801	49
06-Apr-97	1538	2218	728	51
07-Apr-97	1515	2157	694	53
08-Apr-97	1508	2094	644	58
09-Apr-97	1627	2190	622	61
10-Apr-97	1739	2279	602	65
11-Apr-97	1863	2396	597	67
12-Apr-97	2035	2550	582	70
13-Apr-97	2151	2646	566	73
14-Apr-97	2273	2768	565	71
15-Apr-97	2371	2899	591	67

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
16-Apr-97	2389	2904	573	62
17-Apr-97	2376	2843	526	61
18-Apr-97	2382	2796	474	62
19-Apr-97	2431	2807	440	66
20-Apr-97	2439	2753	387	73
21-Apr-97	2454	2721	349	80
22-Apr-97	2474	2740	346	81
23-Apr-97	2443	2703	340	81
24-Apr-97	2412	2656	323	81
25-Apr-97	2379	2631	334	83
26-Apr-97	2325	2527	285	84
27-Apr-97	2433	2681	326	80
28-Apr-97	2483	2681	282	86
29-Apr-97	2508	2674	254	88
30-Apr-97	2537	2762	304	81
01-May-97	2557	2833	345	73
02-May-97	2509	2766	322	69
03-May-97	2491	2786	355	65
04-May-97	2408	2655	305	61
05-May-97	2287	2499	271	62
06-May-97	2217	2400	240	60
07-May-97	2123	2273	208	61
08-May-97	2092	2243	210	61
09-May-97	2123	2291	224	60
10-May-97	2122	2276	209	59
11-May-97	2091	2235	202	60
12-May-97	2119	2342	277	57
13-May-97	2166	2423	305	51
14-May-97	2157	2406	299	52
15-May-97	2212	2508	340	47
16-May-97	2165	2537	419	50
17-May-97	2159	2602	493	52
18-May-97	2198	2615	469	53
19-May-97	2226	2518	345	54
20-May-97	2269	2545	333	58
21-May-97	2344	2605	322	62
22-May-97	2449	2680	299	69
23-May-97	2518	2695	256	79
24-May-97	2647	2831	268	84
25-May-97	2745	2914	258	88
26-May-97	2849	3035	279	93
27-May-97	2978	3178	303	101
28-May-97	3242	3503	382	118
29-May-97	3625	3908	423	136
30-May-97	3884	4176	440	147
31-May-97	3939	4263	478	153

Table 4 Simulated Daily Average Discharges, Dry Season 1998

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
04-Jan-98	4311	7891	4000	436
05-Jan-98	3322	7098	4125	357
06-Jan-98	2993	6765	4111	343
07-Jan-98	2868	6601	4062	332
08-Jan-98	2805	6481	3997	323
09-Jan-98	2751	6364	3928	316
10-Jan-98	2687	6225	3849	312
11-Jan-98	2692	6152	3766	307
12-Jan-98	2723	6119	3694	299
13-Jan-98	2655	5997	3629	288
14-Jan-98	2559	5842	3562	281
15-Jan-98	2533	5760	3498	272
16-Jan-98	2537	5727	3448	261
17-Jan-98	2513	5664	3400	251
18-Jan-98	2492	5603	3350	242
19-Jan-98	2465	5533	3299	234
20-Jan-98	2395	5405	3239	230
21-Jan-98	2338	5289	3176	226
22-Jan-98	2333	5237	3122	219
23-Jan-98	2339	5209	3077	209
24-Jan-98	2292	5099	3017	210
25-Jan-98	2217	4943	2939	212
26-Jan-98	2146	4787	2853	211
27-Jan-98	2187	4769	2786	205
28-Jan-98	2165	4684	2720	201
29-Jan-98	2106	4550	2642	199
30-Jan-98	2037	4408	2566	195
31-Jan-98	2040	4363	2510	189
01-Feb-98	2064	4354	2469	180
02-Feb-98	2069	4330	2431	172
03-Feb-98	2083	4319	2397	164
04-Feb-98	2103	4320	2370	156
05-Feb-98	2084	4285	2348	150
06-Feb-98	2012	4176	2307	145
07-Feb-98	1934	4056	2261	141
08-Feb-98	1856	3922	2205	140
09-Feb-98	1759	3752	2132	139
10-Feb-98	1765	3700	2066	132
11-Feb-98	1852	3766	2035	124
12-Feb-98	1823	3697	1992	120
13-Feb-98	1831	3652	1938	118
14-Feb-98	1862	3635	1887	115
15-Feb-98	1882	3620	1846	110
16-Feb-98	1877	3587	1814	106
17-Feb-98	1851	3535	1781	99
18-Feb-98	1855	3517	1750	92
19-Feb-98	1830	3465	1716	85
20-Feb-98	1802	3402	1675	79
21-Feb-98	1752	3300	1620	74
22-Feb-98	1710	3191	1549	70
23-Feb-98	1633	3023	1460	70

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
24-Feb-98	1542	2819	1349	71
25-Feb-98	1575	2792	1279	63
26-Feb-98	1493	2622	1194	65
27-Feb-98	1413	2435	1090	68
28-Feb-98	1465	2424	1026	68
01-Mar-98	1467	2366	971	72
02-Mar-98	1469	2325	925	70
03-Mar-98	1503	2336	896	65
04-Mar-98	1601	2461	915	57
05-Mar-98	1630	2498	916	53
06-Mar-98	1613	2461	894	49
07-Mar-98	1593	2401	853	48
08-Mar-98	1638	2451	847	39
09-Mar-98	1596	2374	814	39
10-Mar-98	1585	2328	776	36
11-Mar-98	1522	2209	718	34
12-Mar-98	1496	2144	679	32
13-Mar-98	1421	2007	623	38
14-Mar-98	1398	1944	585	40
15-Mar-98	1384	1901	555	40
16-Mar-98	1406	1906	537	38
17-Mar-98	1424	1912	523	37
18-Mar-98	1439	1916	511	36
19-Mar-98	1481	1965	513	31
20-Mar-98	1489	1972	507	27
21-Mar-98	1454	1906	477	26
22-Mar-98	1509	1977	487	21
23-Mar-98	1367	1745	405	27
24-Mar-98	1309	1650	364	23
25-Mar-98	1214	1515	339	34
26-Mar-98	1196	1472	304	28
27-Mar-98	1291	1600	333	27
28-Mar-98	1303	1604	325	26
29-Mar-98	1239	1476	267	33
30-Mar-98	1191	1394	238	39
31-Mar-98	1293	1524	260	35
01-Apr-98	1351	1603	277	30
02-Apr-98	1471	1784	327	20
03-Apr-98	1400	1668	287	23
04-Apr-98	1377	1627	268	21
05-Apr-98	1450	1710	274	17
06-Apr-98	1465	1731	273	11
07-Apr-98	1419	1659	255	17
08-Apr-98	1392	1624	243	14
09-Apr-98	1354	1559	215	13
10-Apr-98	1329	1506	191	16
11-Apr-98	1266	1398	149	20
12-Apr-98	1289	1417	143	18
13-Apr-98	1288	1442	138	-12
14-Apr-98	1300	1447	131	-12
15-Apr-98	1271	1393	110	-8

Date	Chrui Changvar	Koh Norea	Phnom Penh Port
16-Apr-98	1296	1413	106
17-Apr-98	1360	1474	115
18-Apr-98	1390	1471	81
19-Apr-98	1460	1566	94
20-Apr-98	1572	1741	141
21-Apr-98	1631	1789	124
22-Apr-98	1726	1910	149
23-Apr-98	1815	1985	149
24-Apr-98	1795	1924	122
25-Apr-98	1756	1850	98
26-Apr-98	1727	1820	101
27-Apr-98	1620	1678	77
28-Apr-98	1591	1655	89
29-Apr-98	1607	1679	97
30-Apr-98	1646	1744	119
01-May-98	1640	1750	128
02-May-98	1600	1688	107
03-May-98	1703	1850	161
04-May-98	1723	1878	168
05-May-98	1641	1744	119
06-May-98	1617	1727	131
07-May-98	1542	1585	72
08-May-98	1462	1433	8
09-May-98	1552	1547	30
10-May-98	1623	1626	37
11-May-98	1712	1745	66
12-May-98	1744	1775	70
13-May-98	1791	1787	35
14-May-98	1810	1840	67
15-May-98	1754	1790	67
16-May-98	1800	1888	111
17-May-98	1775	1867	114
18-May-98	1773	1895	142
19-May-98	1821	1932	133
20-May-98	1845	1926	106
21-May-98	1930	1985	85
22-May-98	2062	2081	58
23-May-98	2181	2178	42
24-May-98	2322	2301	31
25-May-98	2410	2355	8
26-May-98	2521	2475	21
27-May-98	2553	2458	-16
28-May-98	2743	2673	13
29-May-98	2997	2918	11
30-May-98	3243	3215	69
31-May-98	3409	3405	99

Table 5 Simulated Daily Average Discharges, Dry Season 1999

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
04-Jan-99	4284	6848	2865	317
05-Jan-99	3171	5957	3023	244
06-Jan-99	2805	5597	3022	233
07-Jan-99	2686	5460	2994	222
08-Jan-99	2650	5412	2969	211
09-Jan-99	2521	5254	2934	203
10-Jan-99	2463	5181	2904	190
11-Jan-99	2420	5131	2884	176
12-Jan-99	2326	5009	2850	169
13-Jan-99	2179	4795	2785	169
14-Jan-99	2114	4654	2707	168
15-Jan-99	2080	4555	2637	163
16-Jan-99	2044	4448	2565	160
17-Jan-99	2048	4369	2482	161
18-Jan-99	2126	4387	2418	158
19-Jan-99	2147	4354	2360	154
20-Jan-99	2112	4276	2310	146
21-Jan-99	2051	4178	2267	140
22-Jan-99	1988	4082	2226	133
23-Jan-99	1968	4039	2196	126
24-Jan-99	1918	3963	2164	120
25-Jan-99	1864	3877	2127	115
26-Jan-99	1836	3821	2092	108
27-Jan-99	1793	3739	2047	103
28-Jan-99	1763	3668	2002	98
29-Jan-99	1700	3549	1945	96
30-Jan-99	1618	3395	1872	94
31-Jan-99	1624	3344	1808	88
01-Feb-99	1699	3389	1771	81
02-Feb-99	1717	3364	1729	83
03-Feb-99	1656	3236	1666	84
04-Feb-99	1559	3027	1563	90
05-Feb-99	1715	3097	1475	89
06-Feb-99	1936	3297	1447	86
07-Feb-99	1960	3302	1424	83
08-Feb-99	1907	3213	1382	77
09-Feb-99	1904	3168	1332	71
10-Feb-99	1880	3086	1269	65
11-Feb-99	1803	2938	1195	61
12-Feb-99	1576	2578	1070	65
13-Feb-99	1580	2533	1008	53
14-Feb-99	1603	2535	981	49
15-Feb-99	1560	2448	936	47
16-Feb-99	1524	2377	902	46
17-Feb-99	1448	2235	838	45
18-Feb-99	1445	2193	799	45
19-Feb-99	1495	2234	787	43
20-Feb-99	1433	2127	749	46
21-Feb-99	1396	2057	711	41
22-Feb-99	1452	2130	721	37
23-Feb-99	1500	2194	725	29

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
24-Feb-99	1425	2072	679	31
25-Feb-99	1412	2022	643	31
26-Feb-99	1364	1929	598	30
27-Feb-99	1406	1975	594	23
28-Feb-99	1342	1862	552	26
01-Mar-99	1237	1687	487	30
02-Mar-99	1321	1796	505	24
03-Mar-99	1243	1670	463	28
04-Mar-99	1262	1686	460	27
05-Mar-99	1242	1642	438	30
06-Mar-99	1326	1749	455	24
07-Mar-99	1391	1830	464	18
08-Mar-99	1374	1794	442	16
09-Mar-99	1352	1745	415	15
10-Mar-99	1361	1751	406	12
11-Mar-99	1396	1786	400	9
12-Mar-99	1324	1657	346	11
13-Mar-99	1182	1434	271	14
14-Mar-99	1151	1407	276	14
15-Mar-99	1195	1478	302	10
16-Mar-99	1098	1317	245	16
17-Mar-99	956	1108	181	22
18-Mar-99	1011	1178	194	18
19-Mar-99	1080	1274	214	15
20-Mar-99	1062	1230	195	19
21-Mar-99	1048	1197	181	21
22-Mar-99	1124	1297	202	19
23-Mar-99	1150	1331	206	15
24-Mar-99	1067	1173	137	21
25-Mar-99	1081	1176	119	17
26-Mar-99	1252	1409	167	9
27-Mar-99	1288	1472	188	2
28-Mar-99	1308	1506	206	2
29-Mar-99	1243	1369	144	11
30-Mar-99	1196	1276	106	16
31-Mar-99	1110	1129	48	21
01-Apr-99	1096	1101	38	25
02-Apr-99	1094	1098	33	24
03-Apr-99	1159	1213	76	18
04-Apr-99	1151	1227	100	19
05-Apr-99	1175	1276	125	18
06-Apr-99	1203	1295	120	21
07-Apr-99	1192	1246	82	22
08-Apr-99	1222	1282	85	20
09-Apr-99	1379	1490	126	12
10-Apr-99	1395	1523	139	9
11-Apr-99	1308	1455	164	15
12-Apr-99	1297	1458	177	14
13-Apr-99	1370	1578	218	6
14-Apr-99	1206	1335	147	12
15-Apr-99	1107	1193	114	18

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
16-Apr-99	1071	1097	61	23
17-Apr-99	1088	1104	43	25
18-Apr-99	1104	1105	49	34
19-Apr-99	1187	1210	58	34
20-Apr-99	1337	1373	78	36
21-Apr-99	1538	1608	110	37
22-Apr-99	1659	1792	168	30
23-Apr-99	1745	1976	211	-23
24-Apr-99	1834	2158	248	-76
25-Apr-99	1883	2194	227	-83
26-Apr-99	1963	2239	191	-88
27-Apr-99	2016	2316	165	-140
28-Apr-99	2020	2343	143	-188
29-Apr-99	1995	2323	126	-211
30-Apr-99	2098	2432	140	-202
01-May-99	2219	2525	148	-165
02-May-99	2283	2586	190	-120
03-May-99	2321	2645	248	-83
04-May-99	2398	2803	316	-92
05-May-99	2598	2983	299	-89
06-May-99	2967	3310	281	-64
07-May-99	3313	3602	261	-30
08-May-99	3526	3846	311	-8
09-May-99	3375	3800	412	-8
10-May-99	3139	3603	447	-13
11-May-99	2903	3332	417	-8
12-May-99	2707	3061	361	6
13-May-99	2559	2828	291	17
14-May-99	2654	2869	191	-32
15-May-99	3481	3477	-22	-33
16-May-99	5045	4661	-351	14
17-May-99	6627	5759	-763	89
18-May-99	7446	6459	-859	121
19-May-99	7363	6603	-673	88
20-May-99	6937	6564	-417	-42
21-May-99	6800	6563	-332	-94
22-May-99	6964	6677	-379	-93
23-May-99	7084	6848	-310	-76
24-May-99	7355	6998	-385	-30
25-May-99	7782	7158	-579	42
26-May-99	8274	7369	-777	125
27-May-99	8774	7631	-941	199
28-May-99	9163	7833	-1069	258
29-May-99	9372	7945	-1131	294
30-May-99	9465	8012	-1139	313
31-May-99	9687	8134	-1202	348

Table 6 Simulated Daily Average Discharges, Dry Season 2000

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
04-Jan-00	5687	9369	4279	613
05-Jan-00	4574	8474	4433	541
06-Jan-00	4174	8097	4433	516
07-Jan-00	3978	7887	4400	494
08-Jan-00	3840	7691	4333	484
09-Jan-00	3781	7563	4256	475
10-Jan-00	3759	7477	4182	466
11-Jan-00	3720	7381	4115	455
12-Jan-00	3674	7292	4056	440
13-Jan-00	3604	7203	4018	422
14-Jan-00	3488	7065	3980	405
15-Jan-00	3382	6928	3936	393
16-Jan-00	3308	6826	3895	379
17-Jan-00	3197	6676	3850	372
18-Jan-00	3066	6487	3789	368
19-Jan-00	2941	6302	3724	362
20-Jan-00	2839	6140	3656	356
21-Jan-00	2821	6078	3601	345
22-Jan-00	2798	6027	3561	334
23-Jan-00	2754	5957	3524	323
24-Jan-00	2723	5879	3475	320
25-Jan-00	2731	5822	3412	321
26-Jan-00	2789	5836	3361	315
27-Jan-00	2779	5789	3318	310
28-Jan-00	2819	5816	3292	298
29-Jan-00	2781	5763	3268	287
30-Jan-00	2671	5615	3225	282
31-Jan-00	2636	5544	3182	276
01-Feb-00	2575	5434	3130	271
02-Feb-00	2556	5375	3080	263
03-Feb-00	2523	5310	3038	253
04-Feb-00	2440	5196	2998	243
05-Feb-00	2339	5046	2942	236
06-Feb-00	2315	4984	2896	227
07-Feb-00	2255	4872	2839	224
08-Feb-00	2221	4781	2780	220
09-Feb-00	2223	4737	2726	214
10-Feb-00	2296	4795	2699	202
11-Feb-00	2257	4735	2671	195
12-Feb-00	2205	4651	2632	188
13-Feb-00	2174	4586	2591	182
14-Feb-00	2171	4545	2549	176
15-Feb-00	2101	4399	2480	181
16-Feb-00	2086	4290	2389	185
17-Feb-00	2173	4316	2326	182
18-Feb-00	2222	4300	2259	182
19-Feb-00	2304	4321	2198	181
20-Feb-00	2346	4304	2137	181
21-Feb-00	2387	4301	2089	177
22-Feb-00	2414	4296	2051	171
23-Feb-00	2430	4289	2022	165

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
24-Feb-00	2398	4245	2002	158
25-Feb-00	2272	4090	1968	152
26-Feb-00	2148	3919	1918	148
27-Feb-00	2141	3890	1885	138
28-Feb-00	2127	3859	1865	134
29-Feb-00	1985	3622	1778	140
01-Mar-00	2085	3639	1700	145
02-Mar-00	2245	3750	1647	143
03-Mar-00	2281	3751	1607	139
04-Mar-00	2258	3706	1576	130
05-Mar-00	2195	3616	1540	121
06-Mar-00	2101	3480	1492	115
07-Mar-00	2039	3373	1443	111
08-Mar-00	2024	3323	1401	105
09-Mar-00	1980	3231	1350	101
10-Mar-00	1933	3129	1292	98
11-Mar-00	1978	3129	1243	94
12-Mar-00	2022	3140	1204	90
13-Mar-00	2025	3099	1157	86
14-Mar-00	2038	3047	1093	85
15-Mar-00	2060	3025	1045	82
16-Mar-00	2096	3009	995	83
17-Mar-00	2100	2952	936	84
18-Mar-00	2063	2820	845	89
19-Mar-00	2160	2889	819	91
20-Mar-00	2149	2829	773	94
21-Mar-00	2173	2854	766	88
22-Mar-00	2168	2851	764	83
23-Mar-00	2121	2806	760	78
24-Mar-00	1981	2630	722	76
25-Mar-00	1940	2570	698	71
26-Mar-00	1968	2596	692	67
27-Mar-00	1956	2529	643	70
28-Mar-00	2000	2564	626	63
29-Mar-00	2054	2649	645	52
30-Mar-00	1979	2525	593	50
31-Mar-00	2064	2659	632	42
01-Apr-00	2059	2657	632	39
02-Apr-00	1882	2401	557	41
03-Apr-00	1766	2230	505	43
04-Apr-00	1677	2118	483	46
05-Apr-00	1614	2003	436	49
06-Apr-00	1629	2017	430	45
07-Apr-00	1584	1940	397	44
08-Apr-00	1541	1866	370	47
09-Apr-00	1565	1904	388	50
10-Apr-00	1630	1993	409	48
11-Apr-00	1761	2172	448	40
12-Apr-00	1803	2211	444	38
13-Apr-00	1920	2344	458	37
14-Apr-00	1914	2279	405	42

Date	Chrui Changvar	Koh Norea	Phnom Penh Port
15-Apr-00	1856	2244	430
16-Apr-00	1877	2209	376
17-Apr-00	1946	2173	288
18-Apr-00	2172	2327	235
19-Apr-00	2378	2577	284
20-Apr-00	2539	2811	364
21-Apr-00	2665	2937	364
22-Apr-00	2718	3049	414
23-Apr-00	2732	3095	439
24-Apr-00	2744	3096	427
25-Apr-00	2778	3130	423
26-Apr-00	2758	3100	410
27-Apr-00	2710	2991	352
28-Apr-00	2744	3010	338
29-Apr-00	2787	3014	307
30-Apr-00	2887	3126	328
01-May-00	2974	3206	326
02-May-00	3034	3203	275
03-May-00	3139	3277	253
04-May-00	3133	3338	310
05-May-00	3079	3321	325
06-May-00	3187	3344	252
07-May-00	3506	3603	215
08-May-00	3636	3792	278
09-May-00	3604	3859	369
10-May-00	3550	3858	414
11-May-00	3560	3867	414
12-May-00	3663	3881	331
13-May-00	3891	4032	270
14-May-00	4262	4204	109
15-May-00	4665	4523	55
16-May-00	5061	4839	-1
17-May-00	5660	5174	-241
18-May-00	6380	5636	-455
19-May-00	7074	6087	-656
20-May-00	7496	6366	-779
21-May-00	7797	6596	-833
22-May-00	8286	6903	-981
23-May-00	9743	7769	-1445
24-May-00	13350	9995	-2501
25-May-00	17666	12804	-3647
26-May-00	20078	14466	-4256
27-May-00	20291	14719	-4262
28-May-00	19672	14382	-4058
29-May-00	18784	13847	-3797
30-May-00	17890	13282	-3543
31-May-00	17108	12775	-3324

Table 7 Simulated Daily Average Discharges, Dry Season 2001

Date	Chrui Changvar	Koh Norea	Phnom Penh Port	Monivong Bridge
04-Jan-01	5353	5353	4690	626
05-Jan-01	4618	4618	4753	556
06-Jan-01	4309	4309	4697	523
07-Jan-01	4181	4181	4624	484
08-Jan-01	4098	4098	4547	465
09-Jan-01	4031	4031	4460	459
10-Jan-01	3979	3979	4372	457
11-Jan-01	3935	3935	4286	453
12-Jan-01	3783	3783	4230	433
13-Jan-01	3617	3617	4180	416
14-Jan-01	3566	3566	4098	347
15-Jan-01	3511	3511	4020	291
16-Jan-01	3500	3500	3968	272
17-Jan-01	3464	3464	3929	274
18-Jan-01	3448	3448	3910	279
19-Jan-01	3364	3364	3893	289
20-Jan-01	3222	3222	3854	302
21-Jan-01	3144	3144	3807	309
22-Jan-01	3104	3104	3755	314
23-Jan-01	3082	3082	3706	316
24-Jan-01	3064	3064	3660	316
25-Jan-01	3046	3046	3612	315
26-Jan-01	3045	3045	3565	312
27-Jan-01	3034	3034	3515	309
28-Jan-01	3014	3014	3467	305
29-Jan-01	2961	2961	3414	299
30-Jan-01	2884	2884	3356	290
31-Jan-01	2871	2871	3313	278
01-Feb-01	2863	2863	3272	270
02-Feb-01	2864	2864	3237	263
03-Feb-01	2829	2829	3191	260
04-Feb-01	2798	2798	3144	257
05-Feb-01	2755	2755	3092	255
06-Feb-01	2709	2709	3028	255
07-Feb-01	2702	2702	2973	250
08-Feb-01	2638	2638	2899	251
09-Feb-01	2625	2625	2828	248
10-Feb-01	2619	2619	2764	243
11-Feb-01	2633	2633	2705	239
12-Feb-01	2634	2634	2650	236
13-Feb-01	2632	2632	2597	232
14-Feb-01	2662	2662	2562	224
15-Feb-01	2628	2628	2530	218
16-Feb-01	2566	2566	2491	211
17-Feb-01	2599	2599	2482	195
18-Feb-01	2502	2502	2456	188
19-Feb-01	2420	2420	2410	185
20-Feb-01	2418	2418	2364	179
21-Feb-01	2410	2410	2314	174
22-Feb-01	2382	2382	2259	171
23-Feb-01	2378	2378	2209	165
24-Feb-01	2383	2383	2170	159
25-Feb-01	2352	2352	2126	155
26-Feb-01	2298	2298	2066	154
27-Feb-01	2280	2280	2004	151
28-Feb-01	2292	2292	1956	147
01-Mar-01	2274	2274	1903	145
02-Mar-01	2244	2244	1834	146
03-Mar-01	2306	2306	1790	142
04-Mar-01	2376	2376	1776	133
05-Mar-01	2337	2337	1753	130
06-Mar-01	2163	2163	1674	134
07-Mar-01	2224	2224	1630	125
08-Mar-01	2232	2232	1589	121
09-Mar-01	2120	2120	1501	121
10-Mar-01	2084	2084	1416	118
11-Mar-01	2109	2109	1375	115
12-Mar-01	2101	2101	1360	113
13-Mar-01	2039	2039	1315	111
14-Mar-01	2038	2038	1295	102
15-Mar-01	2081	2081	1294	98
16-Mar-01	2164	2164	1272	95
17-Mar-01	2252	2252	1254	92
18-Mar-01	2311	2311	1236	89
19-Mar-01	2216	2216	1206	95
20-Mar-01	2204	2204	1187	85
21-Mar-01	2291	2291	1210	72
22-Mar-01	2335	2335	1177	71
23-Mar-01	2378	2378	1089	72
24-Mar-01	2431	2431	1020	76
25-Mar-01	2469	2469	1001	79
26-Mar-01	2467	2467	1011	79
27-Mar-01	2415	2415	972	83
28-Mar-01	2440	2440	935	85
29-Mar-01	2476	2476	894	92
30-Mar-01	2539	2539	860	95
31-Mar-01	2615	2615	822	103
01-Apr-01	2745	2745	763	111
02-Apr-01	2917	2917	723	119
03-Apr-01	3021	3021	705	125
04-Apr-01	3085	3085	730	123
05-Apr-01	3065	3065	748	115
06-Apr-01	2965	2965	723	110
07-Apr-01	2873	2873	700	106
08-Apr-01	2805	2805	674	99
09-Apr-01	2705	2705	646	97
10-Apr-01	2618	2618	627	93
11-Apr-01	2586	2586	642	86
12-Apr-01	2563	2563	641	81
13-Apr-01	2498	2498	608	79
14-Apr-01	2396	2396	564	76
15-Apr-01	2348	2348	577	72
16-Apr-01	2305	2305	553	66
17-Apr-01	2289	2289	530	62
18-Apr-01	2326	2326	547	56
19-Apr-01	2324	2324	542	51
20-Apr-01	2289	2289	502	49
21-Apr-01	2227	2227	456	49
22-Apr-01	2149	2149	410	51
23-Apr-01	2113	2113	403	50
24-Apr-01	2073	2073	378	49
25-Apr-01	1996	1996	354	54
26-Apr-01	1978	1978	313	55
27-Apr-01	1941	1941	261	60
28-Apr-01	2017	2017	295	58
29-Apr-01	2099	2099	311	51
30-Apr-01	2184	2184	352	48
01-May-01	2231	2231	354	45
02-May-01	2228	2228	331	46
03-May-01	2249	2249	358	46
04-May-01	2220	2220	318	47
05-May-01	2125	2125	257	53
06-May-01	2147	2147	204	58
07-May-01	2251	2251	234	55
08-May-01	2230	2230	236	56
09-May-01	2242	2242	261	53
10-May-01	2258	2258	278	47
11-May-01	2266	2266	290	45
12-May-01	2194	2194	273	51
13-May-01	2248	2248	283	49
14-May-01	2348	2348	335	46
15-May-01	2324	2324	318	52
16-May-01	2354	2354	368	63
17-May-01	2656	2656	409	80
18-May-01	3194	3194	314	108
19-May-01	3739	3739	208	133
20-May-01	4034	4034	246	151
21-May-01	4229	4229	256	162
22-May-01	4453	4453	244	173
23-May-01	4540	4540	264	177
24-May-01	4384	4384	340	163
25-May-01	4121	4121	409	144
26-May-01	3927	3927	400	136
27-May-01	3889	3889	372	142
28-May-01	4039	4039	406	159
29-May-01	4442	4442	388	183
30-May-01	5035	5035	277	215
31-May-01	5757	5757	34	254

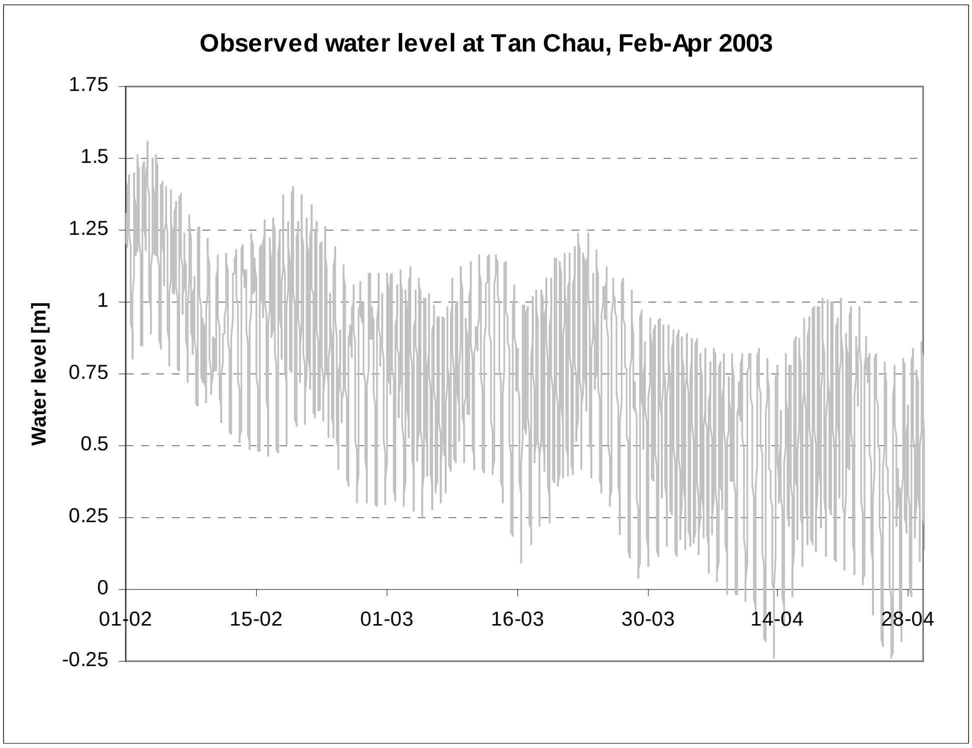


Fig. 2.1 Hourly Water Level at Tan Chau, February to April 2003

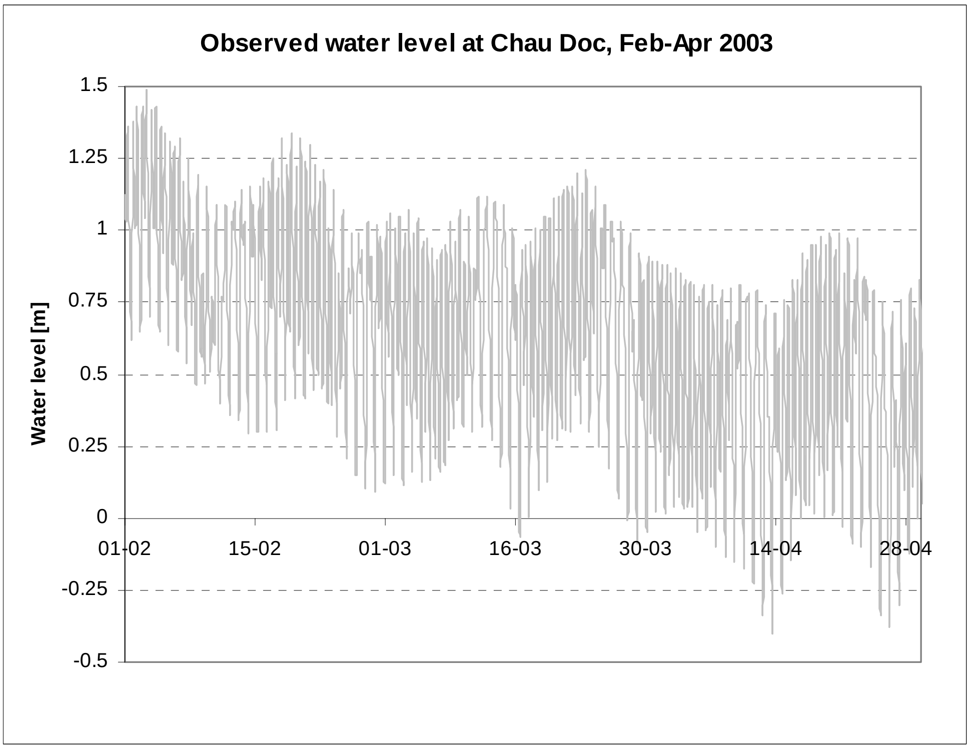


Fig. 2.2 Hourly Water Level at Chau Doc, February to April 2003

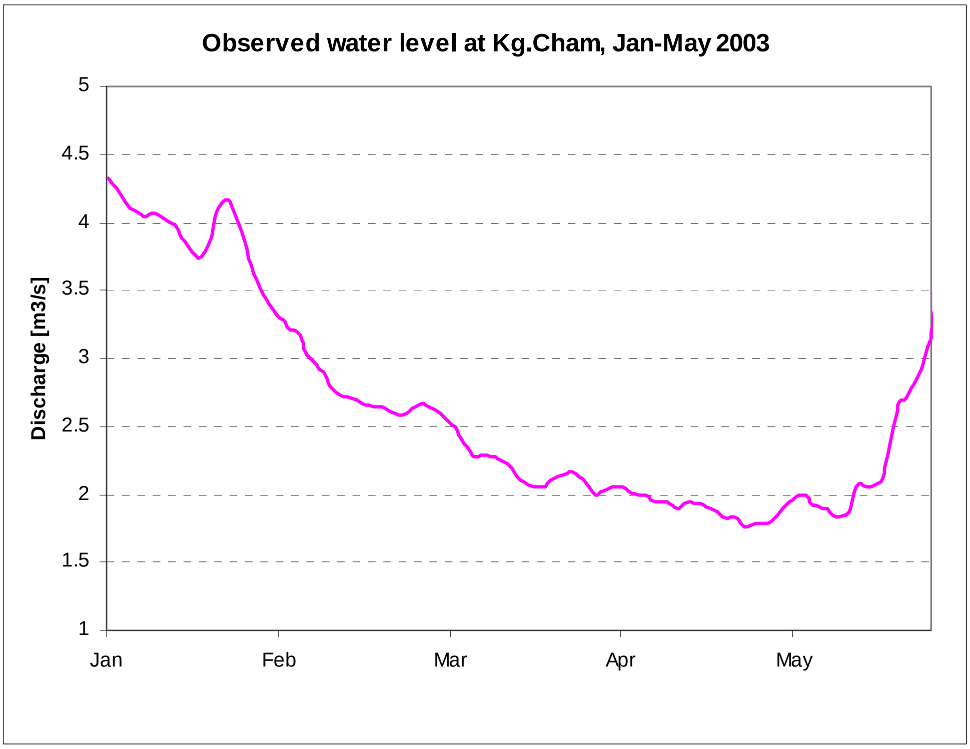


Fig. 2.3 Daily Water Level at Kompong Cham, January to May 2003

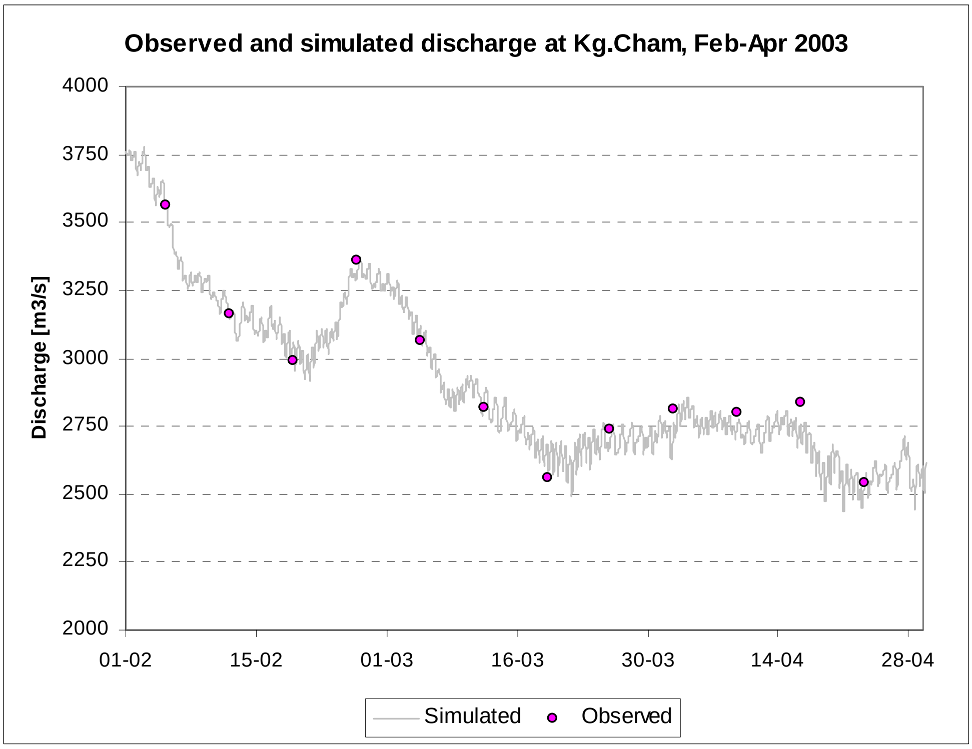


Fig. 2.4 Weekly Discharge Measurement at Kompong Cham, February to April 2003

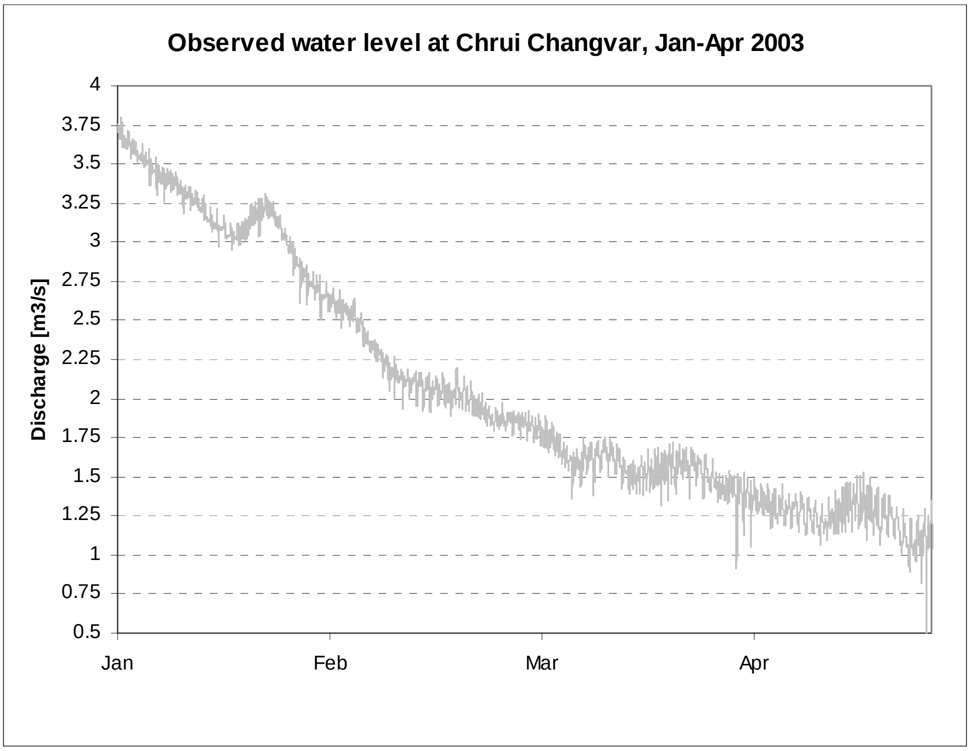


Fig. 2.5 Hourly Water Levels at Chrui Changvar, January to April 2003

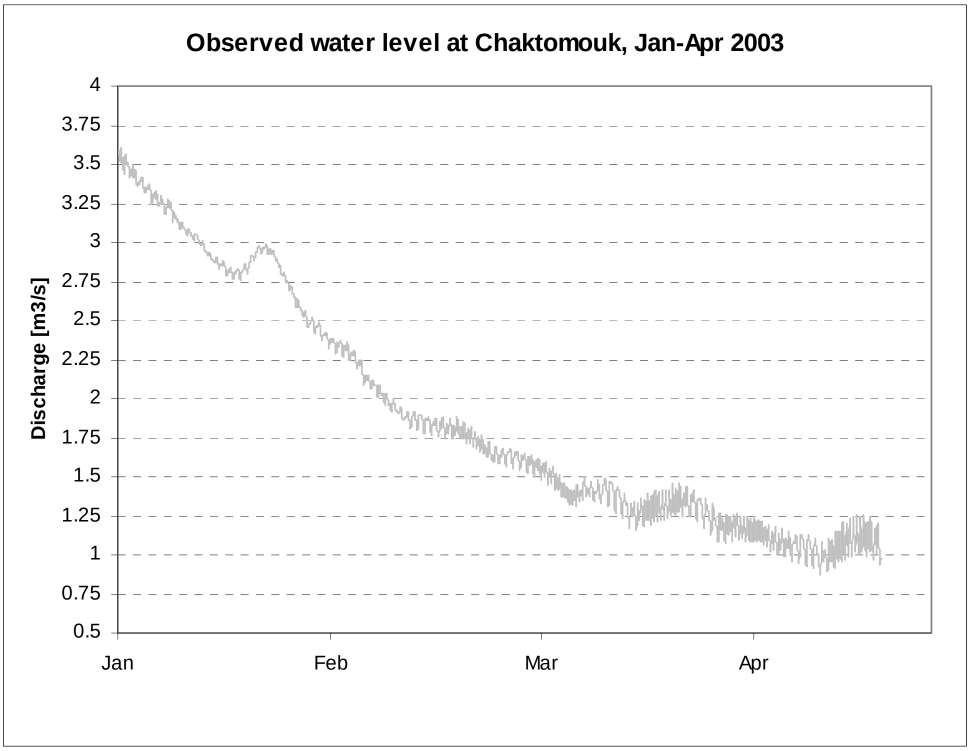


Fig. 2.6 Hourly Water Levels at Chaktomouk, January to April 2003

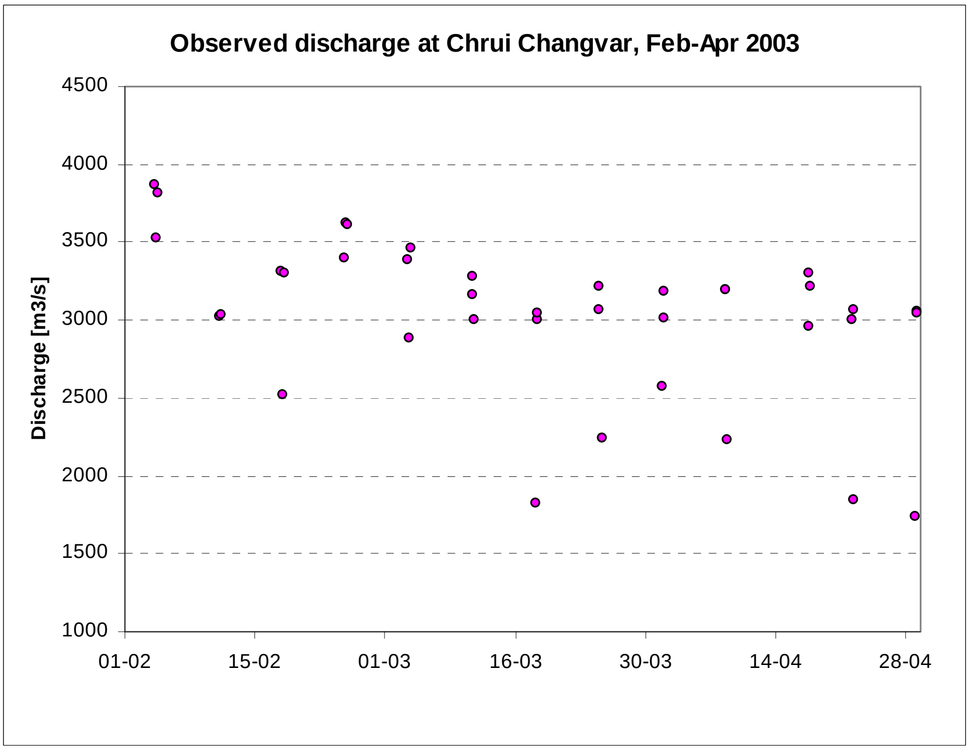


Fig. 2.7 Weekly Discharge Measurements at Chrui Changvar, February to April 2003

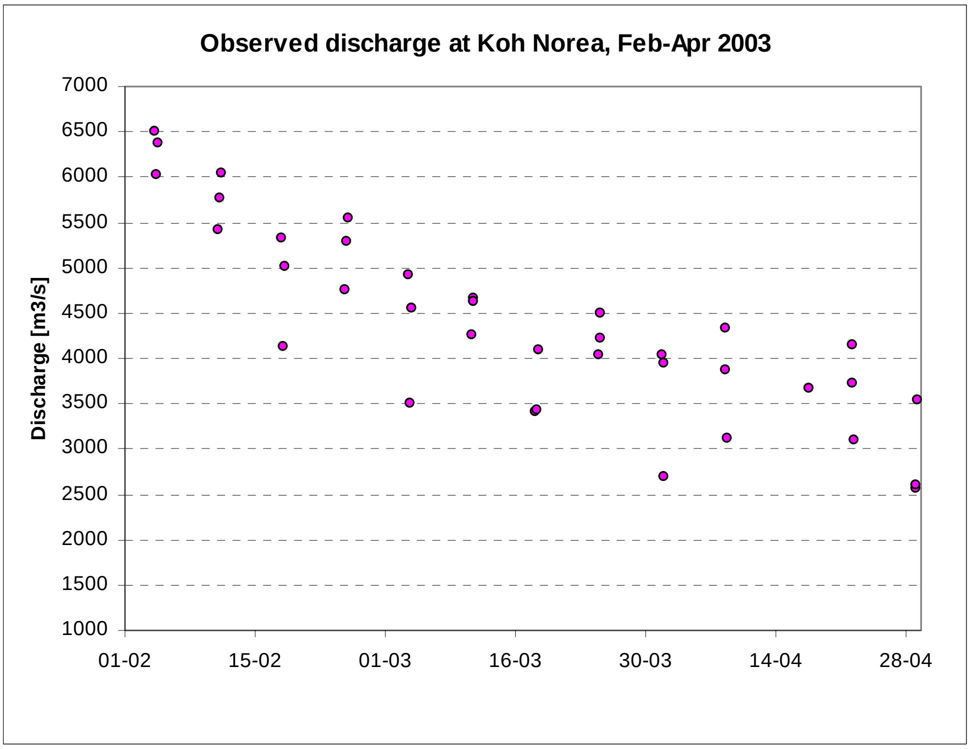


Fig. 2.8 Weekly Discharge Measurements at Koh Norea, February to April 2003

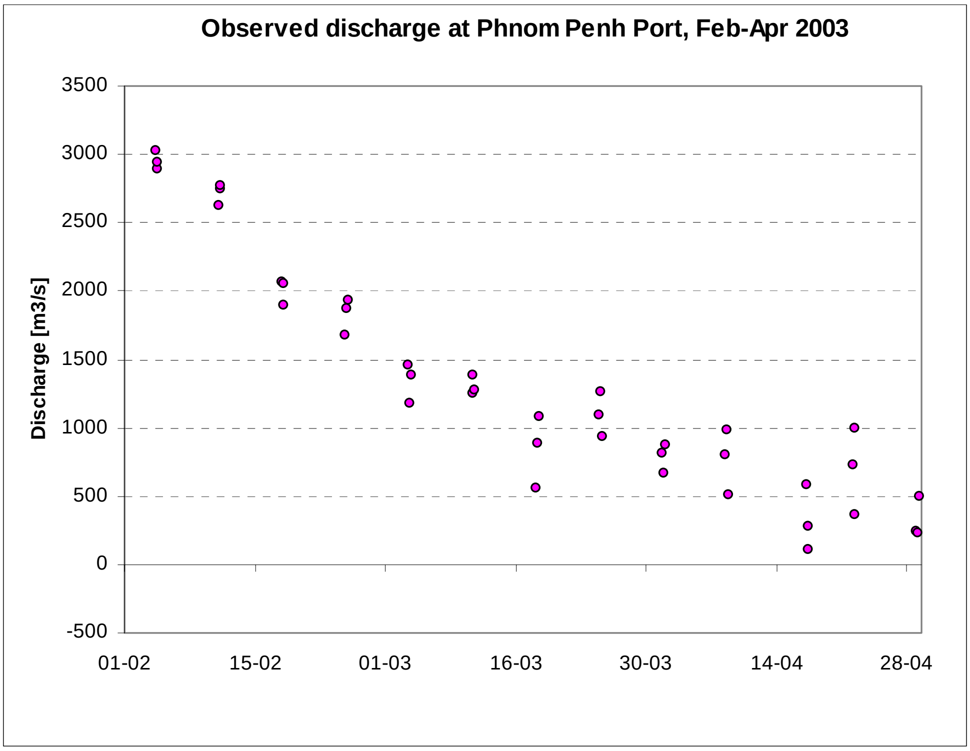


Fig. 2.9 Weekly Discharge Measurements at Phnom Penh Port, February to April 2003

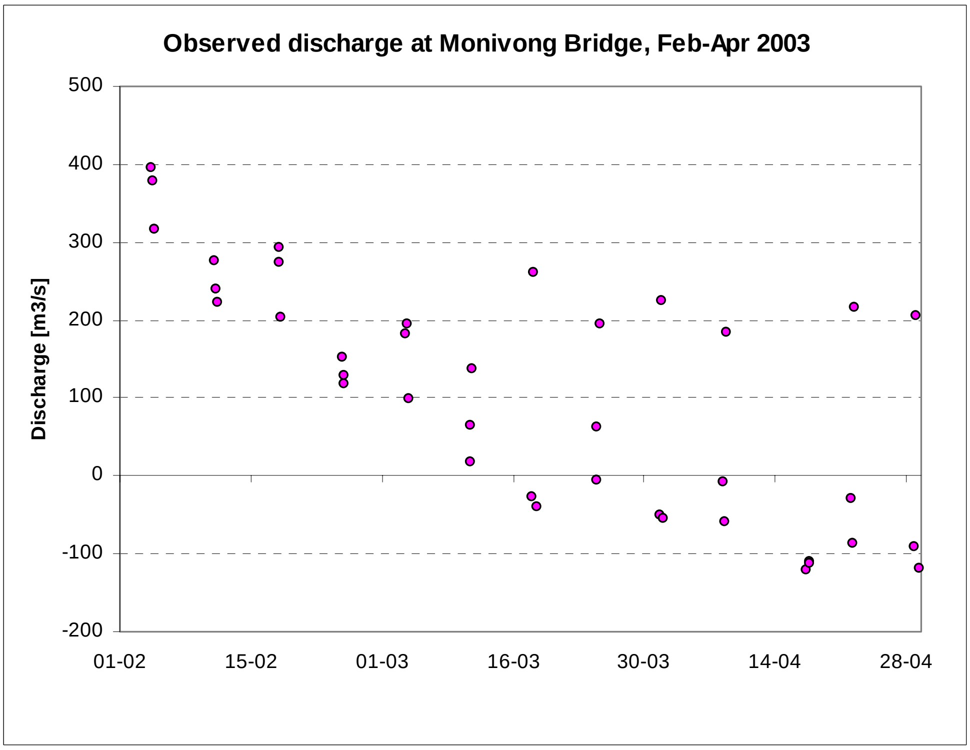


Fig. 2.10 Weekly Discharge Measurements at Monivong Bridge, February to April 2003

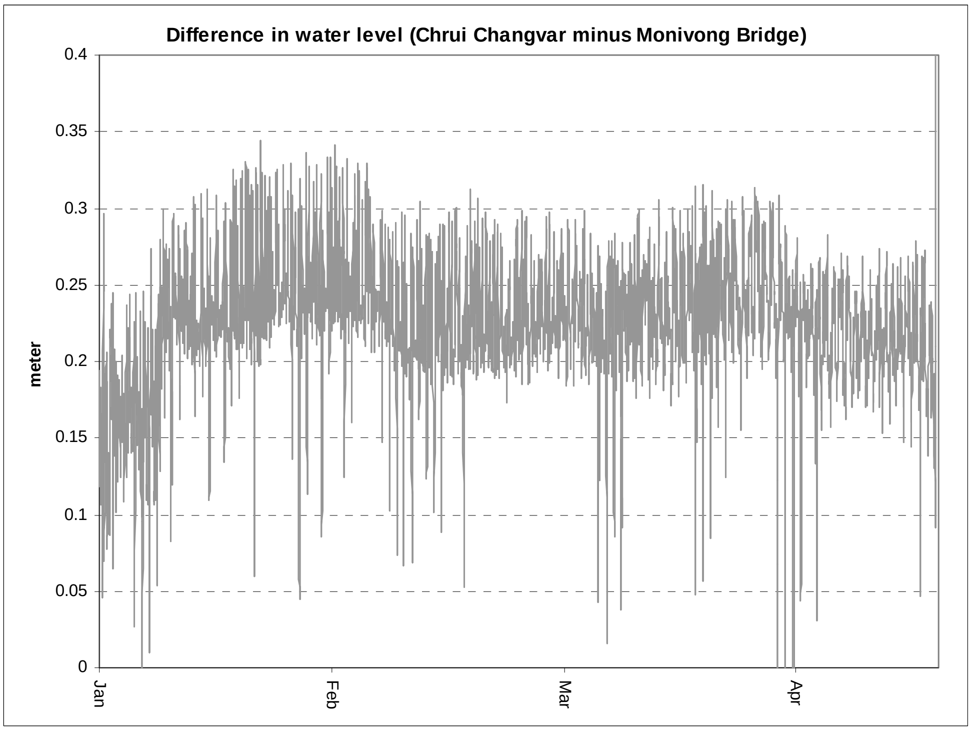


Fig. 2.11 Difference in Water Level between Chrui Changvar and Chaktomouk, January to April 2003

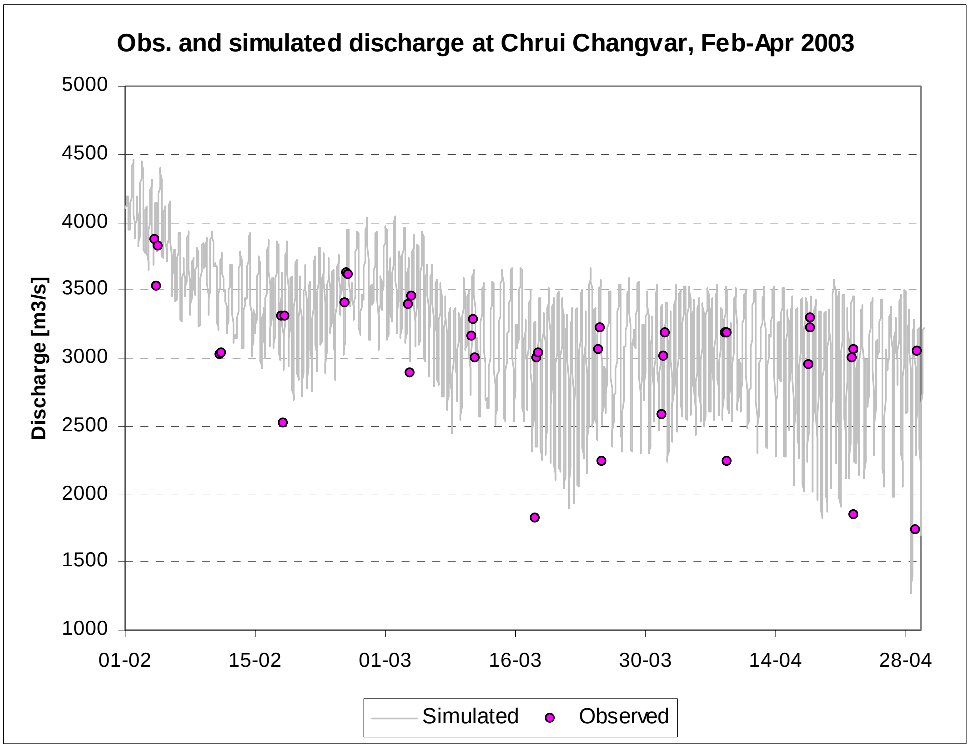


Fig. 2.12a Simulated and Observed Discharge at Chrui Changvar, February to April 2003

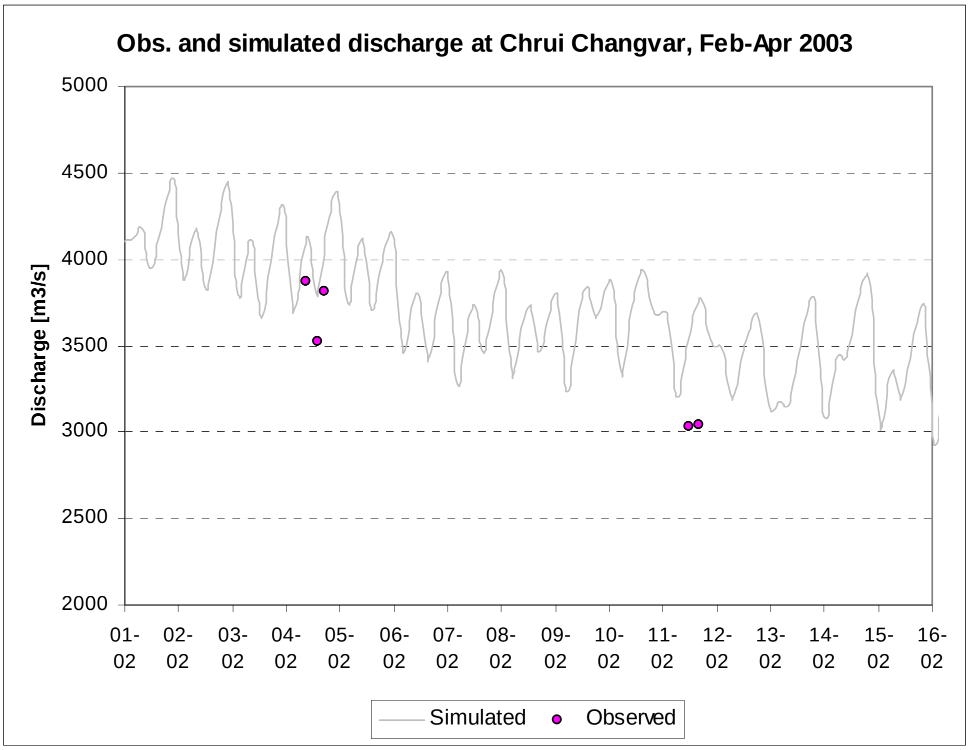


Fig. 2.12b Simulated and Observed Discharge at Chrui Changvar, First Half of February 2003

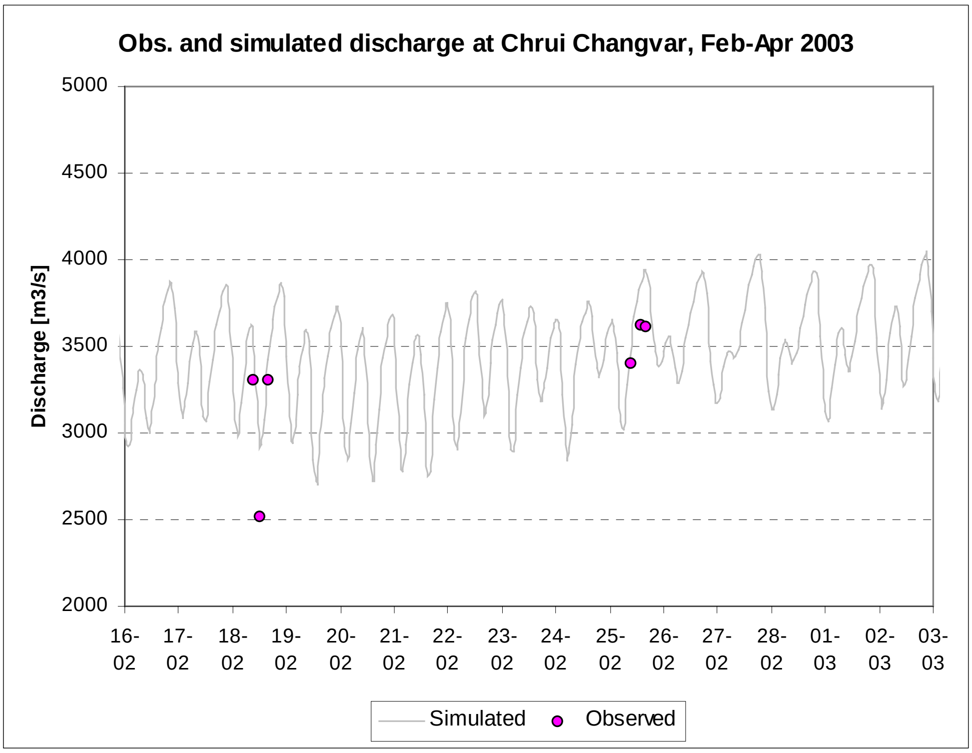


Fig. 2.12c Simulated and Observed Discharge at Chrui Changvar, Second Half of February 2003

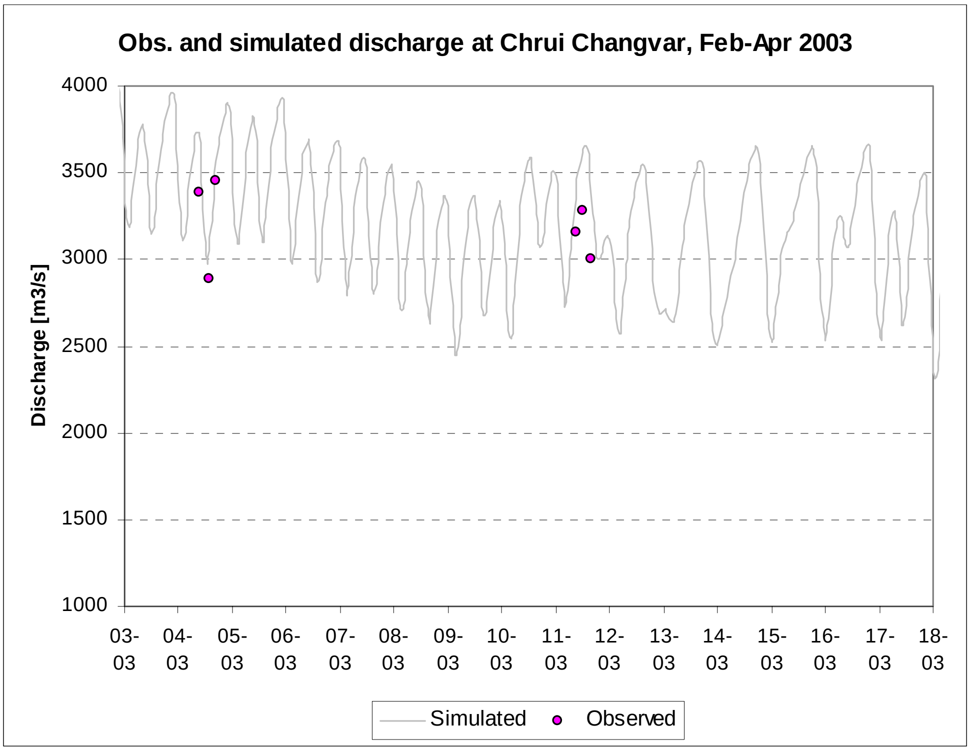


Fig. 2.12d Simulated and Observed Discharge at Chrui Changvar, First Half of March 2003

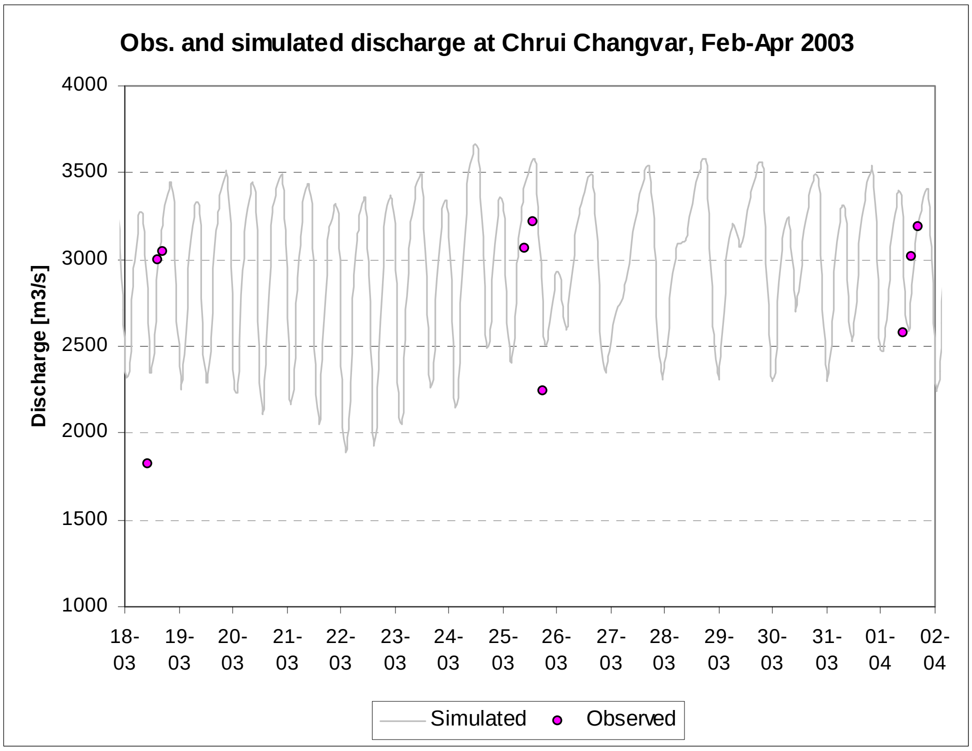


Fig. 2.12e Simulated and Observed Discharge at Chrui Changvar, Second Half of March 2003

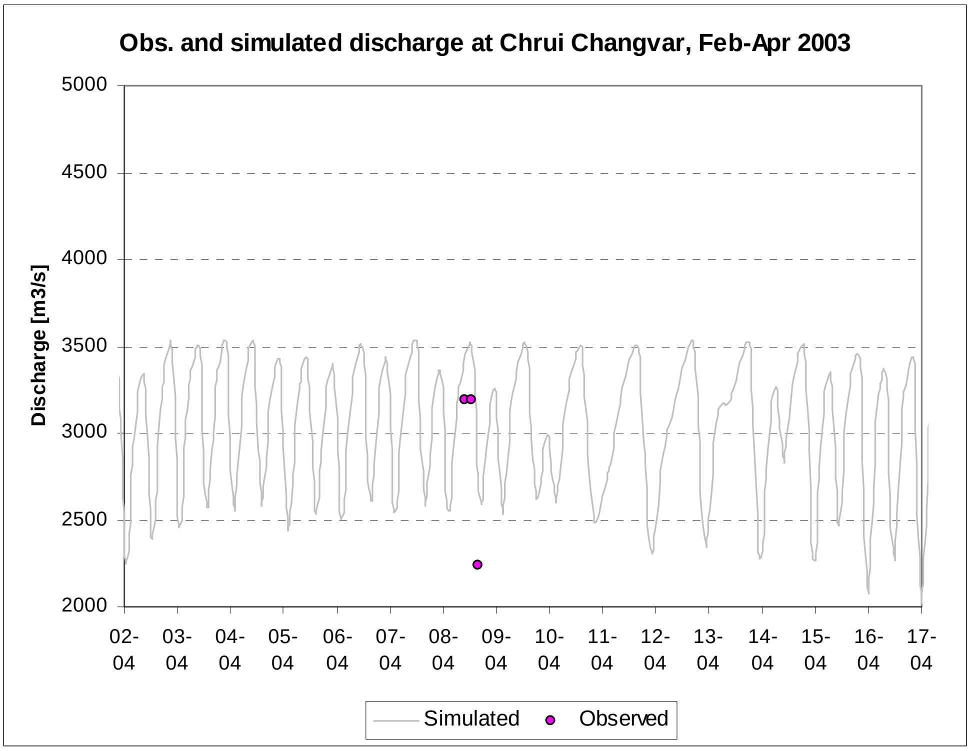


Fig. 2.12f Simulated and Observed Discharge at Chrui Changvar, First Half of April 2003

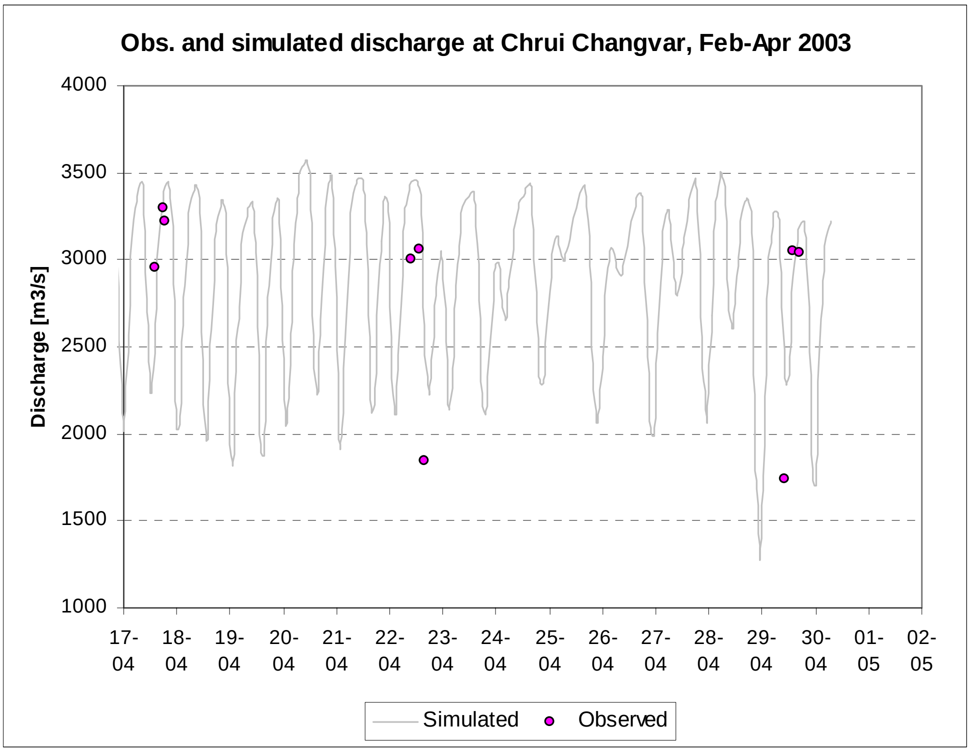


Fig. 2.12g Simulated and Observed Discharge at Chrui Changvar, Second Half of April 2003

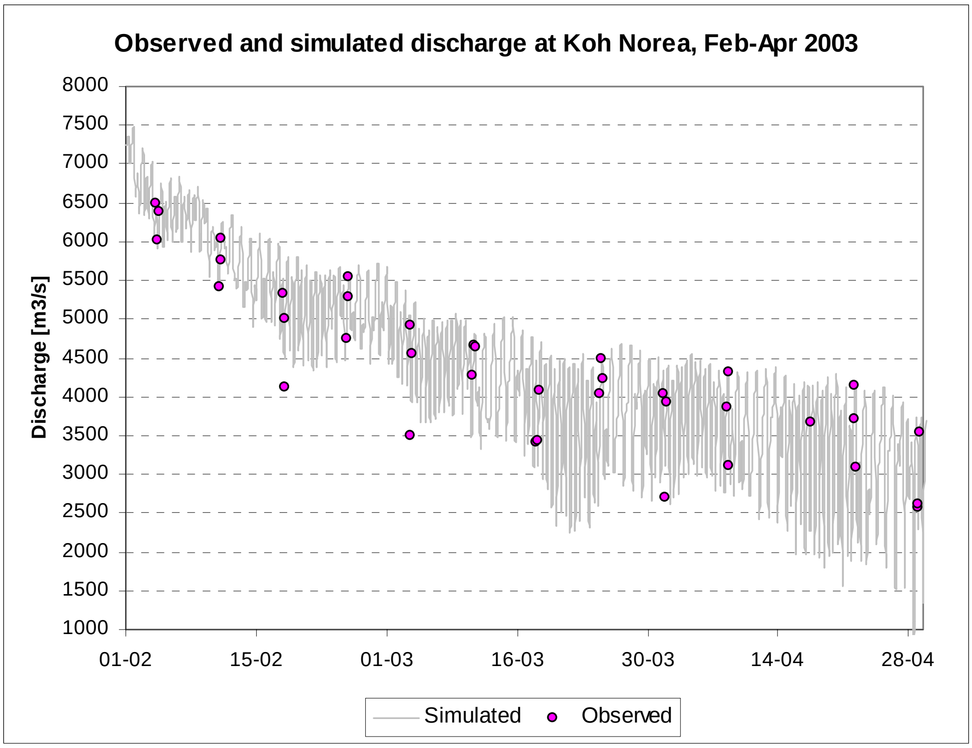


Fig. 2.13a Simulated and Observed Discharge at Koh Norea, February to April 2003

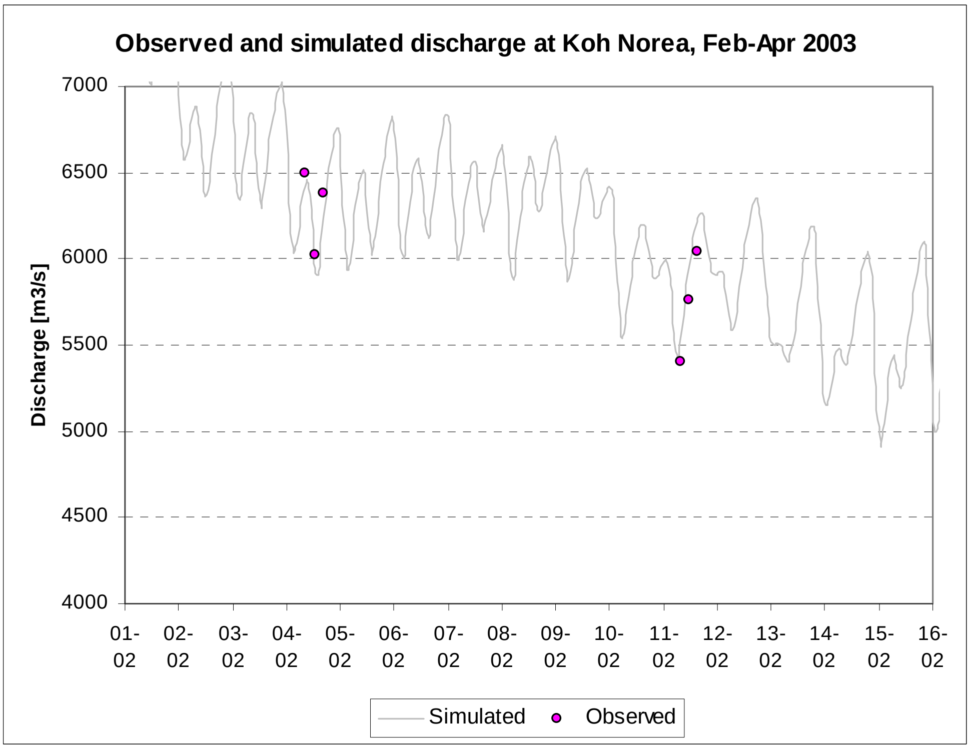


Fig. 2.13b Simulated and Observed Discharge at Koh Norea, First Half of February 2003

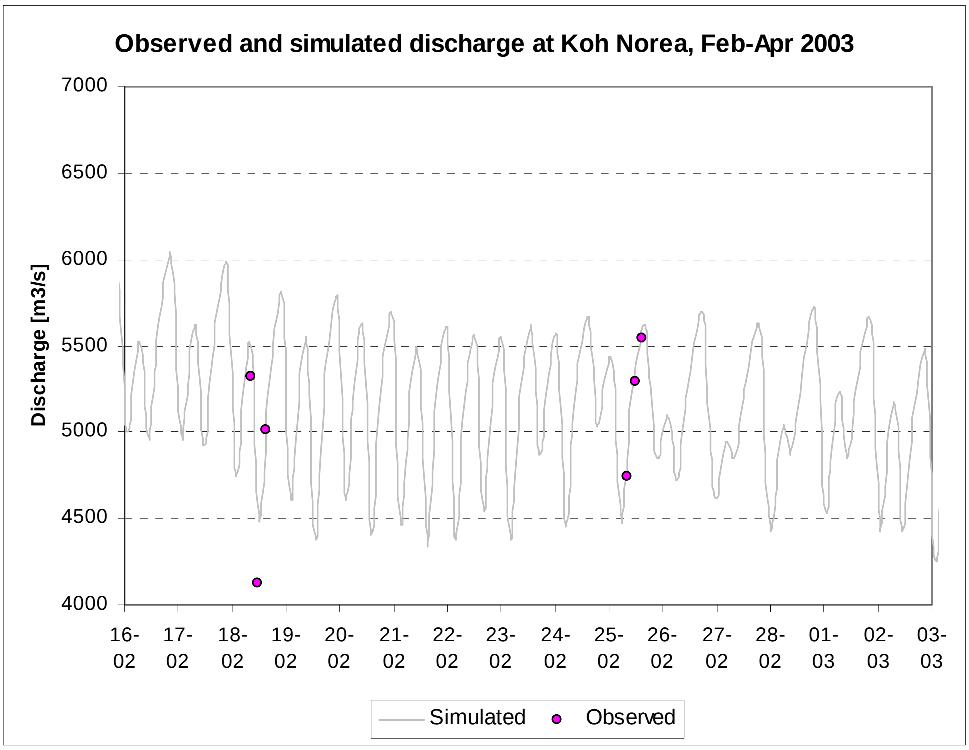


Fig. 2.13c Simulated and Observed Discharge at Koh Norea, Second Half of February 2003

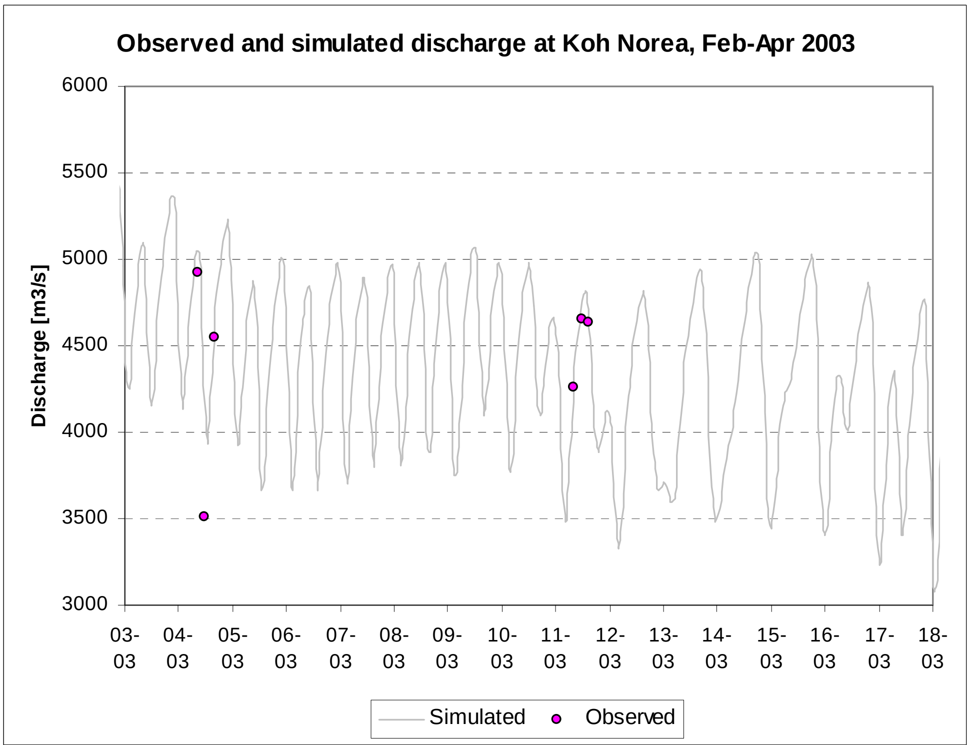


Fig. 2.13d Simulated and Observed Discharge at Koh Norea, First Half of March 2003

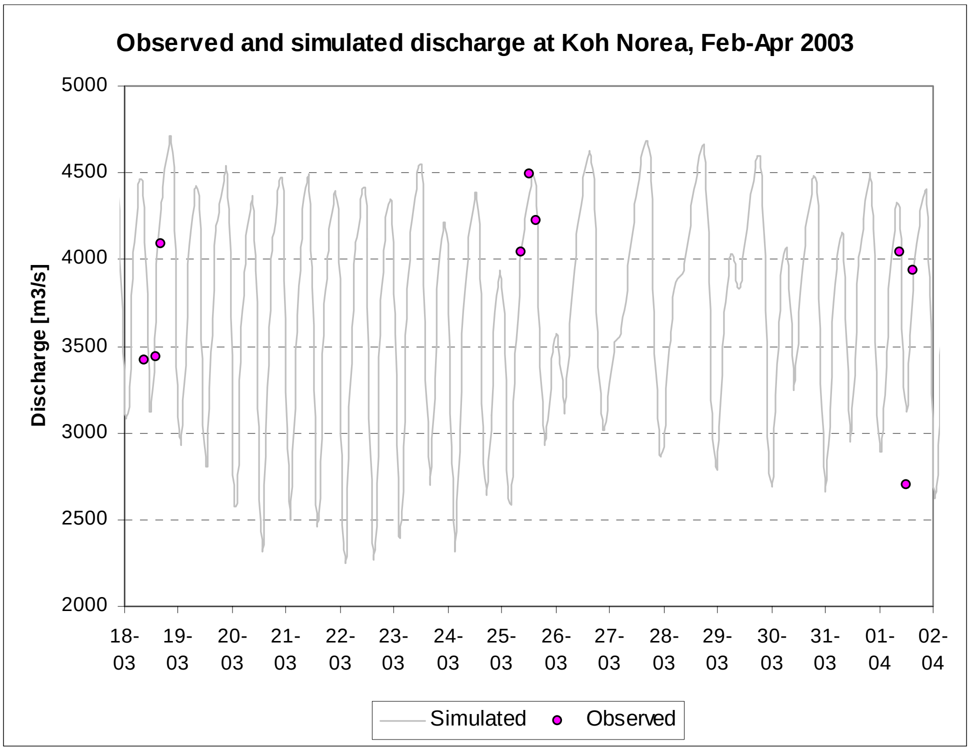


Fig. 2.13e Simulated and Observed Discharge at Koh Norea, Second Half of March 2003

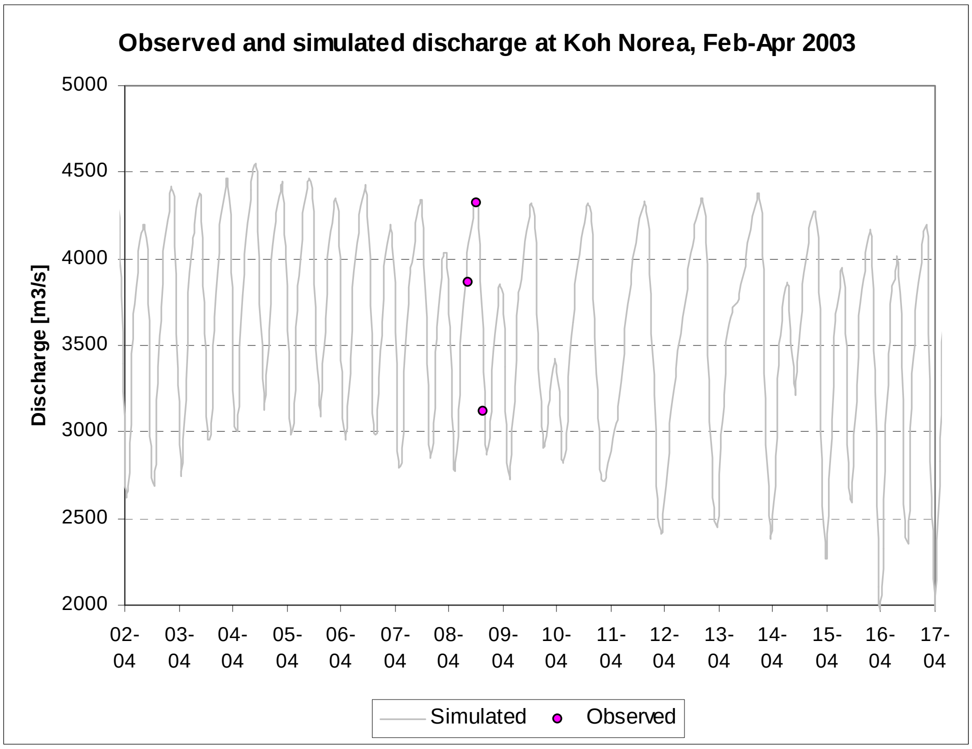


Fig. 2.13f Simulated and Observed Discharge at Koh Norea, First Half of April 2003

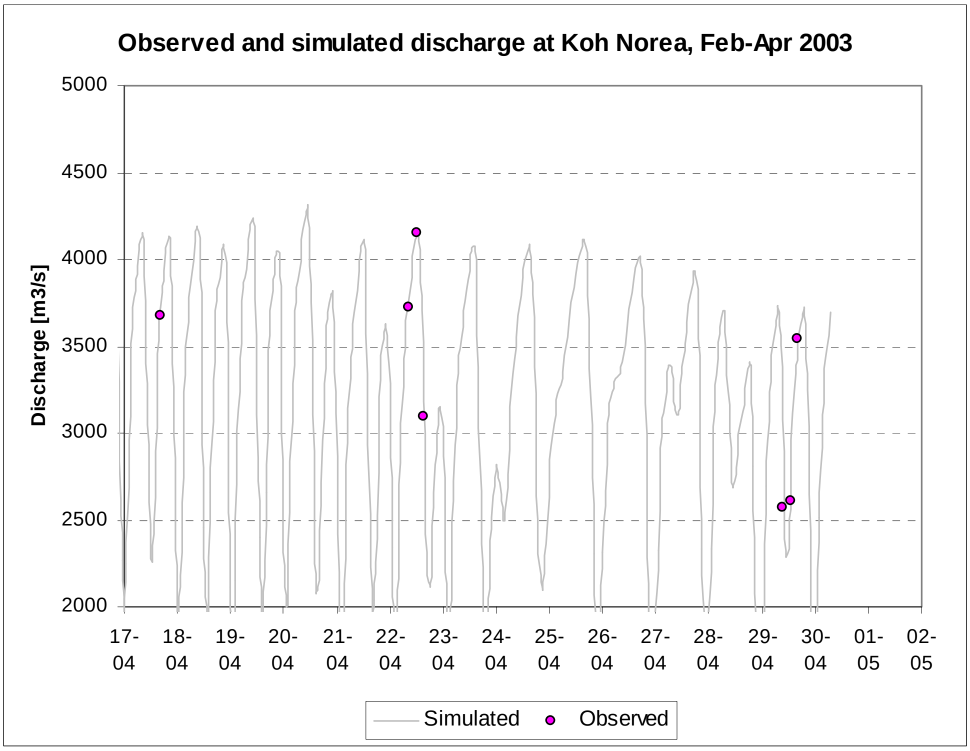


Fig. 2.13g Simulated and Observed Discharge at Koh Norea, Second Half of April 2003

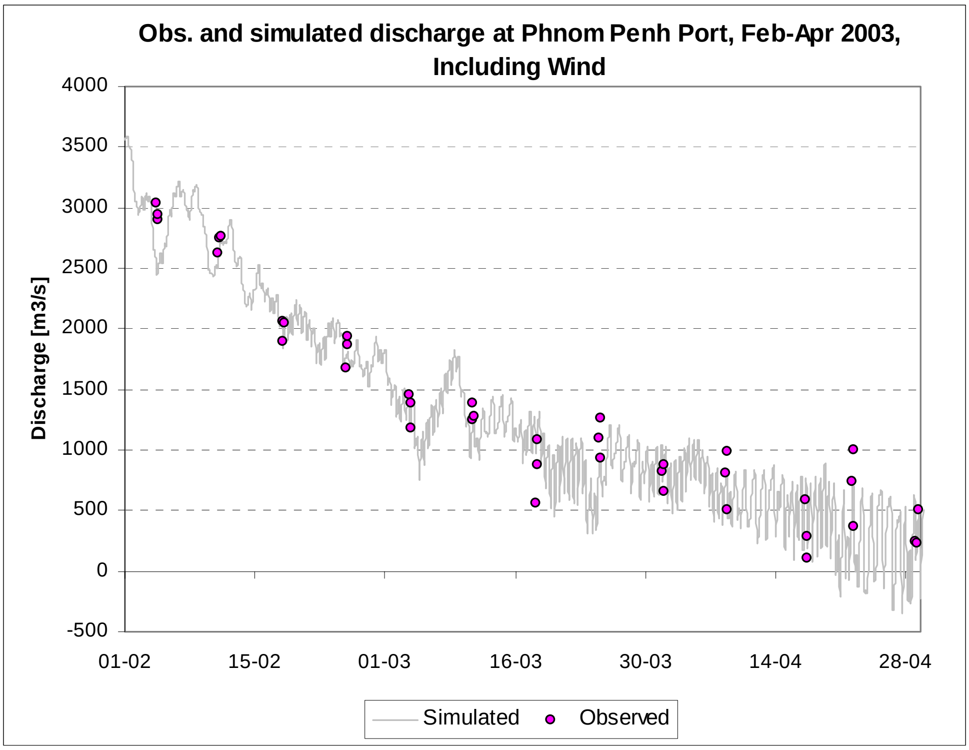


Fig. 2.14a(1/2) Simulated and Observed Discharge at Phnom Penh Port, February to May 2003 -- <u>including wind</u>

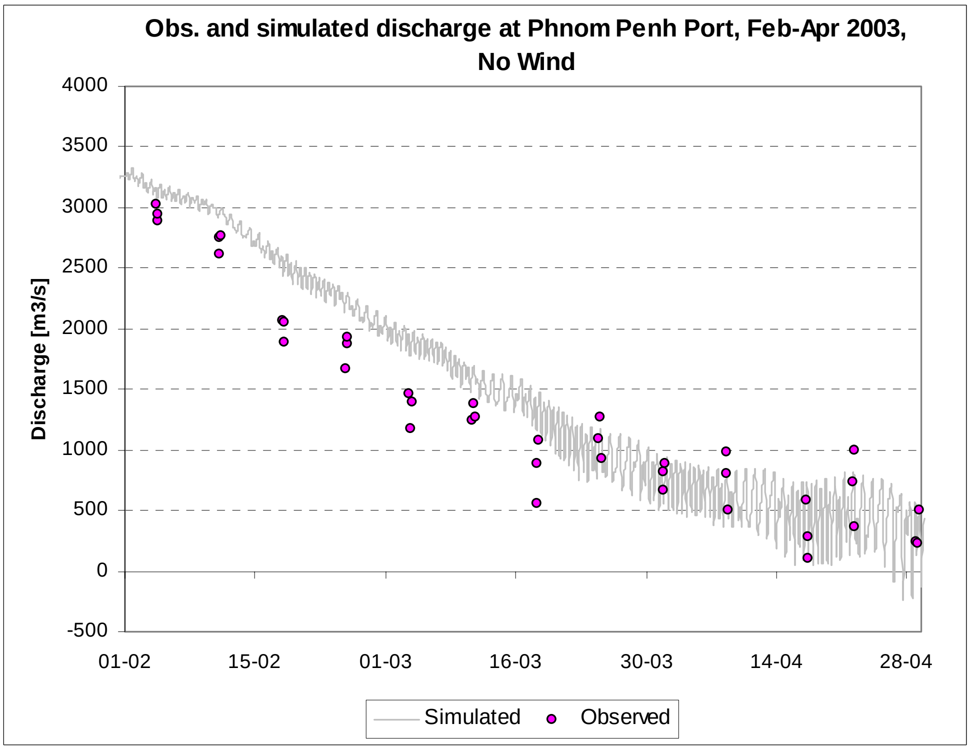


Fig. 2.14a(2/2) Simulated and Observed Discharge at Phnom Penh Port, February to May 2003 -- <u>no wind</u>

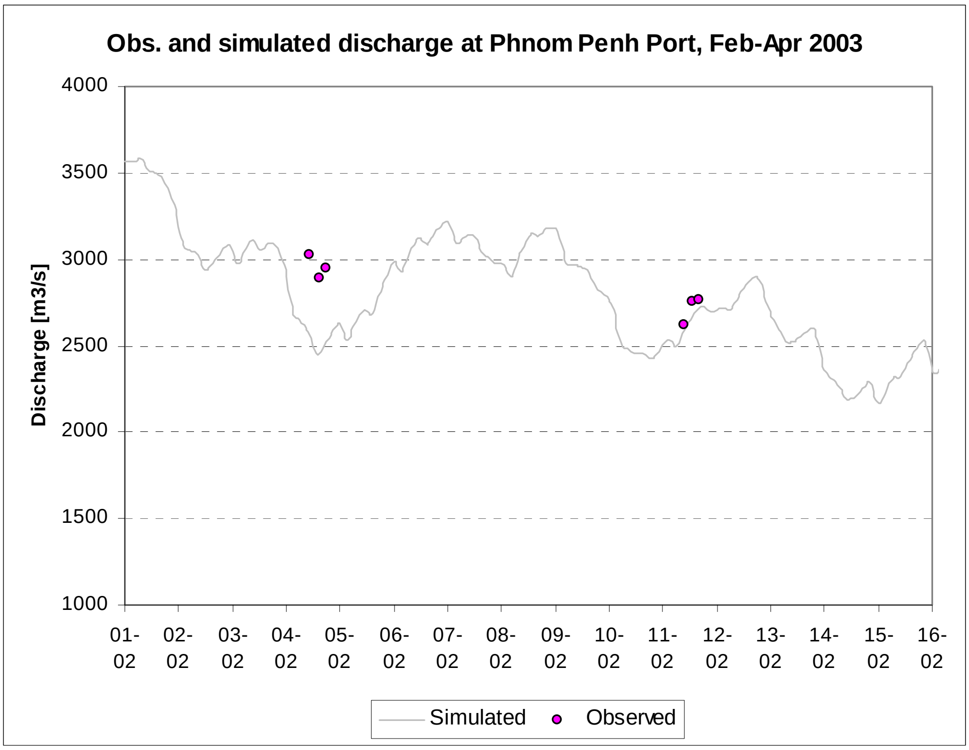


Fig. 2.14b Simulated and Observed Discharge at Phnom Penh Port, First Half of February 2003

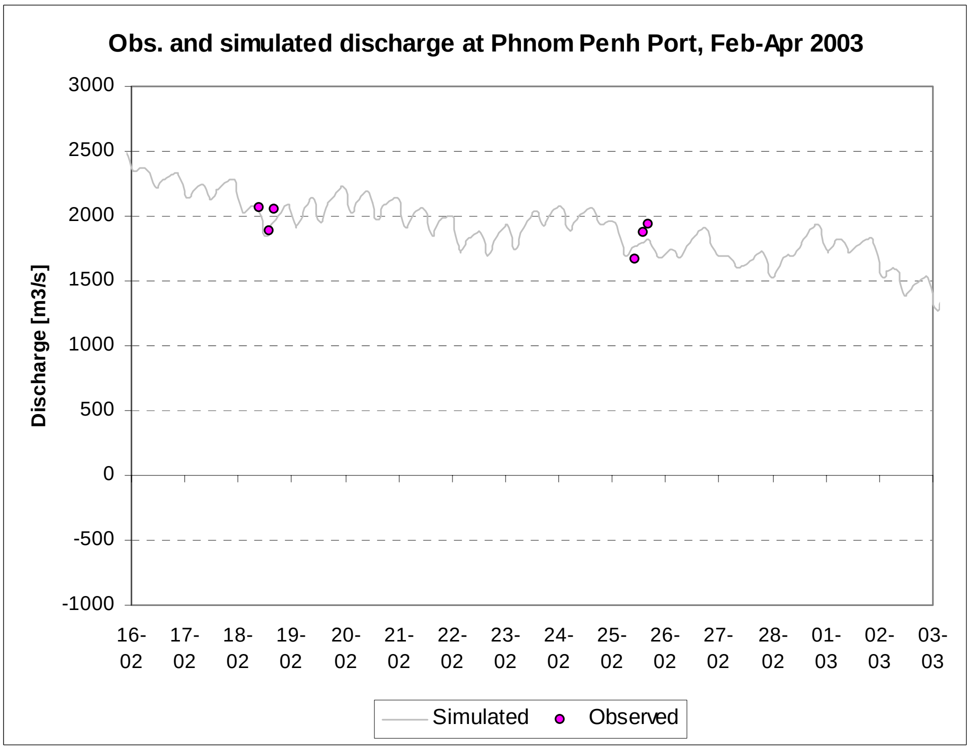


Fig. 2.14c Simulated and Observed Discharge at Phnom Penh Port, Second Half of February 2003.

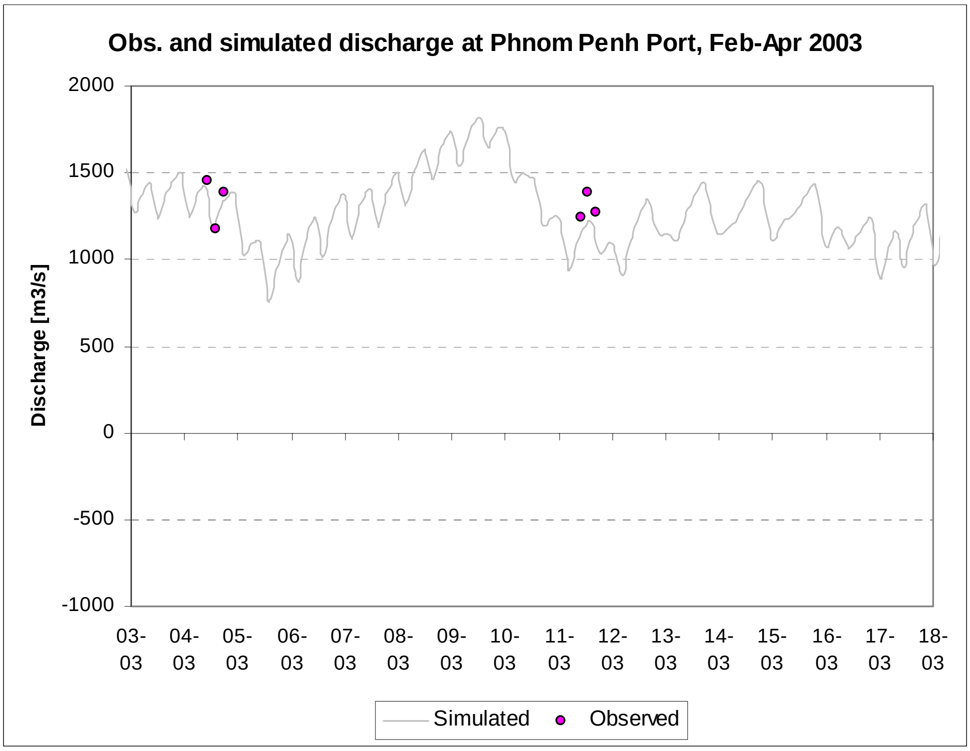


Fig. 2.14d Simulated and Observed Discharge at Phnom Penh Port, First Half of March 2003

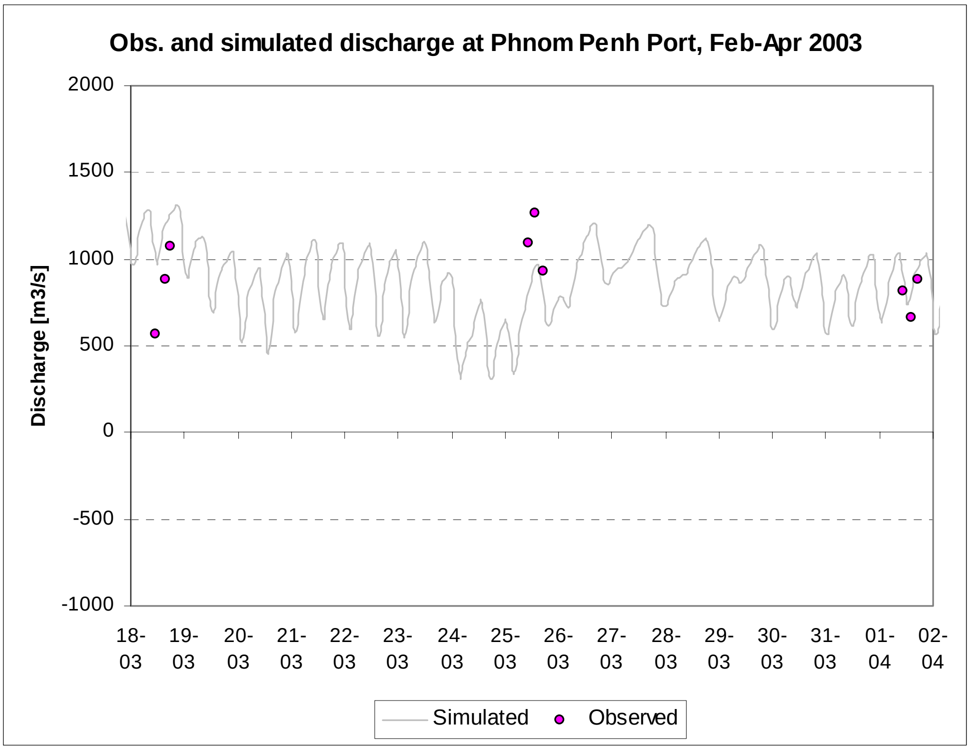


Fig. 2.14e Simulated and Observed Discharge at Phnom Penh Port, Second Half of March 2003

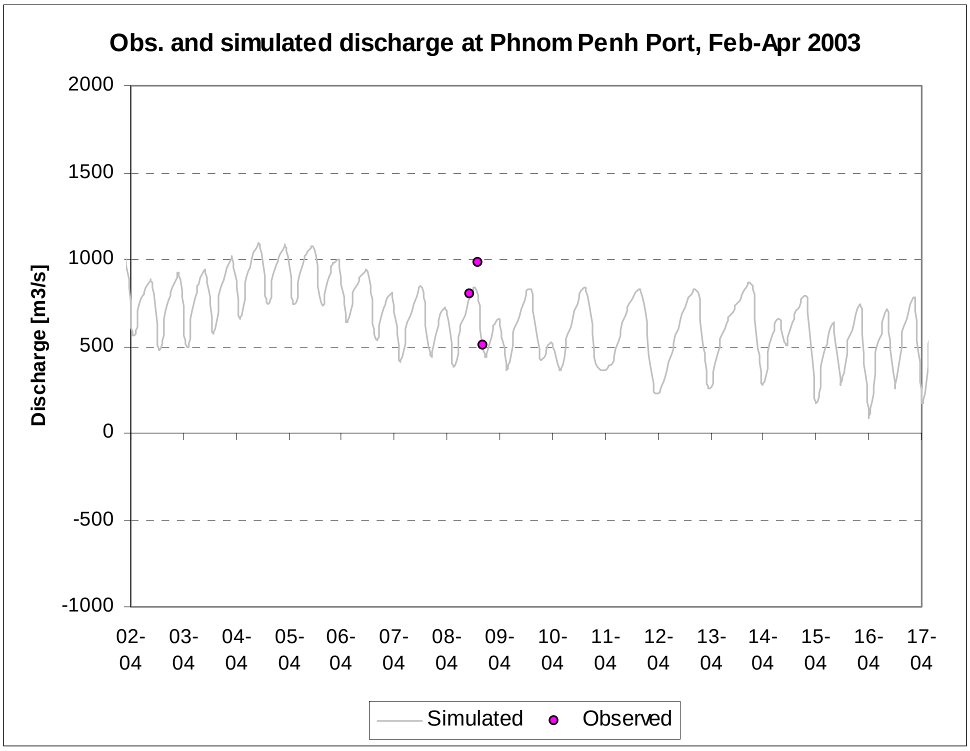


Fig. 2.14f Simulated and Observed Discharge at Phnom Penh Port, First Half of April 2003

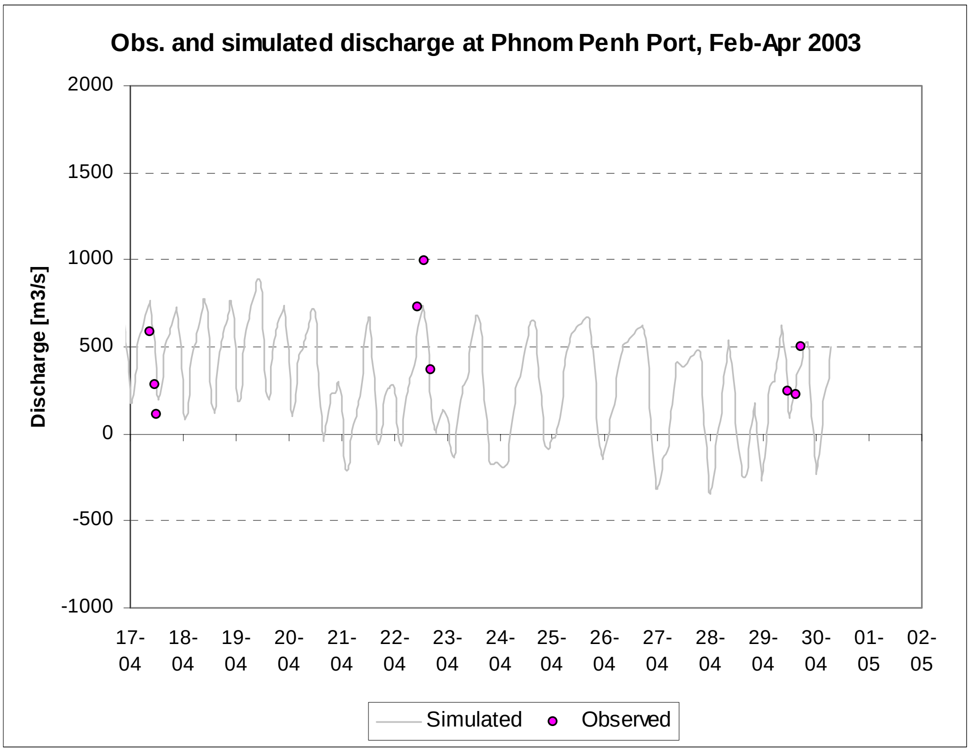


Fig. 2.14h Simulated and Observed Discharge at Phnom Penh Port, Second Half of April 2003

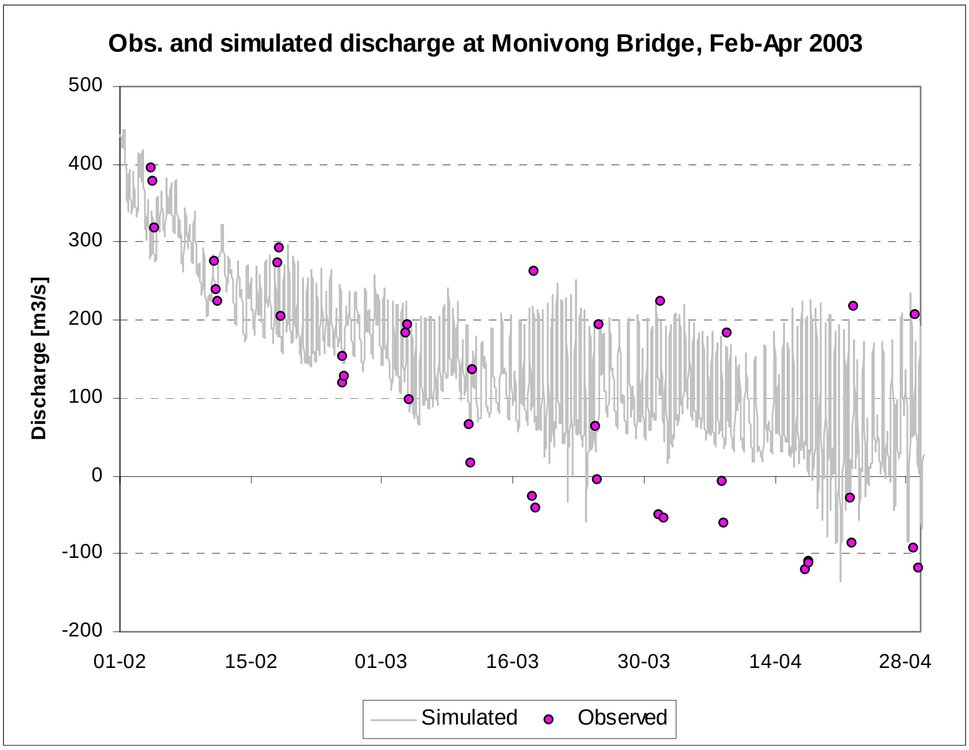


Fig. 2.15a Simulated and Observed Discharge at Monivong Bridge, February to April 2003

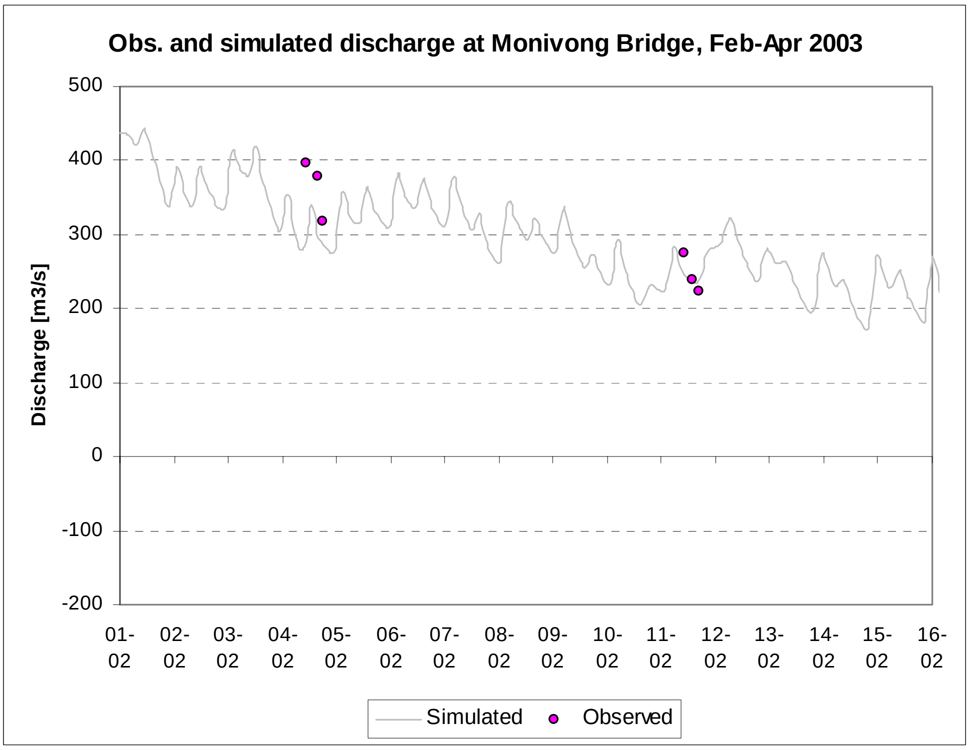


Fig. 2.15b Simulated and Observed Discharge at Monivong Bridge, First Half of February 2003

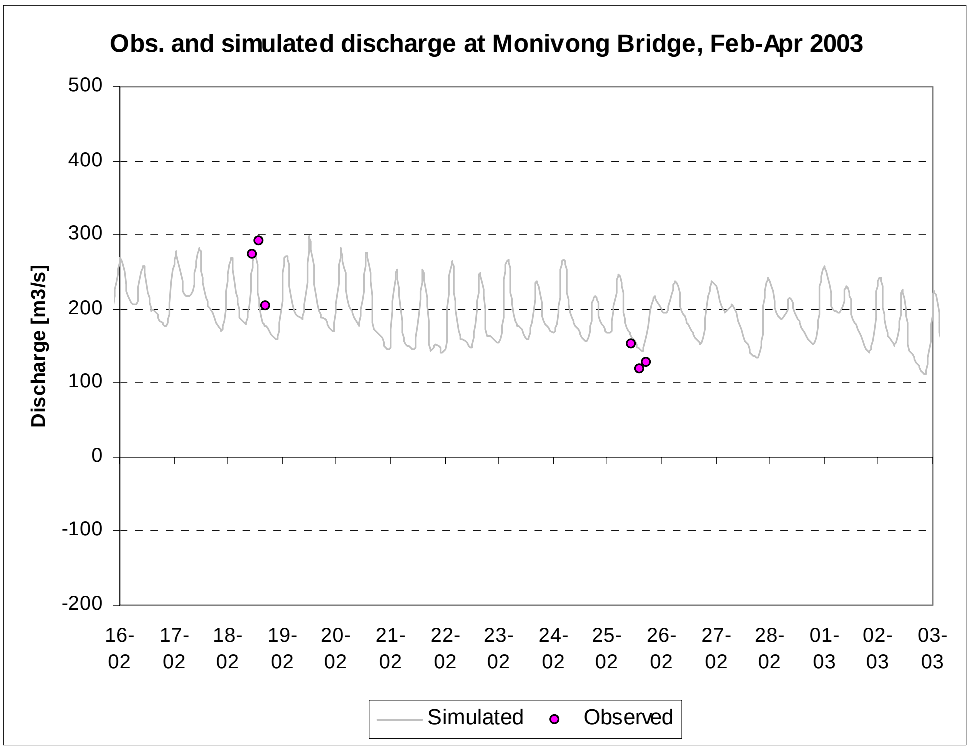


Fig. 2.15c Simulated and Observed Discharge at Monivong Bridge, Second Half of February 2003

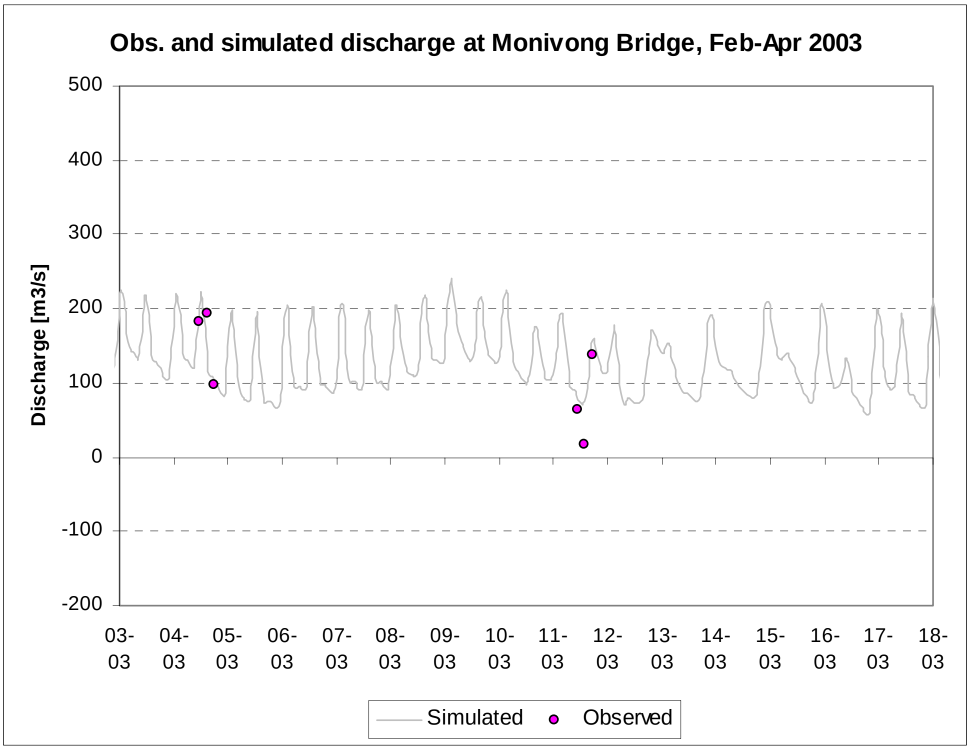


Fig. 2.15d Simulated and Observed Discharge at Monivong Bridge, First Half of March 2003

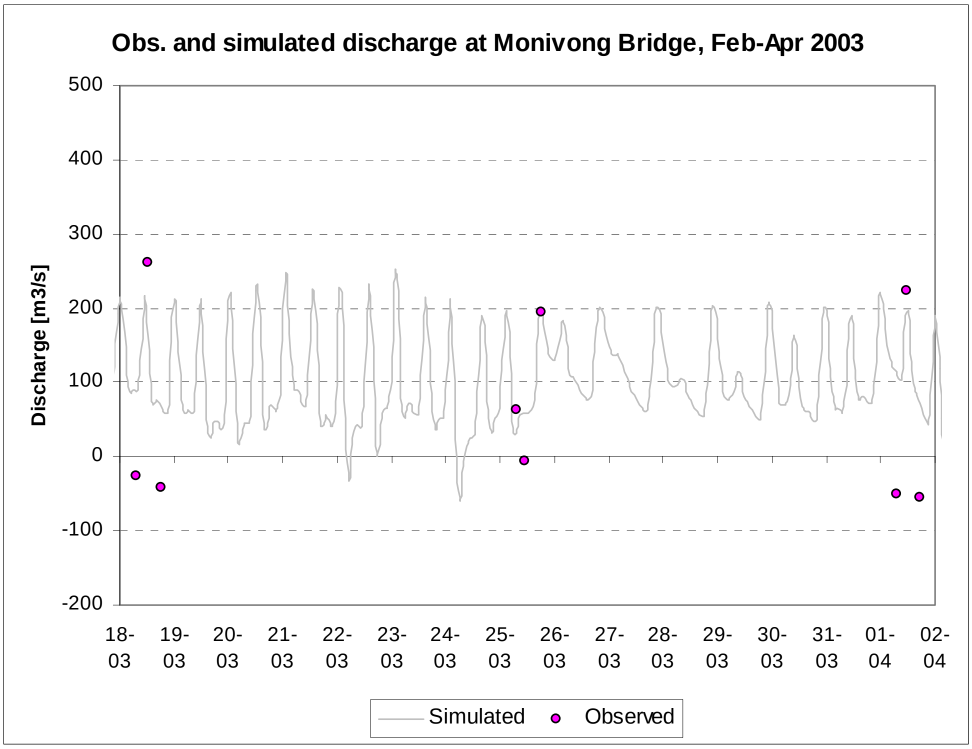


Fig. 2.15e Simulated and Observed Discharge at Monivong Bridge, Second Half of March 2003

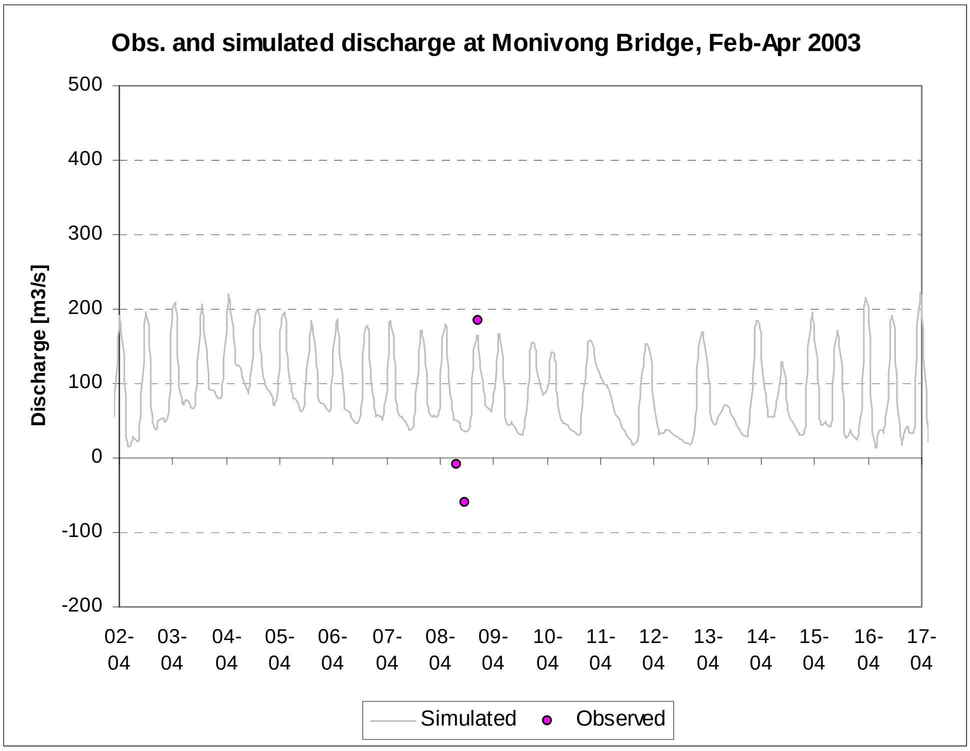


Fig. 2.15f Simulated and Observed Discharge at Monivong Bridge, First Half of April 2003

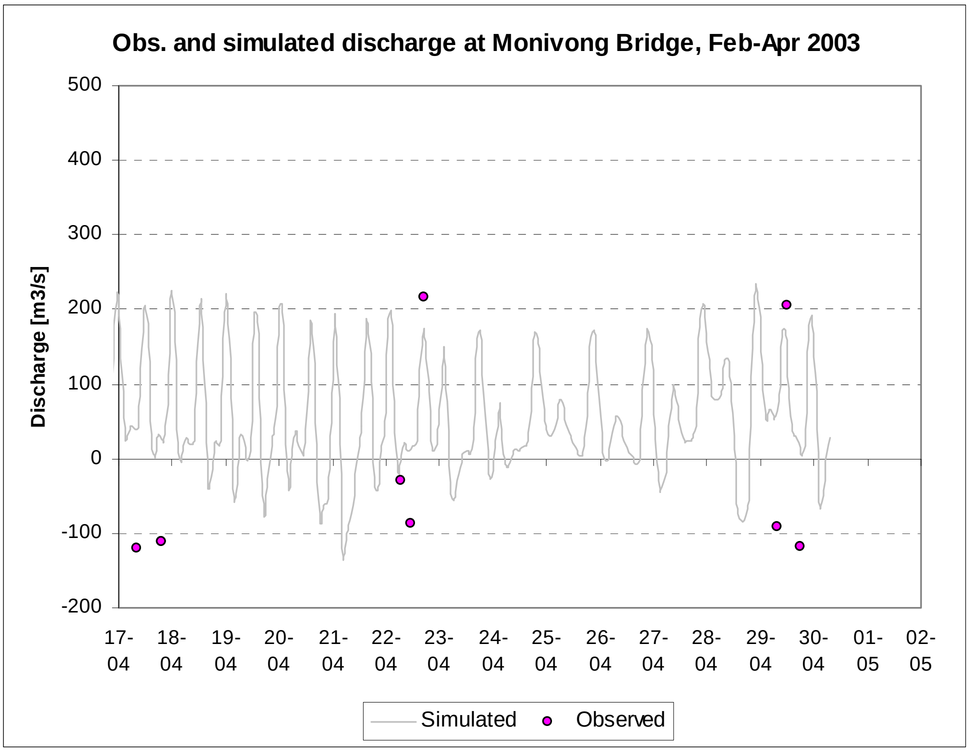


Fig. 2.15g Simulated and Observed Discharge at Monivong Bridge, Second Half of April 2003

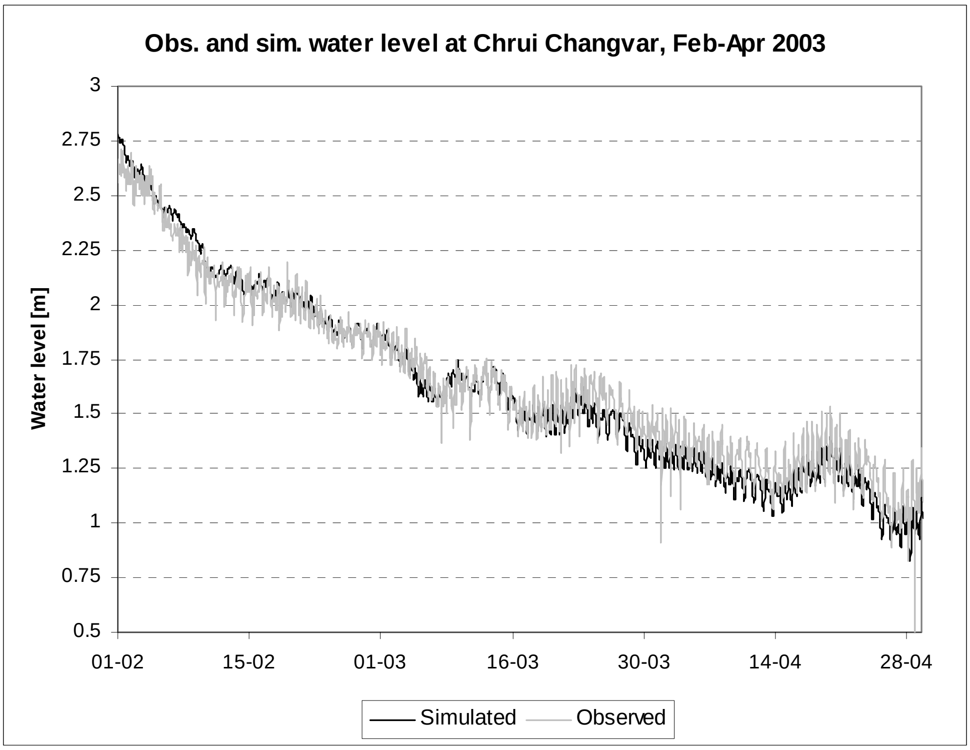


Fig. 2.16a Simulated and Observed Water Level at Chrui Changvar, February to April 2003

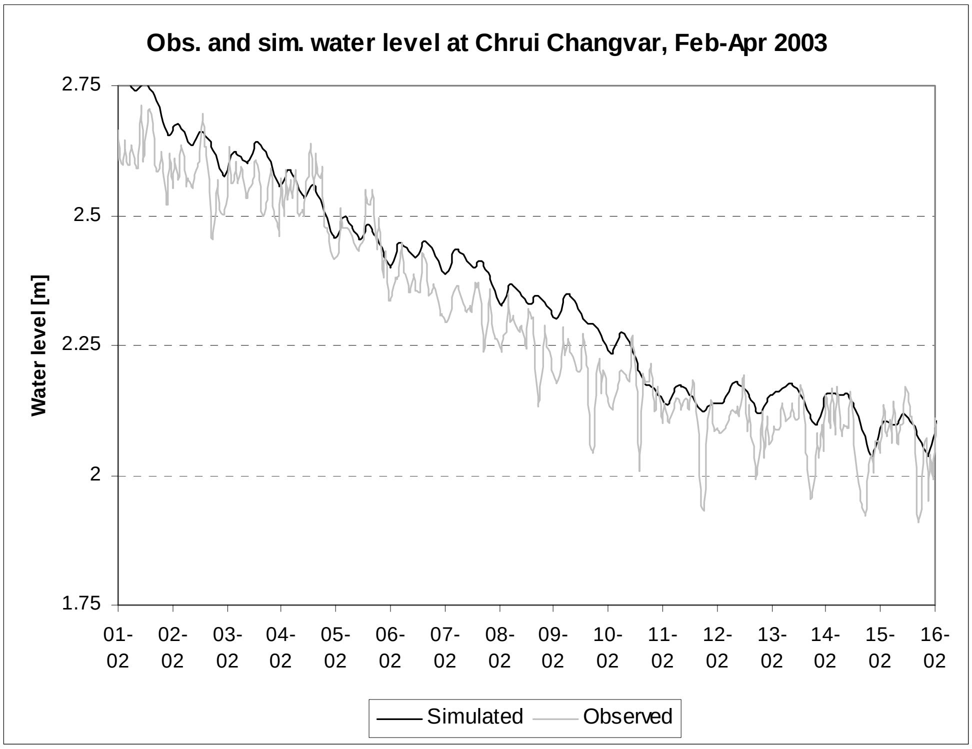


Fig. 2.16b Simulated and Observed Water Level at Chrui Changvar, First Half of February 2003

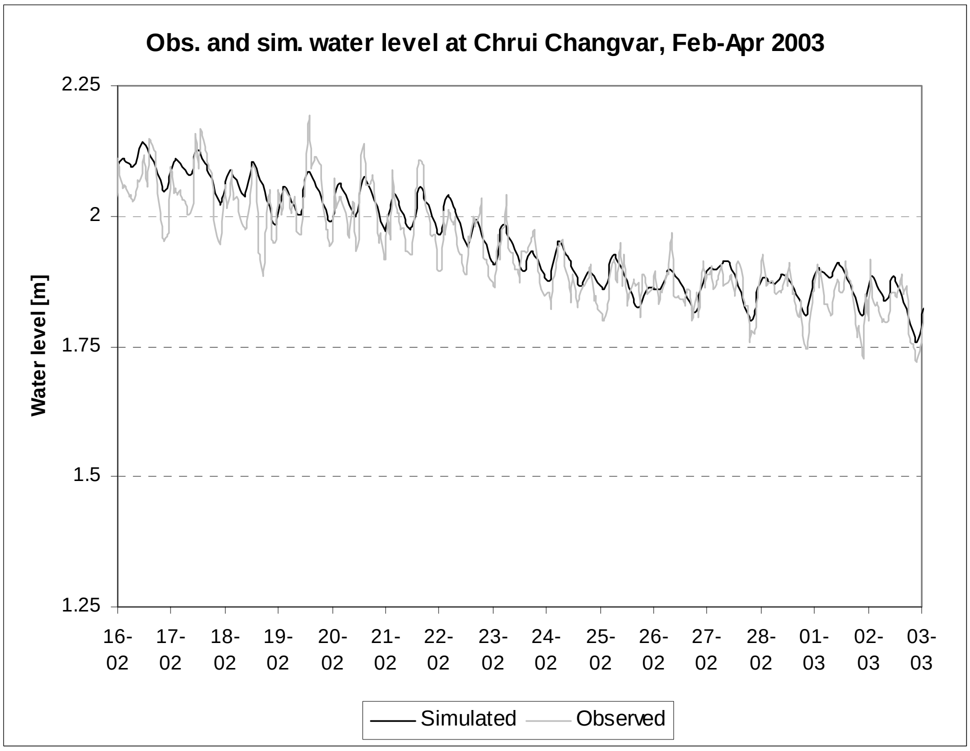


Fig. 2.16c Simulated and Observed Water Level at Chrui Changvar, Second Half of February 2003

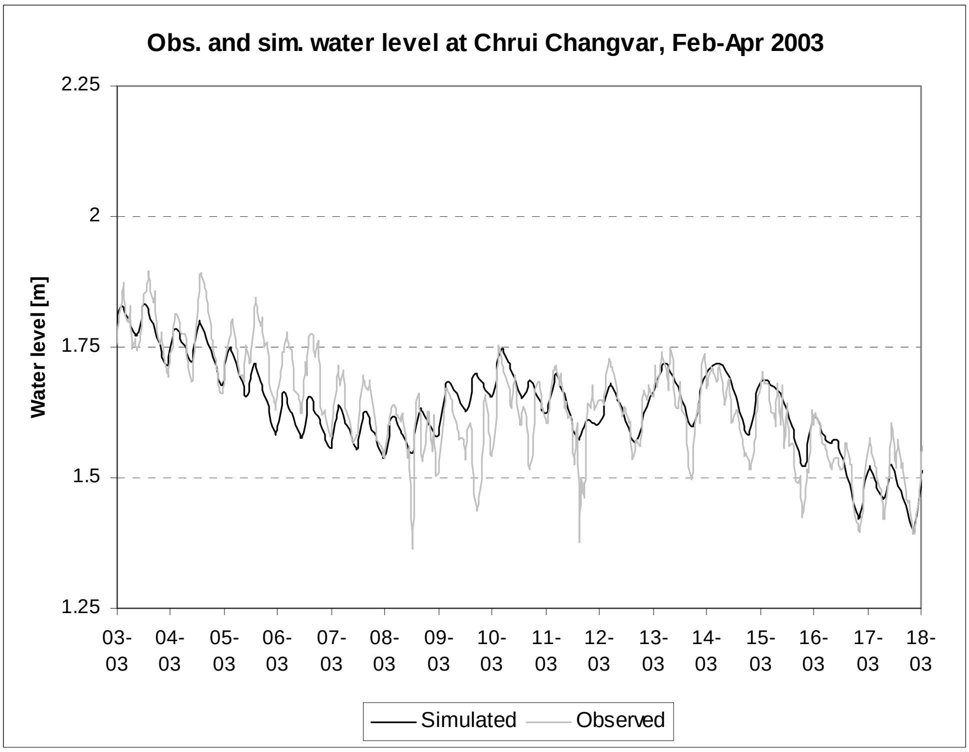


Fig. 2.16d Simulated and Observed Water Level at Chrui Changvar, First Half of March 2003

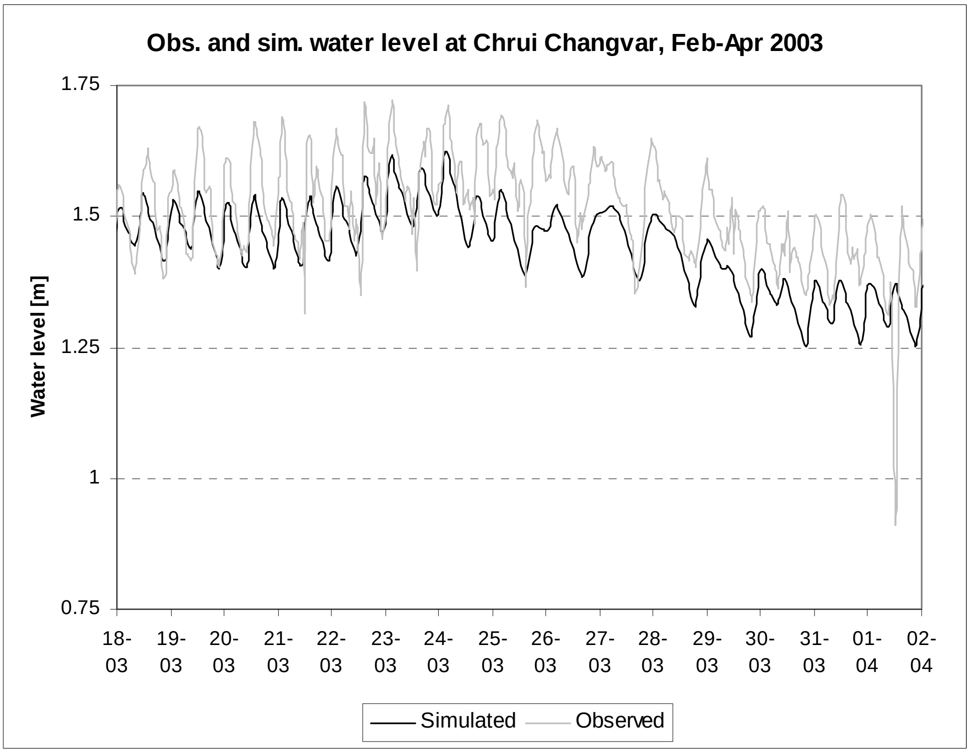


Fig. 2.16e Simulated and Observed Water Level at Chrui Changvar, Second Half of March 2003

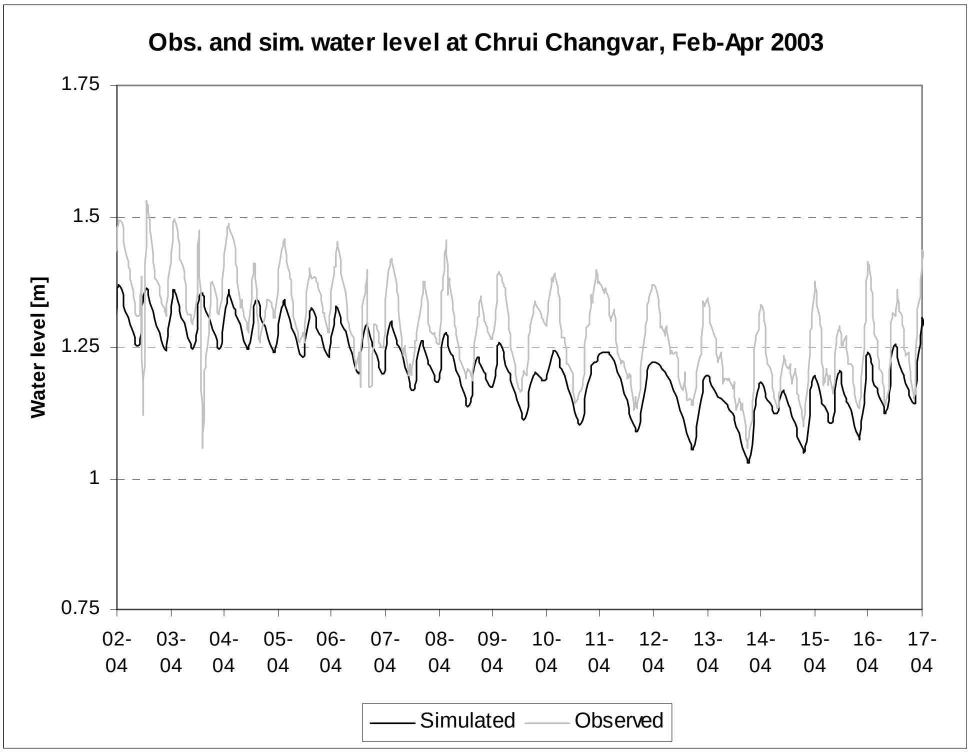


Fig. 2.16f Simulated and Observed Water Level at Chrui Changvar, First Half of April 2003

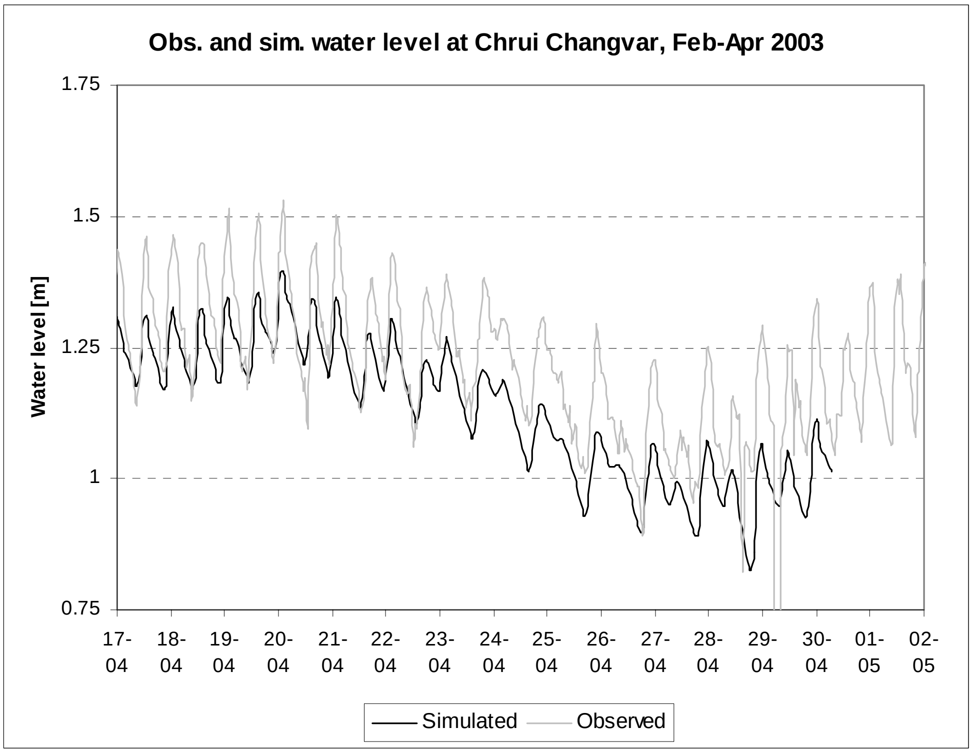


Fig. 2.16g Simulated and Observed Water Level at Chrui Changvar, Second Half of April 2003

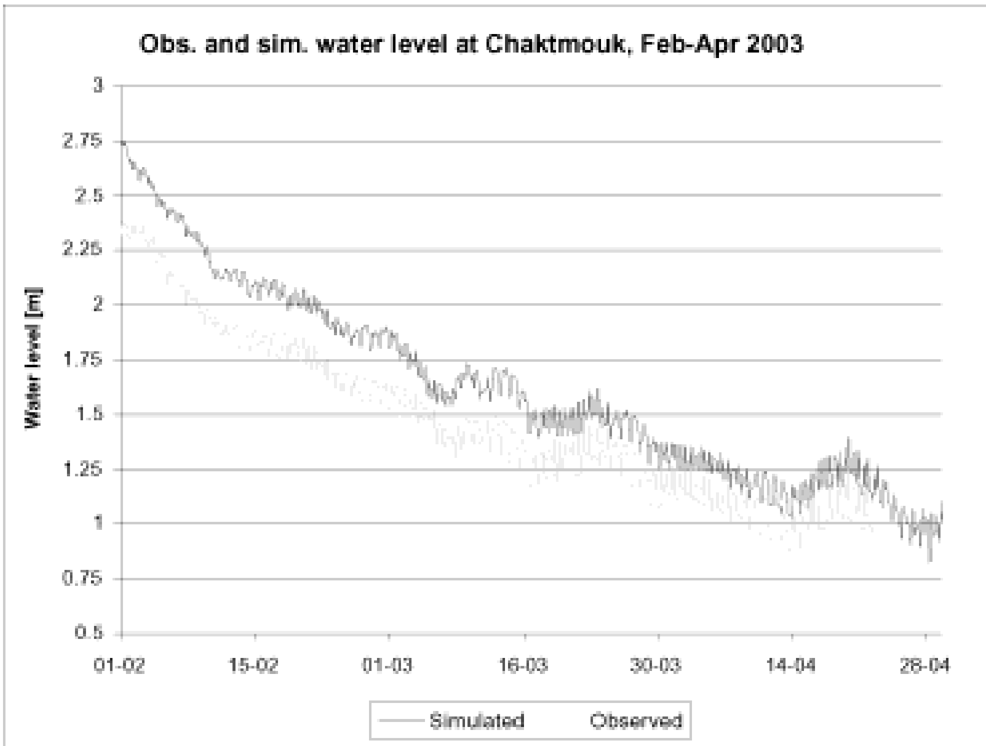


Fig. 2.17a Simulated and Observed Water Level at Chaktomouk, February to April 2003

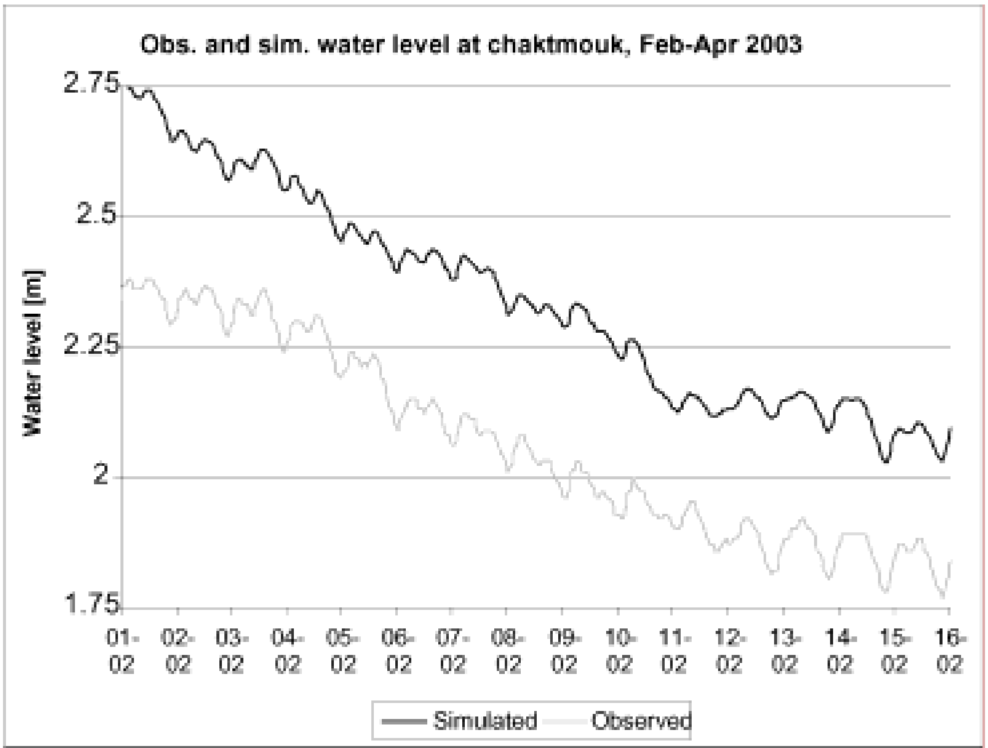


Fig. 2.17b Simulated and Observed Water Level at Chaktomouk, First Half of February 2003

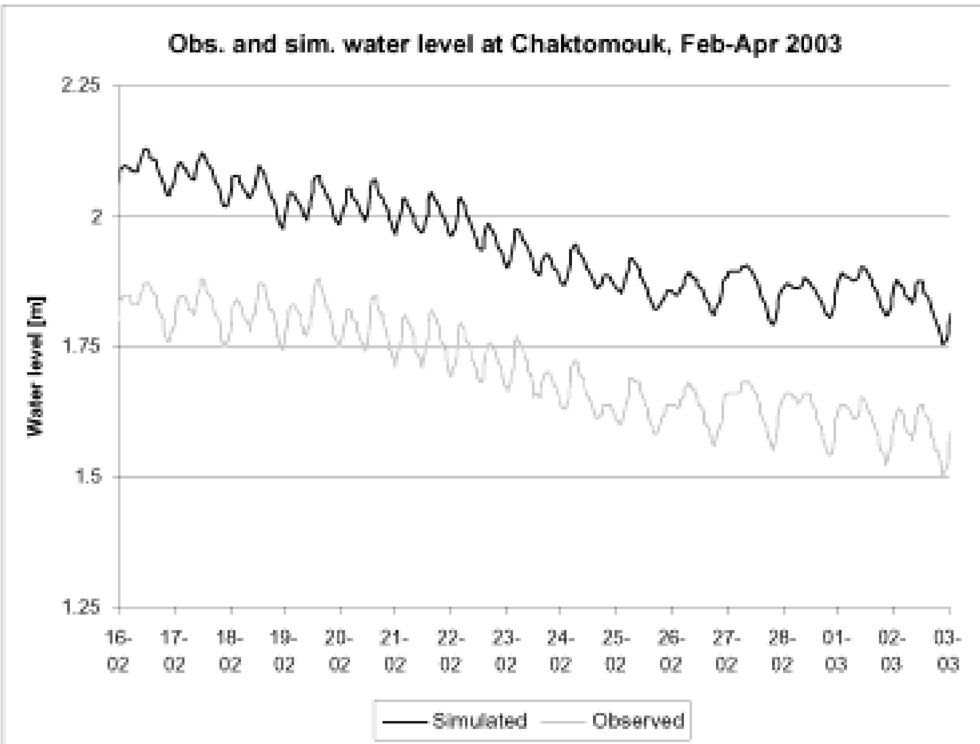


Fig. 2.17c Simulated and Observed Water Level at Chaktomouk, Second Half of February 2003

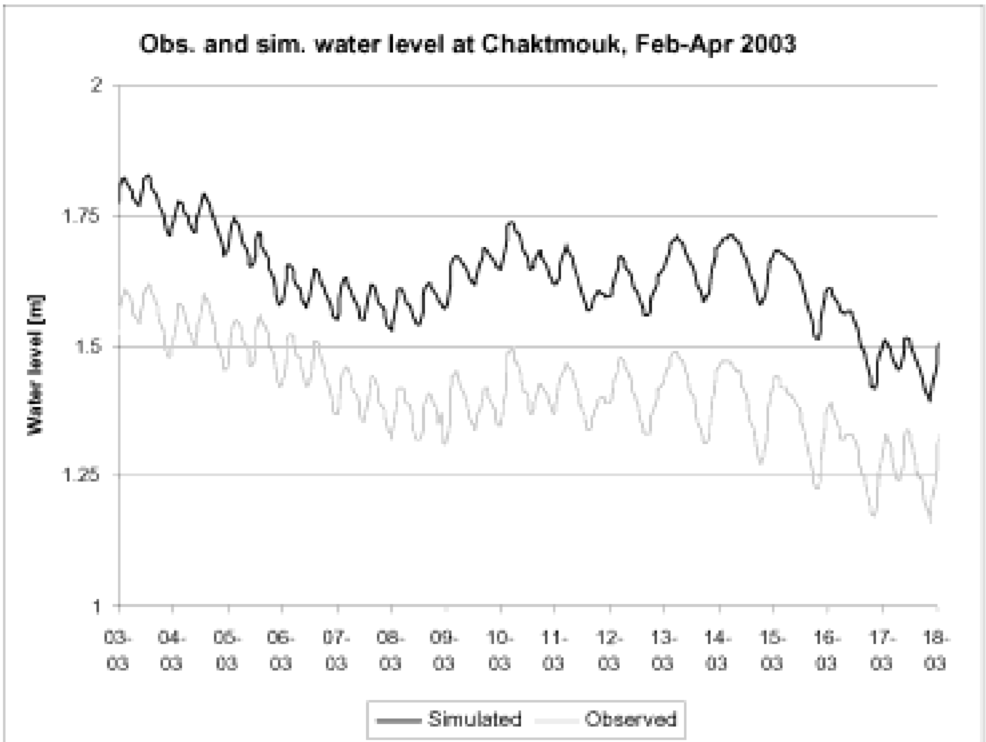


Fig. 2.17d Simulated and Observed Water Level at Chaktomouk, First Half of March 2003

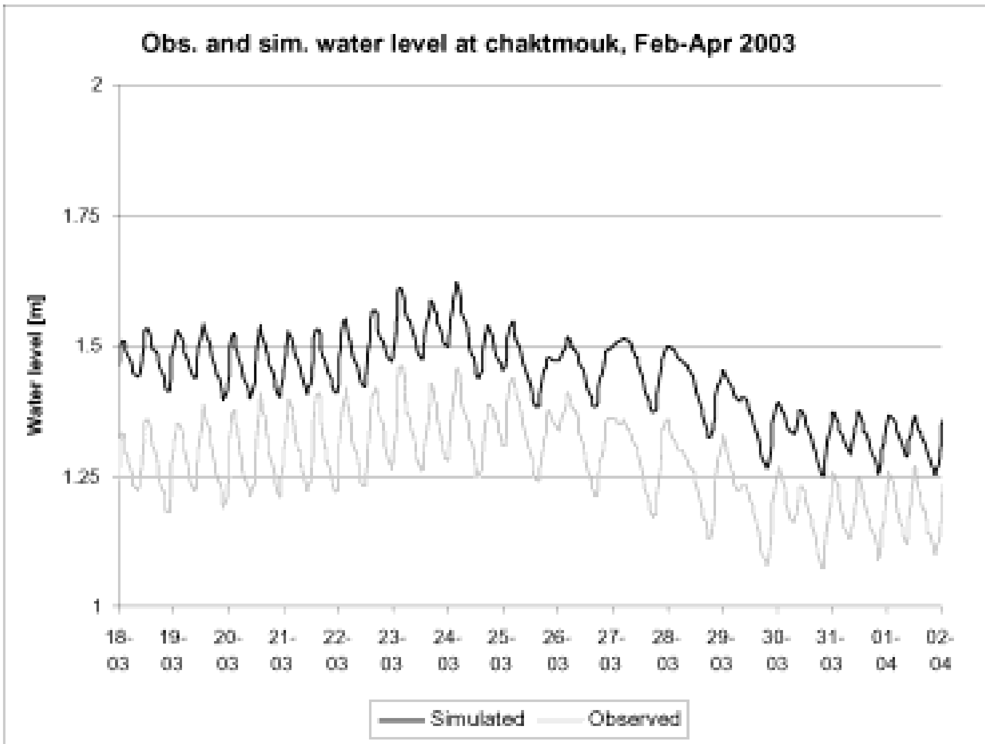


Fig. 2.17e Simulated and Observed Water Level at Chaktomouk, Second Half of March 2003

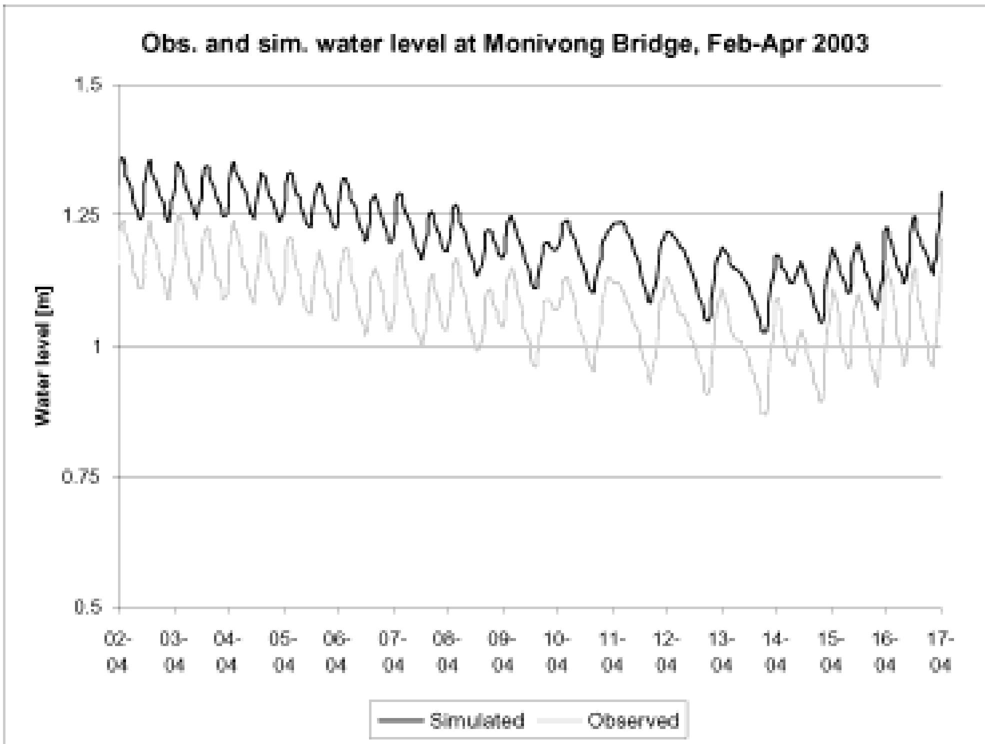


Fig. 2.17f Simulated and Observed Water Level at Chaktomouk, First Half of April 2003

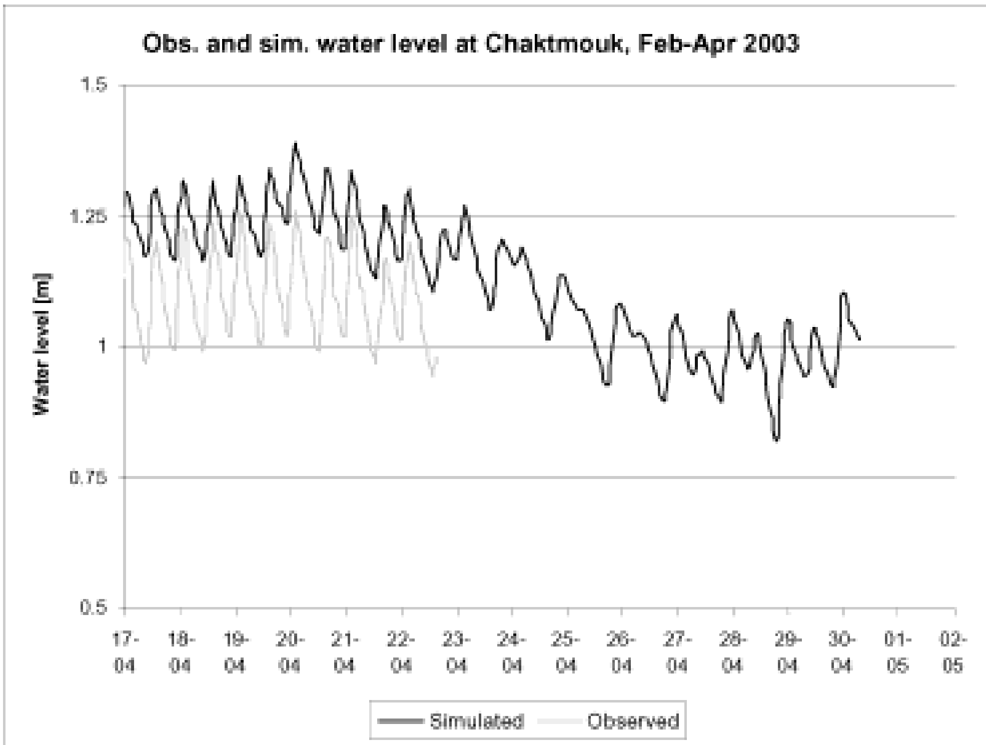


Fig. 2.17g Simulated and Observed Water Level at Chaktomouk, Second Half of April 2003

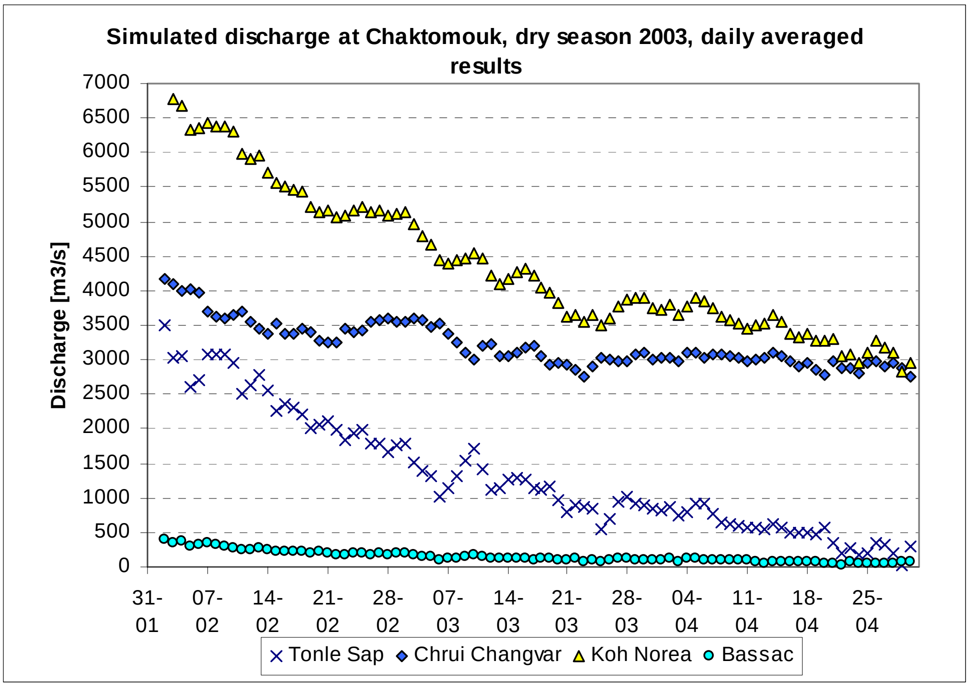


Fig. 2.18 Simulated Daily Average Discharge at the Four River Branches in Chaktomouk (Average of 24 Hourly values)

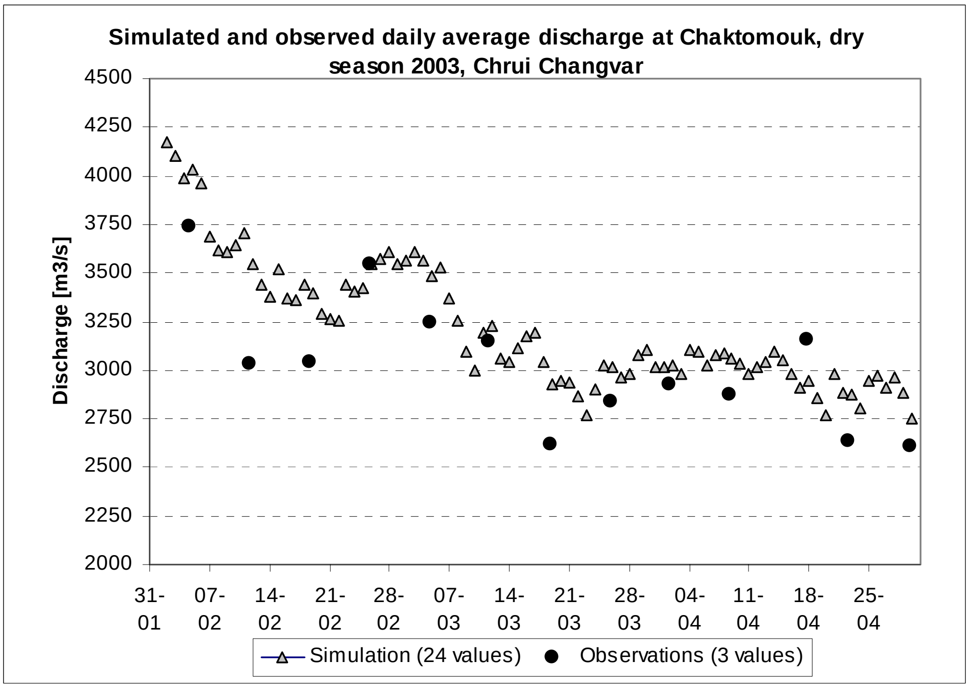


Fig. 2.19 Simulated Daily Average Discharge (Average of 24 Hourly values) and Observed Daily Average Discharge (3 values per week) at Chrui Changvar

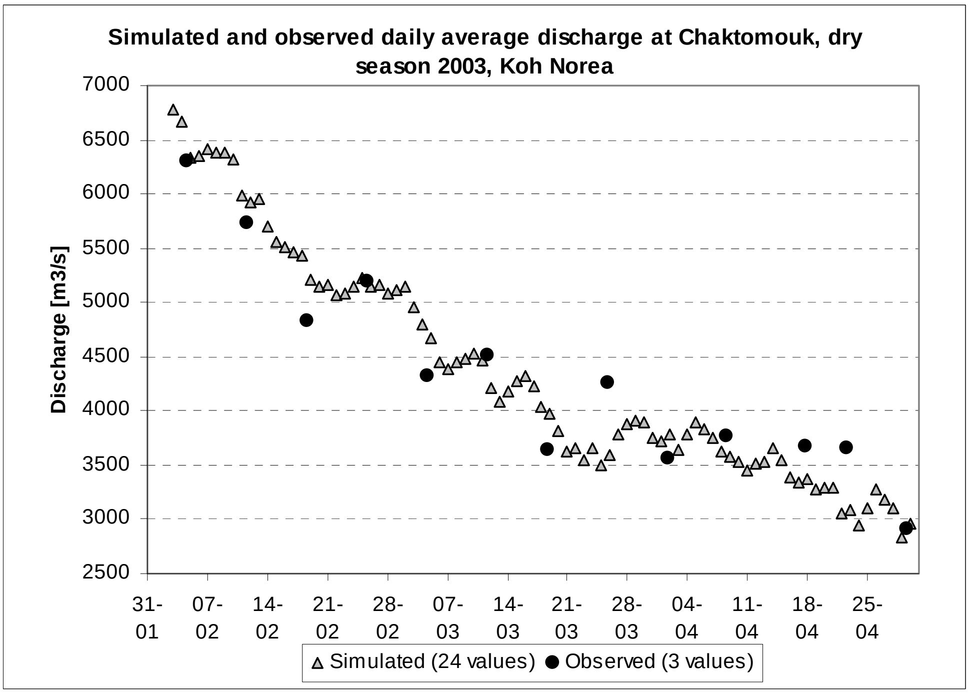


Fig. 2.20 Simulated Daily Average Discharge (Average of 24 Hourly values) and Observed Daily Average Discharge (3 values per week) at Koh Norea

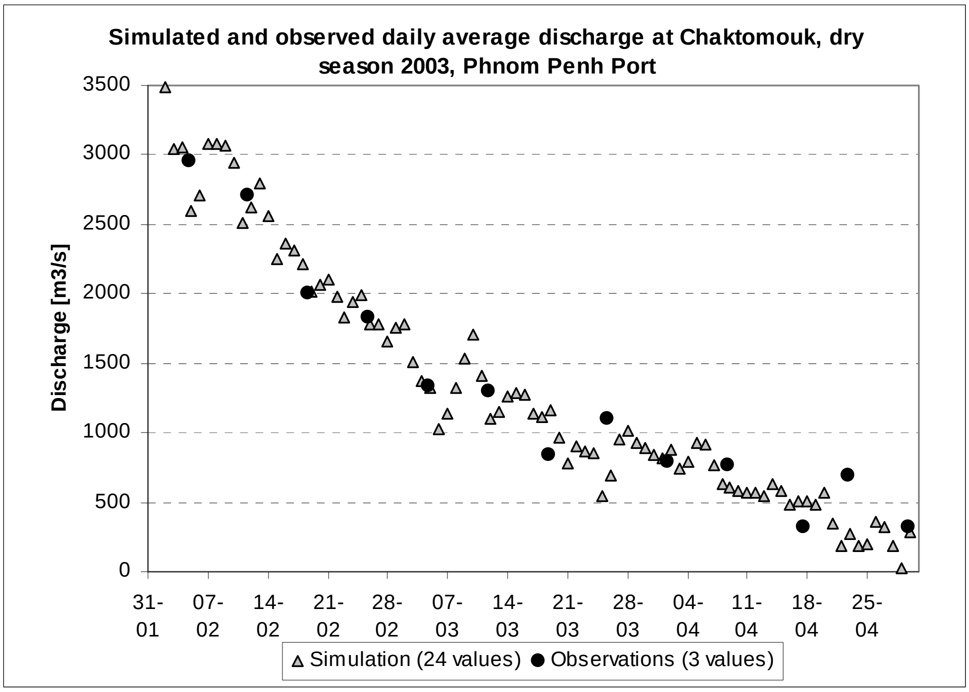


Fig. 2.21 Simulated Daily Average Discharge (Average of 24 Hourly values) and Observed Daily Average Discharge (3 values per week) at Phnom Penh Port

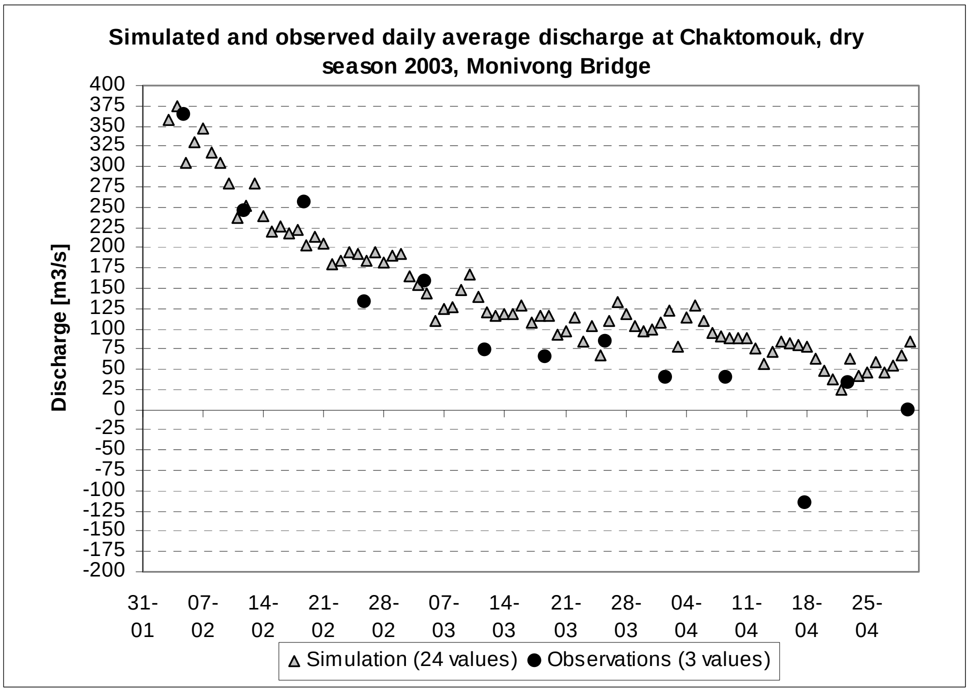


Fig. 2.22 Simulated Daily Average Discharge (Average of 24 Hourly values) and Observed Daily Average Discharge (3 values per week) at Monivong Bridge

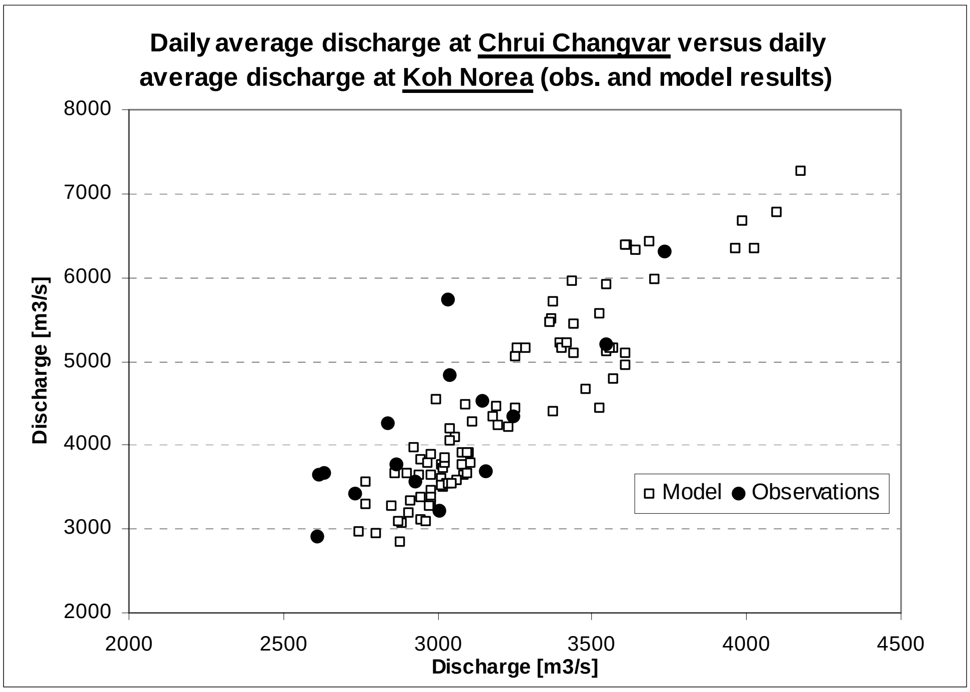


Fig. 2.23 Observed Daily Average Discharge at Chrui Changvar versus Daily Average Discharge at Koh Norea

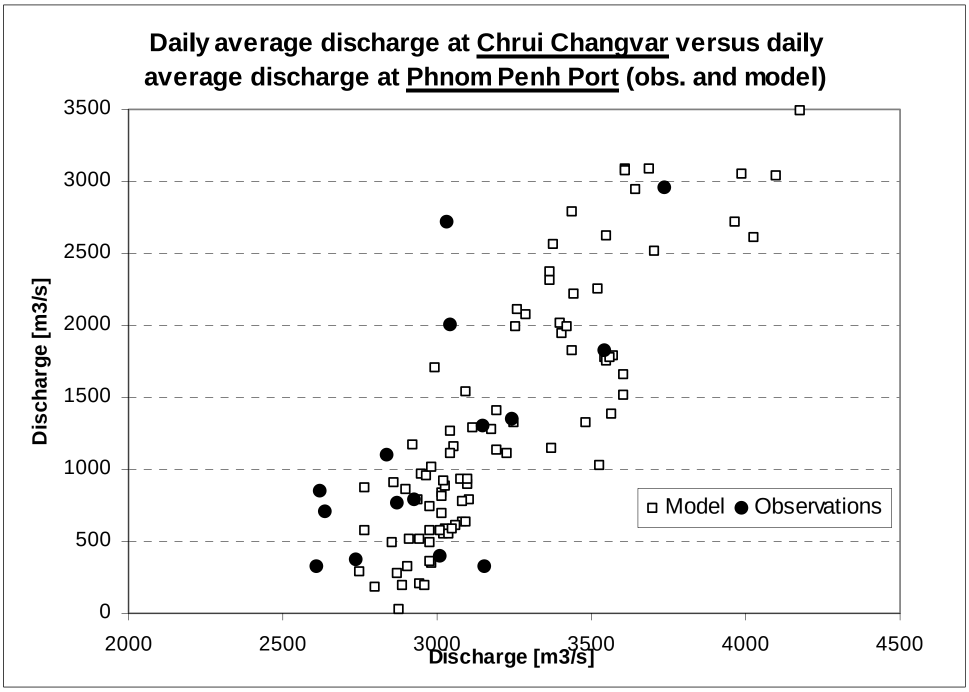


Fig. 2.24 Observed Daily Average Discharge at Chrui Changvar versus Daily Average Discharge at Phnom Penh Port

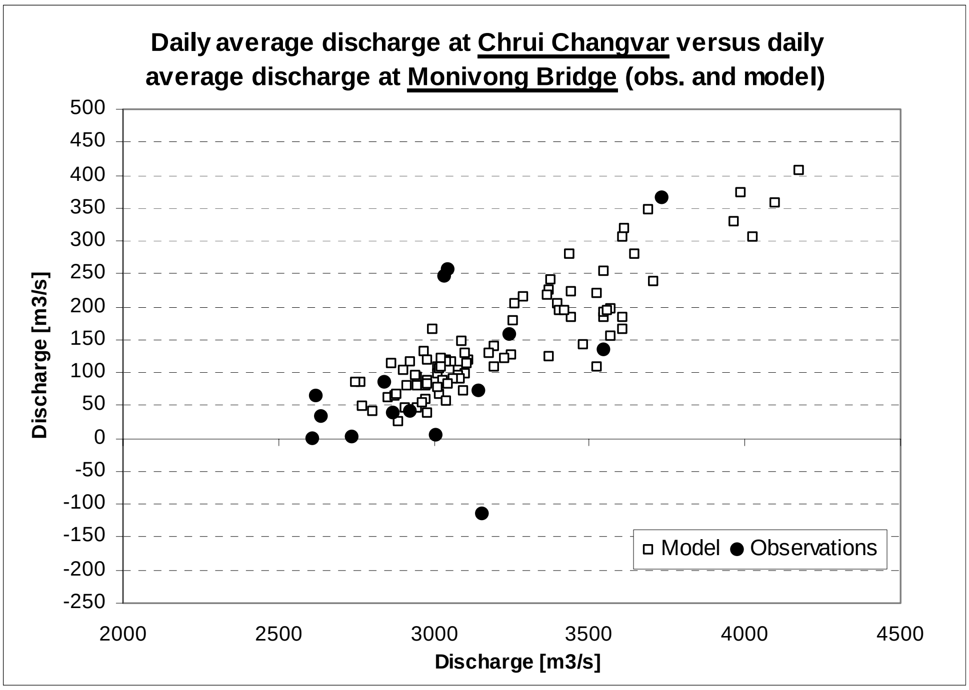


Fig. 2.25 Observed Daily Average Discharge at Chrui Changvar versus Daily Average Discharge at Monivong Bridge

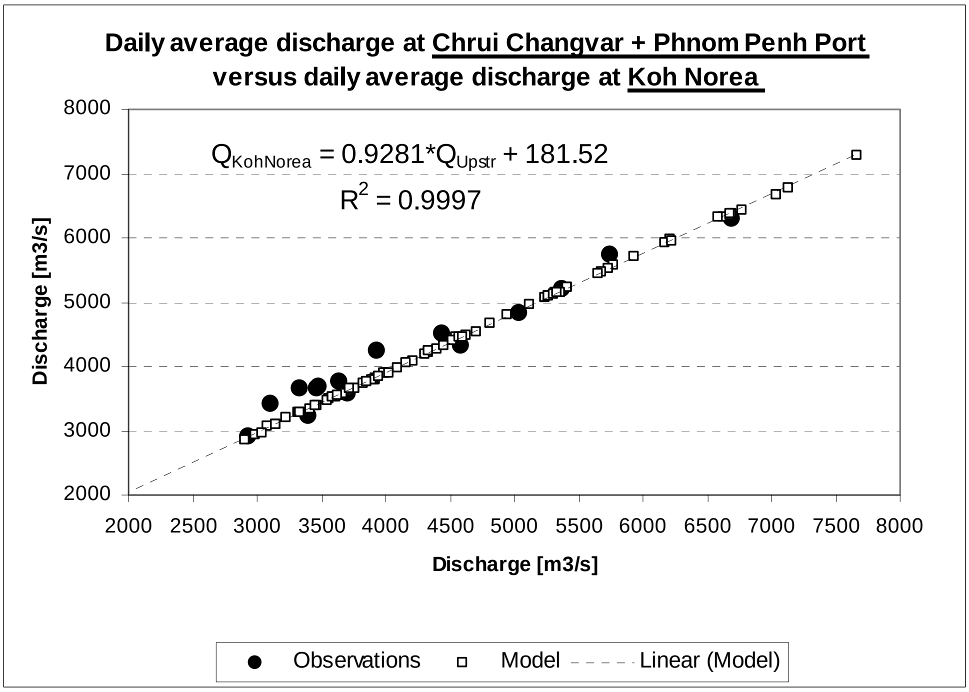


Fig. 2.26 Observed Daily Average Discharge upstream of Chaktomouk (Chrui Changvar plus Phnom Penh Port) versus Daily Average Discharge at Koh Norea

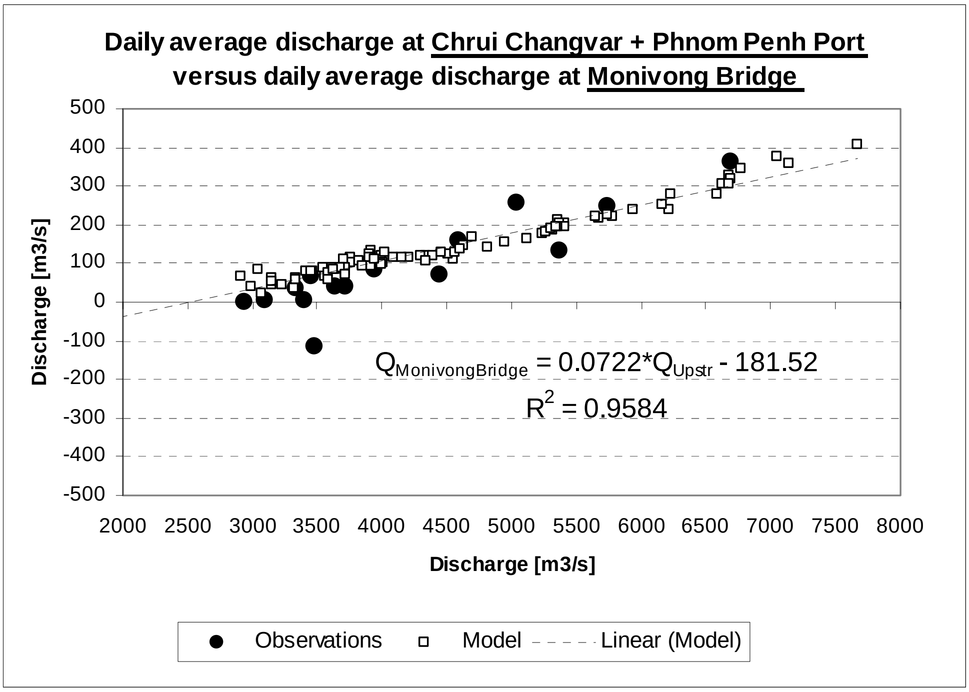


Fig. 2.27 Observed Daily Average Discharge upstream of Chaktomouk (Chrui Changvar plus Phnom Penh Port) versus Daily Average Discharge at Monivong Bridge

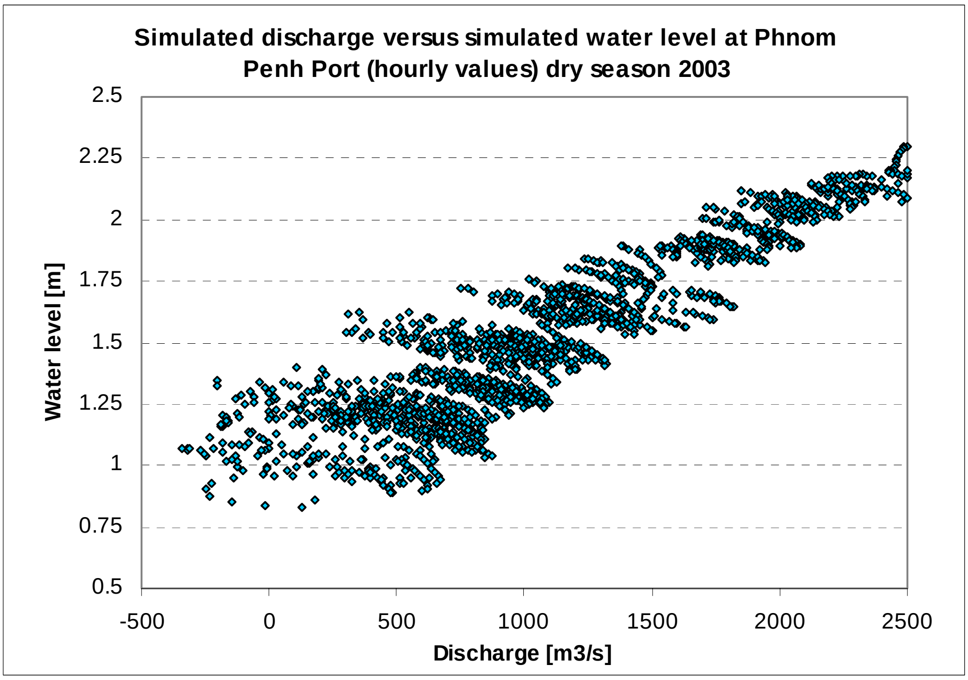


Fig. 2.28 Simulated Hourly Discharge versus Simulated Hourly Water Level at Phnom Penh Port, Dry Season 2003

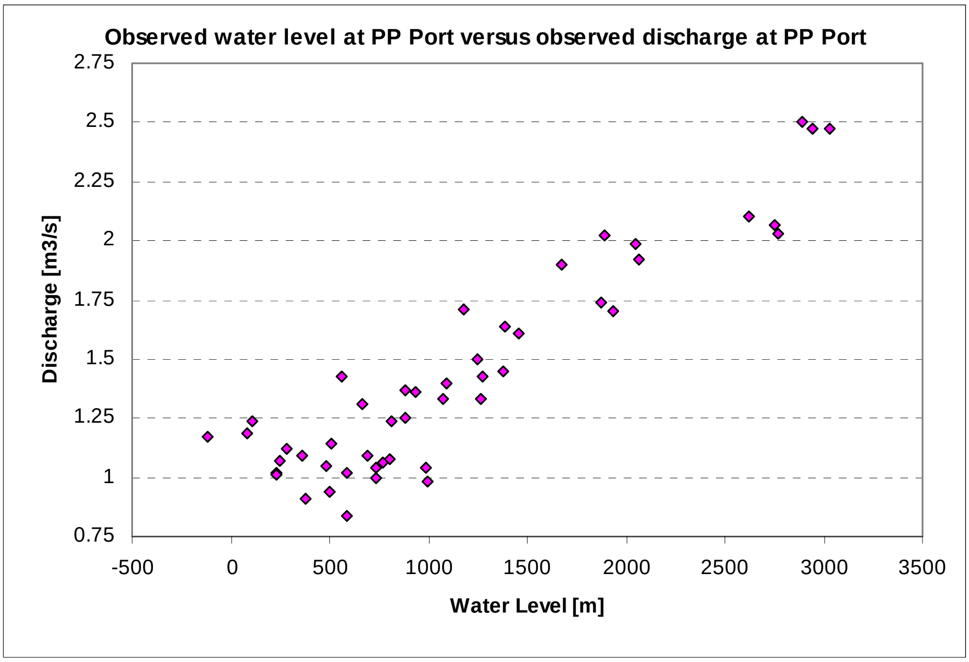


Fig. 2.29 Observed Discharge versus Observed Water Level at Phnom Penh Port, Dry Season 2003

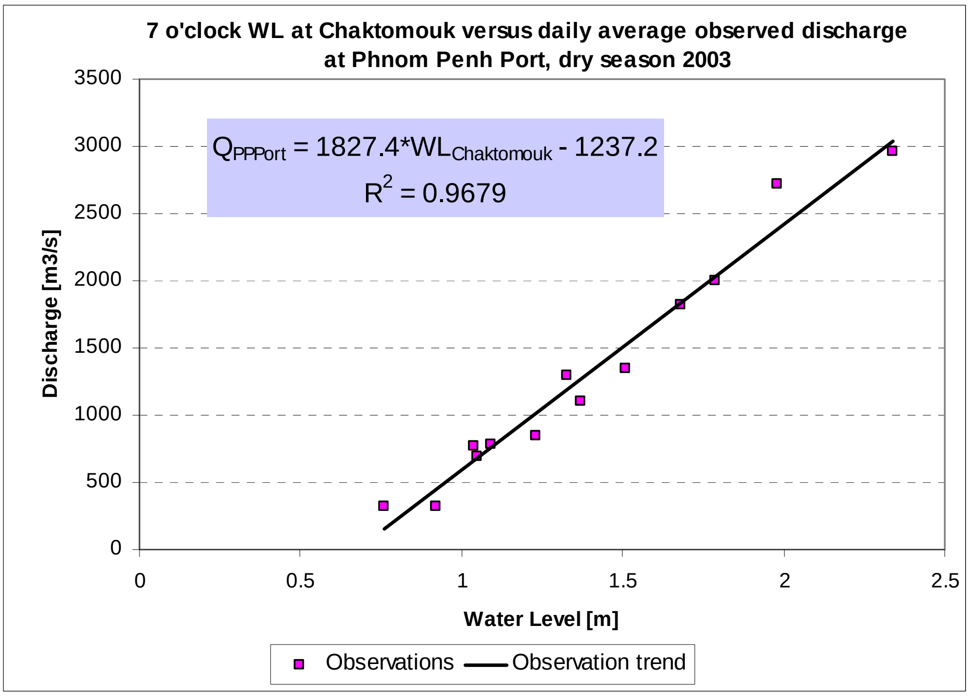


Fig. 2.30a Observed Daily Average Discharge at Phnom Penh Port versus 7 o'clock Water Level at Chaktomouk, Dry Season 2003

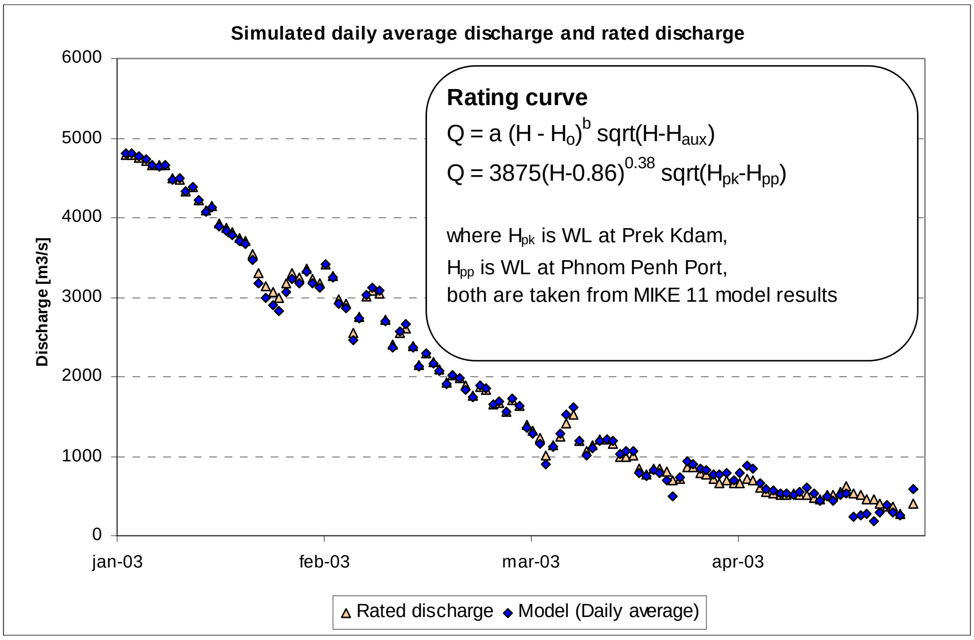


Fig. 2.30b Simulated and Rated Daily Average Discharge at Phnom Penh Port, Dry Season 2003

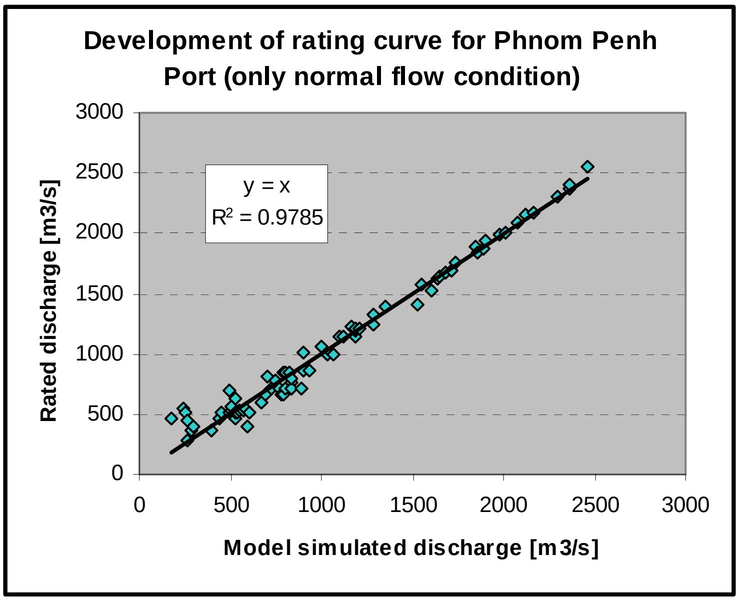


Fig. 2.30c Simulated versus Rated Daily Average Discharge at Phnom Penh Port, Dry Season 2003

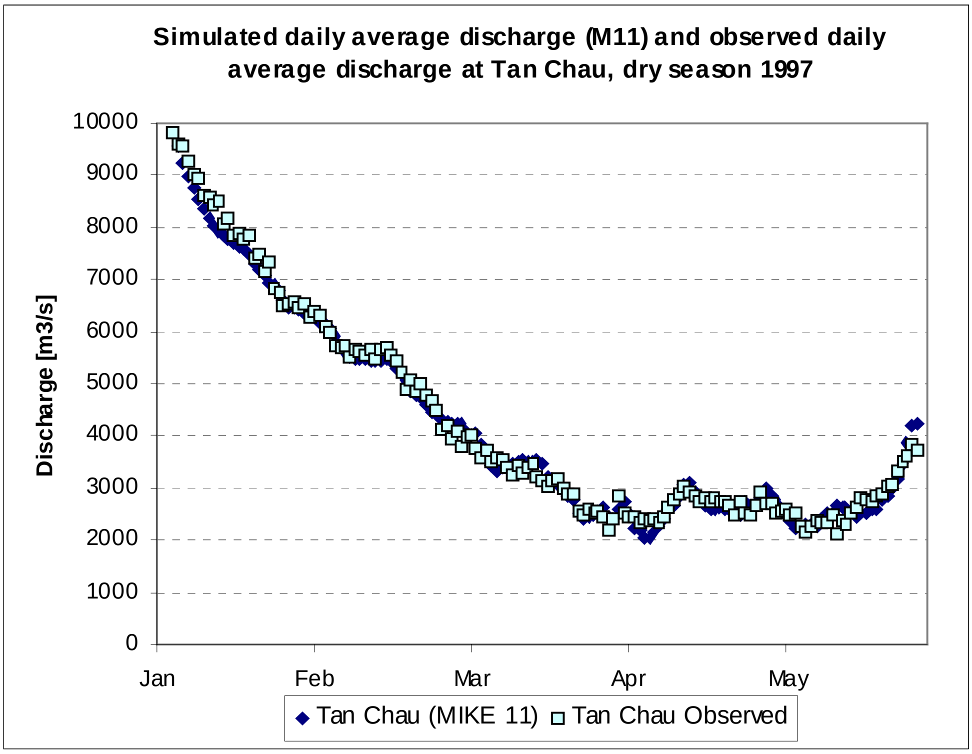


Fig. 2.31 Observed and Simulated Average Daily Discharge at Tan Chau, Dry Season 1997

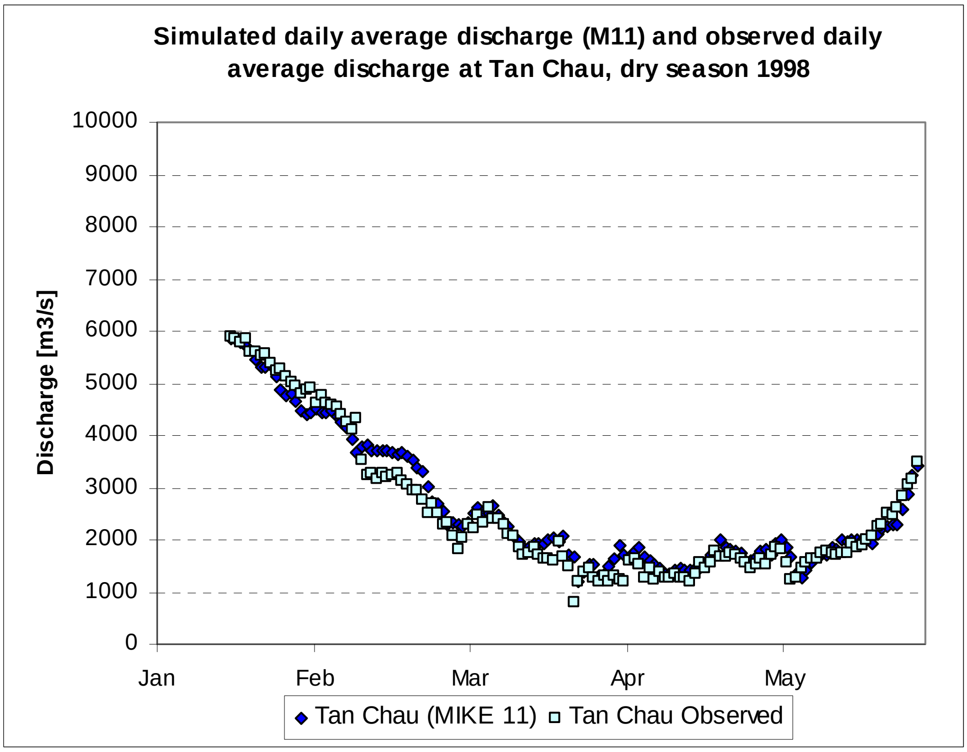


Fig. 2.32 Observed and Simulated Average Daily Discharge at Tan Chau, Dry Season 1998

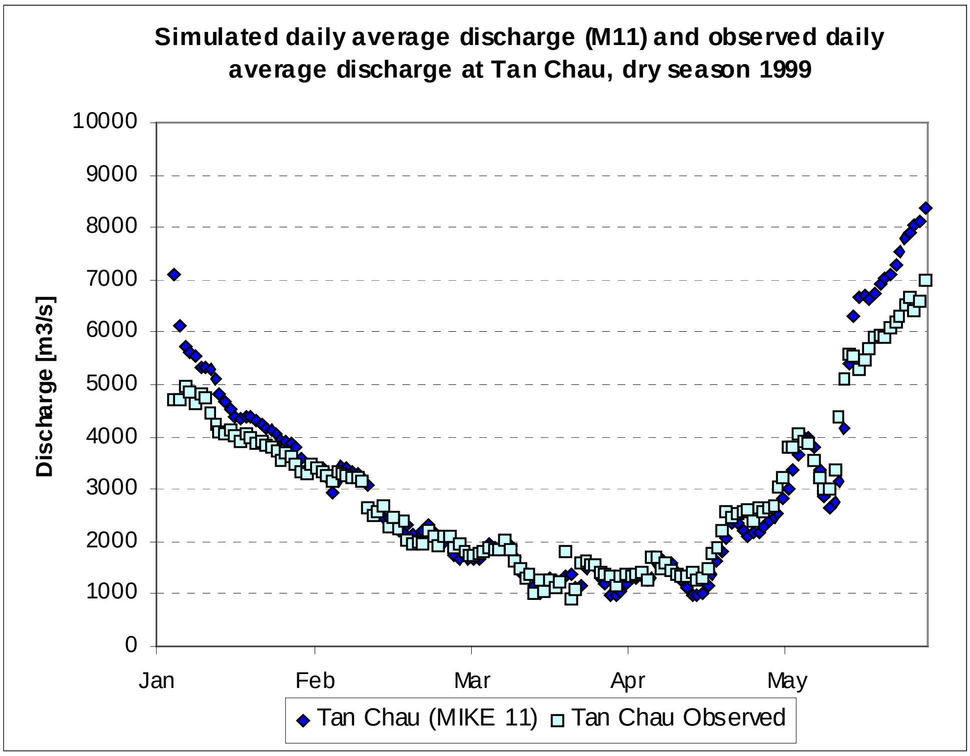


Fig. 2.33 Observed and Simulated Average Daily Discharge at Tan Chau, Dry Season 1999

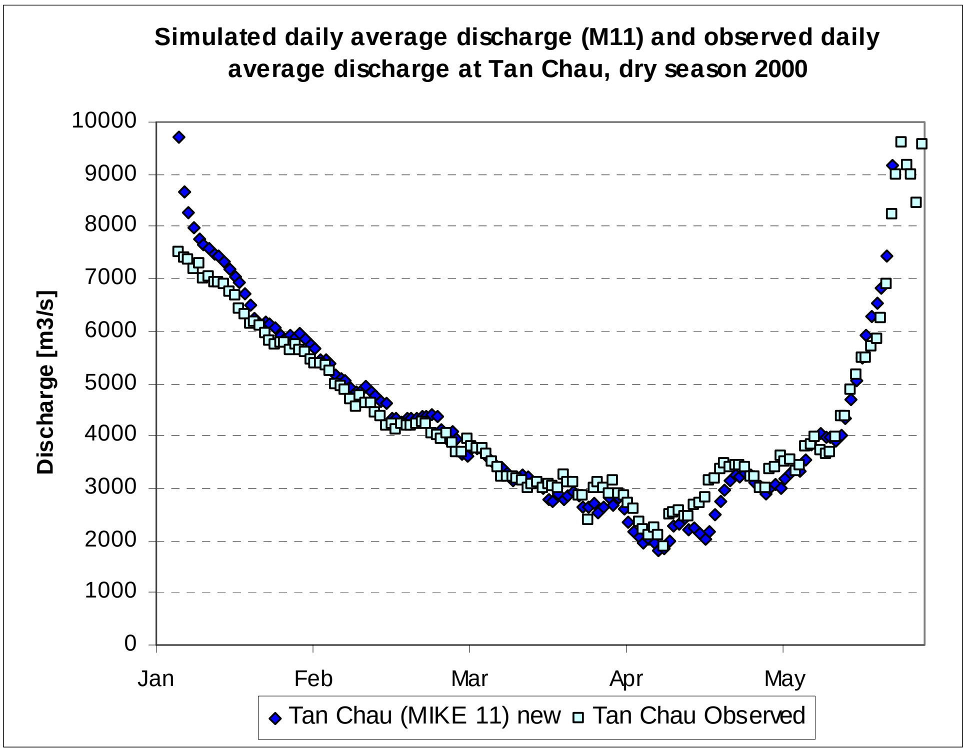


Fig. 2.34 Observed and Simulated Average Daily Discharge at Tan Chau, Dry Season 2000

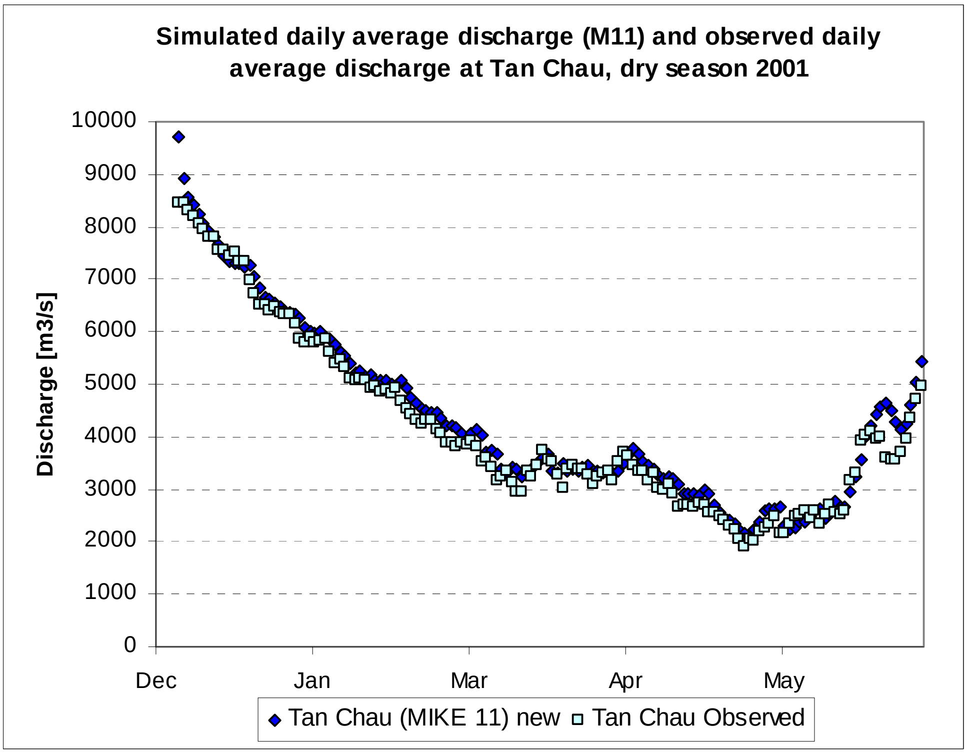
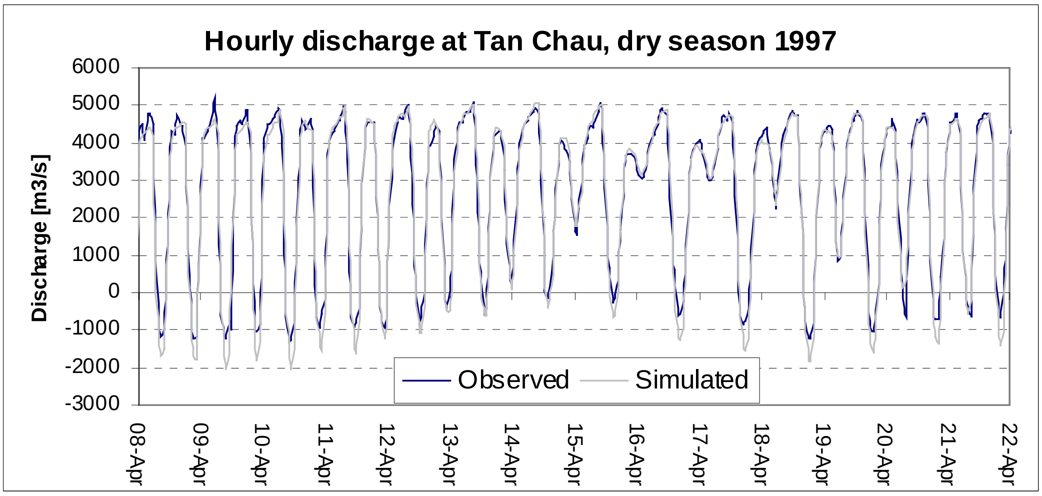
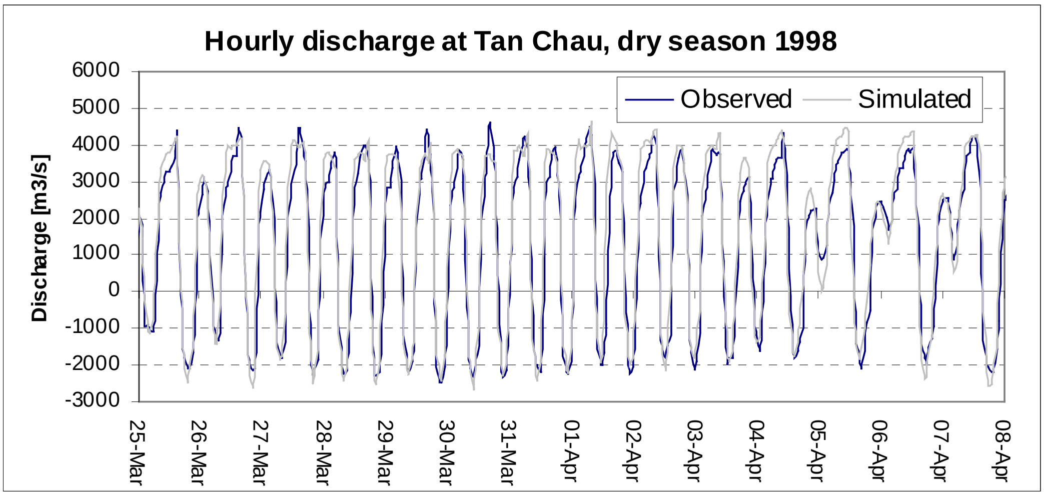


Fig. 2.35 Observed and Simulated Average Daily Discharge at Tan Chau, Dry Season 2001





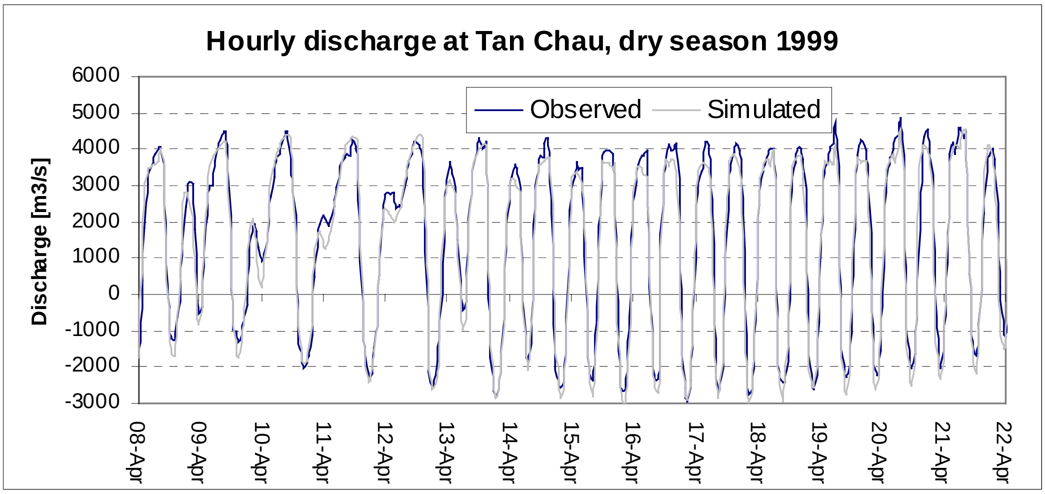
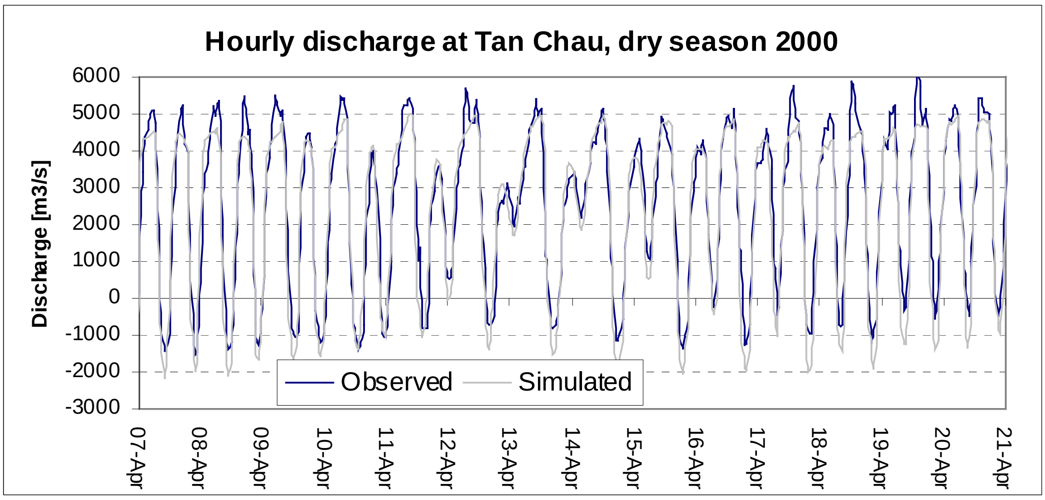


Fig. 2.36 Observed and Simulated Hourly Daily Discharge at Tan Chau, part of Dry Season 1997, 1998 and 1999



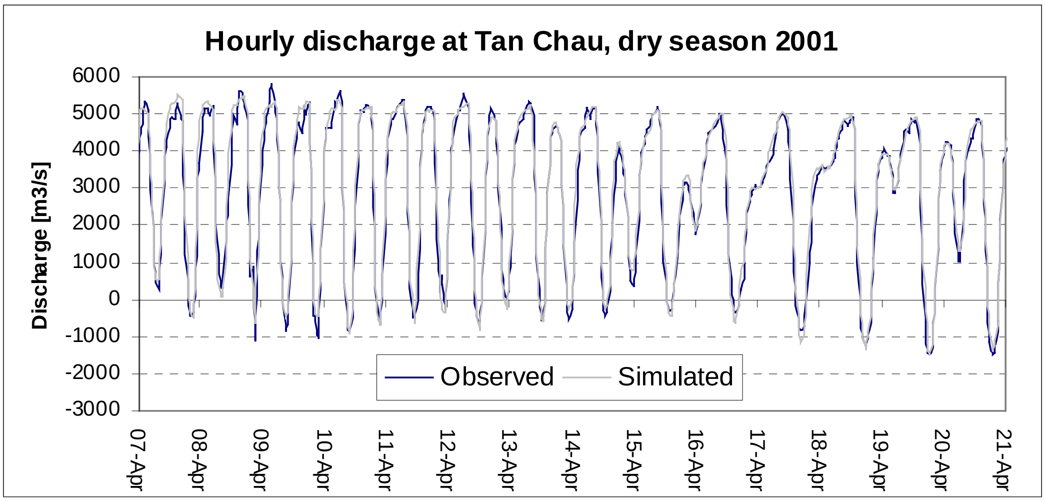


Fig. 2.37 Observed and Simulated Hourly Daily Discharge at Tan Chau, part of Dry Season 2000 and 2001

Fig. 3.1 Location of Major Roads in Phnom Penh, Kompong Cham and Neak Luong areas

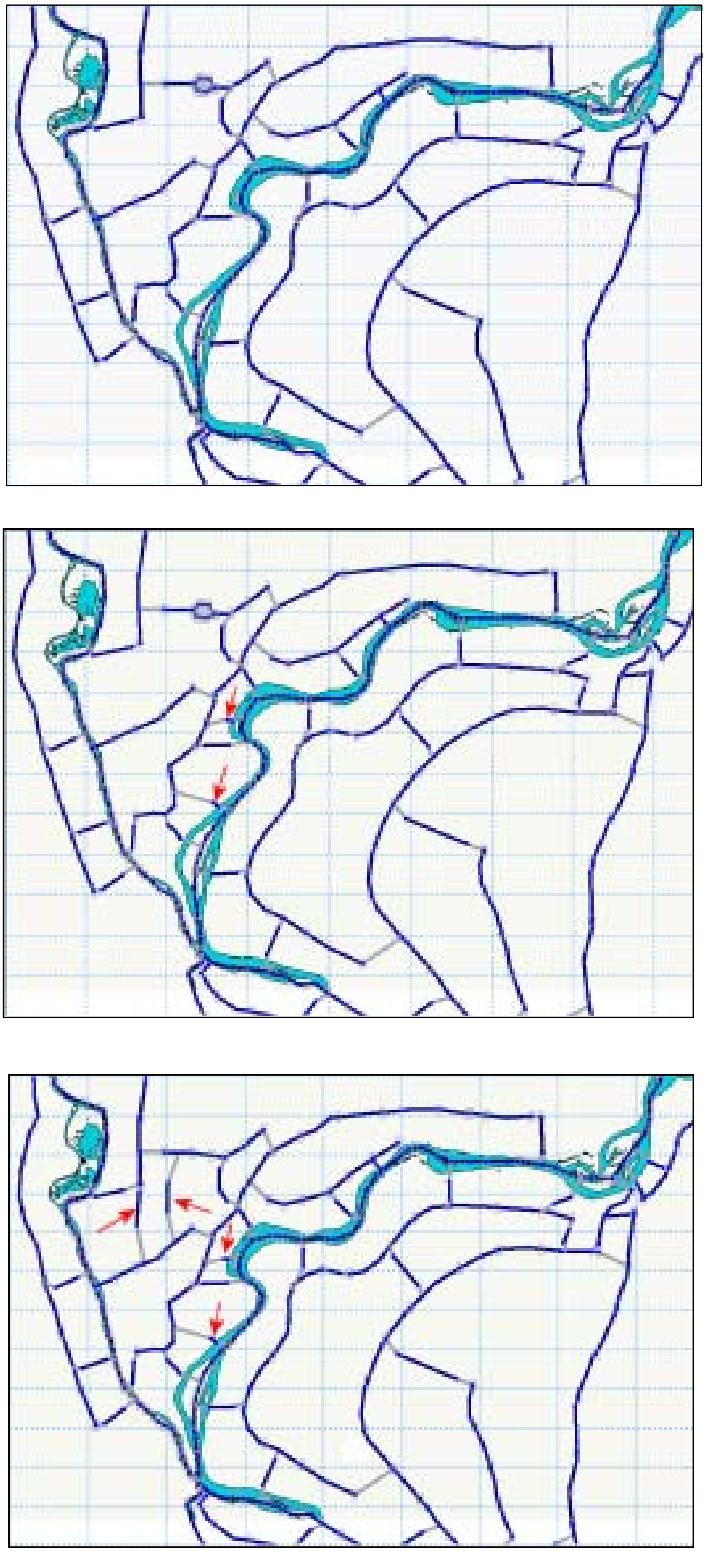


Fig. 3.2 Model Layout for Situations (after 1960, 1920-1960, before 1920)

Top: after 1960

Middle: between late 1920s and 1940s as well as between 1940s and 1960s

Bottom: Prior to 1920

(arrows indicate new branches)

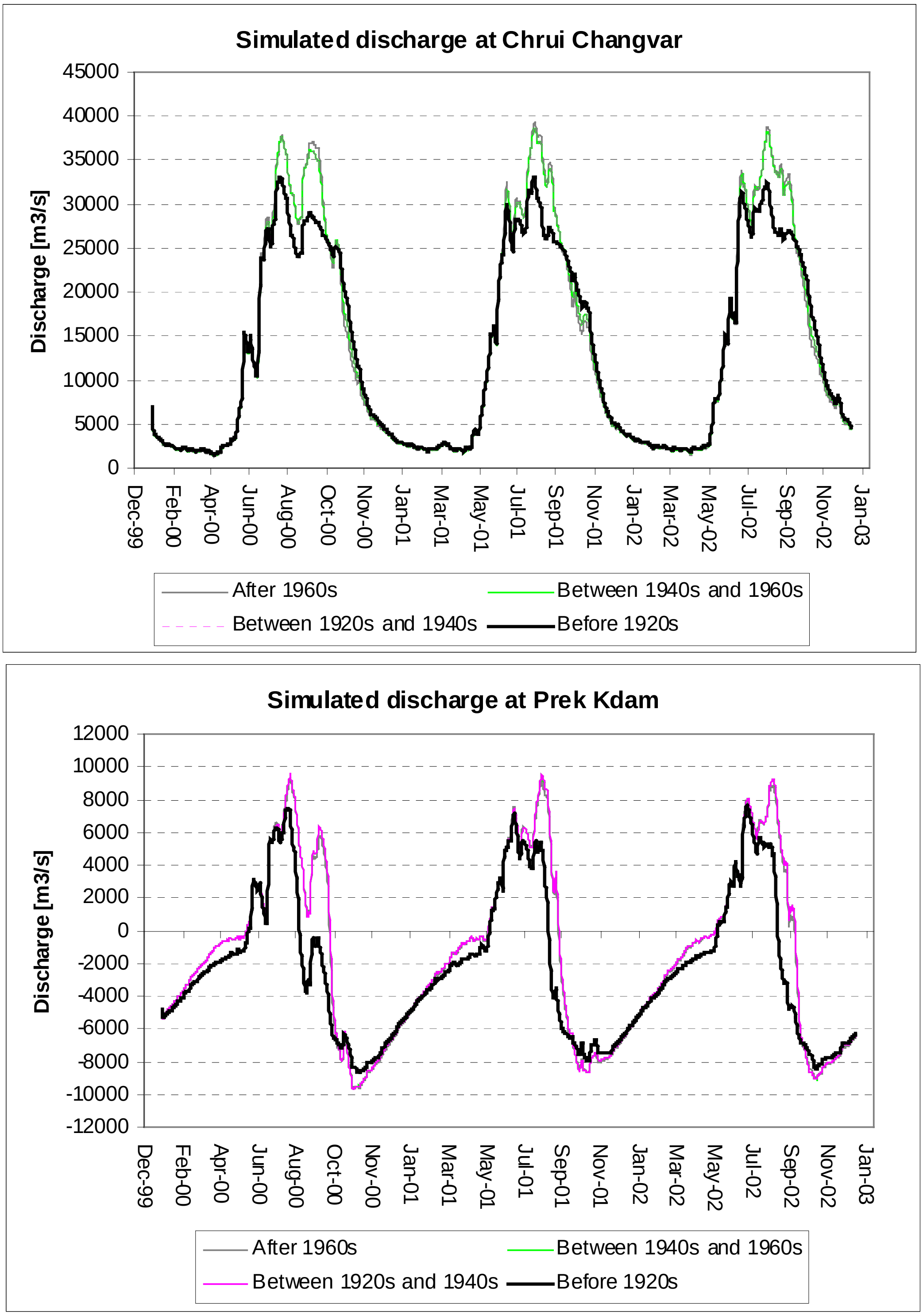
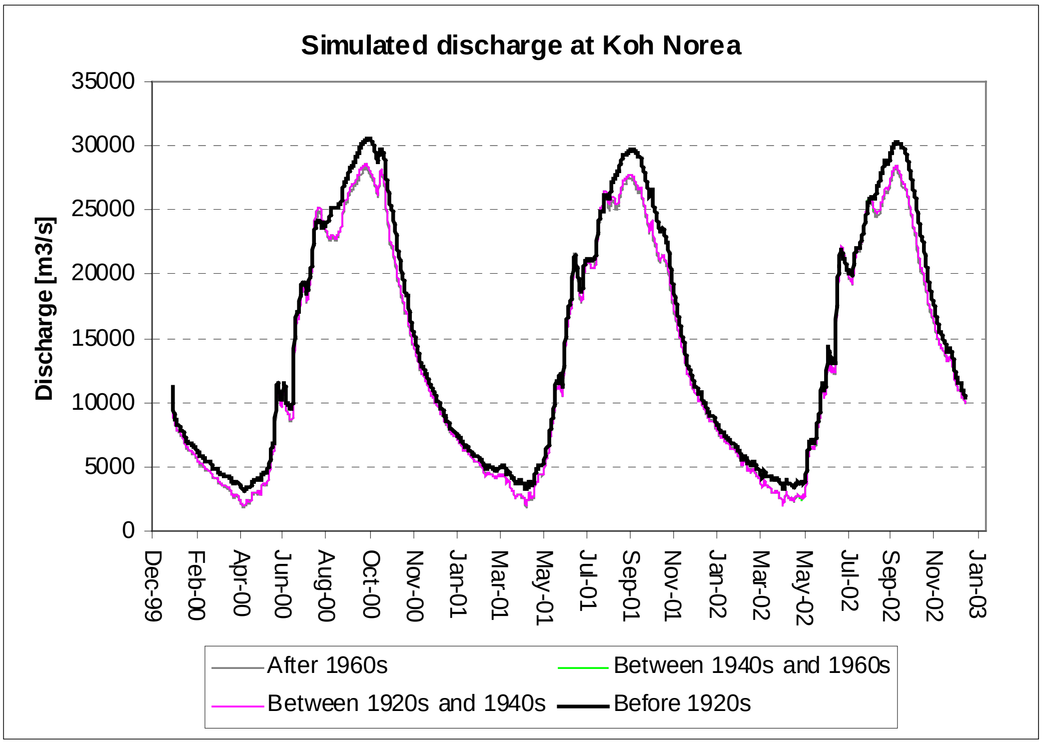


Fig. 3.3 Simulated Discharge for Embankment Conditions
(Chrui Changvar and Prek Kdam)



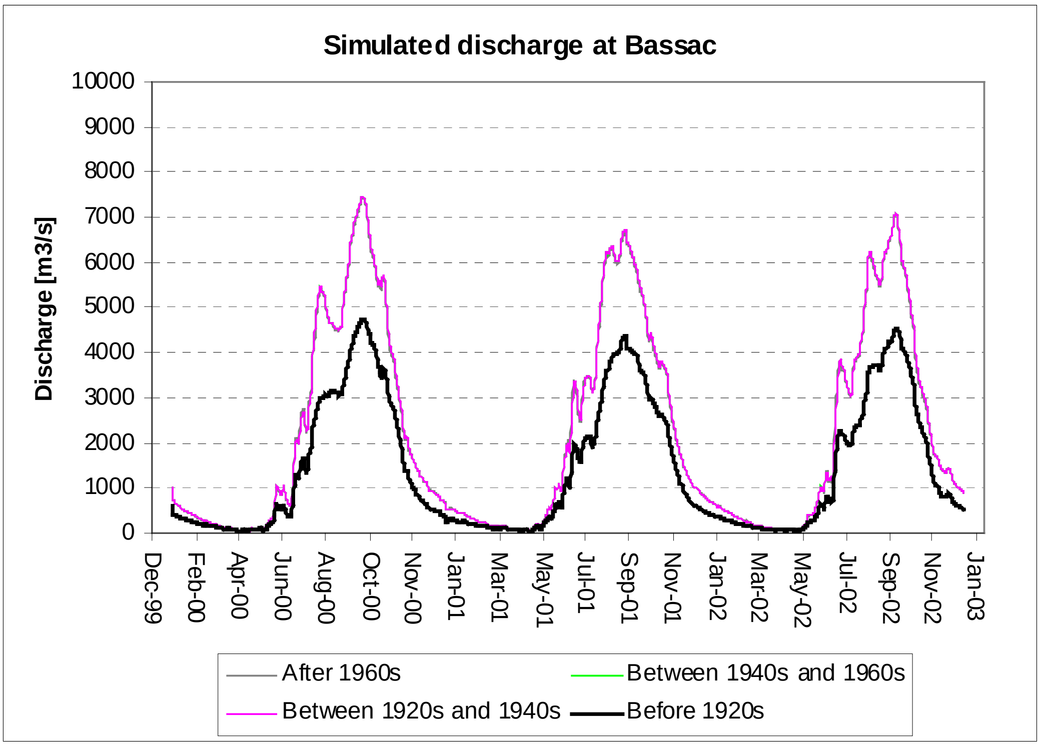


Fig. 3.4 Simulated Discharge for Embankment Conditions (Koh Norea and Bassac)

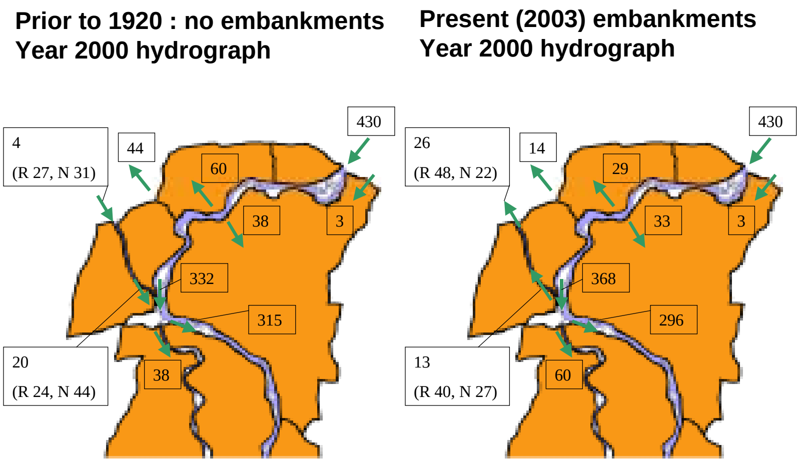


Fig. 3.5 Water Balance from June 1st to November 1st, 2000
[No Embankments (left), Present Embankments (right)]

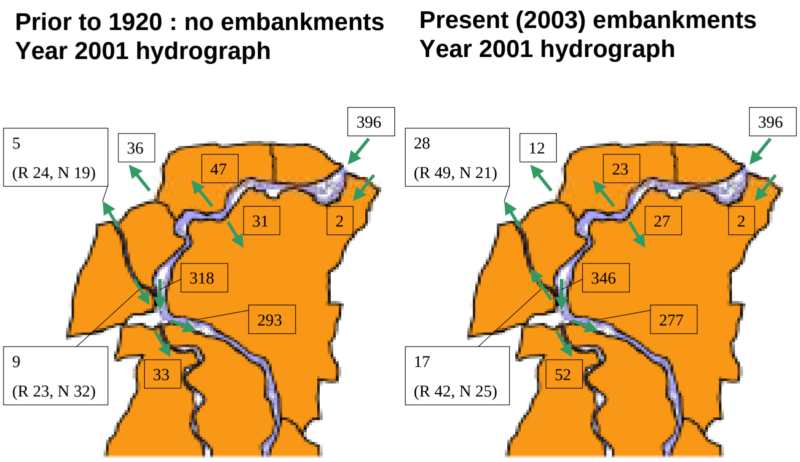


Fig. 3.6 Water Balance from June 1st to November 1st, 2001
[No Embankments (left), Present Embankments (right)]

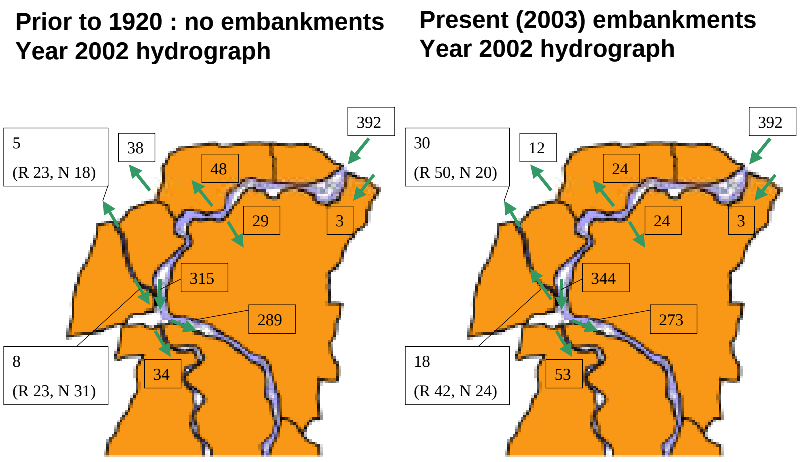


Fig. 3.7 Water Balance from June 1st to November 1st, 2002
[No Embankments (left), Present Embankments (right)]

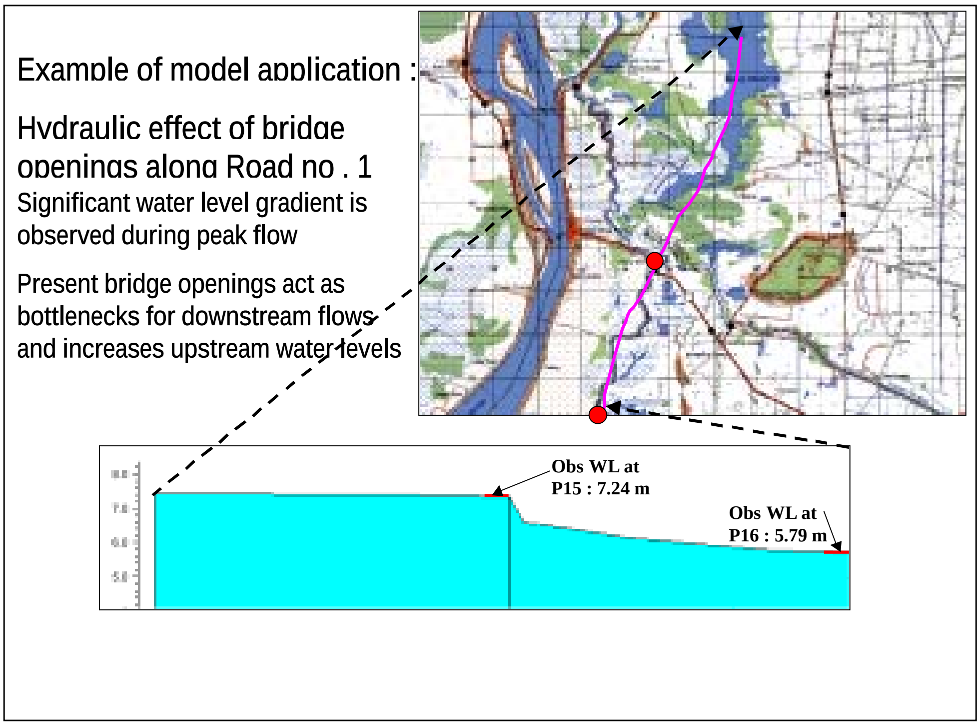


Fig. 4.1 Simulated Longitudinal Profile of Water Level for the Peak Flood in 2002 [Profile is across the embankment of road no.1 and shows the existing condition.]

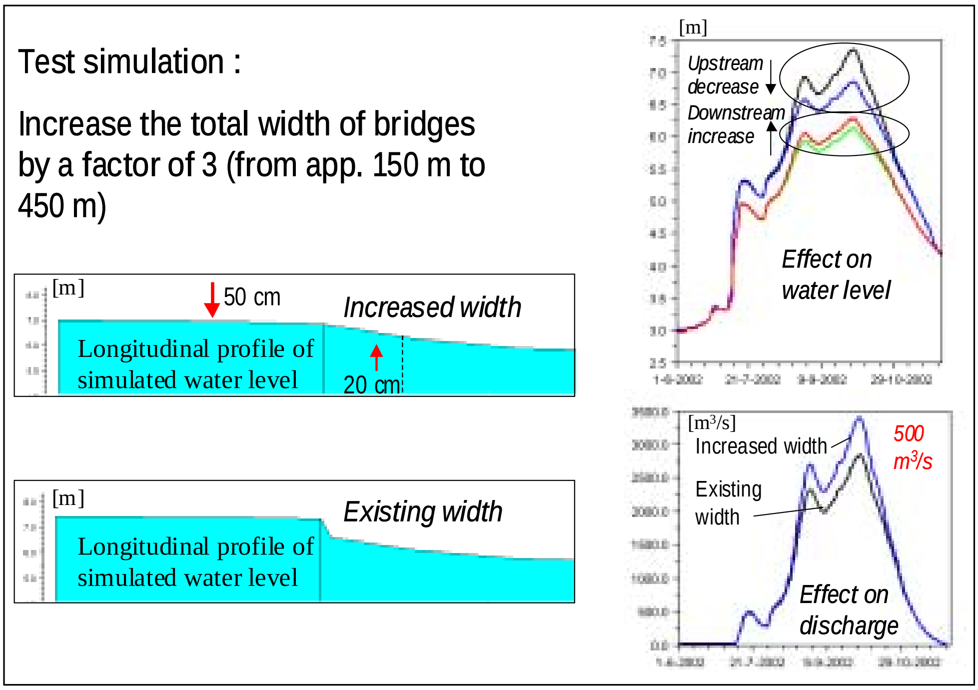


Fig. 4.2 Effect of Larger Bridge Openings on Water Levels and Discharges

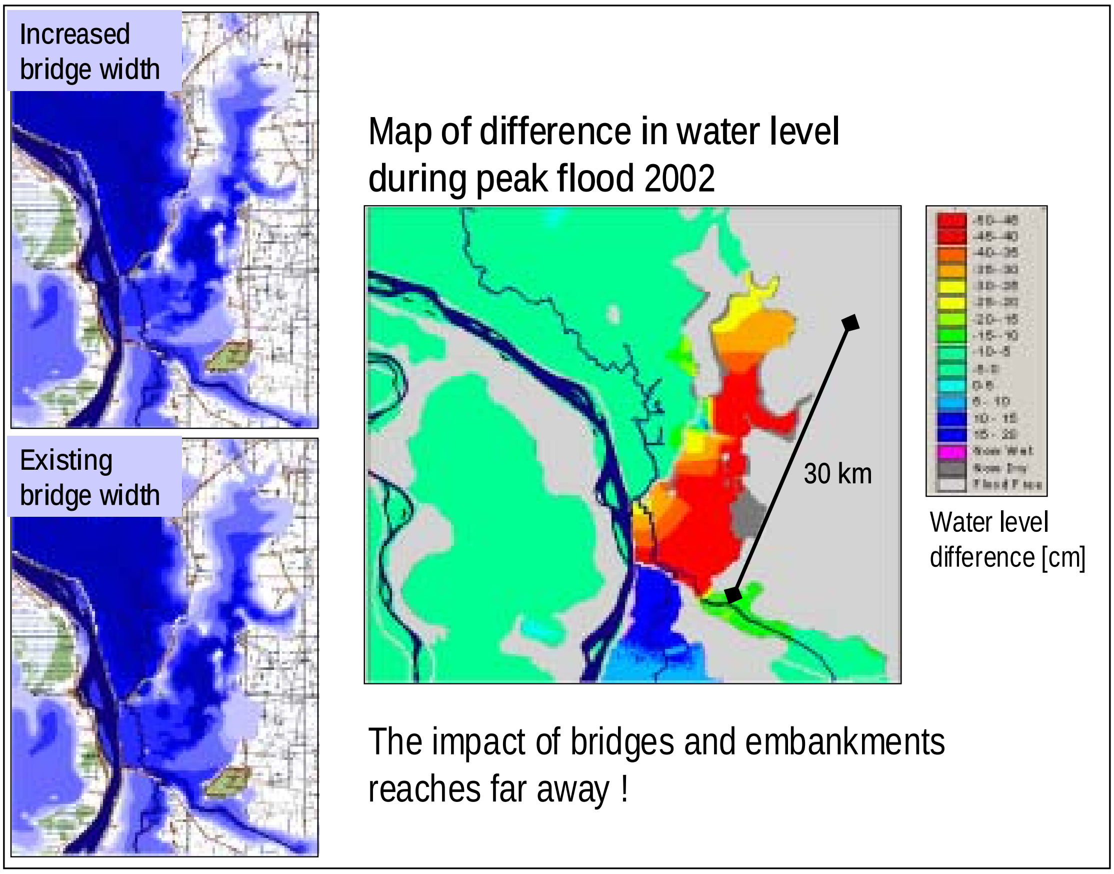


Fig. 4.3 Flood Inundation Maps for Existing and Test Case
[Difference map to the right showing the Water Level difference between test case and existing condition]

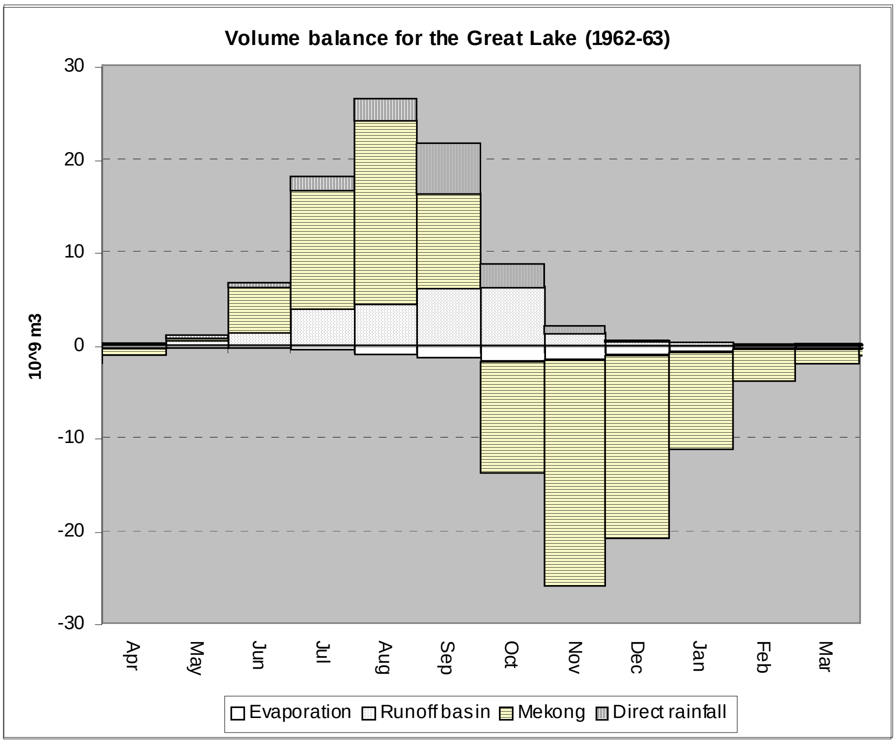


Fig. 5.1 Volume Balance for Hydrological Year 1962 (monthly basis) [Reprinted from ref /3/]

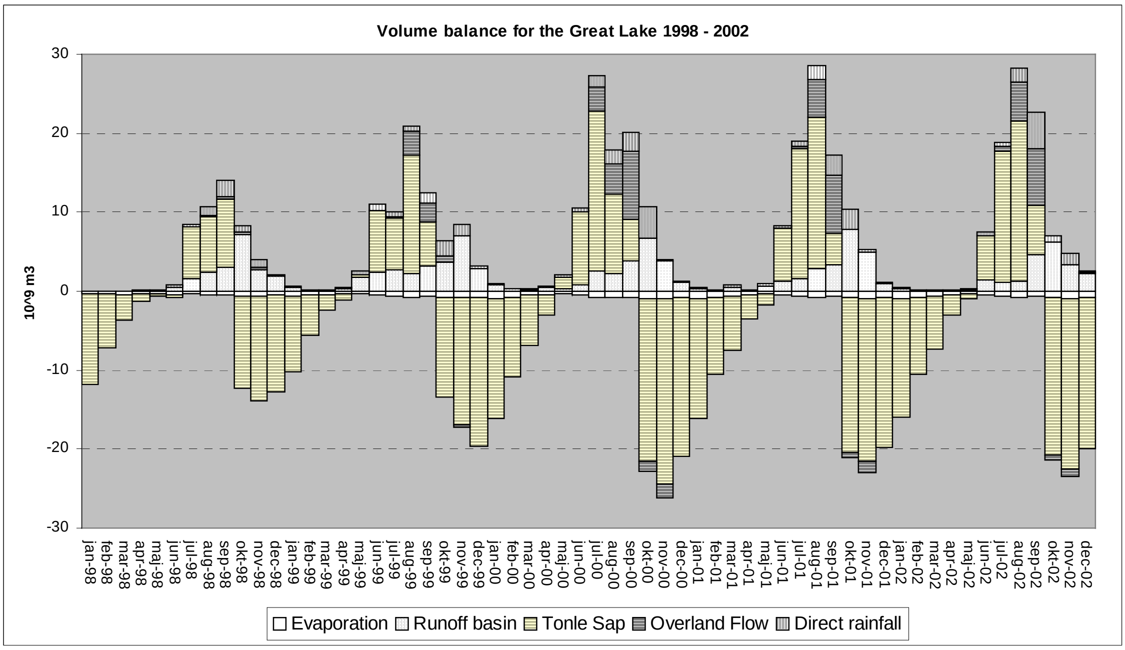


Fig. 5.2 Volume Balance for the Great Lake 1998-2002 (monthly basis)

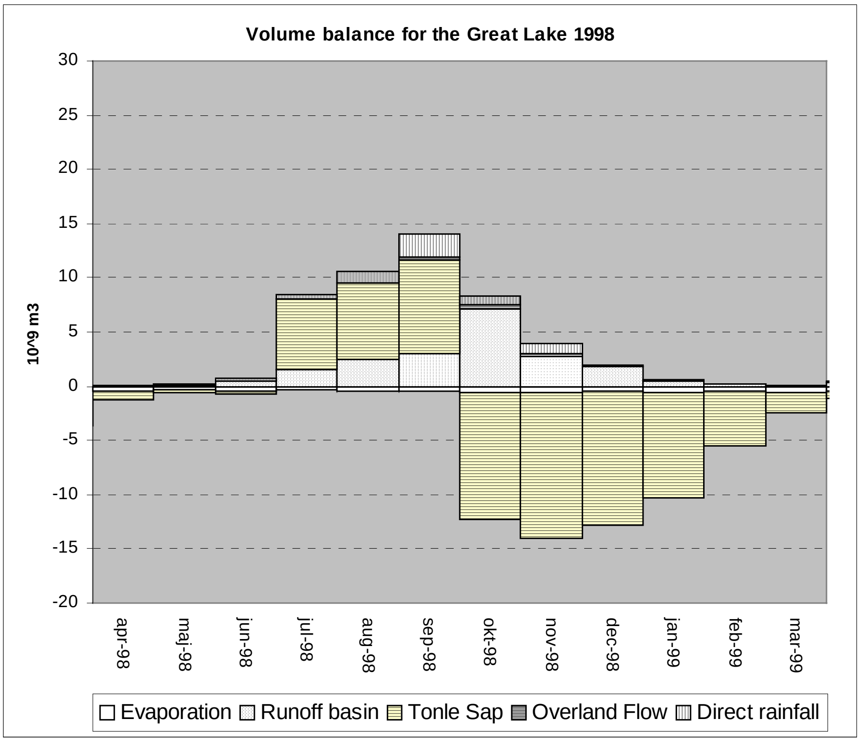


Fig. 5.3 Volume Balance for Hydrological Year 1998 (monthly basis)

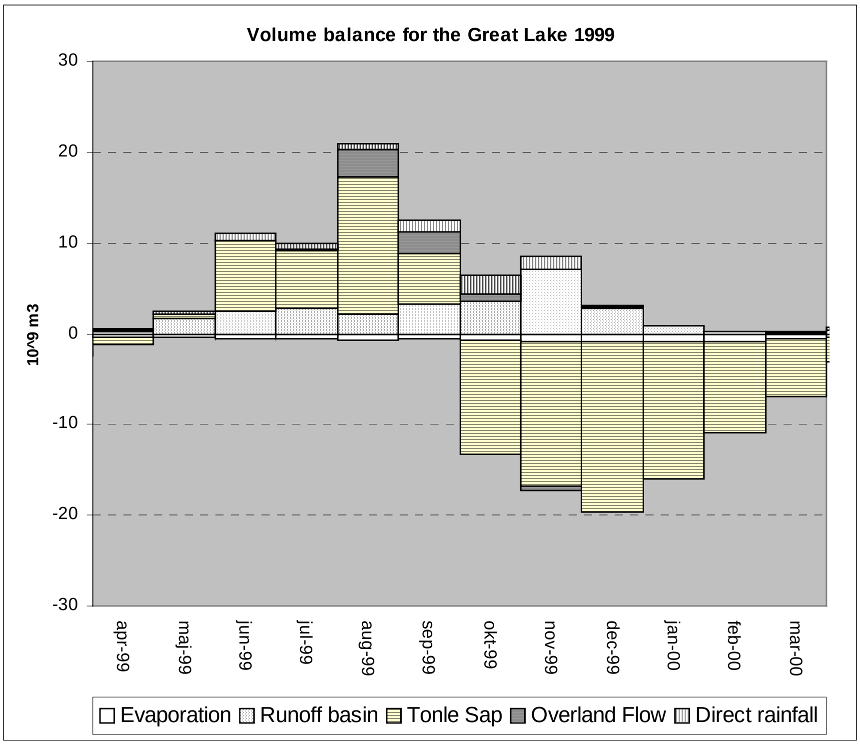


Fig. 5.4 Volume Balance for Hydrological Year 1999 (monthly basis)

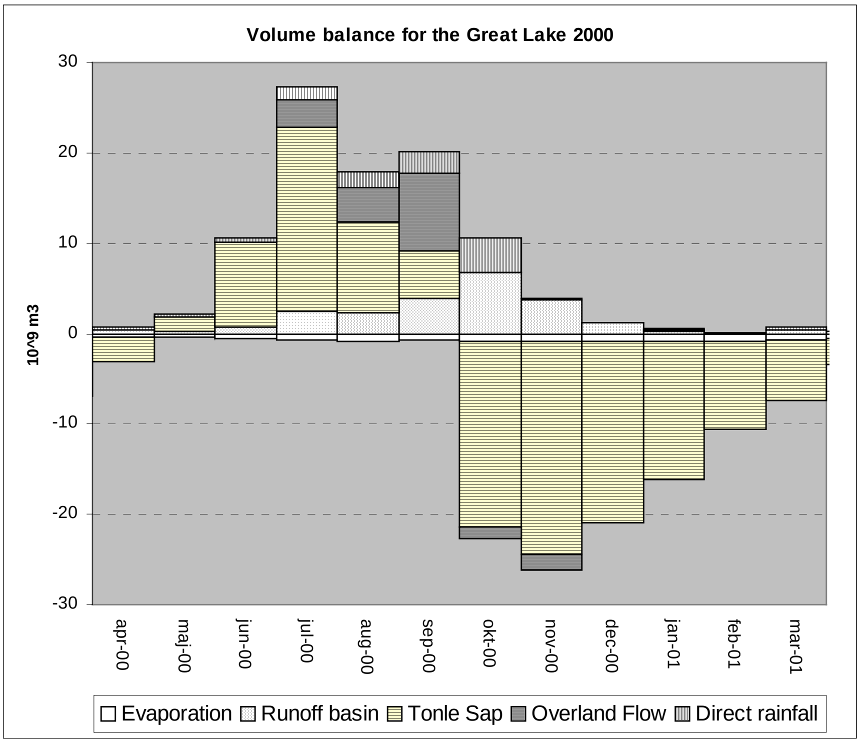


Fig. 5.5 Volume Balance for Hydrological Year 2000 (monthly basis)

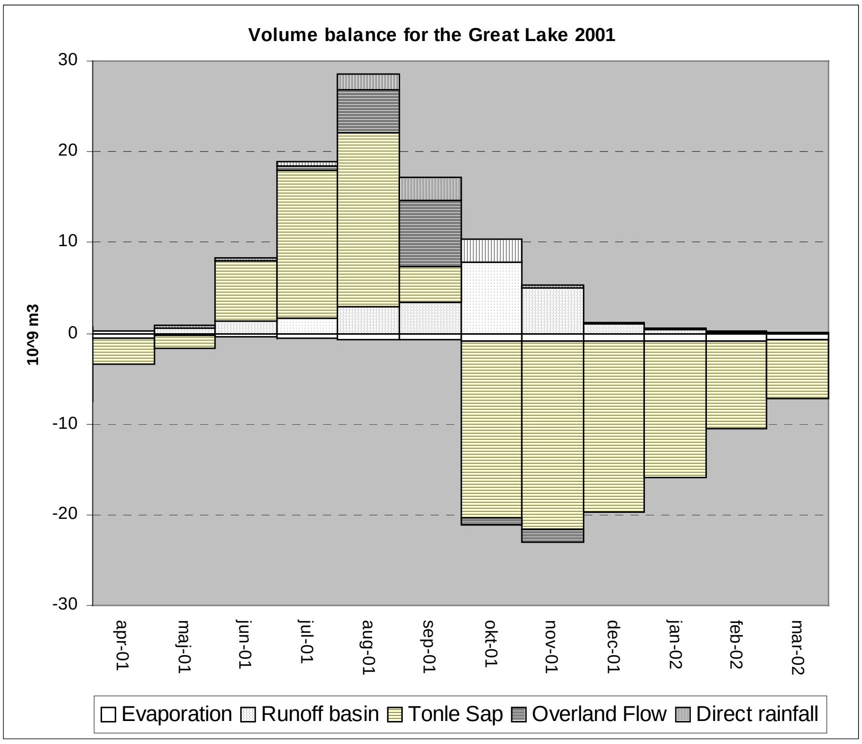


Fig. 5.6 Volume Balance for Hydrological Year 2001 (monthly basis)

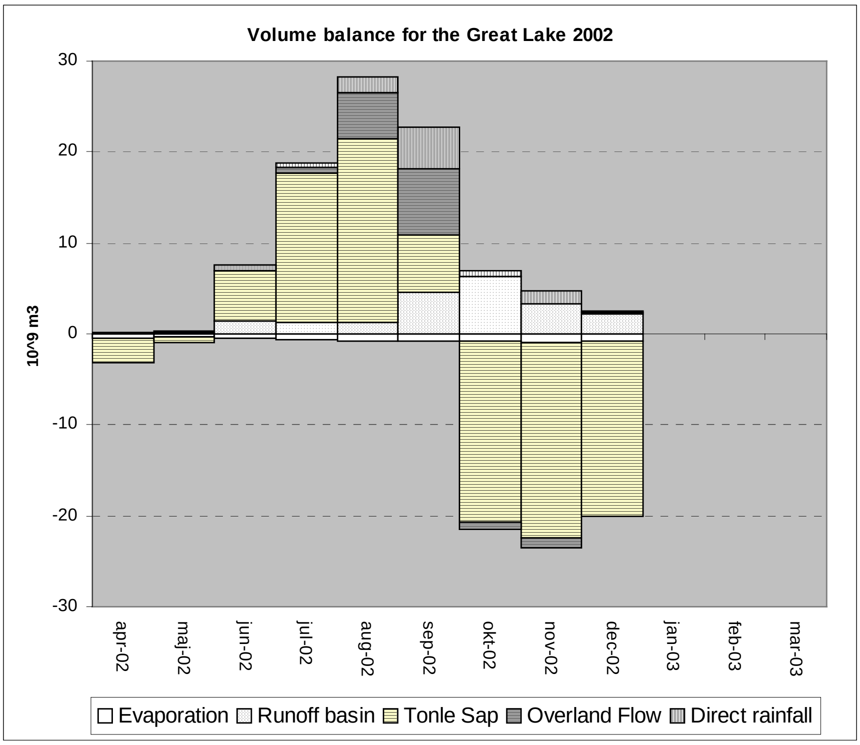


Fig. 5.7 Volume Balance for Hydrological Year 2002 (monthly basis)

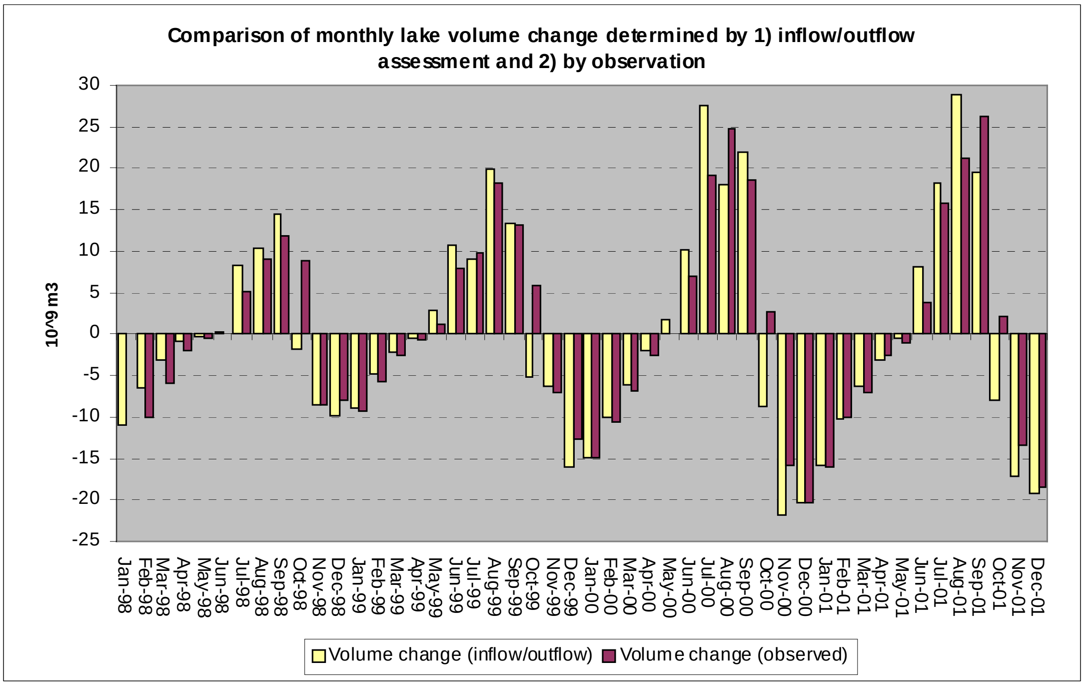


Fig. 5.8 Lake Volume and Monthly Change in Lake Volume Based on Observed Water Level and the Derived Level-Volume Relation

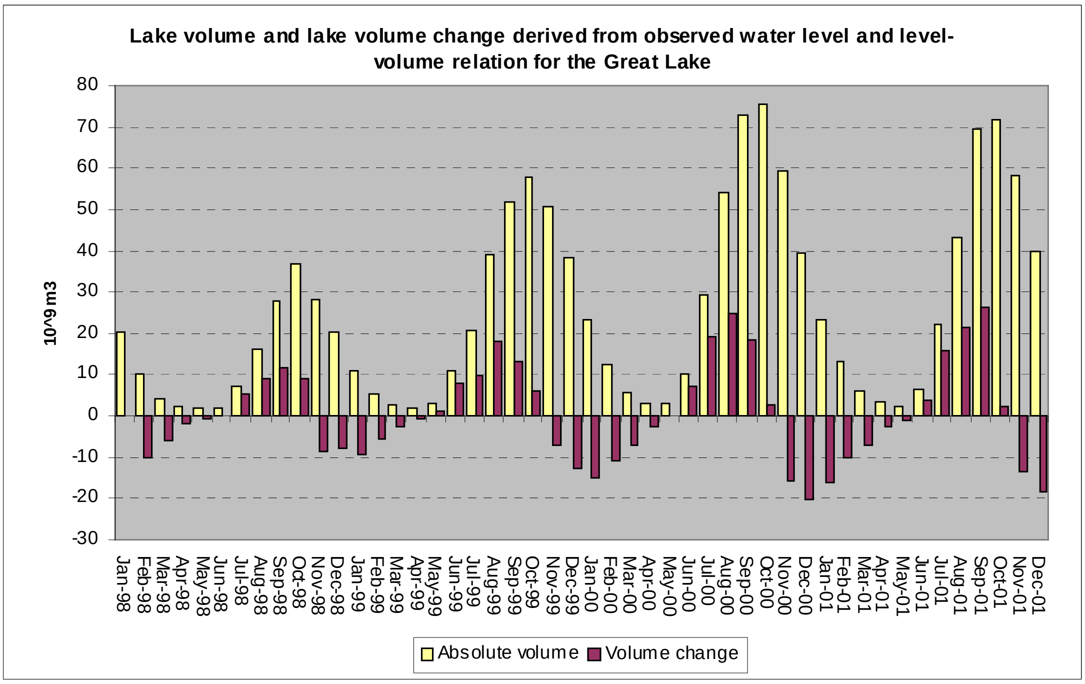


Fig. 5.9 Monthly Change in Lake Volume Based on (1) Inflow/Outflow Assessment and (2) by Observed Water Level and Level-Volume relation