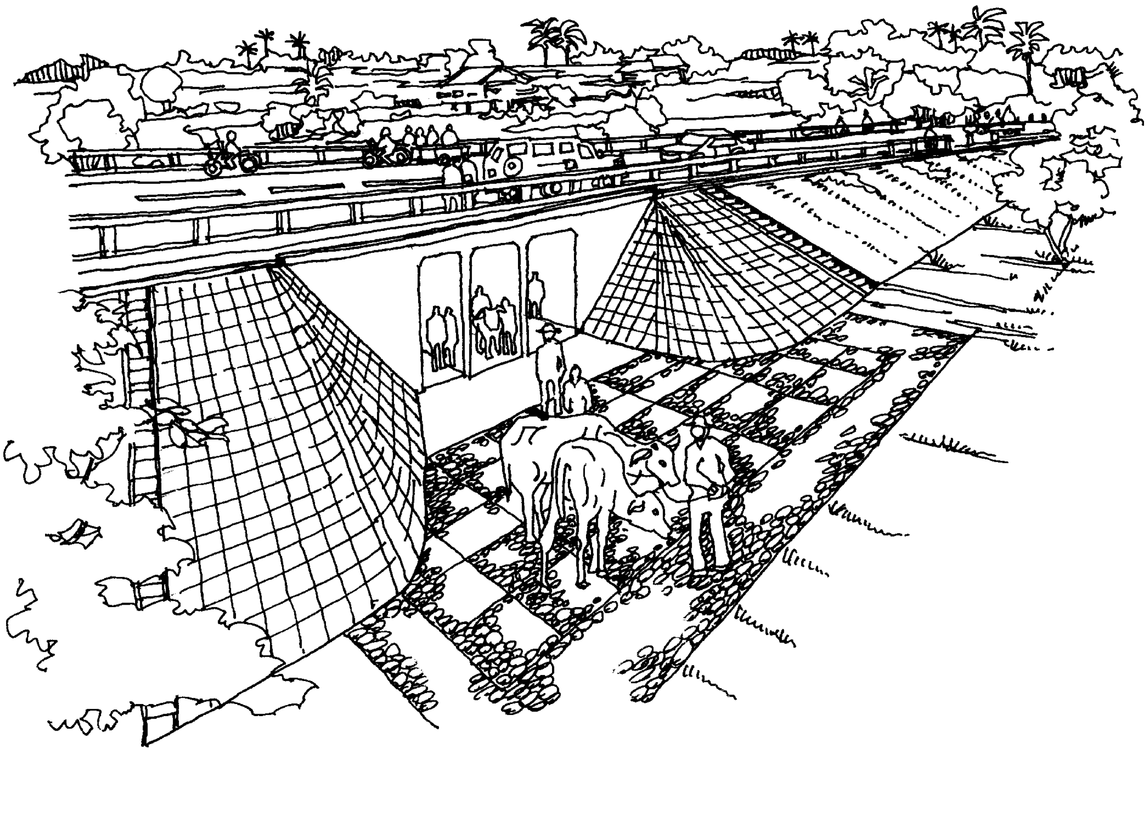
CHAPTER 9 FLOOD AND FLOOD MITIGATION



CHAPTER 9 FLOOD AND FLOOD MITIGATION

9.1 General

2000 Flood was the recorded maximum flood in and around Phnom Penh, and this flood is the basis of this Study. Other major floods in the recent past are the 1996 Flood and 2001 Flood. Following subsections first describe flooding condition and flood damage especially along the target national road of NR-1(C-1), analysis on mechanism of floods, development of hydraulic simulation model, and relating plans of flood mitigation. Then, basic concept and concrete flood mitigation plan for the NR-1(C-1) are formulated. Finally, in relation to preliminary design of the proposed road embankment and openings, protection plan for the road sections facing the Mekong River against erosion by waves or flows, and protection plan for the openings against erosion and local scour around the opening structures such as bridges and box culverts are formulated.

9.2 Flood and Flood Damage

9.2.1 Flooding Condition of 2000 Flood

Fig. 9-2-1 is the Landsat Image on September 26th, 2000 showing the peak flooding condition during 2000 Flood along the Mekong River including Phnom Penh, NR-1(C-1), NR-1(C-2) and NR-11. Wide inundation happened in the Left Bank Side Flood Plain of the Mekong River during 2000 Flood, which have width of inundation about 40 to 50 km around Phnom Penh and about 17 to 20 km around Neak Loueng.

In the Right Bank Side Flood Plain, which is called as Colmatage Area surrounded by NR-1(C-1) and the road along the left bank of the Bassac River, the area is also inundated like lake. The inundation water came into this area through the existing openings such as existing Colmatage canals, Cut-off No.1 and No.2 along the NR-1(C-1), and through the existing openings such as Colmatage canals along the right bank of the Bassac River.

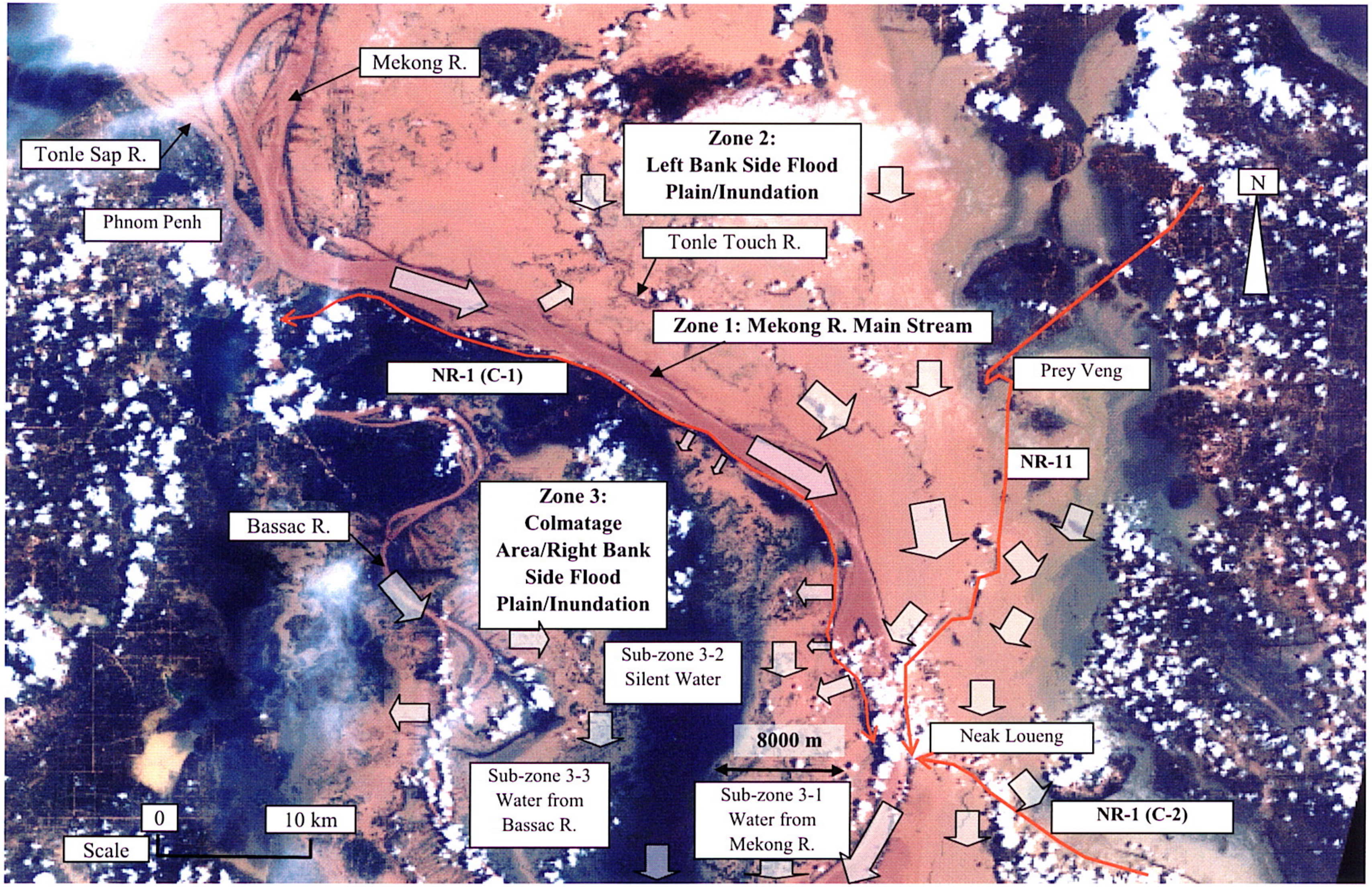


Fig. 9-2-1 Flooding Condition of 2000 Flood (Landsat Image on Sep. 26, 2000)

9.2.2 Flood Survey

In order to grasp the flooding conditions in and around the Study Area, flood survey by questionnaire to people was conducted in this Study. The target floods surveyed were 1996, 2000 and 2001 Floods. The locations and interval of the survey are as follows:

Table 9-2-1 Locations and Interval of the Flood Survey

Road	Section	Interval of Sampling
1. NR-1(C-1)	Phnom Penh to Neak Loueng.	1) Beside the road: 500 m interval. 2) Outside the road: 500 m interval.
2. NR-1(C-2)	Neak Loueng to Kampong Seang (about 9 km eastern direction from Neak Loueng).	Same interval as NR-1(C-1).
3. NR-11	Neak Loueng to Prey Veng and Prey Veng to Tuol Totueng (Jct. with NR-7).	1) Beside the road: 1 km interval. 2) Outside the road: 1 km interval.
4. NR-7	Tuol Totueng to Kampong Cham, and Kampong Cham to Skun.	Same interval as NR-11.
5. NR-6 and NR-6A	Skun to Phnom Penh.	Same interval as NR-11.

Note: In order to keep sampling number as much as possible, interval of sampling was adjusted depending on the actual distribution of houses along the national roads to be surveyed.

Major items of the flood survey are as follows:

1) Inundation depth, duration and flow direction.
2) Reason of floods (people's opinion).
3) Evacuation places during floods.
4) Flood damage (people, house, agriculture and fishery).
5) Benefit from floods (increasing agricultural and fishery production).
6) Affection by the two artificial Cut-offs along the NR-1(C-1) made during 2000 Flood.
7) Comments and suggestions from people on flood mitigation and road improvement.

Sampling number of the flood survey is as follows:

Table 9-2-2 Sampling Number of Flood Survey

Road	Section	Sampling Number		
		Beside Road	Outside of Road	Total
NR-1(C-1)	Phnom Penh - Neak Loueng (West)	110	111	221
NR-1(C-2)	Neak Loueng (East) - Kampong Seang	16	8	24
NR-11	Neak Loueng (East) - Prey Veng	33	21	54
	Prey Veng - Tuol Totueng (Jct. with NR-7)	70	60	130
NR-7	Tuol Totueng - Kampong Cham - Skun	46	47	93
NR-6 & 6A	Skun - Phnom Penh	67	63	130
Total		342	310	652

Results of flood survey are incorporated in the subsequent subsections.

9.2.3 Overflow Places

Based on the flood survey, site reconnaissance and other information, overflowed/breached sections and their length along the NR-1(C-1), NR-1(C-2) and NR-11 by 2000 Flood are estimated as shown in Fig. 9-2-2.

NR-1(C-2) and NR-11

Along the previous NR-1(C-2) from Neak Loueng (East) to about 9 km, overflows including breaches happened at 5 places. Furthermore, large overflow happened along the secondary road connecting at Km 9+000 of the NR-1(C-2). 17 overflows including breached sections could be observed along the NR-11 (from Neak Loueng to Prey Veng).

NR-1(C-1)

As for the NR-1(C-1), section from middle part of the NR-1(C-1) to Neak Loueng (West) is located in the severe places against flood, where Mekong River probably had made overflows in the old days before constructing the NR-1(C-1), and the floodwater had crossed and entered into the Colmatage Area. Although the floodwater has reached up to the top of the road embankment in many places, only three overflows happened along NR-1(C-1) during 2000 Flood.

Other National Road (NR-6A)

As for the NR-6A from Phnom Penh to northern direction about 34 km, the road goes along the Mekong River. Among this reach, the section of NR-6A between Phnom Penh to about 26 km located parallel with the Mekong River, where flood from the Mekong River does not attack directly. However, the section between 26 km and 33 km locates along the severe vending portion of the Mekong River, where flood flow of the Mekong River tends to attack the openings along the road. At this place, floodwater level reached nearly to the bottom of the beams of the bridges during 2000 Flood.

9.2.4 Flood Water Level along the NR-1(C-1)

Based on the observed water levels, results of flood survey, site reconnaissance and the related information about 2000 Flood, the maximum flood water levels along the NR-1(C-1) was estimated as shown in Fig. 9-2-3. Among the data, the observed water levels at Neak Loueng and Chrouy Changvar along the Mekong River and Chaktomuk along the Bassac River are the most basic water level data. Furthermore, the observed water levels at Prek Yourn Water Gate and Koki Thom Water Gate during 2000 Flood was also referred by revising the observed water level based on the topographic survey of this Study.

The maximum water level during 2000 Flood was almost same as the road elevation with total length of about 29 km. Overflow happened at three places with total length of about 1100 meters and overflow depth of 0 to 0.5 meter. There were no natural breached sections along the NR-1(C-1) by 2000 Floods. However, although both of the artificial Cut-offs was originally about 10 to 20 meters length each, due to erosion by strong current, only 3 days later, they became longer to the existing length of about 160 meters.

Estimated floodwater level along the NR-1(C-2) and NR-11 are shown in the Appendix B.

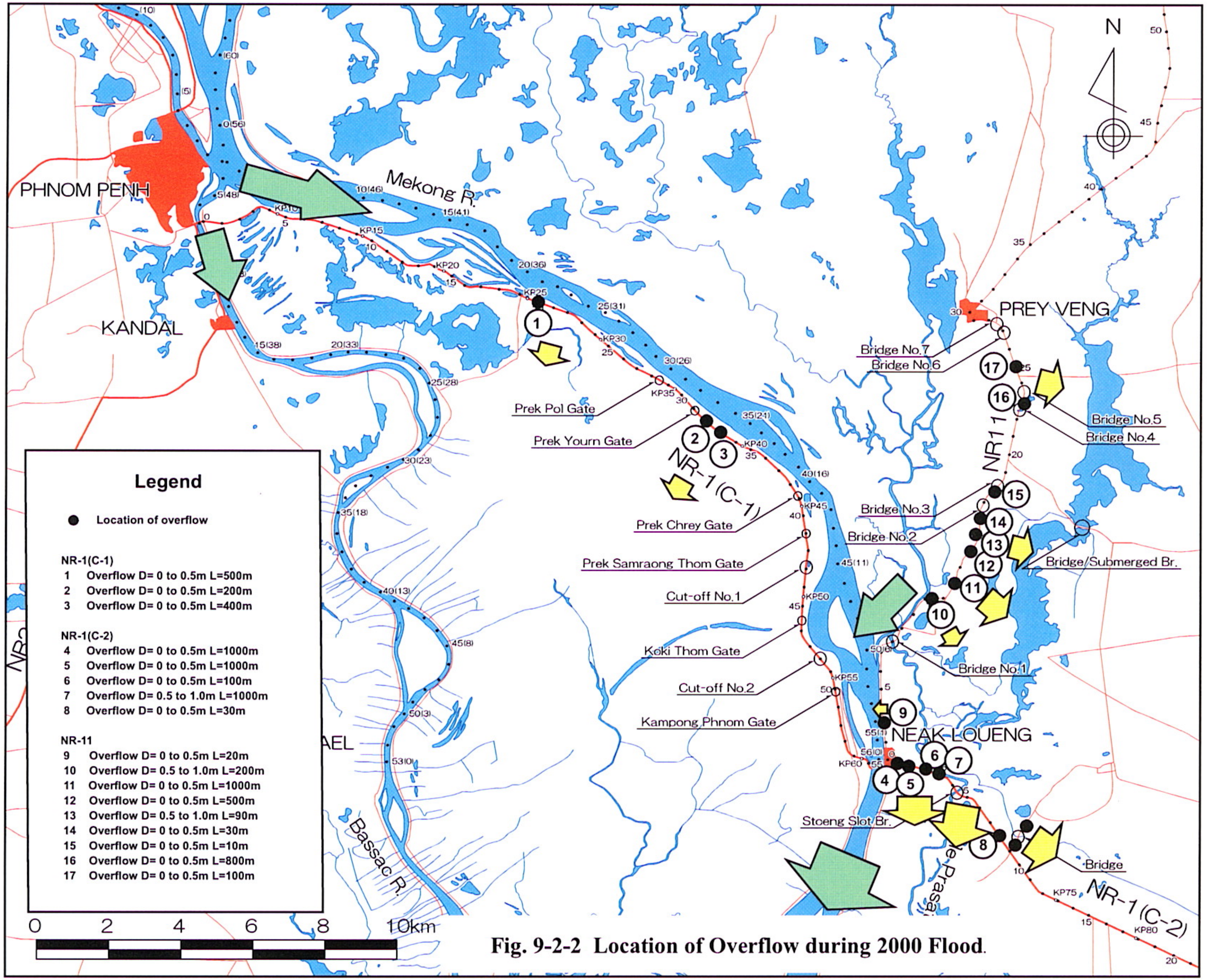


Fig. 9-2-2 Location of Overflow during 2000 Flood.

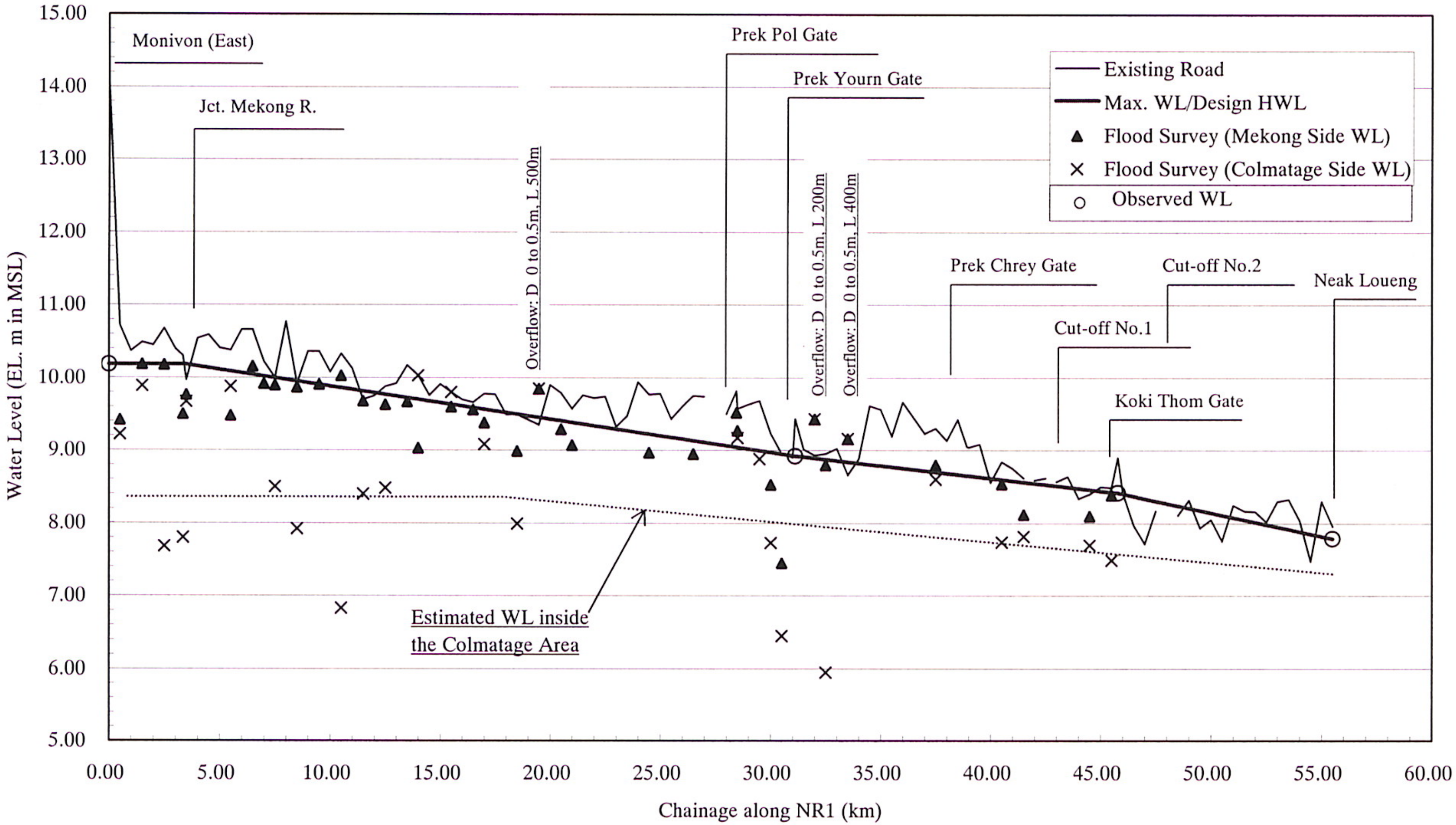


Fig. 9-2-3 Estimated Maximum Water Level along NR-1(C-1) during 2000 Flood

9.2.5 Inflow Discharge from NR-1(C-1)

Based on the information of flood condition along the NR-1(C-1), inflow discharge including overflow discharge along the NR-1(C-1) during the 2000 Flood was estimated as shown in Table 9-2-3, which also shows the existing inflow capacity in the case of without overflow.

Table 9-2-3 Inflow Discharge/Capacity along NR-1(C-1)

(Unit: m^3/s)

Kind of Opening	Inflow Discharge during 2000 Flood	Present Inflow Capacity (Without overflow)
New Water Gates	321.2 (3 nos. except Prek Chrey)	442.6 (4 nos.)
Old Water Gates (2 nos.)	50.3	50.3
Pipe Culverts (2 nos.)	2.1	2.1
Cut-off No.1	1364.7	1364.7
Cut-off No.2	400.0	400.0
Overflow (3 places)	137.5	-
Total	2275.8	2259.7

Remarks: Above inflow discharge is calculated based on the estimated flood water level at the opening points and difference of water level at the opening points between Mekong Side and Colmatage Side during 2000 Flood. By the existing secondary roads along the Mekong River, the maximum water levels along NR-1(C-1) has local variations in detail: for example the maximum water level in Mekong Side at the cut-off sites are estimated to be slightly lower than the estimated maximum water level along NR-1(C-1) shown in Fig. 9-2-3, which is due to local topography along NR-1(C-1).

9.2.6 Flood Damage

(1) Flood Damage along NR-1(C-1)

1) Damage to the Road and Opening Structures

Along the NR-1(C-1), overflowed portion during 2000 Flood were only three. However, as the flood water level was very near to the edge of embankment of the road, surface condition of the NR-1(C-1) was deteriorated by the water.

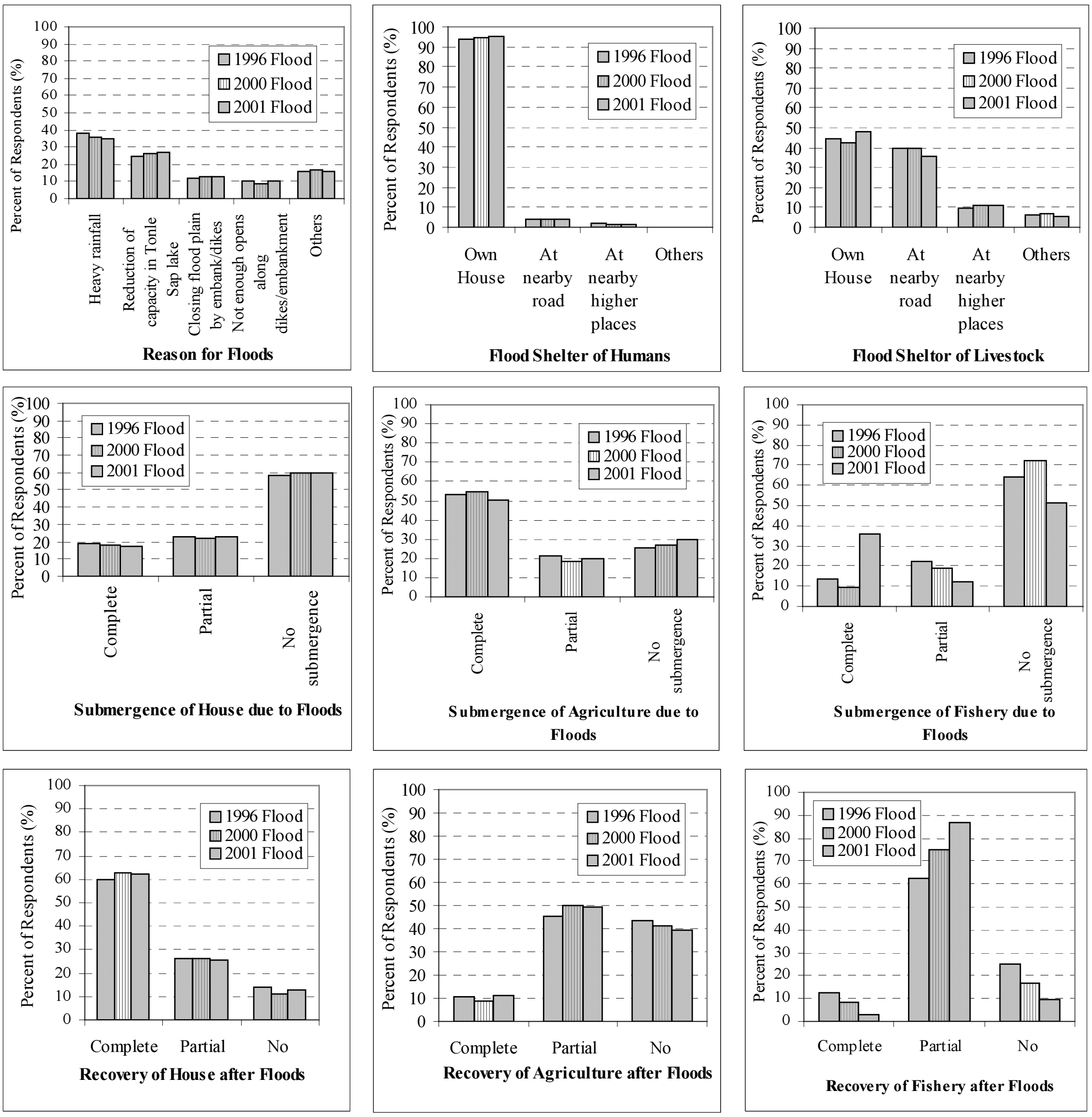
At the three new water gates (Prek Pol, Prek Yourn and Kokir Thom), erosion in the downstream channel was happened by the strong current through the gate structure. Furthermore, at the Cut-off No.1, local scouring with depth of about 4 to 5 meters was caused around the opening by strong current. The scouring around the Cut-off No.2 was also caused by the current, as the velocity was smaller than Cut-off No.1, depth of scouring at Cut-off No.2 was only about 1 to 2 meters.

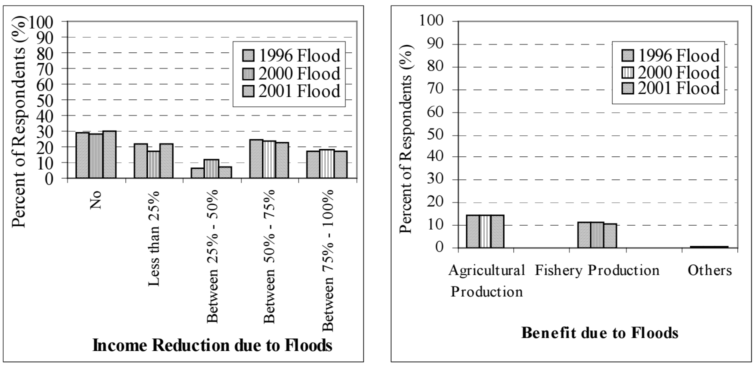
2) Social and Economic Damage

The results of statistical analysis for the questionnaire on the flood damage along NR-1(C-1) are shown in Fig.9-2-4. According to the results, the followings are implied.

<u>Difference among flood in 1996, 2000 and 2001</u>

There is no significant difference on flood damages in 1996, 2000 and 2001. This result implies that the openings do not make significant flood damage.





Effects by the Two Artificial Openings of NR-1

Response	No. of Respondents	Percent (%)
Positive	75	84.3
Negative	14	15.7
Total No. of Respondents	89	100

Fig. 9-2-4 Results of Statistical Analysis on the Flood Damage along NR-1(C-1)

Reason for floods

Local people think that heavy rainfall can cause flooding. They also recognize the effect of Tonle Sap Lake on storing run-off and/or river flow from the Mekong River.

Flood shelter

Almost all local people stayed at their own house during the flood. On the contrast, 40% of all livestock evacuated to nearby road. Fig. 9-2-5 shows the places where people and livestock evacuated during 2000 Flood (bar chart) and during 2002 Flood (map). This figure also shows the evacuation places along NR-11. Along NR-1(C-1), at chainage of 20 km to 55 km, nearby road is likely to be used as an evacuation place for people and livestock. These people and livestock along the NR-1(C-1) probably come from the secondary roads beside the Mekong River, which are tend to be inundated during floods. On the contrary, the evacuated people and livestock along NR-11 mainly come from nearby low-lying places. Furthermore, some of the evacuated people and livestock along NR-11 probably come from the secondary road along the right bank of the Mekong River by using floating houses.

Submergence due to floods

Agricultural land is more vulnerable against floods than houses and fishery.

Recovery after floods

Houses are more easily recovered than agricultural land and fishery.

Income reduction due to floods

Half of all local people got little income reduction. However, the remains suffered more than 50% income reduction.

Benefit due to floods

Some local people think there is benefit for agriculture and fishery due to floods.

Effect of two artificial openings

More than 80 % of all respondents feel positive effect of the openings.

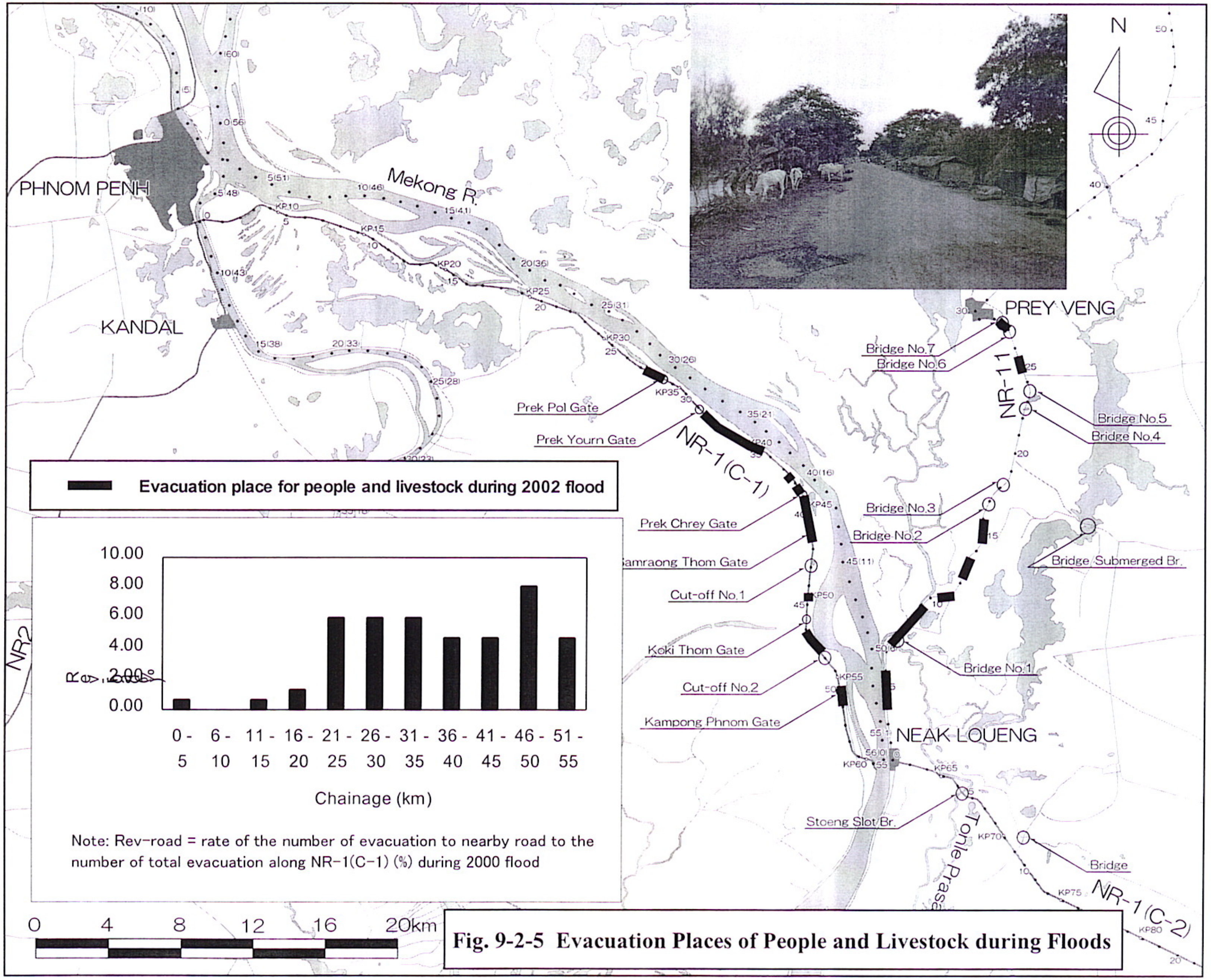


Fig. 9-2-5 Evacuation Places of People and Livestock during Floods

(2) Flood Damage along NR-1(C-2), NR-11, NR-7 and NR-6A

1) Damage to Road and Opening Structures

Big overflowed/breached section with about 270 meters length was happened along the previous NR-1(C-2) around the severe vending portion of the Prek Banam River (upstream part of the Tonle Prasat River) at about 3 km eastward from Neak Loueng.

Flood damage along the NR-11 between Neak Loueng during 2000 Flood was very severe with overflow at 17 places including breaches at 8 places. Abutments and approaches of the Bridge No.3, No.6 and No.7 were eroded or washed away. The road was severely eroded in many places. Along the NR-11 from Neak Loueng to the northern direction, flood damage along the road was not so severe with only overflow at one or two places.

2) Social and Economic Damage

Making comparison with the results for NR-1(C-1), based on the flood survey, summarizes the flood damage along NR-11, NR-7 and NR-6A as shown in Table 9-2-4.

Table 9-2-4 Flood Damage along NR-11, NR-7 and NR-6A

	NR-11	NR-7	NR-6A
Reason for Floods	- Influence of Tonle Sap Lake was more important.	- Less influence of the openings was recognized.	- Almost same as NR-1
Flood Shelter	- More people escaped to nearby road.	- Less number of livestock escaped to nearby road.	- Almost same as NR-1
Submergence due to Floods	- Fewer houses were submerged. - More agricultural land and fishery was submerged.	- Fewer houses were submerged. - 2000 flood caused wider submergence of agricultural land.	- Fewer houses were submerged. - More Agricultural land was submerged.
Recovery after Floods	- Less percentage of fisheries was recovered.	- More agriculture was partially recovered.	- More houses were completely recovered.
Income Reduction due to Floods	- More people had no income reduction.	- More people had no income reduction.	- More people had no income reduction.
Benefit to Floods	- Almost same as NR-1	- There is another benefit.	- Almost same as NR-1

9.3 Mechanism of Floods

9.3.1 Flooding Zones

The wide inundation in the Right and Left Bank Side Flood Plains of the Mekong River together with the water in the Main Stream of the Mekong River looks like one large water surface in general (refer to Fig. 9-2-1). However, in detail, the above large water surface can be divided by the existing NR-1(C-1), a part of NR-11 along the Mekong River, and secondary roads along the both banks of the Mekong River. Therefore, the above large water surface of the inundation along the Mekong River and surrounded areas can be physically divided into three zones as follows:

Zone 1: Mekong River Main Stream.
Zone 2: Left Bank Side Flood Plain of the Mekong River
from Kampong Cham to country Border crossing the NR-11 and the NR-1(C-2).
Zone 3: Right Bank Side Flood Plain between the Mekong River and the Bassac River
from Phnom Penh to country border through the Colmatage Area along the NR-1(C-1).

The water of Zone 1 and Zone 2 inter-connects at the Junction of the Tonle Touch River with the Mekong River at about 6 km upstream from Neak Loueng. The openings along the NR-1(C-1) have the effect of lowering flood water level along the Mekong River Main Stream in the first. Then, this effect will be transmitted through this Junction of the Tonle Touch River with the Mekong River to the Left Bank Side Flood Plain such as lowering the inundation water level along NR-11 and NR-1(C-2), and decreasing the flood discharge to NR-1(C-2).

As the Colmatage Area had a function of releasing floodwater along the NR-1(C-1) during 2000 Flood, and also had a function of like a retarding basin, this area is also important regarding the potential capacity for releasing floodwater of the Mekong River especially during emergency cases like 2000 Flood.

Inside the Right Bank Side Flood Plain (Zone 3), three sub-zones can be seen (see Fig. 9-2-1) as follows:

a) "Sub-zone 3-1" with water from the Mekong River (eastern part)
b) "Sub-zone 3-2" with silent water (central part)
c) "Sub-zone 3-3" with water from the Bassac River (western part)

"Sub-zone 3-1" with water from the Mekong River contains sediment such as suspended solid. "Sub-zone 3-2" with silent water is estimated not containing sediment. "Sub-zone 3-3" with water from the Bassac River also contains sediment.

<u>Discharge Capacity of the "Sub-zone 3-1" with Water from the Mekong River:</u>

Supposing that above sub-zones reveals flood flow characteristics inside the Right Bank Side Flood Plain (Zone 3), order of the potential discharge capacity of the "Sub-zone 3-1" with water from the Mekong River can be roughly estimated at 3,600 m^3/s as follows:

a) Width of the "Sub-zone 3-1" with water from the Mekong River (W): 8000 meters
b) Inundation depth (D): 3 meters
c) Water surface slope (S): 1/30,000
d) Roughness Coefficient (n): 0.06 to 0.1
e) Velocity(V): V=1/n x D(2/3) x S(1/2) = 0.12 to 0.20 m/s
(Average 0.16 say 0.15 m/s)
f) Discharge Capacity (Q):Q=V x W x D=0.15 x 8,000 x 3= 3,600 m^3/s

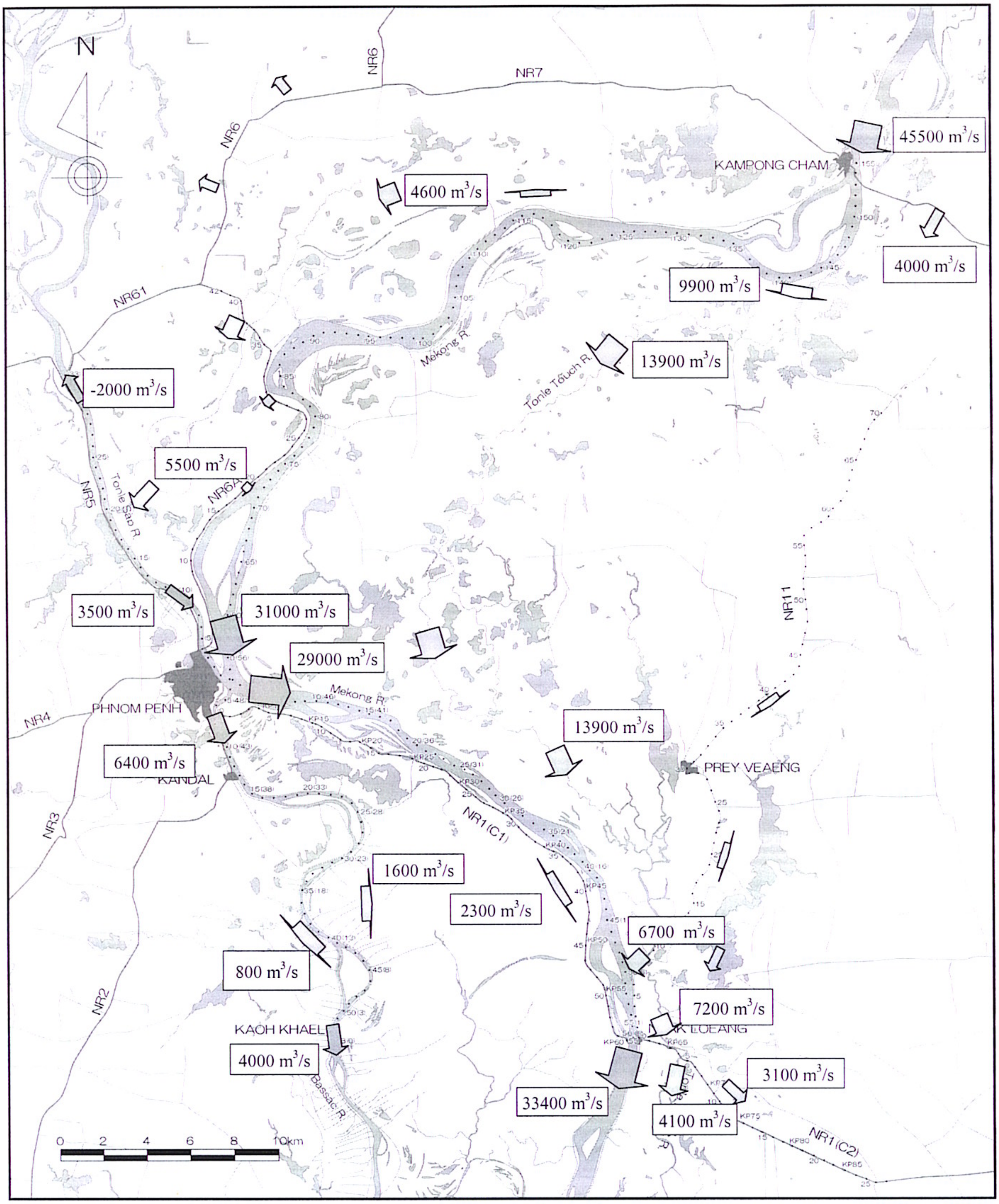
The above 3,600 m^3/s is regarded as one of the basic value for considering the discharge capacity of the "Sub-zone 3-1" with water from the Mekong River.

9.3.2 Rough Estimation of Discharge Balance

During 2000 Flood, MRC measured flood discharge of the Mekong River Main Stream at Kampong Cham, Chrouy Changvar and Neak Loueng, Tonle Sap River at Phnom Penh Port and Prek Kdam, and Bassac River at Chaktomuk and Kaoh Khael by using Acoustic Doppler

Current Profiler (ADCP) three times: Pre-flood, Center and Post flood. Based on these observation data and the estimated discharge over or through the NR-1(C-2) by ADB and estimated inflow discharge from NR-1(C-1) by this Study etc., discharge balance around the peak of 2000 Flood was roughly estimated as shown in Fig. 9-3-1. The key factors of the discharge balance are as follows:

a) Difference of discharge between Kampong Cham and Chrouy Changvar due to inundation along both banks of the Mekong River in this reach.
b) Reverse discharge to the Tonle Sap Lake and discharge to Mekong River through the Tonle Sap River.
c) Discharge to the Mekong River Main Stream and the Bassac River from the Junction with the Tonle Sap River and the Bifurcation of the Bassac River.
d) Discharge at Neak Loueng and Kaoh Khael.



Data source:

1) Discharge observation data by Chaktomuk Project of MRC.
2) ADB Review Study on NR-1 after 2000 Flood.
3) JICA NR-1 Study.

Fig. 9-3-1 Rough Estimation of Discharge Balance during 2000 Flood

9.4 Development of Hydraulic Simulation Model

9.4.1 Scope of the Development of the Hydraulic Simulation Model

(1) Purpose of Hydraulic Simulation

The main purpose of hydraulic simulation in the present study is as follows:

- To evaluate the effect of two artificial Cut-offs (Cut-off No.1 and No.2) made during 2000 Flood on reducing the flood water level along the Mekong River.
- To provide information for evaluating several alternatives for openings.

In this study, in order to evaluate the hydraulic effects of the openings and other existing Colmatage Gates etc., unsteady hydraulic simulation model has been developed by using MIKE 11, which is a famous international hydrological and hydrodynamic simulation software produced by Danish Hydraulic Institute (DHI).

(2) Covering Area of the Simulation Model

The simulation model covers the Mekong River reach from Phnom Penh to Neak Loueng and Bassac River from Phnom Penh to Kaoh Khael including the surrounding flood plain areas.

(3) Related Studies

In the study area, a similar hydraulic simulation model had been developed by DHI Water & Environment (DHI) in association with HAECON N.V. for the Mekong River Commission Secretariat (MRCS)[1]. Furthermore, ongoing JICA Hydrological Study for the Mekong River Basin[2] has also been developing a hydraulic simulation model to describe comprehensive annual run-off including flooding process, which has the main target to grasp base flow of the rivers.

These studies cover wider area such as the Mekong River Mainstream Basin from Kampong Cham to country border, the Tonle Sap River Basin including the Tonle Sap Lake and the Bassac River Basin. It is expected that the sophisticated hydraulic simulation model will be developed based upon ongoing detailed hydrological observation in near future. However, these models ignore relatively small features such as the openings because of covering wider area.

The simulation model of this study was developed by referring the model developed by the JICA Hydrological Study. The data of river network and river cross sections has been extracted and imported by cooperation with JICA Office and the JICA Hydrological Study Team. Then, some more modification such as inserting additional cross-sectional data for river and flood plain, openings along the NR-1(C-1 and C-2) and NR-11 has been made. The model of this study concentrates to evaluate the effect of the openings for 2000 Flood.

1 MRCS: “A Comprehensive Study on the Chaktomuk Area. Environment, Hydraulics and Morphology. Phase 1”, 2002.

2 JICA: “The Study on Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin”, 2001-2003.

9.4.2 Framework of the Simulation Model

(1) Model Structure

Schematic structure of the simulation model is shown in Fig.9-4-1. The Mekong River, the Bassac River and the Tonle Sap River are connected as a river network, and the surrounding flood plain is taken into account tributaries and distributaries with storage areas. The input and output of the simulation model are as follows:

Model Input

- Geomorphology within study area including cross sectional shape of the channel, elevation and storage area of the flood plain and dimension of the openings.
- Time series of discharge at upstream end of the simulated area (boundary condition at upstream end).
- Relationship between water surface level and discharge at downstream end of the simulated area (boundary condition at downstream end).

The detail of the model input is described later.

Model Output

- Time series of water surface elevation for whole simulated area.
- Time series of discharge for whole simulated area excluding the upstream end of the simulated area.

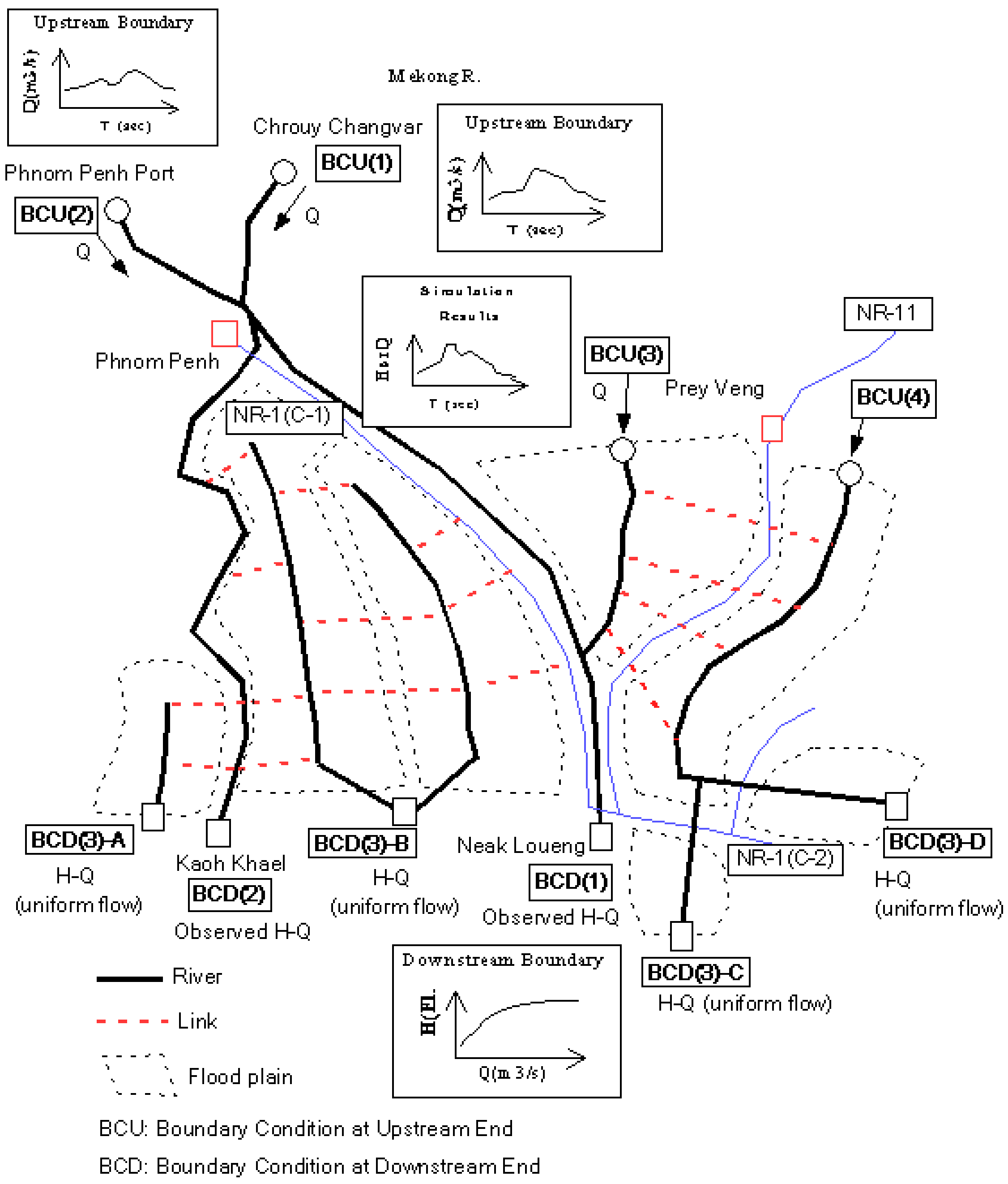


Fig. 9-4-1 Model Structure of Hydraulic Simulation

(2) Assumption for Model

The most important assumption in this simulation model is as follows:

Assumption: The boundary conditions are not influenced by the condition of the openings.

If the openings strongly affect the flow pattern at the boundary of the model, the model cannot be used for discussing about the openings with keeping same boundary conditions.

(3) Data for Geomorphology

In this model, the following data for geomorphology were employed.

River network

Data of ongoing JICA Hydrological Study for the Mekong River Basin were used.

Channel cross sectional shape

Data of ongoing JICA Hydrological Study for the Mekong River Basin were basically used. In addition, the results of bathymetric survey (sounding survey) by MPWT in 1999 of the Mekong River, the Bassac River and the Tonle Sap River were combined with those.

Flood plain shape

A Contour map of flood plain in 1960s was used. Then, the geometry around small rivers in the flood plain was modified to adjust flow capacity of the flood plain. Furthermore, storage capacity of the left bank flood plain of the Mekong River from Kampong Cham to Chrouy Changvar was taken into account in the simulation node of the upstream end of the left bank flood plain of the Mekong River.

Dimension of openings

Each of the openings is modeled as a discharge-controlled structure based upon field survey.

(4) Boundary Conditions

At each upstream end of the channel and the flood plain, the time series of the discharge is given as a boundary condition. On the other hand, the relationship between water surface level and discharge is given at the downstream end. The boundary conditions used in the simulation and the method to give boundary conditions is summarized in Table 9-4-1 and 9-4-2.

(5) Tuning Parameters and Model Verification

Manning's coefficients of both the channel and the flood plain are the tuning parameters of the model. By giving the following values for the channel and the flood plain, the simulated water surface elevation and the discharge allocation within the simulated area around the flood peak reasonably agreed with the observed one.

- Channel: Manning's coefficient n=0.03
- Flood Plain: Manning's coefficient n=0.1

Table 9-4-1 Boundary Conditions at Upstream End

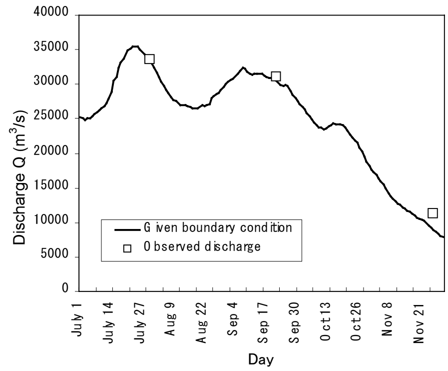
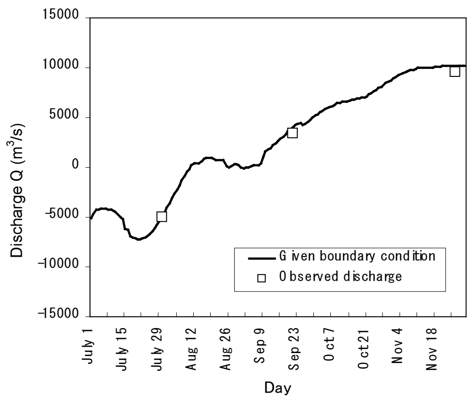
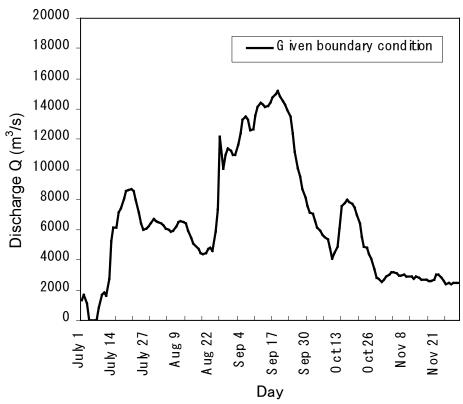
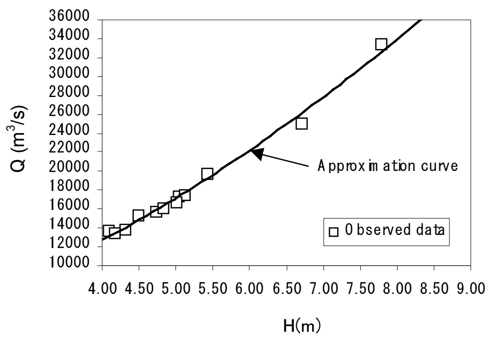
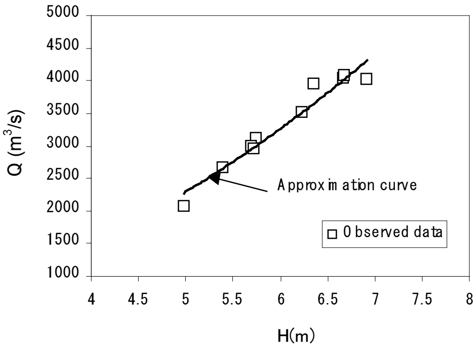
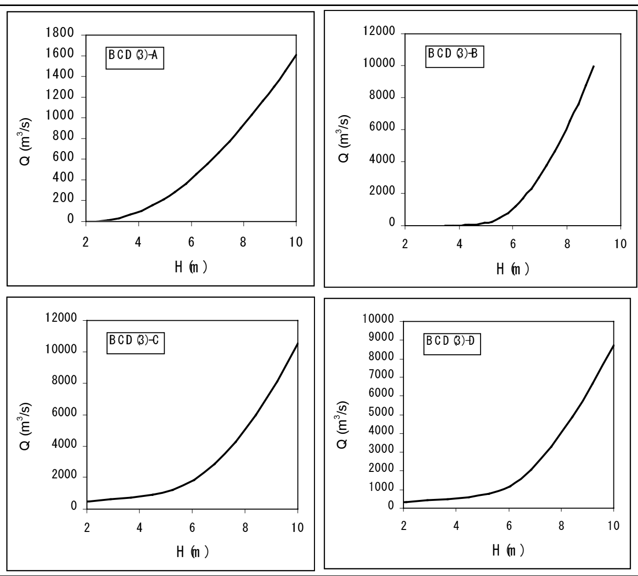
	Method to give boundary condition	Given boundary condition
BCU(1) Chrouy Changvar	The discharge is basically given by converting the observed water surface level to discharge. However, according to the discharge measurement during 2000 Flood, the relationship between water surface level and discharge at Chrouy Changvar is not unique, strongly affected by the flow condition in the Tonle Sap River. As discussed in Chap.8, the discharge adding the discharge at Phnom Penh Port in the Tonle Sap River has an almost unique relation with the water surface level at Chrouy Changvar. In the present study, the added discharge is firstly calculated by using the observed water surface level at Chrouy Changvar. The discharge at the Phnom Penh port was then subtracted from the added discharge to get the discharge at Chrouy Changvar.	
BCU(2) Phnom Penh Port	The difference of the water surface levels at Phnom Penh Port and Prek Kdam in the Tonle Sap River determines the discharge at Phnom Penh Port, according to the discharge measurement during 2000 Flood. The approximation curve to describe the relationship between the water surface difference and the discharge is applied. The calculated discharge by using the observed water surface elevation included unreasonable fluctuation. Therefore, moving average for each 1 week was applied in order to make it smooth.	
BCU(3) Left bank flood plain of the Mekong River	Based upon the observed discharge during 2000 Flood and the estimated discharge from the openings, the peak discharge to enter the left hand side flood plain of the Mekong River has been estimated. The estimated peak discharge includes the discharge through the Moat Khmung Bridge near Kampong Cham. The shape of the time series of discharge was assumed to be proportional to the difference of the discharges at Kampong Cham and Chrouy Changvar.	
BCU(4) East of NR11	The inlet discharge here was assumed to be zero.	Inlet discharge is always zero.

Table 9-4-2 Boundary Conditions at Downstream End

	Method to give boundary condition	Given boundary condition
BCD(1) Neak Loueng	Based upon observed water surface level and discharge, the rating curve was established as discussed in Chap. 8. The rating curve was used as a boundary condition.	
BCD(2) Kaoh Khael	Based upon observed water surface level and discharge, the rating curve was established as discussed in Chap. 8. The rating curve was used as a boundary condition.	
BCD(3) Outlet of flood plain	Based upon the observed water surface level and the estimated discharge on the flood plain, rating curves are made by assuming that Manning's coefficient and energy slope do not change. Each of the rating curves was used as a boundary condition.	

9.4.3 Effects of the Two Artificial Cut-offs

Fig. 9-4-2 shows the simulated results of the water level at Chrouy Changvar, Phnom Penh Port, Neak Loueng, Colmatage area near Cut-off No.1, Prey Veng and Stung Slot (Stoeng Slot) Bridge for both cases with and without two artificial Cut-offs.

The results show that the maximum water surface level at Neak Loueng with the Cut-offs could be about 19 cm lower than that without the openings. This is because of the reduction of the discharge near Neak Loueng in the Mekong River due to the Cut-offs. This change influences whole simulated area, making water surface elevation with the openings at Phnom Penh Port and Prey Veng about 9 cm lower than that without the Cut-offs.

At the flood peak, Phnom Penh was very dangerous against flooding. If the water surface level had been slightly higher, very serious flooding might have occurred at Phnom Penh. In that sense, to reduce water surface level is very important even though it is quite small. It can be concluded that the artificial Cut-offs played important role to reduce the water surface level and made the risk of flooding at Phnom Penh lower.

On the other hand, the maximum water surface elevation with the Artificial Cut-offs at Colmatage area near Cut-off No.1 is about 60 cm higher than that without the Cut-offs. However, according to the flood survey, the rise of water surface level in the Colmatage area resulted in little significant problems.

Another point is that the Artificial Cut-offs also contributed to reduce flood discharge to NR-1(C-2). The lowered water level near Neak Loueng in the Mekong River brought about increase of discharge to the Mekong River from the Left Bank Side Flood Plain through the Tonle Touch River. This made reduction of discharge to NR-1(C-2), which should also be protected against flood.

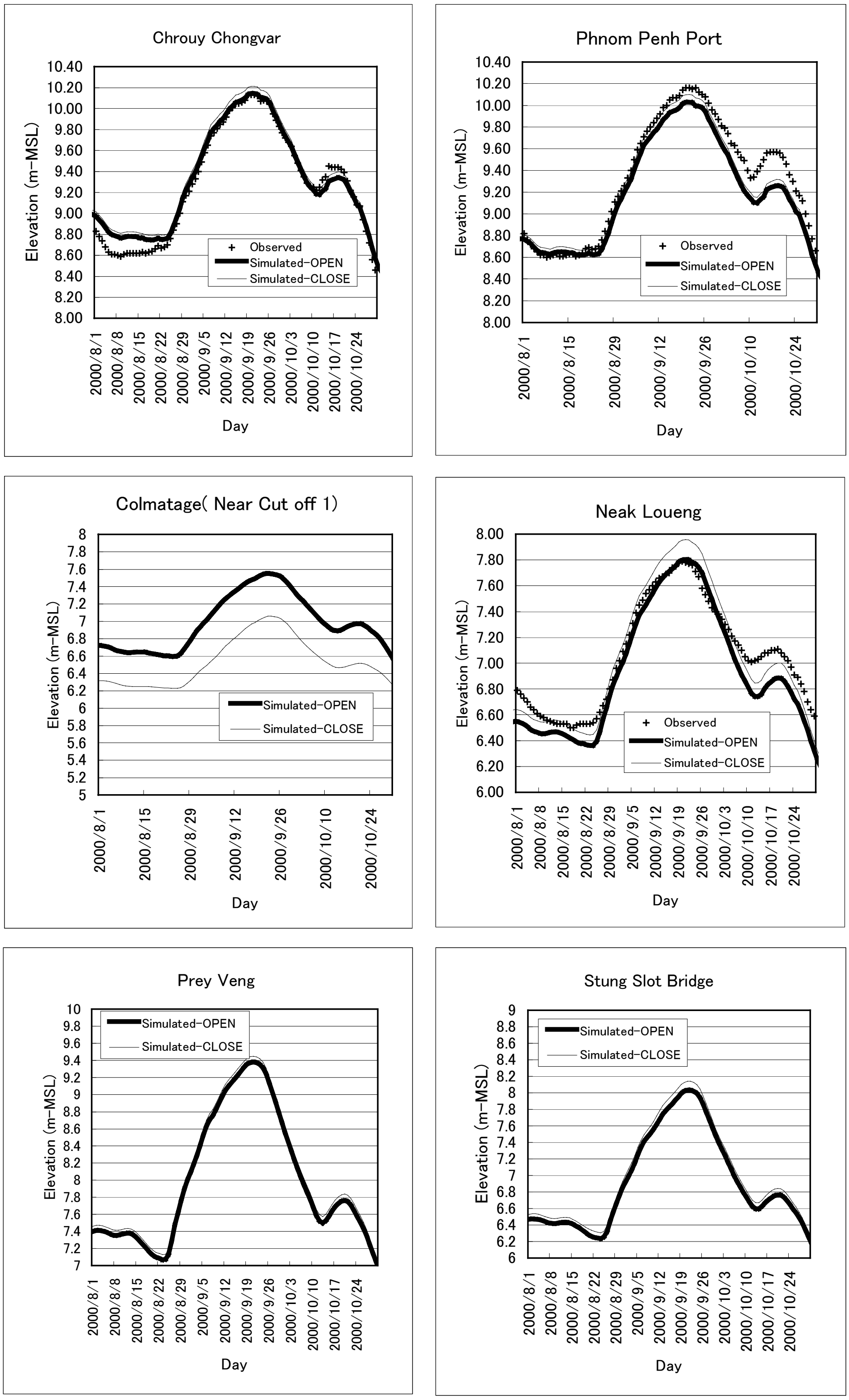


Fig. 9-4-2 Simulated Results of Water Surface Elevation with and without Openings

9.5 Relating Plans for Flood Mitigation

There are no on-going major projects such as river improvement of the Mekong River and other rivers. There are only two major existing plans or strategy for flood mitigation for the Mekong River Basin including the Study Area. They are as follows:

1) Korea International Cooperation Agency (KOICA); "Flood Control Planning for Development of the Mekong Delta (Basinwide)", MRC, September 2000.
2) Mekong River Commission (MRC); "MRC Strategy on Flood Management and Mitigation", November 2001.

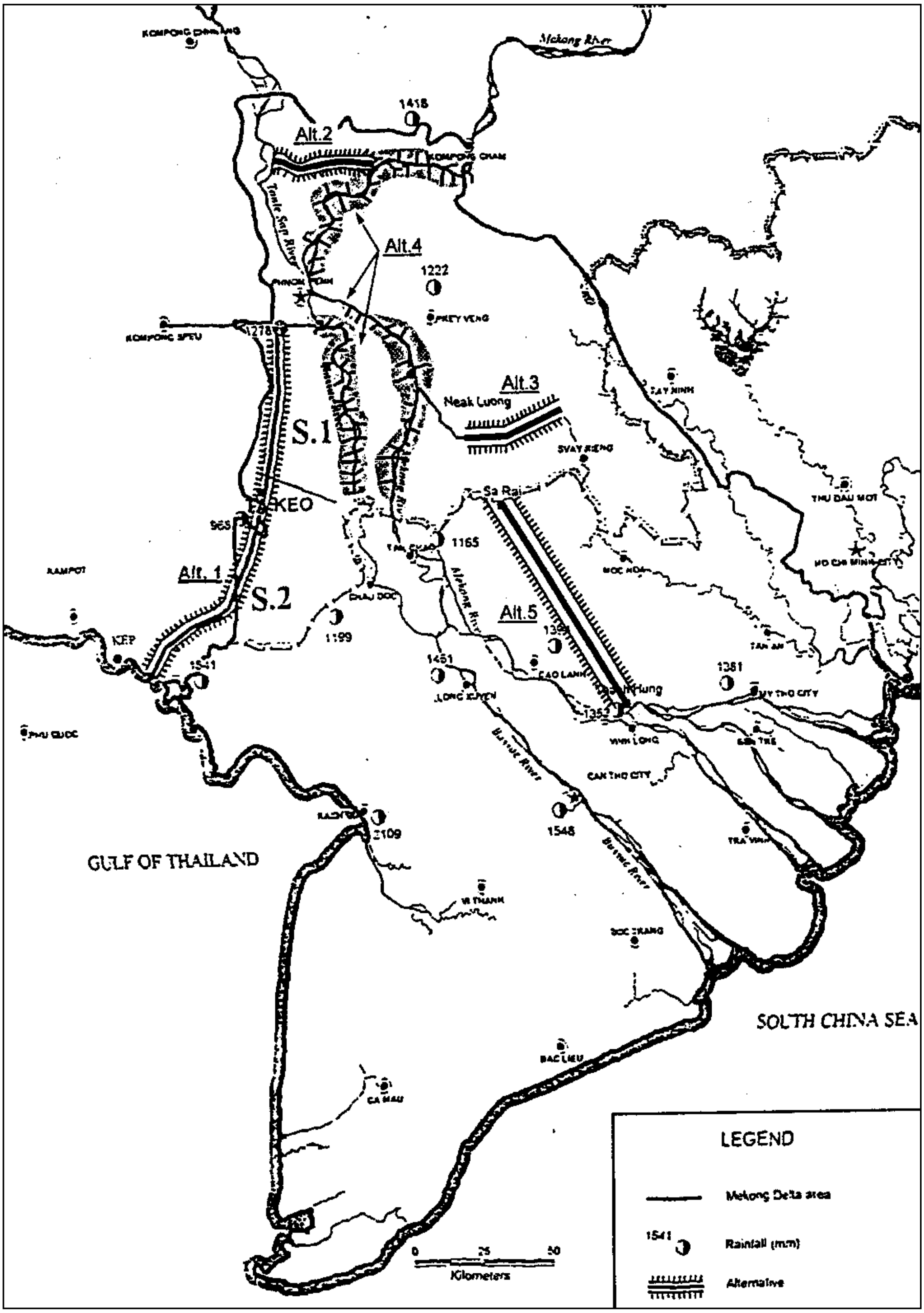
In addition to the above existing plans or strategy, existing dams or dam plans in the Mekong River Basin, and improvement plan of canal with dikes along country border of Vietnam and Cambodia are described below.

(1) Flood Mitigation Plan of KOICA

KOICA formulated a master for long-term and short-term flood control plan for the Mekong River Basin downstream from Kampong Cham, the Tonle Sap River downstream from the Tonle Sap Lake in Cambodia to the South China Sea in Vietnam. This plan proposed alternative flood control plans including large-scale flood control structures as follows (refer to Fig. 9-5-1):

Alternative 1: Diversion canal with dikes from Takeo to the Gulf of Thailand.
Alternative 2: Diversion canal with dikes from Kampong Cham to Tonle Sap River.
Alternative 3: Diversion canal with dikes from Neak Loueng to the West Vaico River through Stung Slot and Prek Trabek.
Alternative 4: Gated Colmatage Canal System (Colmatage Canal along the Mekong and Bassac Rivers in Cambodia).
Alternative 5: Main canal with dikes from Sarai to Thanh Hang

KOICA concluded that these alternatives are all feasible and recommended to be implemented. However, as the project size is too large, it will need more time to formulate realistic priority plans among the master plan.



Data Source: KOICA; "Flood Control Planning for Development of the Mekong Delta (Basinwide)", MRC, September 2000

Fig. 9-5-1 Proposed Flood Control Plan by KOICA

(2) MRC's Strategy on Flood Management

Mekong River Commission (MRC) has formulated a Strategy on Flood Mitigation in November 2001. This Strategy is still a conceptual level. Therefore, MRC is going to conduct a further study and implement "The MRC Strategy for Flood Management and Mitigation (FMM)", which may start from middle of 2003. The target area of the project is very wide covering the Lower Mekong River Basin composed of Laos, Thailand, Cambodia and Vietnam. The purpose of the project is to formulate policy and guideline for flood mitigation and management mainly for non-structural measures, capacity building in these countries, and monitoring and flood forecasting etc. It will not include planning of structural measures such as river improvement, embankment and relating structures. Guideline formulation on the international matter relating to the flood mitigation works by one country to neighboring countries will also be included in this project. As the target area will be wide and the strategy will be integrated ones, the project period might be several years.

(3) Existing Dams and Dam Plans

In the Mekong River Basin, several large dams have been developed for hydropower generation. Among the existing major hydropower projects including large dams with install capacity of more than 10 MW, 2 projects locate along the main stream of Upper Mekong River in Yunnan Province in China, 5 projects locate along the tributaries in Laos, 4 projects locate along the tributaries in Thailand and 2 projects locate along the tributaries in Vietnam.

As for the existing dam or hydropower development plans, various kinds of studies have been conducted by various agencies such as ADB, MRC and others. They proposed hydropower development along the Mekong River Main Stream or tributaries. However, it will take more time to make realistic plans, which can solve natural and social environment problems relating to the projects.

As for the flood mitigation effects by the dams, it is generally said that these dams or dam plans will not make adverse impacts to the flooding condition in the Lower Mekong Basin Countries composed of Laos, Thailand, Cambodia and Vietnam. However, it is necessary to conduct further study on the effects of flood control by the dams including hydrological and hydraulic simulation.

(4) Dikes along Vietnam Border

It was informed to MRC from Vietnam that Vietnam is planning to improve the existing irrigation canal with 57 km length along country border in the right bank side flood plain of the Mekong River. Relating to this canal improvement, dikes will be constructed along the northern side (country border side) of the canal, which will include 12 open spillways. One of the purposes of these improvements is irrigation, but effects on flooding condition around the dikes (especially to Cambodian side) are unknown. Furthermore, detail of this plan is still not unknown.

9.6 Design Height for the Road Embankment

Design High Water Level (HWL):

NR-1(C-1) will be designed as the road for all weather condition, which will secure transportation even during floods like 2000 Flood. Considering that the maximum water level of 2000 Flood was the recorded highest water level around NR-1(C-1), even though its return period in terms of water level is about 12 years, this water level should be the Design High Water Level (HWL) for the NR-1(C-1).

Freeboard (dH):

As the surrounding area of NR-1(C-1) will be under water during floods, in order to keep safety and stability of the road embankment against floods, freeboard between the design HWL and the top of embankment (like river dike) is necessary to be taken. Freeboard is necessary for wave height and floating debris. Wave height along the NR-1(C-1) during floods (such as 2000 Flood and 2002 Flood) looks like less than 0.5 meter. Furthermore, freeboard of the other national roads such as NR-6, NR-7 and NR-1(C-2) is set as 0.5 meter. Considering these, the freeboard of the NR-1(C-1) is set as follows:

Freeboard (dH) for road embankment: dH= 0.50 meter

Note: Top of embankment, which is the top of the impermeable soil material of the embankment, should be set above HWL + 0.50 meter.

Along the NR-1(C-1), openings composed of bridges and box culverts will be installed, which will be designed under free flow condition. Considering the wave height, possibility of clogging at the openings by floating debris and possibility of navigation (even though very small numbers of boats pass through the openings during floods), freeboard for openings is set as follows:

Freeboard (dH) for bridge: dH= 1.00 meter
Freeboard (dH) for box culvert: dH= 1.00 meter

Additional Explanation:

(1) Design HWL

Fig. 9-6-1 shows comparison of historical annual maximum water level with the design height of road embankment of ADB Plan for NR-1(C-1 & C-2) in 1997 and that of this Study. From this figure, it can be seen that the event of the maximum water level of 2000 Flood is rare case because almost same water level happened only 2 or 3 times in these 108 years.

Furthermore, there is no clear tendency of increasing the flood water level along the NR1(C1) even after 1970s or 1980s.

Lastly, as the Design HWL of the ADB Plan for NR-1 in 1997 was set as the 10-year flood water level based on the data until 1996, the Design HWL of this Study (2000 flood water level with 12 year return period based on the data until 2000) is about 0.4 meter higher than the ADB Plan in 1997.

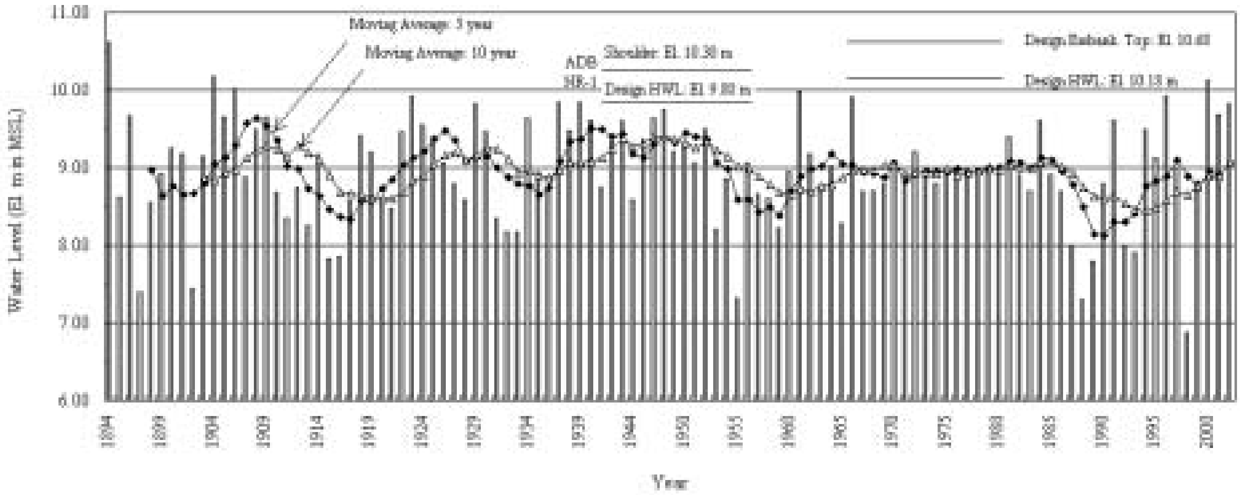


Fig. 9-6-1 Comparison of Annual Max. Water Levels with Design Height of Road Embankment

(2) Freeboard for Road Embankment

Freeboard is necessary against wave and floating debris to the road embankment and openings. The wave height may be not so much different through the whole stretch of NR-1(C-1), and it looks like less than 0.5 meter. Therefore, it is enough to take the freeboard of 0.5 meter for the road embankment along the whole stretch of the NR-1(C-1). Including the freeboard, design top of road embankment can have adequate height over the flood water level like 2000 Flood as indicated in Fig. 9-6-1. Considering the freeboard of 0.5 meter, as a result, the road embankment will have height of excess flood water level with about 25-year return period around Phnom Penh.

9.7 Hydraulic Plan for the Openings

9.7.1 Basic Concept for the Openings

Flood Mitigation Aspect:

In the case of constructing road crossing flood plain, if the purpose of the road does not include flood control like river dikes, it is the principle that the road will not be obstacle to flood flow. This can be also said for NR-1(C-1), NR-1(C-2) and NR-11.

It means that along the NR-1(C-1), openings should be installed so that not to make obstacle to the potential flood flow, which had originally entered into the Colmatage Area in the old days, within the limit of the discharge and retarding capacity of the Colmatage Area. Furthermore, if the openings will be installed, it should be considered so that the introduced floodwater from the openings will not make adverse impacts to the surrounding areas such as agriculture and houses around the NR-1(C-1).

By the hydraulic simulation model of this Study (refer to Section 9.4), it was made cleared that the effect of decreasing flood water level by the two Artificial Cut-offs made along NR-1(C-1) during 2000 Flood was estimated to be 9 cm around Phnom Penh and 19 cm around Neak

Loueng. By the Cut-offs, flooding risks at Phnom Penh and Neak Loueng became lowered during the emergency cases of 2000 Flood, when overflow along the Mekong River around Phnom Penh was almost happened, and emergency protection by using sand bags were provided along the river. Therefore, introducing water into the Colmatage Area and utilization of its retarding effects within the rage of no adverse impacts to the surrounding areas is very important from flood mitigation point of view.

Regarding the type of the openings, for the place where natural channels are formed on the flood plain, it is better to install bridge in general. However, like the NR-1(C-1), as there are almost no natural channels crossing the road and the flood water distribute along the road, it is better to drain the water in the Mekong Side following distributed floodwater. In this case, box culverts are preferably to be adopted as much as possible, and adopt bridges with minimum numbers.

<u>Water Use Aspect:</u>

As the Colmatage Area along the NR-1(C-1) is important for agriculture, farmers along the NR-1(C-1) and also MoWRAM hope to develop agriculture in this area by recovering Colmatage Systems. For the Colmatage Systems, in order to control water into or out from Colmatage Area, it is necessary to install water gates at the crossing point of the Colmatage Canals with the NR-1(C-1). The water gates are operated and maintained by the farmers. Considering their ability of operation and maintenance of the water gates, it is better to adopt small size openings like box culverts with stop log slots for the places for multipurpose use for flood mitigation and water use.

<u>Flow Condition of Box Culverts</u>

As peak of floods along both sides of NR-1(C-1) continue about one month, if flow condition of box culverts is set as submerged flow, embankment around inlet and outlet will be eroded by flow turbulent with long term. In order to reduce erosion around inlet and outlet of box culverts, it is necessary to keep smooth flow as much as possible. Therefore, box culvert is necessary to be designed as free flow condition.

9.7.2 Alternative Cases for Openings

Considering the inflow capacity of the openings along the NR-1(C-1) before and after 2000 Flood, and the potential discharge capacity of the Sub-zone 3-1 with water from the Mekong River, alternative cases for the openings along the NR-1(C-1) are set as follows:

1) Alternative A: Keep existing inflow capacity (63 to 65 % of Qo)
2) Alternative B: Increase inflow capacity (75 to 80 % of Qo)
3) Alternative C: Minimum inflow capacity (14 % of Qo)

Where, Qo is the estimated potential discharge capacity of the Sub-zone 3-1 with water from the Mekong River inside the Colmatage Area (3600 m^3/s). In the Alternative B, 75 to 80% of the discharge capacity of this Sub-zone 3-1 will be utilized as a conservative consideration. The Alternative C is the case only with the existing water gates and pipe culverts, which mean the existing two Cut-offs are closed as they were before 2000 Flood.

9.7.3 Possible Sites for Openings

Location of the Possible Sites for Openings:

Fig. 9-7-1 shows the possible sites of the openings. From the present landuse especially agriculture inside the Colmatage Area, it is difficult to install openings between Km 0+000 and around Km 20+000, where water in the Colmatage Area is stored by the existing road cum embankment crossing from this point to the Bassac River Side. Furthermore, many houses exist along this road section. Therefore, in case of installing new openings, it is necessary to select the sites where surrounding area is vacant lands or wide agricultural lands, and numbers of the houses to be relocated will be small.

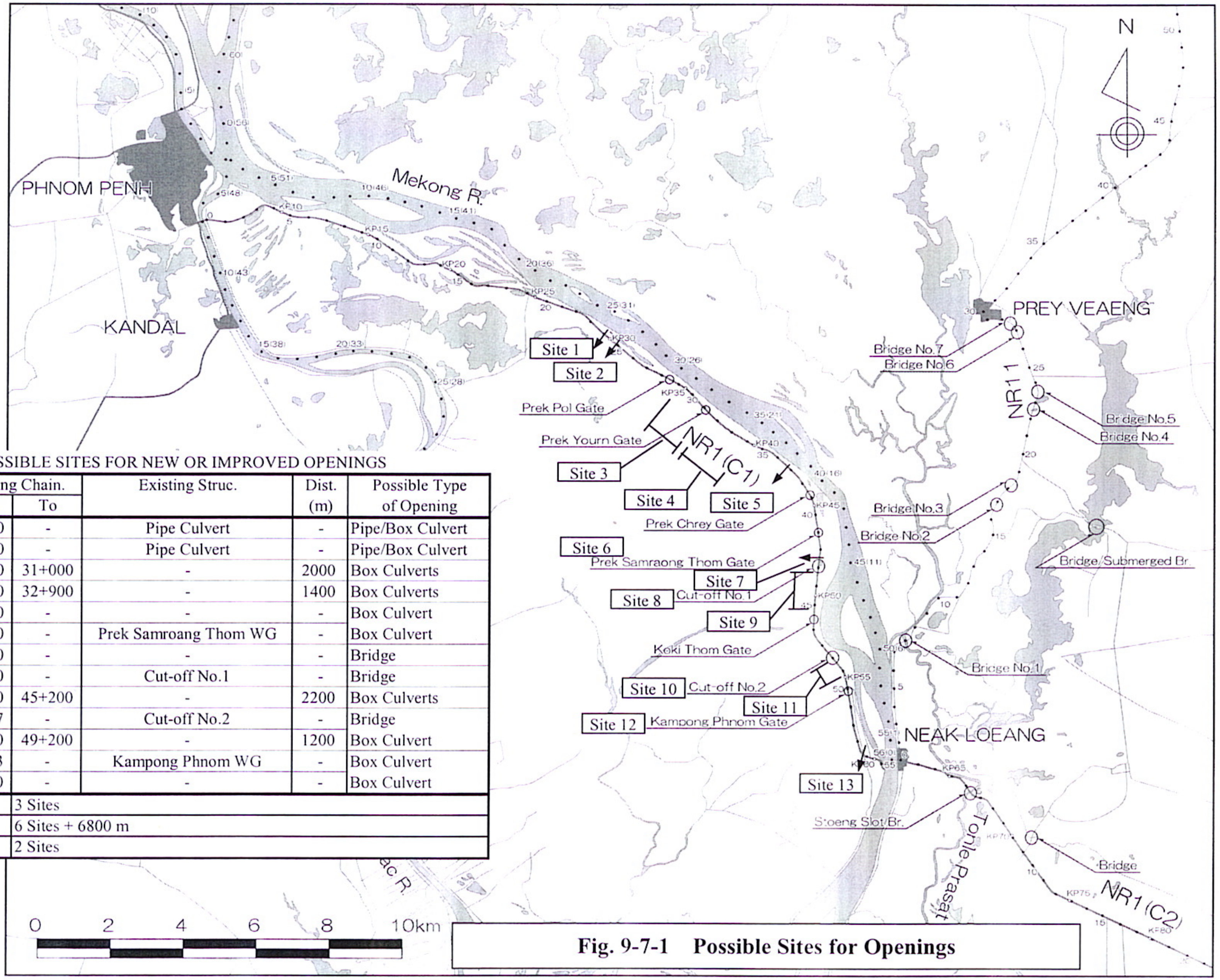
The number of the possible sites is 13 composed of 3 sites for bridge, 10 sites for box culverts including total length of 6800 meters, and 2 sites for replacing the existing pipe culverts.

Among the possible opening sites, there is an abandoned natural by-pass channel at Site No.13 near Neak Loueng, which probably had diverted water of the Mekong River from upstream of Neak Loueng to the downstream of Neak Loueng in the old years (refer to Fig. 9-7-2). However, when the nearby Village (Kampong Phnom) was developed around this place more than 85 years ago, the inlet portion of this abandoned channel was already closed. If this abandoned channel is considered as diversion channel from the Mekong River, it might be meaningful for flood mitigation for Neak Loueng and the Mekong River Main Stream. However it will need more intensive study for this kind of flood control project, which is beyond the scope of this Study. Therefore, among the possible sites of the openings, Site No.13 near Neak Loueng will not be considered for openings in this Study.

Possible Type of Openings at Cut-off No.1 (refer to Fig. 9-7-2):

As the Cut-off No.1 locates at the low-lying area connecting the Mekong River at about Km 39+000 along NR-1(C-1), floodwater of the Mekong River probably had directly entered into this site along the NR-1(C-1) in the old years. In the recent years, some houses and factories had been constructed between Km 39+000 and the Cut-off No.1, intrusion of floodwater may be disturbed in some extent, but it is assumed that some of floodwater has reached along the NR-1(C-1) to this site. Furthermore, the existing secondary road surrounds this site, and floodwater overflowed over the secondary road and reached this site during 2000 Flood. The total discharge of the floodwater from the Mekong River to this site is estimated to be about 1365 m3/s. In order to discharge 1365 m3/s to the Colmatage Side, it is better to adopt bridge(s). This is because if box culvert is adopted, the number of box culverts around this site will be 30 numbers of 2-cell boxes under free flow condition, and it is physically difficult to install such many box culverts around this site.

Furthermore, deep scouring exists around the existing Cut-off No.1, which will make worse the flow condition with turbulence and make serious scouring around piers and abutment. In order to minimize scouring and attain smooth flow through Cut-off No.1, it is better to bury the deep scouring and make additional bridge to keep the flow area of existing Cut-off No.1.



POSSIBLE SITES FOR NEW OR IMPROVED OPENINGS

Candid. Site	Existing Chain. From	Existing Chain. To	Existing Struc.	Dist. (m)	Possible Type of Opening
Site 1	24+000	-	Pipe Culvert	-	Pipe/Box Culvert
Site 2	24+840	-	Pipe Culvert	-	Pipe/Box Culvert
Site 3	29+000	31+000	-	2000	Box Culverts
Site 4	31+500	32+900	-	1400	Box Culverts
Site 5	36+900	-	-	-	Box Culvert
Site 6	41+040	-	Prek Samroang Thom WG	-	Box Culvert
Site 7	42+400	-	-	-	Bridge
Site 8	42+850	-	Cut-off No.1	-	Bridge
Site 9	43+000	45+200	-	2200	Box Culverts
Site 10	47+967	-	Cut-off No.2	-	Bridge
Site 11	48+000	49+200	-	1200	Box Culvert
Site 12	50+033	-	Kampong Phnom WG	-	Box Culvert
Site 13	53+700	-	-	-	Box Culvert
Bridge	3 Sites				
Box Culvert	6 Sites + 6800 m				
Pipe Culvert	2 Sites				

Fig. 9-7-1 Possible Sites for Openings

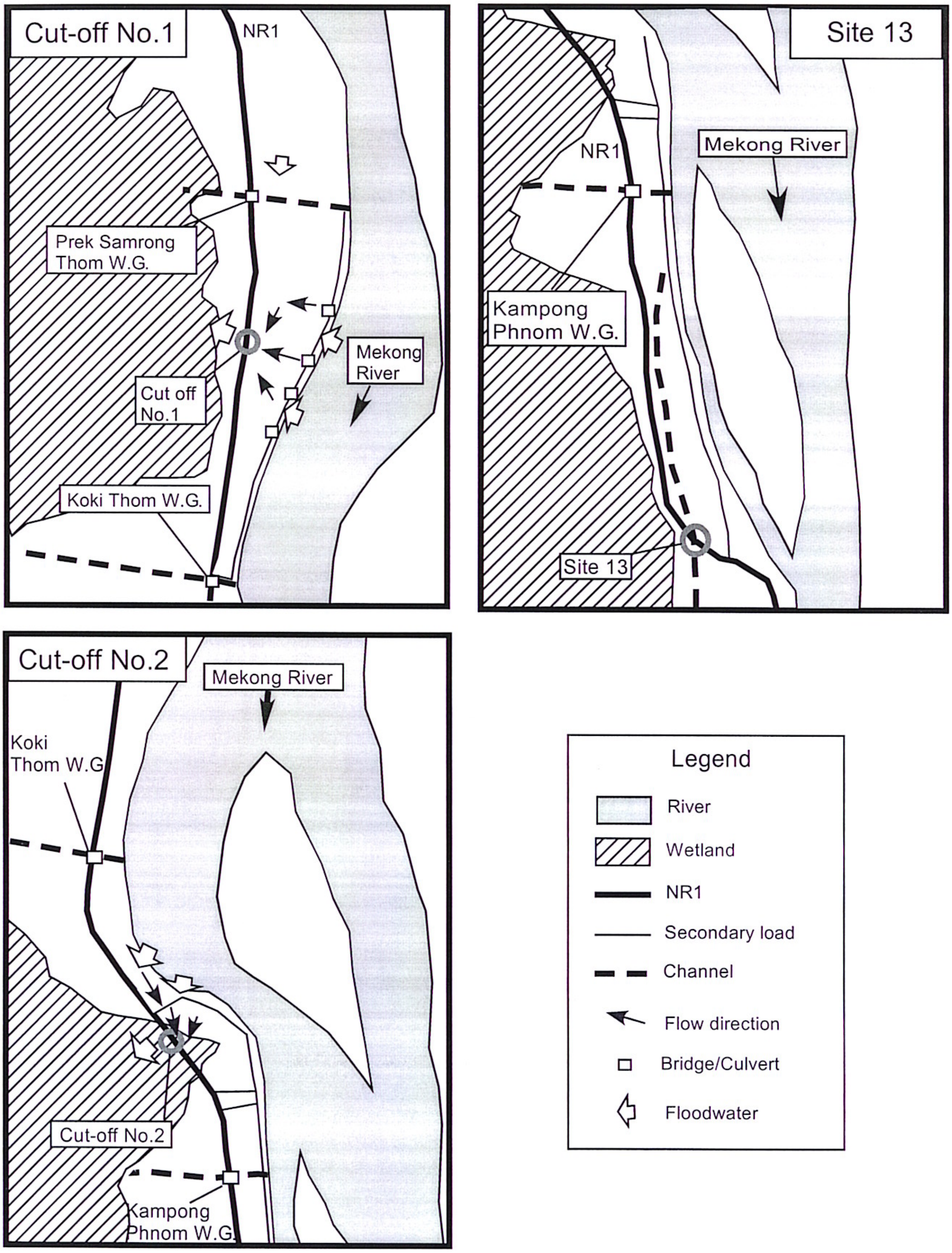


Fig. 9-7-2 Condition of Opening Sites (Site 13, Cut-off No.1, Cut-off No.2)

Possible Type of Openings at Cut-off No.2 (refer to Fig. 9-7-2):

Cut-off No.2 locates at the low-lying area surrounded by the existing secondary road along the Mekong River and the NR-1(C-1), which forms like a polder dikes by these roads. Floodwater overflowed this secondary road from the Mekong River and concentrated around this site during 2000 Flood. The overflow discharge is estimated at about 400 to 450 m^3/s during 2000 Flood. If this 400 to 450 m^3/s is discharged to the Colmatage Side by box culverts, necessary numbers of box with 2 cells under free flow condition will be 9 to 10. Considering the distance around this site of about 2 km, it is difficult to install such many boxes. Therefore, bridge is recommended for this site. Furthermore, around Cut-off No.2, there is a lower topography about 300 meters southward along NR-1(C-1). In addition to this, the flood water from overflow points along the secondary road flows along NR-1(C-1) from northern direction of Cu-off No.2 and attack the existing temporary bridge from diagonal direction. Considering these, it is recommended to bury the existing Cut-off No.2, shift the place to about 300 southward from the existing place and install new bridge at this shifted place, so that to put the opening at the most concentrated place of water and make dispersion of the flood flow into the inundation area in the Mekong Side and make direction of inflow to the bridge be right angle (90°) to the opening.

9.7.4 Alternatives for the Openings

Table 9-7-1 shows summary of alternative plans of openings. The alternatives are as follows:

(1) Alternative A: Keep existing inflow capacity (about 63 to70 % of Qo)

1) ALT. A-1

a) Keep existing discharge capacity of Cut-off No.1 and install bridge at Cut-off No.1. Deep local scouring at the bridge site will be buried up to the surrounding ground elevation by soil materials and extend bridge length to keep same flow area as the existing one.
b) Bury the existing Cut-off No.2, shift it to about 300 meters southward and install a bridge, and keep existing discharge capacity.
c) Improve existing two pipe culverts and existing two old Colmatage Water Gates.

2) ALT. A-1a

a) Deep local scouring at Cut-off No.1 will be buried by soil. Keep existing discharge capacity around Cut-off No.1 site by constructing two bridges: one at Cut-off No.1 Site with existing length. Then, construct an additional bridge at about 400 meters northern side where elevation is the lowest around this site. By these two bridges, equivalent discharge capacity of the existing Cut-off No.1 will be kept.
b) Bury the existing Cut-off No.2, shift it to about 300 meters southward and install a bridge, and keep existing discharge capacity.
c) Improve existing two pipe culverts and existing two old Colmatage Water Gates.

(2) Alternative B: Increase inflow capacity (75 to 80 % of Qo)

1) ALT. B-1

a) Deep local scouring at Cut-off No.1 will be buried by soil. Slightly increase discharge capacity around Cut-off No.1 site by constructing two bridges: one at Cut-off No.1 Site with existing length and one at about 400 meters northern side where elevation is the lowest around this site.

b) Bury the existing Cut-off No.2, shift it to about 300 meters southward and install a bridge, and keep existing discharge capacity.
c) Improve existing two pipe culverts and existing two old Colmatage Water Gates.
d) Install new box culverts with 2 cells at 9 places.

2) ALT. B-1a

a) Keep existing discharge capacity of Cut-off No.1. Deep local scouring at the bridge site will be buried by soil and extend bridge length to keep same flow area as the existing one.
b) Bury the existing Cut-off No.2, shift it to about 300 meters southward and install a bridge, and keep existing discharge capacity.
c) Improve existing two pipe culverts and existing two old Colmatage Water Gates. Install new box culverts with 3 cells at 9 places.

Remarks: Places of new box culverts of ALT. B-1 and B-1a are selected among the places of Possible Sites shown in Fig. 9-7-1, and inundation condition along the both sides of the NR-1(C-1) during 2002 Flood.

(3) Alternative C: Minimum inflow capacity (14 % of Qo)

a) Close Cut-off No.1 and Cut-off No.2.
b) Improve existing two pipe culverts and existing two old Colmatage Water Gates.

As a reference, Table 9-7-1 also shows the case without bridges (new box culverts and existing water gates etc.). In this case, as the necessary places of the box culverts become 45 places for Alternative A and 54 places for Alternative B, it is not realistic for constructing such many box culverts.

Fig. 9-7-3 to 9-7-5 shows the location of openings of the Alternative A (ALT. A-1), Alternative B (ALT. B-1), and Alternative C (ALT. C) respectively.

Table 9-7-1 Sumary of Alternative Plans for Openings

1) Allocation of Discharge Capacity

Alternative Cases	Improv. Cut-off No.1	New Cut-off No.1 (additio-nal)	Improv. Cut-off No.2	Existing JICA Water Gates	Improv. Old Water Gates	Improv. Pipe Culverts	New Box Culverts	Total	% among 3600 m^3/s
	Bridge	Bridge	Bridge						
ALTERNATIVE A-1: Keep Existing Inflow Capacity from NR1(C1) including Cut-off No.1 and No.2.									
ALT A-1	1406	-	410	433	40	3	-	2293	63.7
ALT A-1a	887	502	410	433	40	3	-	2276	63.2
Without Bridges	-	-	-	433	40	3	1829	2306	64.1
ALTERNATIVE B: Increase Inflow Capacity from NR1(C1).									
ALT B-1	887	533	410	433	40	3	422	2729	75.8
ALT B-1a	1406	-	410	433	40	3	422	2715	75.4
Without Bridges	-	-	-	433	40	3	2251	2728	75.8
ALTERNATIVE C: Minimum Inflow Capacity from NR1(C1) - condition before 2000									
ALT-C	-	-	-	433	40	3	-	477	13.2

2) Dimension of Openings

Alternative Cases	Improv. Cut-off No.1	New Cut-off No.1 (additio-nal)	Improv. Cut-off No.2	Existing JICA Water Gates	Improv. Old Water Gates	Improvement of Pipe Culverts		New Box Culverts		Total Number of Opening Places	Interval of Box Culverts
	Bridge	Bridge	Bridge								
ALTERNATIVE A-1: Keep Existing Inflow Capacity from NR1(C1) including Cut-off No.1 and No.2.											
ALT A-1	150 m	-	66 m	4 nos.	2 nos.	1.0m x 1	2 places	-	-	10 places	
ALT A-1a	100 m	63 m	66 m	4 nos.	2 nos.	1.0m x 1	2 places	-	-	11 places	
Without Bridges	-	-	-	4 nos.	2 nos.	1.0m x 1	2 places	3 cells	39 places	45 places	0.21 km
ALTERNATIVE B: Increase Inflow Capacity from NR1(C1).											
ALT B-1	100 m	66 m	66 m	4 nos.	2 nos.	1.0m x 1	2 places	3 cells	9 places	20 places	1 km
ALT B-1a	150 m	-	66 m	4 nos.	2 nos.	1.0m x 1	2 places	3 cells	9 places	21 places	about 1 km
Without Bridges	-	-	-	4 nos.	2 nos.	1.0m x 1	2 places	3 cells	48 places	54 places	0.16 km
ALTERNATIVE C: Minimum Inflow Capacity from NR1(C1) - condition before 2000											
ALT-C	-	-	-	4 nos.	2 nos.	1.0m x 1	2 places	-	-	8 places	

Note: 1) Dimension of box culvert: 2.5m x 2.5 m x 3 cells or 4 cells.

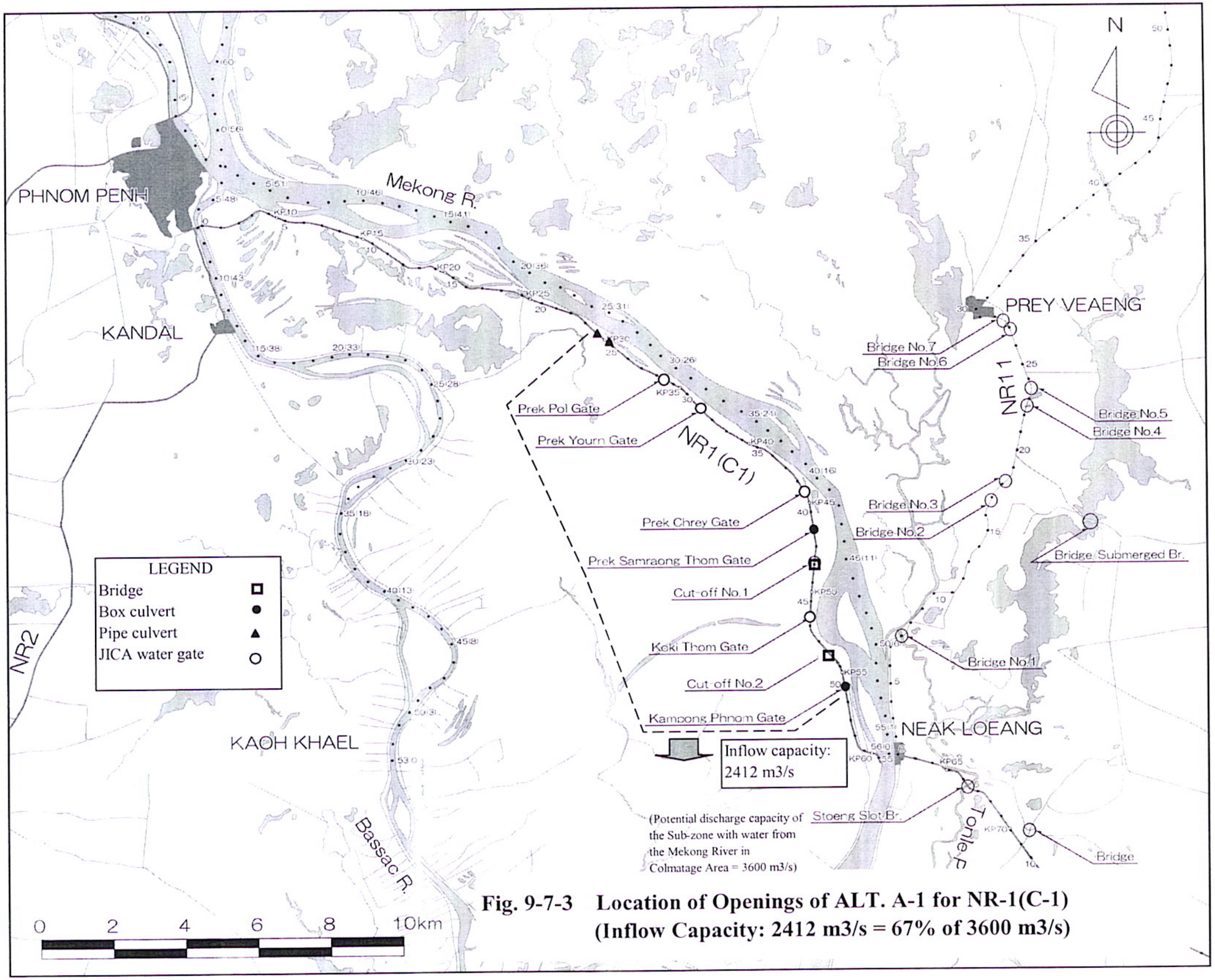


Fig. 9-7-3 Location of Openings of ALT. A-1 for NR-1(C-1)
(Inflow Capacity: 2412 m3/s = 67% of 3600 m3/s)

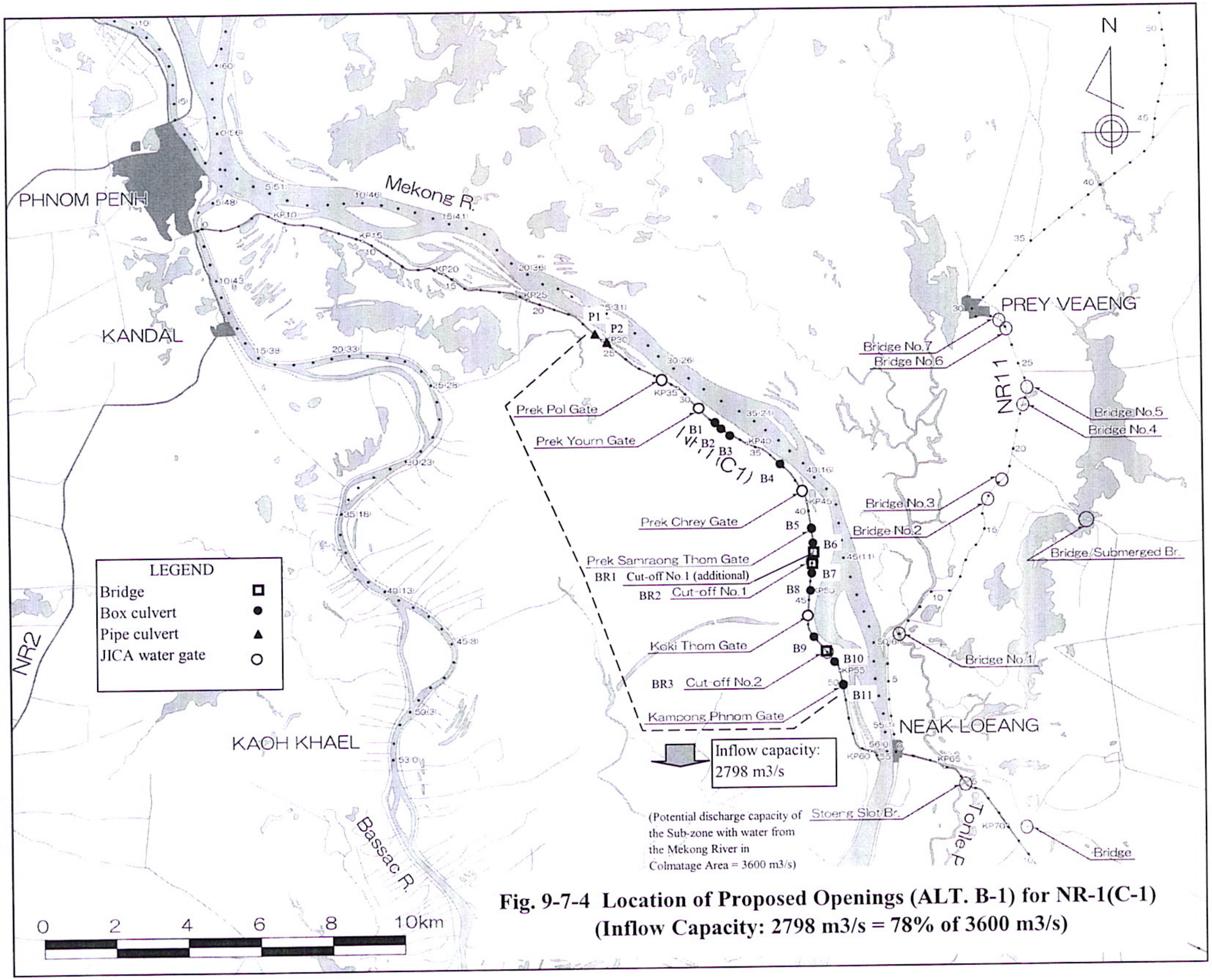


Fig. 9-7-4 Location of Proposed Openings (ALT. B-1) for NR-1(C-1)
(Inflow Capacity: 2798 m3/s = 78% of 3600 m3/s)

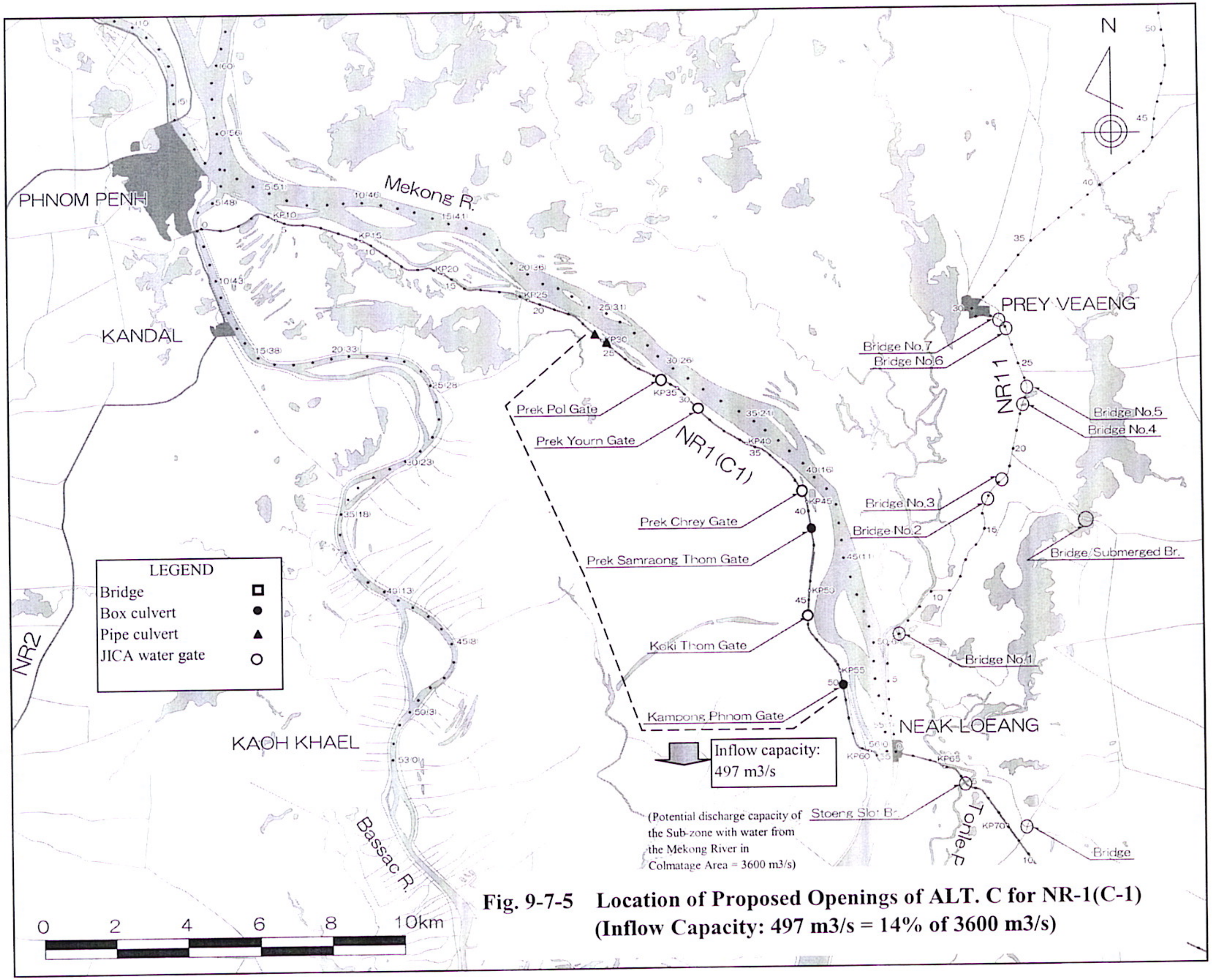


Fig. 9-7-5 Location of Proposed Openings of ALT. C for NR-1(C-1)
(Inflow Capacity: 497 m3/s = 14% of 3600 m3/s)