No.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
THE GOVERNMENT OF LAO P.D.R.

THE STUDY
ON
MEKONG RIVERBANK PROTECTION AROUND VIENTIANE MUNICIPALITY
IN
THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

FINAL REPORT

VOLUME 4
SUPPORTING REPORT

DECEMBER 2004

NIKKEN Consultants, Inc.
NEWJEC Inc.

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COMPOSITION OF FINAL REPORT

VOLUME 1	**EXECUTIVE SUMMARY**
VOLUME 2	**MAIN REPORT**
VOLUME 3	**MANUAL FOR RIVERBANK PROTECTION**
SECTOR A	**PLANNING & DESIGN**
SECTOR B	**CONSTRUCTION**
VOLUME 4	**SUPPORTING REPORT**
SECTOR A	**PRESENT CONDITION IN THE STUDY AREA**
SECTOR B	**PREPARATORY STUDY FOR PILOT WORKS**
SECTOR C	**FIELD SURVEY FOR PILOT WORKS**
SECTOR D	**EXECUTION OF PILOT WORKS**
SECTOR E	**TEST OF SIMPLE VEGETATION RIVERBANK PROTECTION**
SECTOR F	**MONITORING OF PILOT WORKS**
SECTOR G	**MONITORING SURVEY FOR PILOT WORKS**
SECTOR H	**RIVERBANK PROTECTION MASTER PLAN**
SECTOR I	**ENVIRONMENTAL CONSIDERATION**
SECTOR J	**TRANSFER OF TECHNOLOGY**
VOLUME 5	**DATA BOOK**

The cost estimate in this study is based on the price level at the beginning of February 2004 and the applied foreign currency exchange rates are as stated below:

EXCHANGE RATE

US Dollar (US$) 1.00 = Lao Kip (Kip) 10,420
Japanese Yen (¥) 100 = Lao Kip (Kip) 9,750
Middle rate as of February 1, 2004

CONTENTS OF SUPPORTING REPORT

SECTOR A

PRESENT CONDITION IN THE STUDY AREA

THE STUDY ON MEKONG RIVERBANK PROTECTION AROUND VIENTIANE MUNICIPALITY IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

FINAL REPORT
VOLUME 4
-SUPPORTING REPORT-

SECTOR A

PRESENT CONDITION IN THE STUDY AREA

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTOR A

PRESENT CONDITION IN THE STUDY AREA

1 HYDRO-METEOROLOGICAL CONDITION

1.1 Climate

According to Lao Geographic ATLAS published by National Geographic Dept., the distribution of the annual average rainfall and annual average temperature in Lao PDR are shown in Figure 1.1. The transition of the annual average temperature and annual rainfall at 4 main observing stations are described in parallel in this figure.

Heavy rainfall is distributed in the mountains area in the northern part, central part, and the southern part of Lao national land, where the regions the annual rainfall of 3000mm or more are recorded are distributed. Vientiane is located in the area from 1400 to 1800mm.

Besides, the annual average temperature exceeds 20℃ in most domestic regions. Vientiane is located in the area of 24℃ or more. There is no snow in most regions excluding some parts of mountains region according to the hearing investigation.

The decrease tendency for the amount of the annual rainfall is seen with Vientiane and Pakxe during rising tendency for the annual average temperature, but there is not remarkable tendency with the other two stations of the main 4 observing stations. It is necessary to accumulate more long-term data to discuss these tendencies.

The monthly maximum and minimum temperature, monthly rainfall, the monthly maximum and minimum humidity with monthly amount of sunny hours at the 4 main observing stations in 1998 are shown in Figure 1.2. The monthly maximum and minimum water level of Mekong River at the 4 main observing stations in 1993 are described in parallel in this figure. At Vientiane, the monthly maximum temperature exceeds 30℃, and the minimum temperature exceeds 20℃ excluding in December.

The rainfall shows the tendency to concentrate from May to September. The monthly maximum and minimum humidity show the same tendency as the monthly rainfall, but monthly sunny hours show the tendency opposite to those data. The change in the monthly maximum water level of each observing station has the tendency which shifts by one month delay of the monthly rainfall.

The difference between the monthly maximum and minimum water level is large in the rainy season, about 4 to 5 m at each observing station, and is small at the dry season, about 1m.
The water level and the discharge at Vientiane and Nongkhai are explained in the next paragraph.

Figure 1.3 shows the distribution of actual evapotranspiration in lower Mekong basin estimated for dry season by Kazama*). The average evapotranspiration is estimated as about

20mm. In this basin, evapotranspiration of near 300mm is seen in some parts of mountains region. Besides, a value close to 0mm is seen in the cultivation zone.

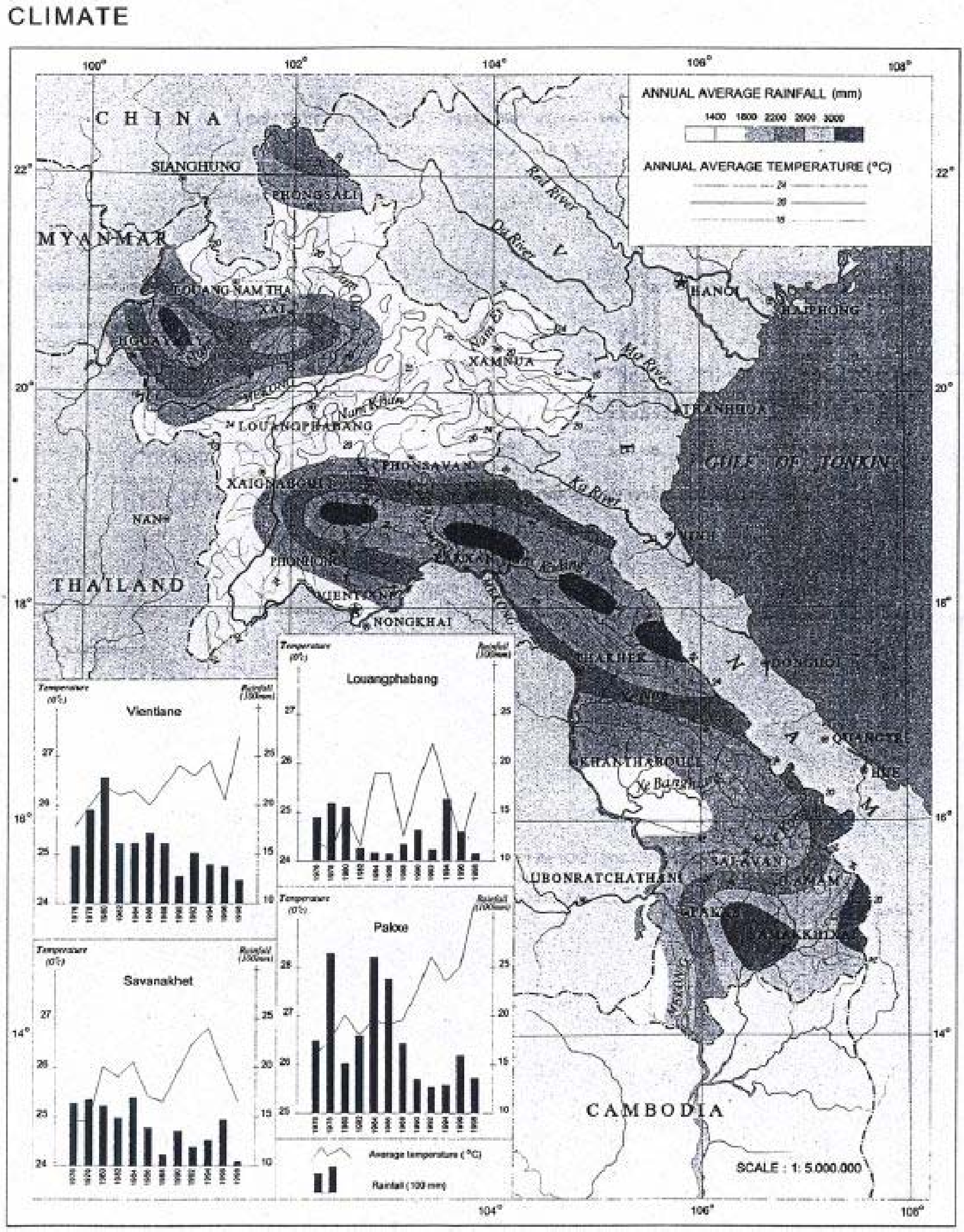


Figure 1.1 The Distribution of Rainfall and Temperature in Lao PDR

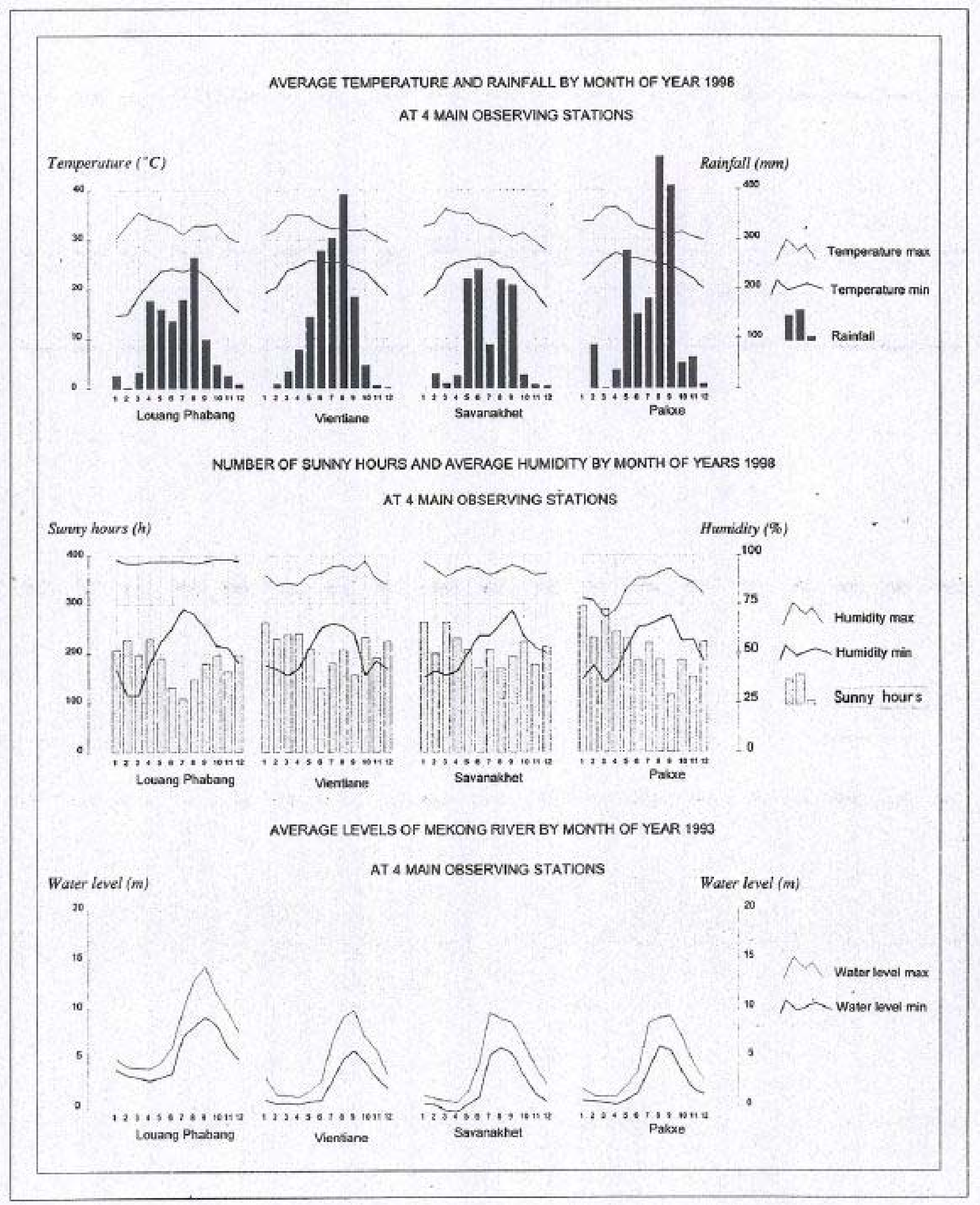


Figure 1.2 Hydro Meteorological Condition at 4 Main Observing Stations

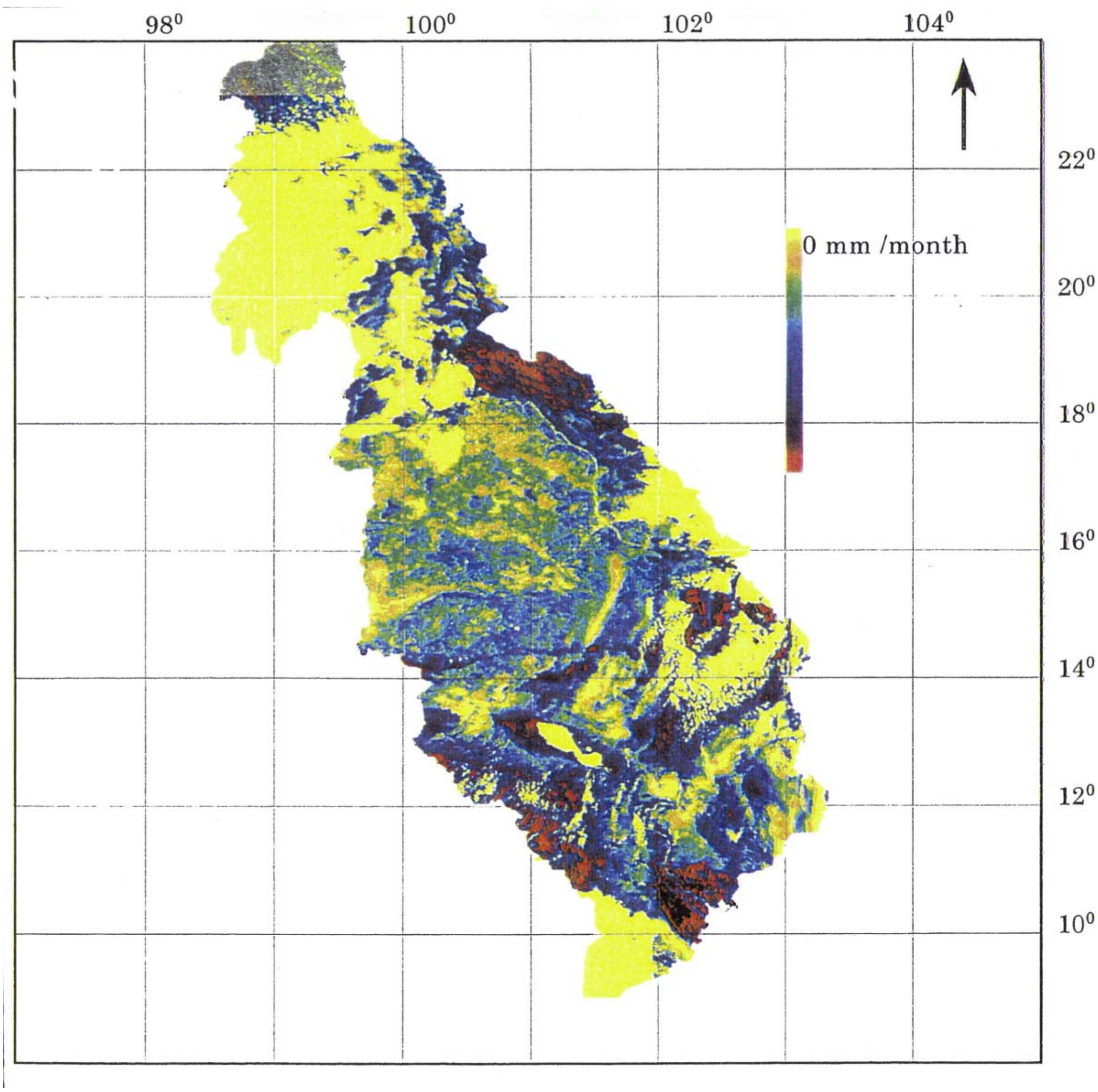


Figure 1.3 Distribution of Actual Evapotranspiration in Lower Mekong Basin

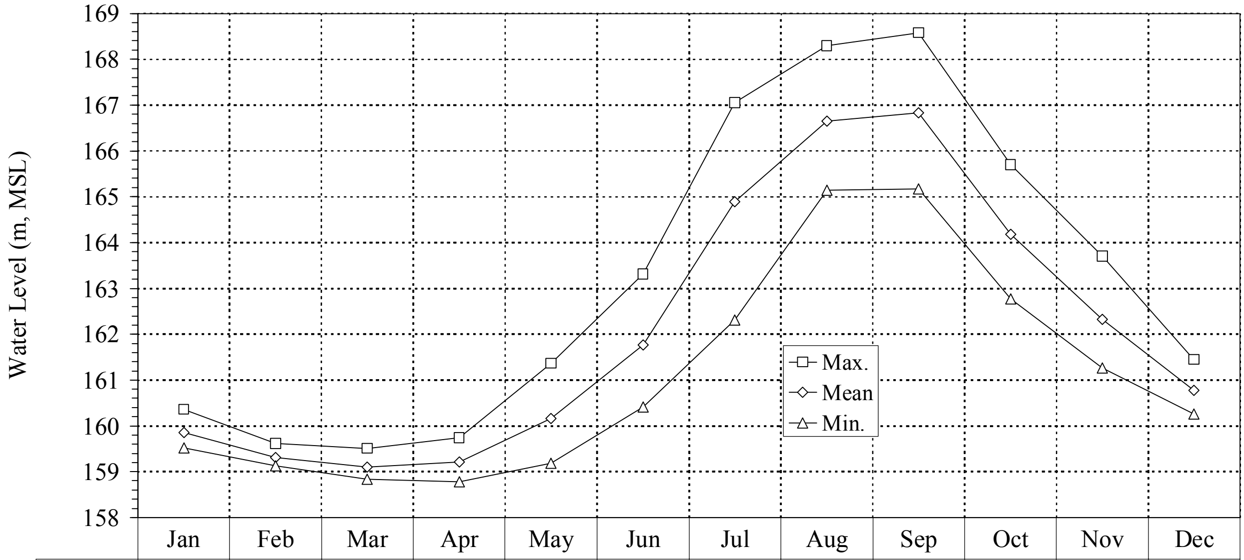
*) So KAZAMA : Evapotranspiration Analysis In The Mekong River Basin BySatellite Images, AIT School of Civil Eng. Water Engineering and Management Program, Bangkok, Thailand, March 1999.

1.2 Water Level and Discharge

Monthly average water level of the Mekong River at Vientiane (KM4) is as shown in Figure 1.4.

The maximum and minimum water level and discharge of each year at Vientiane from 1960 to 2001 are shown in Figures 1.5 and Table 1.1 according to Lower Mekong Hydrologic Yearbook published by Mekong River Commission. The annual maximum water level after 1960 changes within the range from 6.67 to 12.71m, and the minimum water level changes within the range from –0.28 to 0.93m. The annual maximum discharge changes within the

range from 7,500 to 22,900m^3/s, and annual minimum discharge changes within the range from 598 to 1,220m^3/s. Any remarkable correlation is not seen between the annual maximum water level and minimum water level.
Besides, based on collected material, water level duration curve and discharge duration curve averaged for 1989 - 1997 at Vientiane and Nongkhai are shown in Figures 1.6 and Figure 1.7. When the discharge duration curve of Vientiane and Nongkhai is compared, both do not have too much difference though nongkhai shows a little large discharge. Therefore, it is possible to represent by the data of Vientiane as a flow condition of the investigation object region.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max.	160.36	159.62	159.51	159.74	161.36	163.31	167.05	168.30	168.58	165.70	163.70	161.45
Mean	159.85	159.31	159.10	159.21	160.17	161.76	164.89	166.65	166.83	164.18	162.33	160.78
Min.	159.52	159.13	158.84	158.79	159.19	160.42	162.31	165.14	165.17	162.76	161.27	160.26

Month

Figure 1.4 Monthly Average Water Level at KM4 in Vientiane (1992-2001)

1.3 Ground Water Level

The location map and results of the measurement of Mekong River water level and groundwater level at Wat Sibounheuang in Vientiane are shown in Figures 1.8 and 1.9 according to the monitoring report made by Infrastructure Development Institute - Japan.

The groundwater level strongly depends on the water level of Mekong River. It is thought that the coefficient of permeability of the ground in this district is comparatively large so that high pore water pressure is not generated. It is necessary to investigate more to discuss the situation of the whole area of the investigation object region.

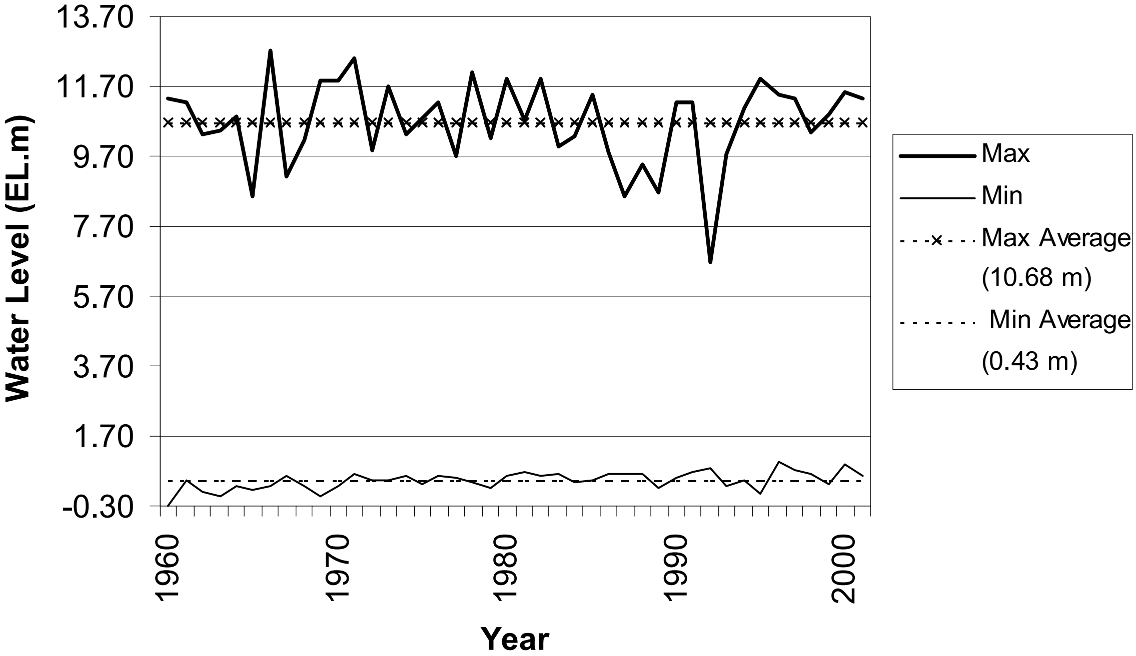


Figure 1.5 (1/2) Annual Maximum and Minimum Water Level and Discharge at Vientiane

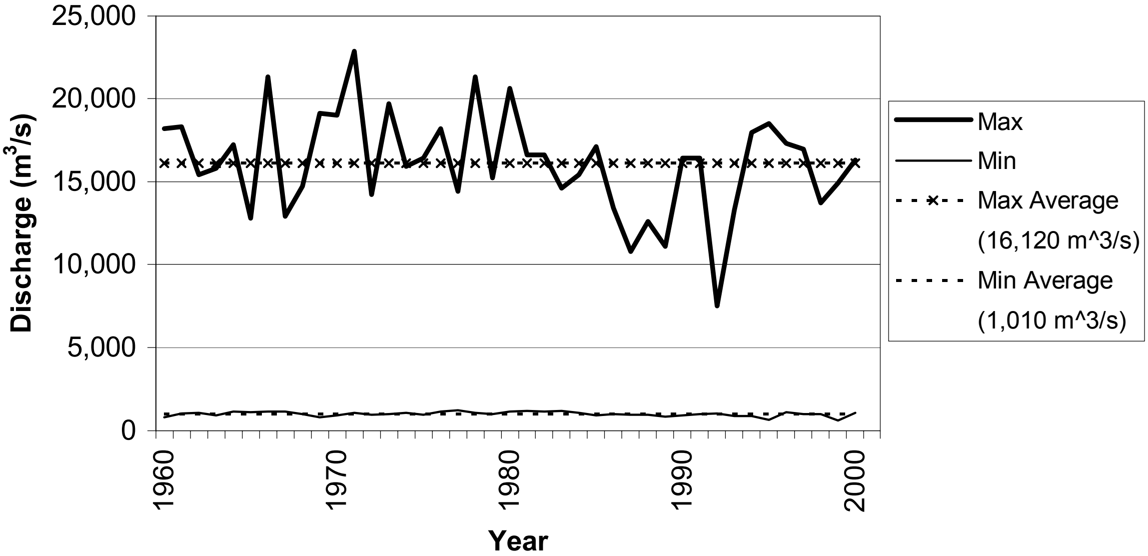


Figure 1.5 (2/2)
Annual Maximum and Minimum Water Level and Discharge at Vientiane

Table 1.1 Annual Maximum and Minimum Water Level and Discharge

Year	Vientiane KM4(Zero of gauge elevation 158.040 m above M.S.L. Ko Lak Datum.)			
	Water Level (m)		Discharge (m^3/s)	
	Max.	Min.	Max.	Min.
1960	11.35	-0.28	18,200	815
1961	11.22	0.45	18,300	1,040
1962	10.30	0.12	15,400	1,070
1963	10.47	0.00	15,800	920
1964	10.83	0.28	17,200	1,170
1965	8.58	0.16	12,800	1,100
1966	12.71	0.26	21,300	1,160
1967	9.15	0.54	12,900	1,170
1968	10.16	0.30	14,700	990
1969	11.87	-0.04	19,100	804
1970	11.85	0.26	19,000	930
1971	12.51	0.62	22,900	1,060
1972	9.86	0.43	14,200	965
1973	11.68	0.45	19,700	1,020
1974	10.32	0.53	15,900	1,090
1975	10.76	0.33	16,400	962
1976	11.27	0.53	18,200	1,140
1977	9.70	0.50	14,400	1,220
1978	12.08	0.38	21,300	1,070
1979	10.20	0.23	15,200	1,020
1980	11.90	0.54	20,600	1,150
1981	10.72	0.65	16,600	1,200
1982	11.90	0.58	16,600	1,170
1983	9.97	0.63	14,600	1,200
1984	10.28	0.40	15,400	1,090
1985	11.50	0.43	17,100	919
1986	9.84	0.64	13,400	986
1987	8.58	0.63	10,800	964
1988	9.50	0.60	12,600	970
1989	8.70	0.21	11,100	853
1990	11.22	0.51	16,400	943
1991	11.22	0.70	16,400	1,010
1992	6.67	0.77	7,500	1,040
1993	9.78	0.30	13,300	880
1994	11.08	0.47	17,959	867
1995	11.95	0.07	18,495	668
1996	11.48	0.93	17,305	1,114
1997	11.34	0.71	16,959	999
1998	10.38	0.62	13,700	997
1999	10.88	0.33	14,900	598
2000	11.53	0.88	16,300	1,070
2001	11.35	0.56		
Max.	12.71	0.93	22,900	1,220
Min.	6.67	-0.28	7,500	598
Ave.	10.68	0.43	16,120	1,010

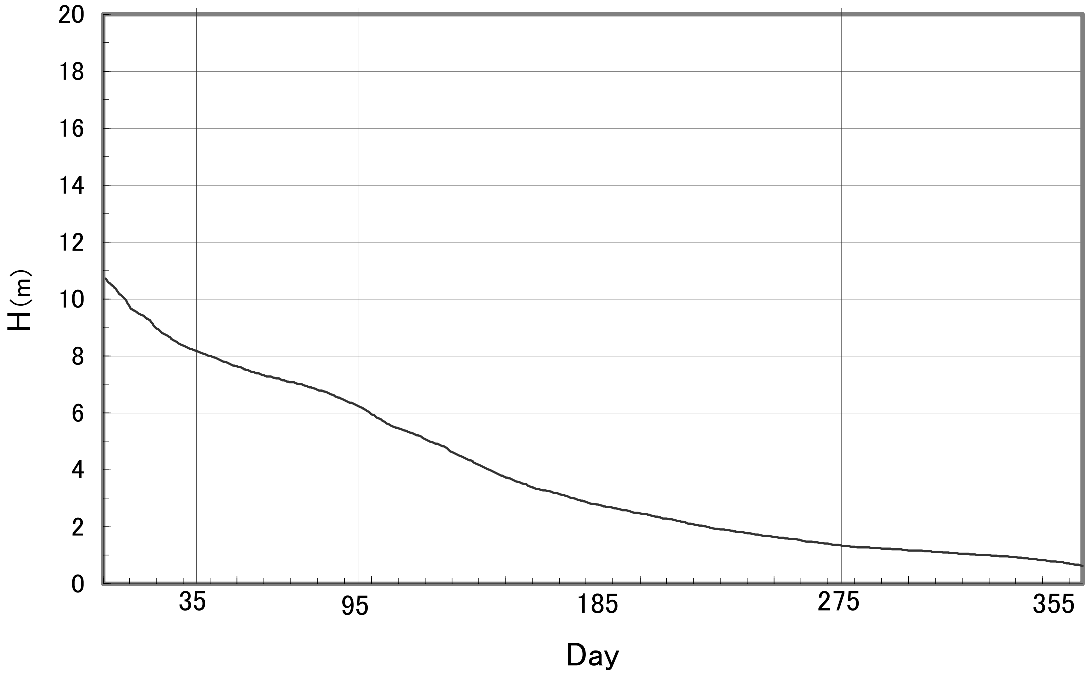


Figure 1.6 (1/2) Water Level Duration Curve Averaged for 1989 - 1997 (at Vientiane)

(Zero of gauge elevation 158.040 m above M.S.L. Ko Lak Datum.)

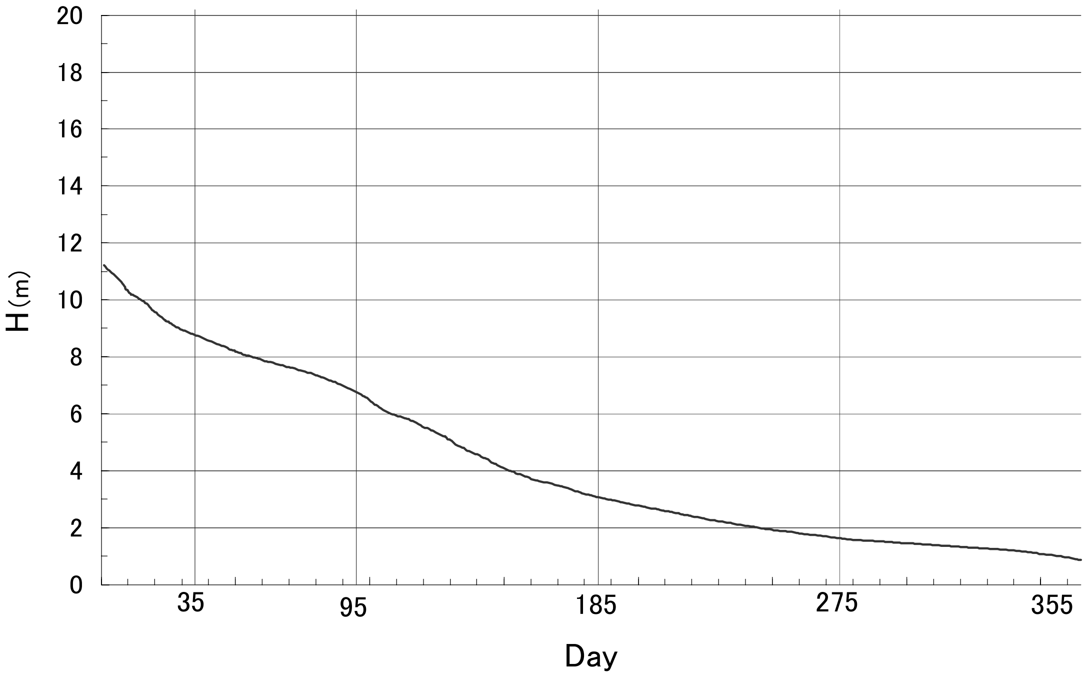


Figure 1.6 (2/2) Water Level Duration Curve Averaged for 1989 - 1997 (at Nongkhai)

(Zero of gauge elevation 154.070 m above M.S.L. Ko Lak Datum.)

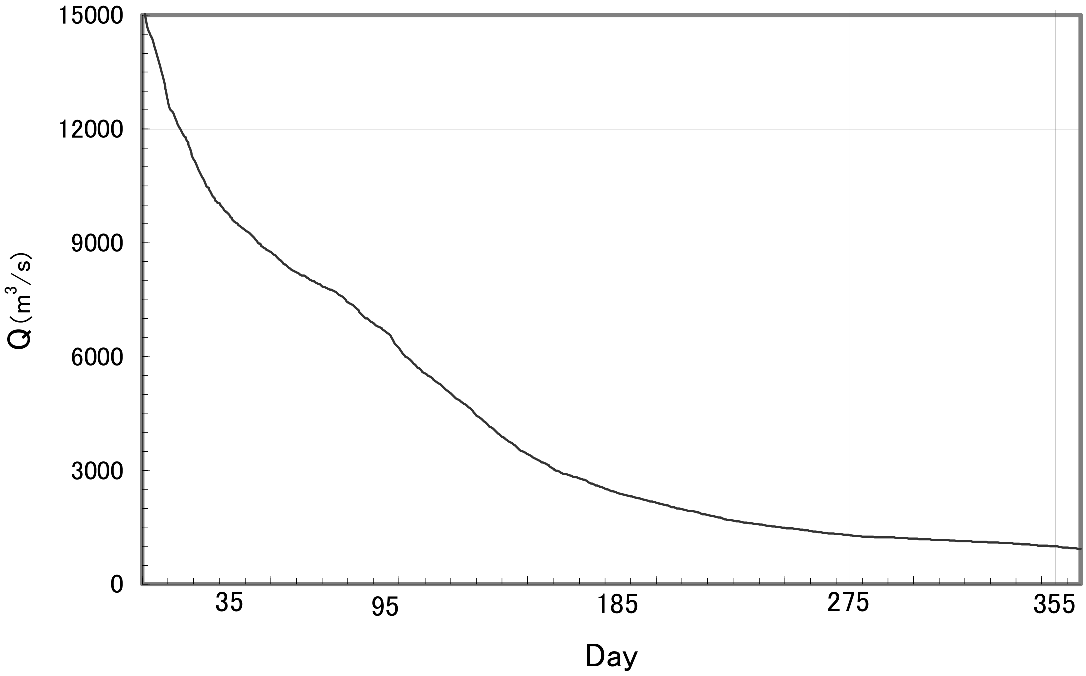


Figure 1.7 (1/2) Discharge Duration Curve Averaged for 1989 - 1997 (at Vientiane)

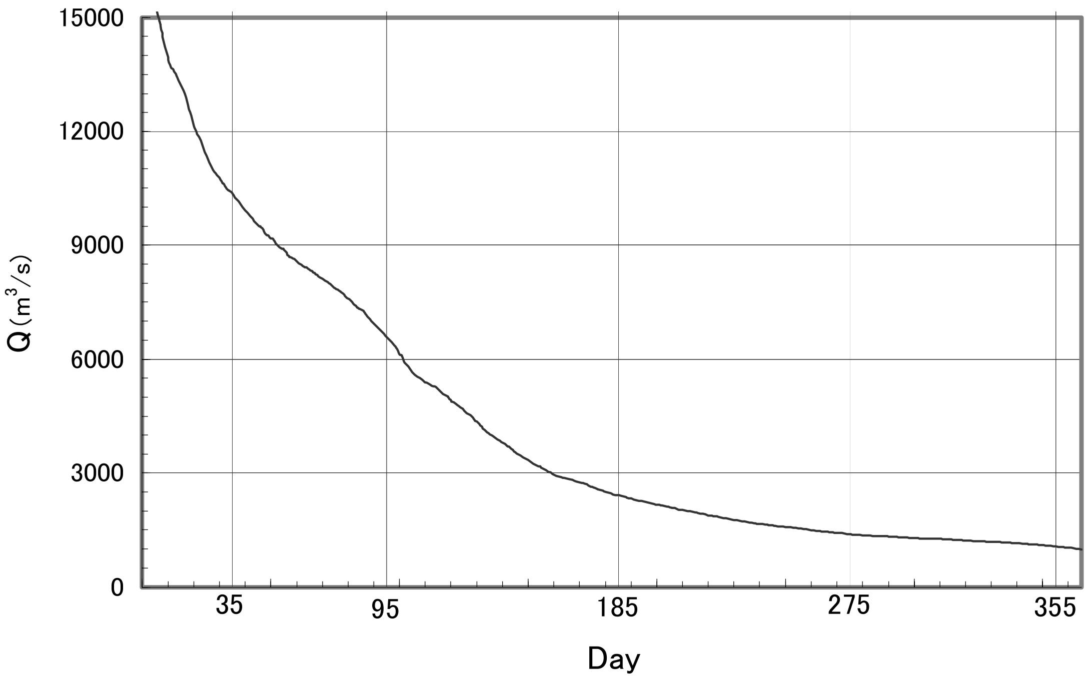


Figure 1.7 (2/2) Discharge Duration Curve Averaged for 1989 - 1997 (at Nongkhai)

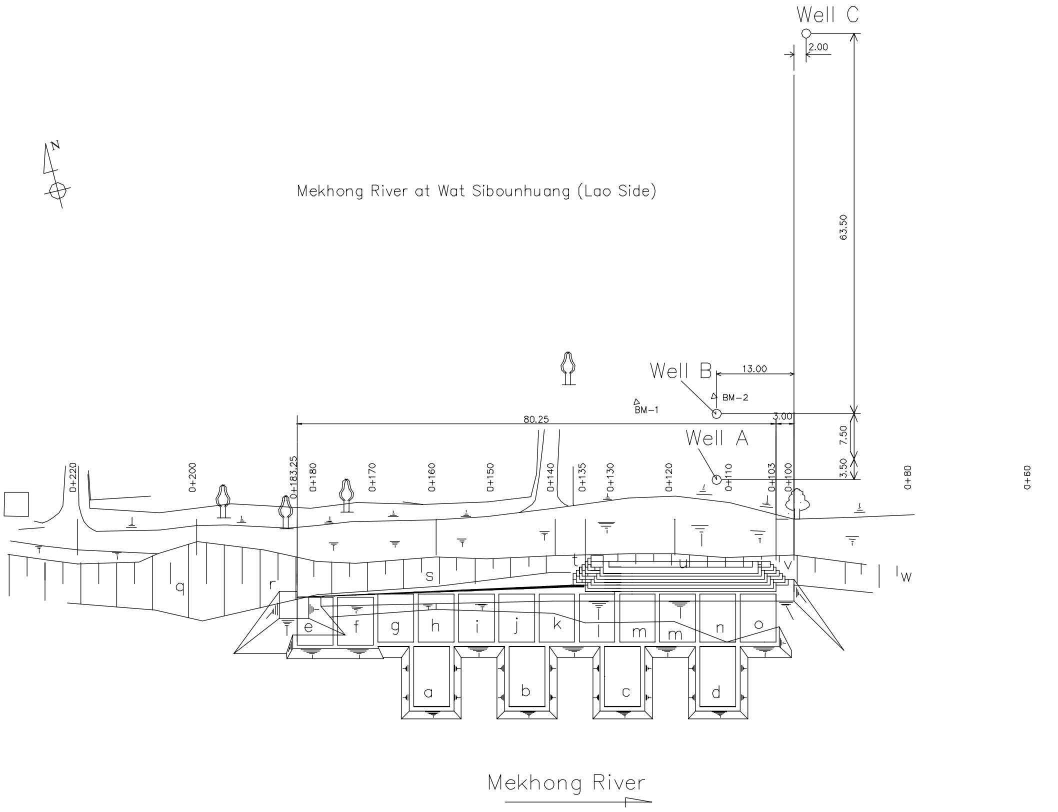


Figure 1.8 Location Map of Measurement of Mekong River Water Level and Groundwater Level (unit:m)

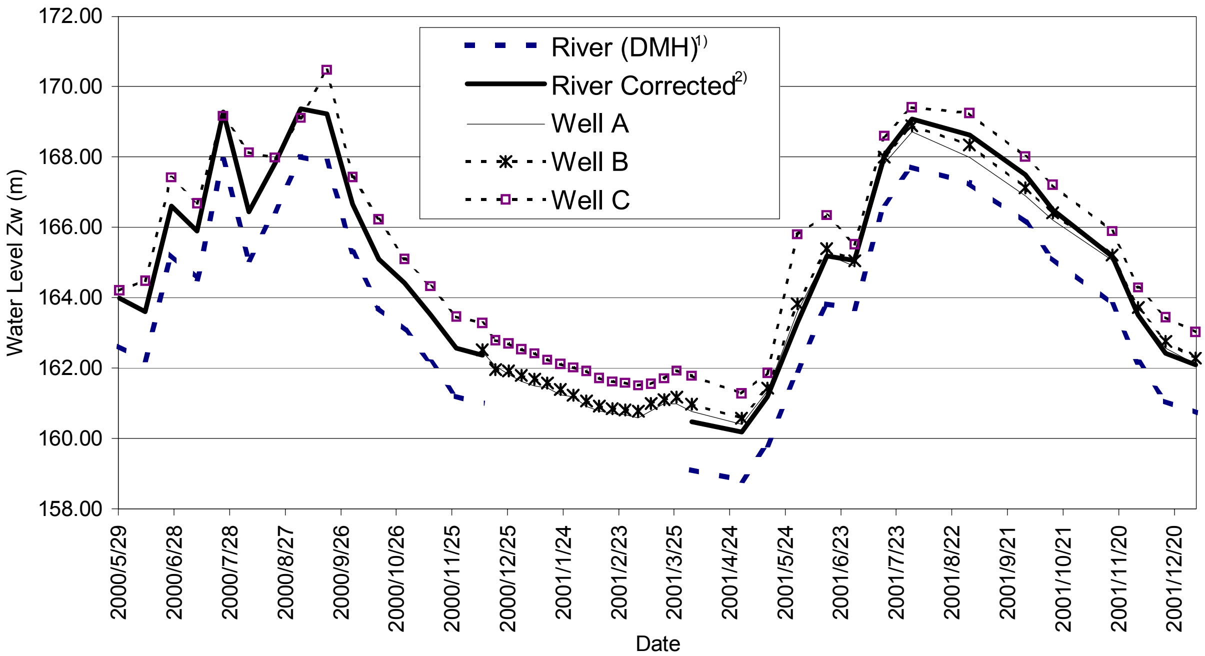


Figure 1.9 River Water and Groundwater Level Variation

Note

1) Guage Station closes to the Wattay International Airport. Chainage:-1-300, maintained by the Department of Meteorology and Hydrology-DMH.

2) Estimated from DMH record. The following equation applies, which is based on the DMH record and the survey at site on 10/12/2000. $Z_{w,s} = Z_{w,DMH} + 1.356$ (m)

2 RIVERBANK CONDITION

2.1 Mekong River Overview

2.1.1 Geological and Geomorphologic Features

The Mekong River rises in the Tibet Plateau, traverses the Indo-China Mountains, running between the Annam Cordillera and the Korat Plateau, running through the Cambodian Plain and the Mekong Delta, and drains into the South-China Sea.

According to Dr. Masahiko Oya, the Mekong River can be divided into three reaches, i.e., Upper Reaches from its sources to Pa Mong near Ban Ang, Middle Reaches from Pa Mong to Khong fall at the Cambodian border, and Lower Reaches from Khong fall to river mouth. The lower portion of the Upper Reaches and entire Middle Reaches are located in the territory of Lao P.D.R.

The depression of Luang Phabang exists in the Upper Reaches with gorge sections at the inlet and outlet sections. The city of Luang Phabang is situated on the river terraces formed by the Mekong and the Nam Khan rivers. These are rocky terraces. As a whole the geological formation of the Mekong River is old including that ascending to Precambrian ages.

The basin of the Middle Reaches is composed of the Korat Plateau on the right bank and the Annam Cordillera on the left bank. The Annam Cordillera is a folded mountain range and being flattened by erosion. The Korat Plateau consists of Mesozioc sand stone and shale. The alluvial plain develops along the Middle Reaches and has a loam or sandy loam layer of about 8 m in depth above the sand and gravel layer. In the alluvial plains along the Mekong and its tributaries, sedimentation is still ongoing.

2.1.2 Longitudinal Profile

According to "Hydrographic Atlas: Mekong River in the Lao PDR and Thailand (April 1996)", Kilometer markers were put along the Mekong River with the distance from the river mouth, and the Lowest Low Water datum (LLW-datum) was established in 1959/60 at each KM-marker for river soundings. Longitudinal profile of the Mekong River is prepared based on the LLW-datum.

The location map and longitudinal profile of the Mekong River are shown in Figures 2.1 and 2.2 for the stretch from KM723 (Khong fall) to KM2373 (Ban Khoan about 60 km upstream of Houayxai). The Mekong River shows stepwise profile alternating mild and steep bed slopes as follows:

Stretch-1 from KM740/80m,MSL to KM950/90m,MSL	: Bed slope 1/21,000
Stretch-2 from KM950/90m,MSL to KM1070/125m,MSL	: Bed slope 1/3,430
Stretch-3 from KM1070/125m,MSL to KM1620/165m,MSL	: Bed slope 1/13,750
Stretch-4 from KM1620/165m,MSL to KM1720/200m,MSL	: Bed slope 1/2,860
Stretch-5 from KM1720/200m,MSL to KM1900/230m,MSL	: Bed slope 1/6,000

Stretch-6 from KM1900/230m,MSL to KM2010/270m,MSL : Bed slope 1/2,750
Stretch-7 from KM2010/270m,MSL to KM2340/345m,MSL : Bed slope 1/4,400

The riverbed slope changes markedly at the section KM1620 near Ban Ang. The slope is steep in the upstream reaches of the section with overall bed slope of 1/4000 though it fluctuates from 1/2750 to 1/6000. Luang Phabang is located in these reaches.

The riverbed slope is milder in the downstream reaches of KM1620. The stretches-1 and 3 are alluvial river reaches. The Study Area including Vientiane City is situated in the upper portion of the stretch-3 and Savannakhet in its lower portion. The stretch-2 has steeper riverbed slope probably due to hard riverbank and bed materials such as exposed rocks.

2.1.3 Riverbanks

(1) Southern Part of Whole Mekong River

Field reconnaissance of southern part of Whole Mekong River in Lao P.D.R. was made from 24 December to 27 December 2001 for the stretch from Vientiane to Khong fall. During the reconnaissance period, the Study Team visited the following sites of eroded riverbank and existing bank protection works in the provinces of Bolikhamxai, Khammouan, Savannakhet, and Champasak guided by DCTPC officers of the relevant provinces:

1) In Bolikhamxai Province: Existing bank protection sites of the Mekong River at the confluence of the Nam Xan River and bank erosion site of the lower Nam Xan River in Pakxan, and riprap groin site in Pakkadan.
2) In Khammouan Province: Existing bank protection work sites at intake pump for water supply and Ban Chom Chen, and bank erosion sites at Tha Khe Ka and Wat That Muang Kao in Thakhek.
3) In Savannakhet Province: Existing bank protection site at Ban Xay Ya Phoum and bank erosion site near water intake tower in Savannakhet.
4) In Champasak Province: Site of eroded riverbank and existing bank protection works at the confluence of the Xe Don and the Mekong rivers, and bank erosion sites along the lower Xe Don River in Pakxe. The Study Team further inspected the river conditions at Khong and Khong fall, and eroded riverbank site of Wat Pou remain.

According to visual observations during the above reconnaissance, riverbanks in the downstream reaches from Vientiane are composed of loam or sandy loam layers same as those around Vientiane City (the Study Area). However, it seems that the loam component increases as it goes toward downstream, and the strata get more uniform so that they are not visually discriminated.

Vertical cliffs of riverbanks commonly seen in the Study Area were seldom found in the downstream reaches. Most of the riverbanks in the downstream reaches keep some slopes even they are suffering from erosions. In other words, the riverbanks in the Study Area seem younger and sediment movements are mere active comparing with those in the

downstream reaches.
This may come from the location of the Study Area. The Study Area is located at just downstream of the abrupt change of riverbed slope, and the sediment movement would be active causing repeated sediment depositions and erosions. The sediment movement may gradually change toward equilibrium condition, as it goes downstream.

A part of the remnants of exterior wall of ancient Wat Phu remain to be registered soon to UNESCO's World Heritage list is located at the eroded riverbank of the Mekong River and is now under the threaten of collapse and washed away. A temple is now located on the eroded bank and buried foundation stones of the wall can be seen on the ground. Some collapsed foundation stones can also be seen on the riverbed during low water season. According to the monks, a statue of Buddha installed in present temple was relocated from former location in 1991 because of the progress of bank erosion and a collapsed Sheba head can also be seen in the riverbed during only the lowest water level period. The riverbank forms steep slope but with no vertical cliff. There is no bank protection works so far. Some bank protection measures will be required to prevent precious cultural heritage from collapsing by erosion. Revetment works covering whole river bank is not recommendable in consideration of the conservation and archaeological prospecting of remains, and harmonization with remains. Further discussion would be needed; however, groin works might be effective to stabilize the bank by accelerating the sedimentation and vegetation at the foot of bank without directory covering the bank. Riprap or wooden pile groins will be adaptable depending on the availability of local materials.

(2) Northern Part of Whole Mekong River

Field reconnaissance of northern part of Whole Mekong River in Lao P.D.R. was made from 27 January to 31 January 2002 for the stretches in Luang Phabang and Bokeo provinces both from land and river. During the reconnaissance period, the Study Team visited the following sites of eroded riverbank and existing bank protection works in the provinces of Luang Phabang and Bokeo guided by DCTPC officers of the relevant provinces:

1) In Luang Phabang Province: Existing bank protection site of the Nam Khan River, a tributary of the Mekong River and several bank erosion sites along the urban area of Luang Phabang.
2) In Bokeo Province: Existing/on-going riprap groin site at Ban Tonpheung located near golden triangle to protect national road, existing bank protection work sites at Ban Mom port and the factory Ban Paoyl-Tinthad, and several bank erosion site in and around Houayxay such as Mixaysaveung and Ban dan.

According to visual observations during the above reconnaissance, the riverbanks along the urban area of Luang Phabang are composed of sandy loam layers with outcrop of bedrock in some places. Vertical cliffs of riverbanks commonly seen in the Study Area were not found at Luang Phabang. Most of the riverbanks keep some gentle slopes and the extent and damage of erosion is relatively small. On the other hand, the riverbanks in Bokeo, most notably existing groin site at Ban Tonpheung form vertical cliffs at many places as can seen in the Study Area. Riverine land use of these eroded riverbanks is mainly small villages, farmland, forest and grassland.

2.2 Riverbank around Vientiane City

2.2.1 Riverbank Conditions

Location map of the Mekong River around Vientiane City (the Study Area) is shown in Figure 2.3. In the figure, the stretches of eroded bank and locations of existing bank protection works are indicated according to the results of field reconnaissance, referring with the latest aerial photos and topographic maps.

Reconnaissance was made for the whole stretch of the Study Area both from land and river and intensive inspections were made at the following sites of existing bank protection works and eroded riverbanks:

1) Sites of existing bank protection works: From the downstream, Thadeua, Friendship Bridge, National Culture Park, Hatdokkeo, Wat Sop, Phanmanh, Wat Taynoy, Muang Wa, Sibounheuang, Ice Factory, Kao Liao Port, and Ban Ang
2) Sites of eroded riverbanks: From the downstream, Lao State Fuel Company, Nahai/ Sithan-Tai, Thakhek/ Ban Hom, Bo O, Chom Cheng, Wat Chan/ Modern Home, Sithanneua, and Wat Taynoy

The riverbanks severely eroded in the Study Area forms vertical cliffs mostly. Photos of typical vertical cliffs are shown in Figure 2.4. According to the IDI Report of Test Works for Bank Protection (March 2000), the geological formation of riverbank generally consists of sandy gravel layer covered with of 6 m to 8 m deep clayey soil on the top as shown in Figure 2.5. The conditions of riverbank and layers are similar for the whole reaches of the Study Area. These bank materials are not consolidated and easily be eroded.

Bank protection works commonly used are gabion works. The existing works are effective to protect the riverbank from erosion, though some works are damaged due to poor foot protection and/or washing away of soil behind the gabion. However, these works are costly.

2.2.2 Riverbank Alignments and Islands

Data used: For the study of riverbank alignments and islands, the following topographic data were collected and used:

1) Topographic maps: Maps of scale 1/100,000
2) Hydrographic survey results: Surveyed in 1961/62 (1961/62-riverbank) and 1995/96 based on aerial photo taken in 1991/92 (1991/92-riverbank).
3) Aerial Photos: Photos taken in 1981/82 (scale: 1/30,000) and 1997/98 (scale: 1/16,000)

Historical changes of riverbanks and islands: The latest and the oldest riverbank data were selected for comparison, i.e., the 1961/62- and 1991/92- riverbank data which differ for 30 years or more. These are superimposed each other in Figure 2.6, and the changes of river banks and islands for about 30 years were studied. During these 30 years, changes in riverbanks are not much as a whole, and the islands remained almost at the same location, in spite the river experienced historic big flood in 1966. The riverbank movements are relatively large in the stretch from KM1574 to KM1553.

Course of main flow: In the Figure 2.6 the locations of the lowest riverbed were also shown, which would show the course of main flow. The course of main flow meanders regularly in cycle and most of the existing eroded riverbanks and those eroded in the past 30 years are located in the reaches where the main flow contacts to the riverbank. These facts indicate that the bank erosions in the Study Area are mainly caused by the attacking river flows and the reaches of flow attacks are historically fixed. Furthermore, judging from the relatively small bank erosion rate, the forces of river flows attacking to the riverbank would be relatively weak.

Meandering cycle: In the river stretch of 60 km from KM1540 to KM1600, seven reaches of flow attacks are identified. Average intervals are about 8.5 km, which correspond to about 10 times of river width. This endorses the empirical relationship of alternative bars derived based on the river data in Japan.

2.2.3 Longitudinal Profile and River Width

Longitudinal profile of the Mekong River in the Study Area was prepared based on the said "Hydrographic Atlas: Mekong River in the Lao PDR and Thailand (April 1996)", and shown in Figure 2.7 for the stretch from KM1540 to KM1600. The longitudinal profile shows the profiles of lowest riverbed, left (Lao-side) and right (Thai-side) riverbank elevations, and LLW-datum.

The Mekong River in the Study Area, located at the upstream reaches of the Stretch-3, has riverbed slope of 1/8100 and average maximum channel depth of 14.87 m. The maximum channel depth was worked out as a difference of elevations between the lowest riverbed and the lower riverbank of left or right side.

River widths were also measured on the Hydrographic Atlas and shown in the Figure 2.7. The average river width of the Mekong River in the Study Area is 856 m including island, and 773 m excluding the islands.

2.2.4 River Section

River sections surveyed in different time of a year are shown in Figure 2.8, excerpting from "Completion Report for Pilot Project Stage I of Mekong River Bank Protection (Basin-Wide: May 1988)". These are the riverbank sections surveyed at three sections in May (dry season), September (flood season), and November (end of flood season) in 1987. It is noted that the lowest riverbeds in dry season are deepened around 4 m in flood season.

2.2.5 Riverbed Materials

According to the "IDI Report for Test Works for Bank Protection (March 2000), riverbed materials were sampled and laboratory tests such as grading analyses and specific gravity tests were conducted for them. Locations of the sampling sites and the results of laboratory tests are shown in Figure 2.9 and Table 2.1. The grain size distributions of the riverbed materials are rather uniform sorted by the river flows. Average of the 60% grain sizes (d60) are worked out at 0.44 mm and the specific gravity at 2.61.

2.2.6 Sediment Flow Conditions

Sediment flow conditions are not visible since it takes place under the water. Channel flow calculation is not possible, since river sections from bank to bank are not available for the Mekong River. An attempt is, therefore, made to estimate the sediment flow conditions applying the empirical relationships developed in Japan.

Basic dimensions and parameters:

1) River width: B = 773 m (856 m with island)
2) River slope: I = 1/8100
3) Water depth: Two conditions of flood flows are considered, i.e., bankful flow and frequent flood flow. The bankful flow depth (Hmb) was estimated from the average maximum channel depth (Hmax = 14.87 m) assuming Hmb/Hmax = 0.65, and the frequent flood flow depth (Hmf) was assumed at 4 m lower than the bank flow water level as follows:
   Hmb = 14.87 x 0.65 = 9.7 m (say 10 m)
   Hmf = 6 m
4) Representative particle size of bed materials: d_R = 0.044 cm taking average d60.
5) Basic parameters:

Parameters	Unit	Bankfull flow	Frequent flow
τ_*	Non	1.70	1.02
H/d	Non	22,700	13,600
B/H	Non	77	129
u_*	cm/sec	11	8.5
u_*/ω_0	Non	1.8	1.4

τ_* : Dimensionless shear stress = $u_*^2 / (s\,g\,d) = H\,I / (s\,d)$
H/d : Depth - particle size ratio
B/H : Width - depth ratio
s : $(\rho_s - \rho_w) / \rho_w$ (= 1.65)
τ : Shear stress of flow = $\rho_w\,g\,H\,I = \rho_w\,u_*^2$
u_* : Shear velocity = $(g\,H\,I)^{0.5} = (\tau / \rho_w)^{0.5}$
ω_0 : Settling velocity of particle (= 6 cm/sec for d_R = 0.044 cm)

Sediment flow conditions: Applying the parameters to the empirical relationships (refer to

Figures 2.10 and 2.11), sediment flow conditions under bankful flow and frequent flood flow conditions were estimated as follows:

Items	Bankful flow	Frequent flow
Type of bar	Alternate/multiple bar	Alternate/multiple bar
Riverbed form	Dune/flat bed	Dune
Velocity coefficient(ϕ) Mean velocity(v_m) Corresponding n	8 to 26 0.9 to 2.9 m/sec 0.059 to 0.018	8 0.7 m/sec 0.054
Sediment transport	Suspension not fully developed	Suspension not fully developed

ϕ : Velocity coefficient = $v_m / u_* = H^{1/6} / (n\ g^{1/2})$
(n: Manning's coefficient of roughness)

The Mekong River in the Study Area falls in the transition zone of the alternative bar and multiple bar channels for both the bankful and frequent flow conditions. According to the estimate, the dune bed under the frequent flood flow conditions may shift to the flat bed conditions under the bankful flow conditions. The riverbed form is one of the important factors ruling channel roughness to flow. The dune bed brings about the highest roughness and the flat bed the smallest roughness to flows. Since the shear velocities of the bankful and frequent flows are not so fast to suspend the bed materials to the water surface, suspended load would concentrate near the bottom of the channel.

2.3 Mechanism of Bank Erosion

Causes of bank erosion: According to the observation and considerations during field reconnaissance of the whole Mekong River in Lao P.D.R. and that around Vientiane City, three major causes could be pointed out for the riverbank erosion. They are bank erosion due to (1) scouring at foot of riverbank, (2) lowering river water level, and (3) slope failure.

Erosion due to scouring at of foot of riverbank: Primary factors of the riverbank erosion are the force of river flow acting on river bank and the resistance to the flow of riverbank soil. The riverbanks of the Mekong River in the Study Area generally consist of sandy gravel layer below 6 m to 8 m deep clayey soil. The sandy gravel is unconsolidated and susceptible to the erosion. On the other side, the shear stress of river flow is bigger and the period subject to flow attack is longer at the bottom of channel. This brings about the side erosion at the foot of riverbank, and the mass of bank soil falls when the weight of soil mass exceeds the shearing stress of the bank. The vertical riverbank cliffs would be formed in this manner and most of the eroded river banks in the Study Area are of this type.

Erosion due to lowering river water level: High water period last long during the flood season and groundwater table in riverbank is kept high during the period. When the flood season ends, the river water is lowered rapidly but the groundwater table gradually; this causes an imbalance in water pressures on the riverbank slope. In case the riverbank materials are fine and the permeability is low, pore pressure acting on the bank slope may cause failure. Difference in water levels between flood and dry season amounts to 10 m or more in the Mekong River. This could also happen when the bank slope is covered with impermeable materials like wet masonry without providing weep holes.

Erosion due to slope failure: Slope failure of river bank may occur at the cliffs newly created. This could happen when additional loads such as earth embankment and buildings were put on the river bank.

Table 2.1 Riverbed Materials around Vientiane City

Measure.section No.	Lao side			River center			Thai side		
	Sample No.	d60	Specific gravity	Sample No.	d60	Specific gravity	Sample No.	d60	Specific gravity
1	40	0.57	2.594	20	0.65	2.651	1	0.50	2.622
2	41	0.43	2.600	21	0.67	2.611	-	-	-
3	42	0.38	2.594	22	0.45	2.619	2	0.57	2.621
4	43	0.28	2.611	23	0.45	2.625	-	-	-
5	44	0.45	2.593	24	0.32	2.606	3	0.75	2.617
6	45	0.30	2.596	25	0.34	2.610	4	0.46	2.620
7	46	0.50	2.603	26	0.40	2.625	5	0.45	2.593
8	7	0.45	-	27	0.43	2.595	6	0.50	2.613
9	47	0.82	2.608	28	0.46	2.619	8	0.49	2.610
10	48	0.45	2.595	29	0.46	2.631	9	0.45	2.599
11	49	0.27	2.596	30	0.24	2.627	10	0.32	2.610
12	50	0.25	2.600	31	0.48	2.610	11	0.43	2.655
13	51	40.00	2.614	32	0.43	2.612	12	0.44	2.633
14	52	0.25	2.604	33	0.48	2.606	13	0.45	2.619
15	53	0.65	2.606	34	0.48	2.624	14	0.45	2.714
16	54	0.21	2.601	35	0.57	2.593	15	53.75	2.630
17	55	0.24	2.597	36	0.40	2.601	16	0.37	2.601
18	-	-	2.596	37	0.44	2.601	17	0.38	2.613
19	57	0.46	2.603	38	0.38	2.603	18	0.45	2.599
20	58	38.33	2.620	39	0.49	2.594	19	0.55	2.643
Average		0.41	2.602		0.45	2.613		0.47	2.623

Note:
1) Source: Report for IDI Test Works, March 2000
2) Samples 15, 51 and 58 were excluded for calculation of d60.
3) Overall average grain size (d60:mm): 0.44
4) Overall average specific gravity: 2.61

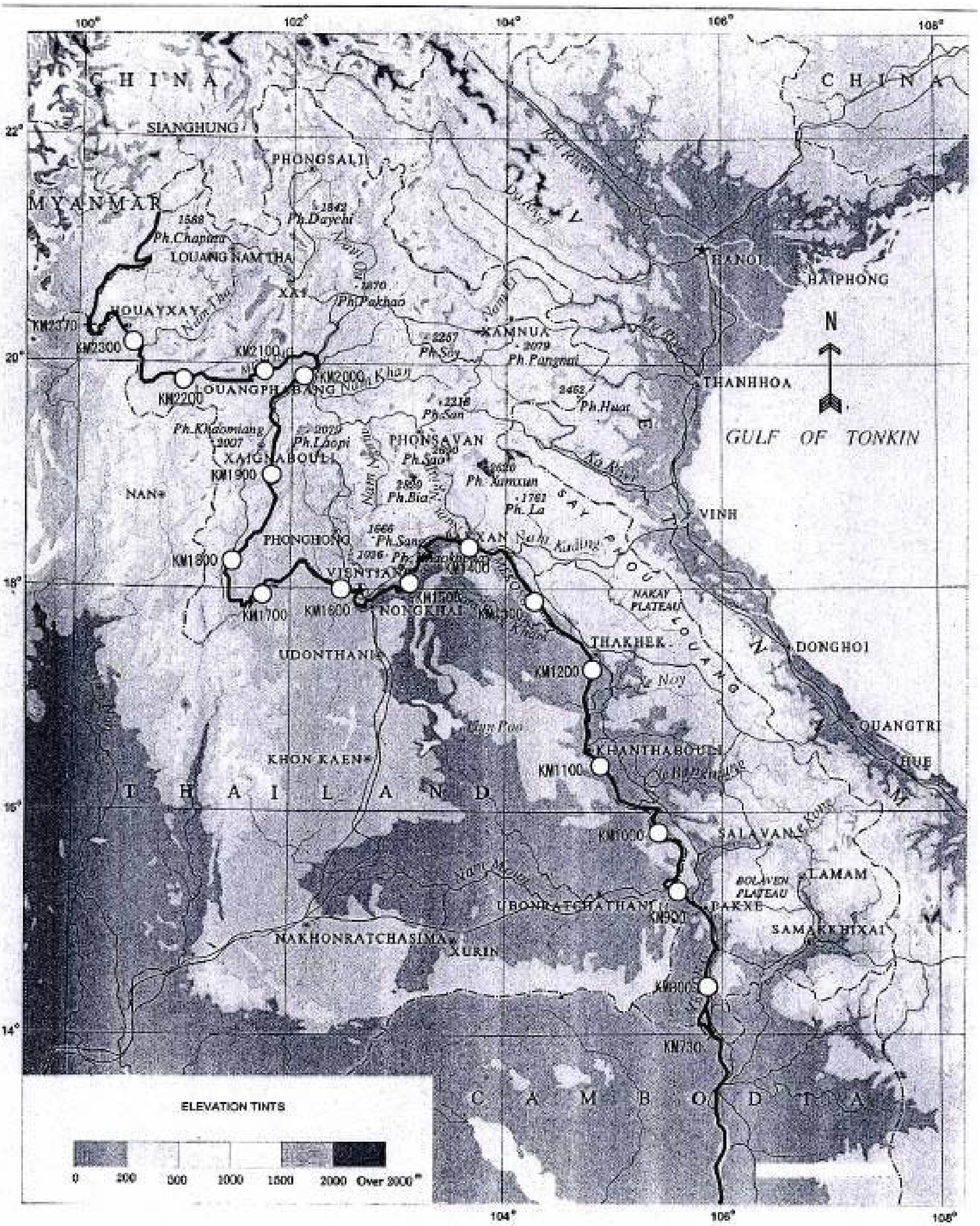


Figure 2.1 General Location Map of Mekong River in Lao PDR

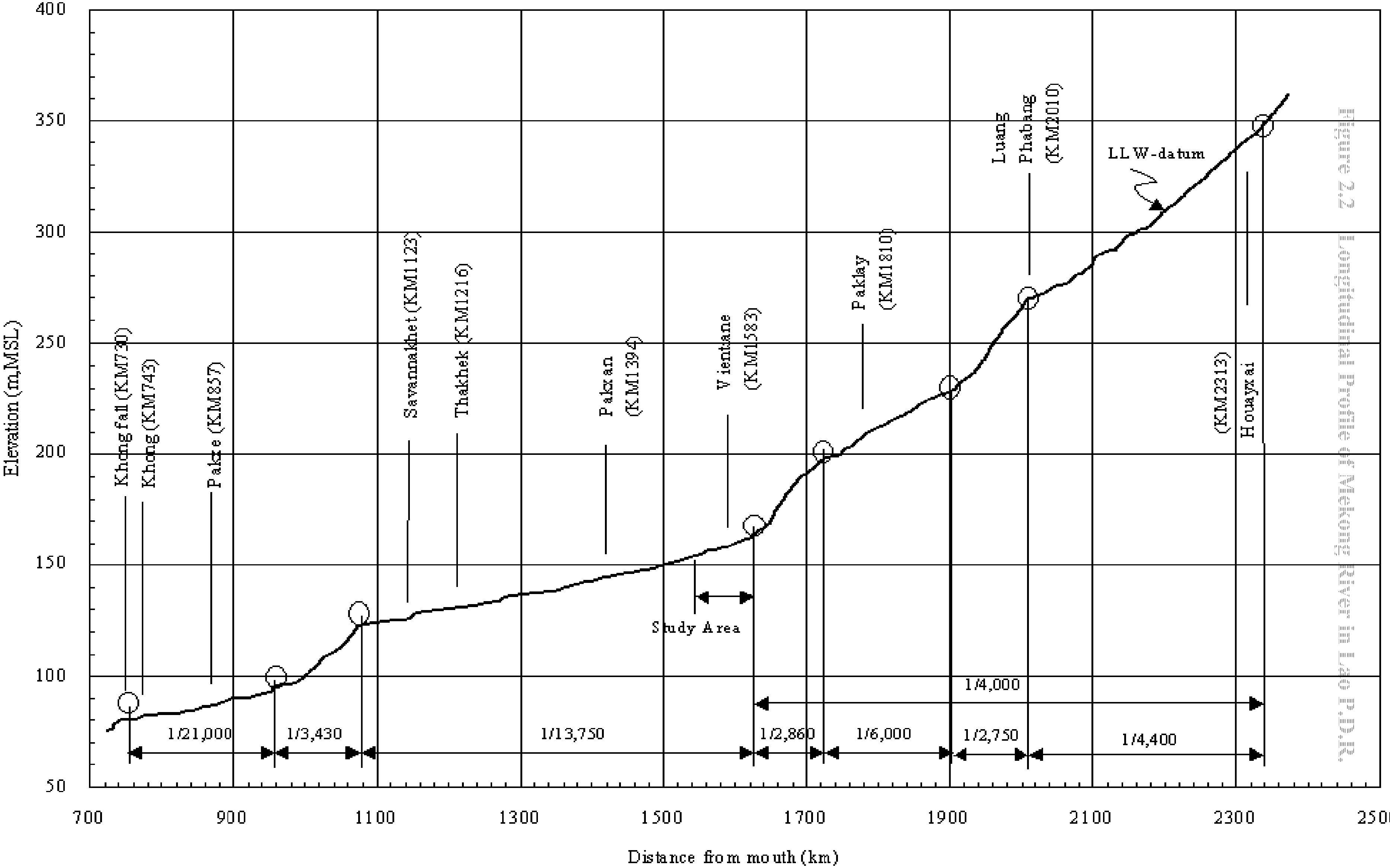


Figure 2.2 Longitudinal Profile of Mekong River in Lao P.D.R. (KM723-KM2373)

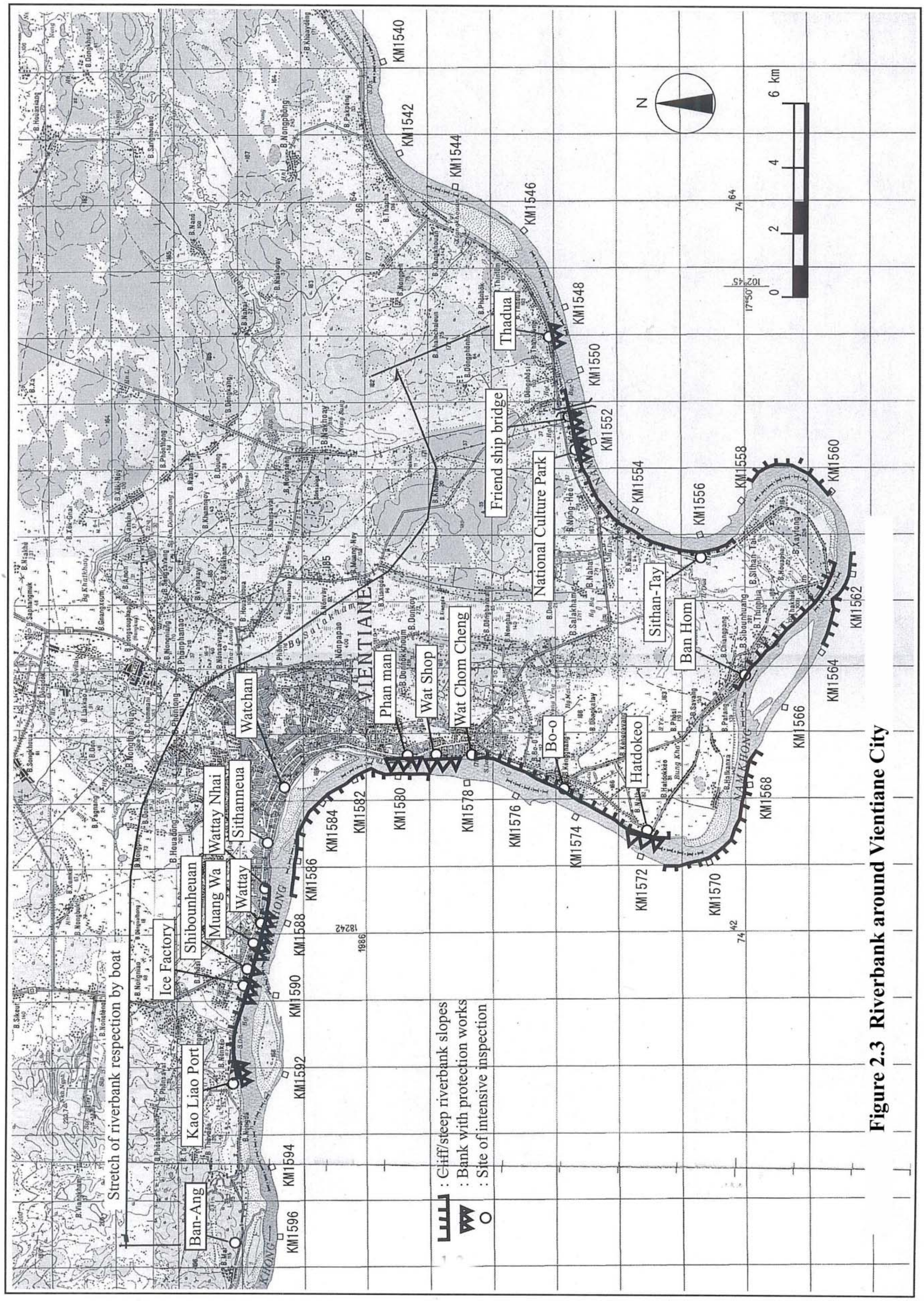


Figure 2.3 Riverbank around Vientiane City

Downstream of Sibounheuang Site (around KM1588)

(Close-up of Riverbank Cliff)

Near Boo Site (around KM1574)

(Close-up of Riverbank Cliff)

Figure 2.4 (1/2) Photos of Vertical Riverbank Cliffs

Near Ban Hom Site (around KM1565)

(Close-up of Riverbank Cliff)

Near Ban Dongphosi Site (around KM1551)

(Close-up of Riverbank Cliff)

Figure 2.4 (2/2) Photos of Vertical Riverbank Cliffs

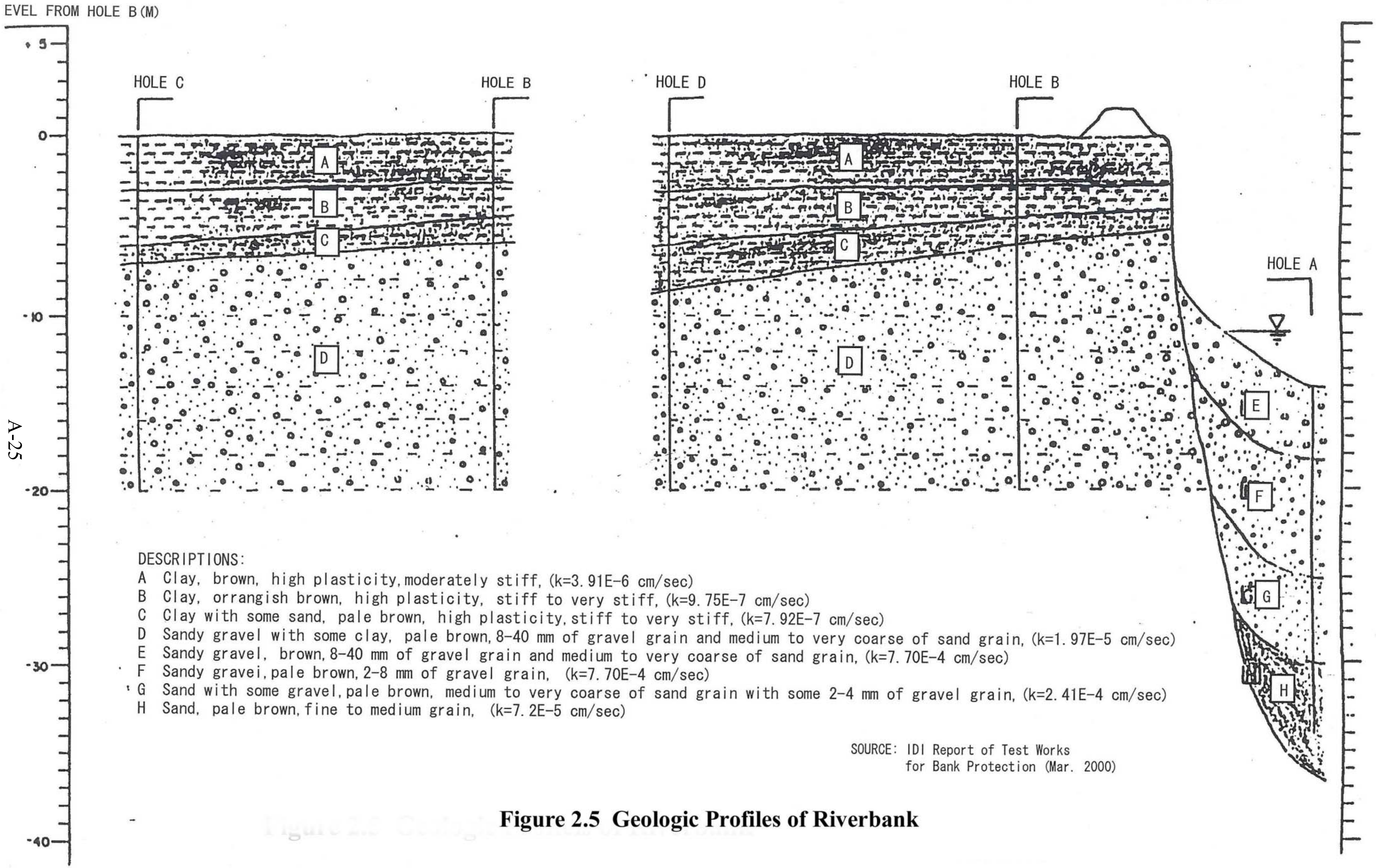


Figure 2.5 Geologic Profiles of Riverbank

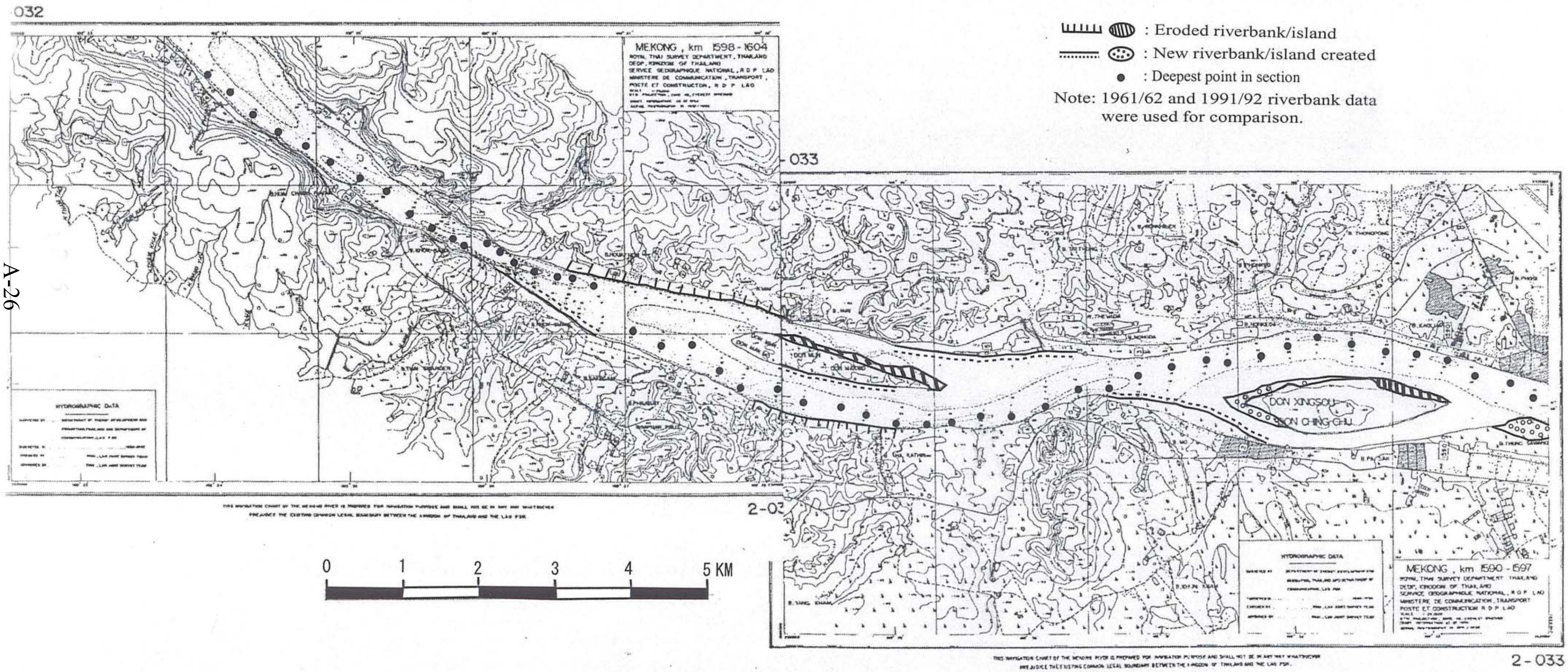


Figure 2.6 (1/4) Historical Changes of Riverbanks and Islands

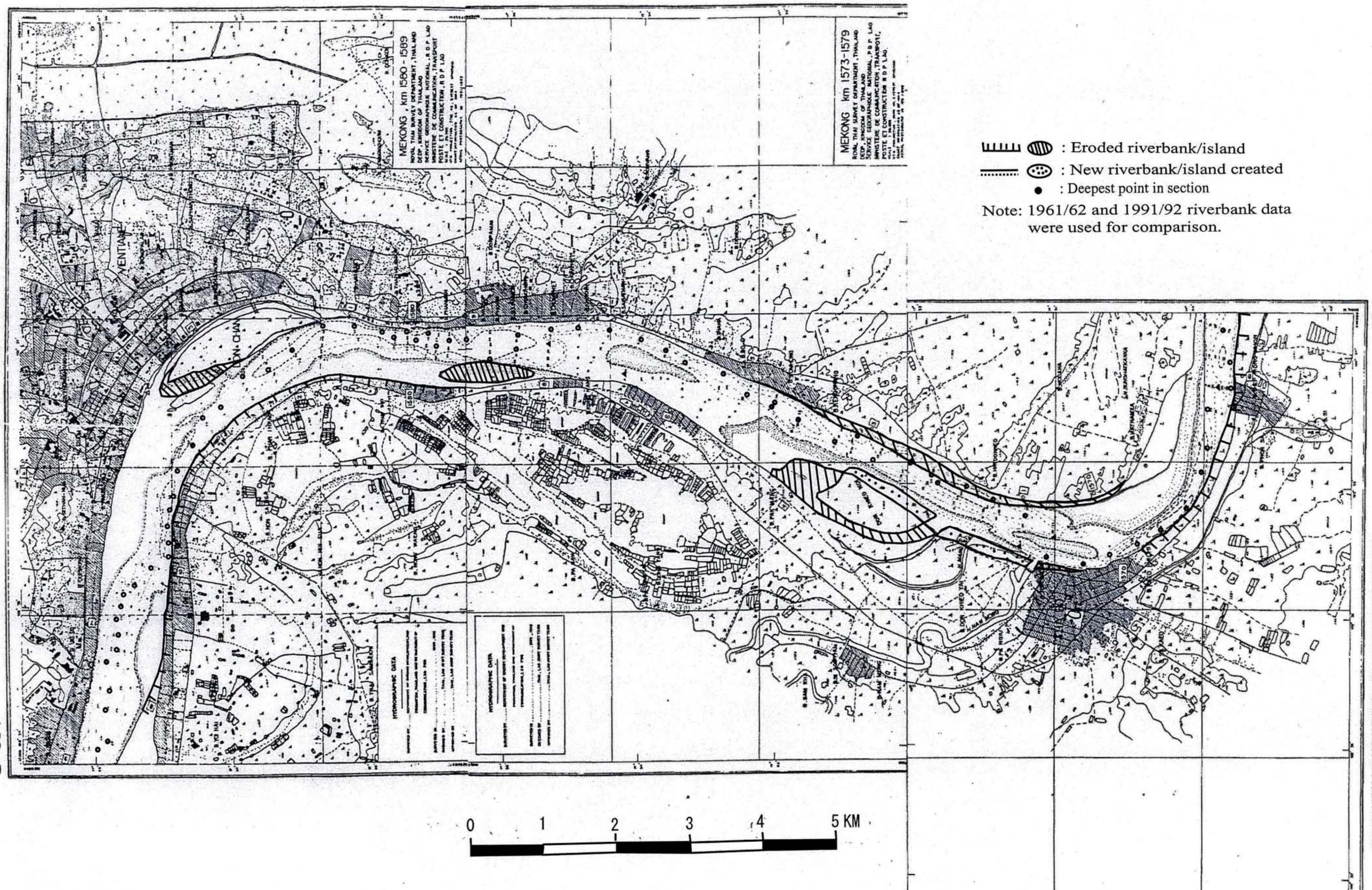


Figure 2.6 (2/4) Historical Changes of Riverbanks and Islands

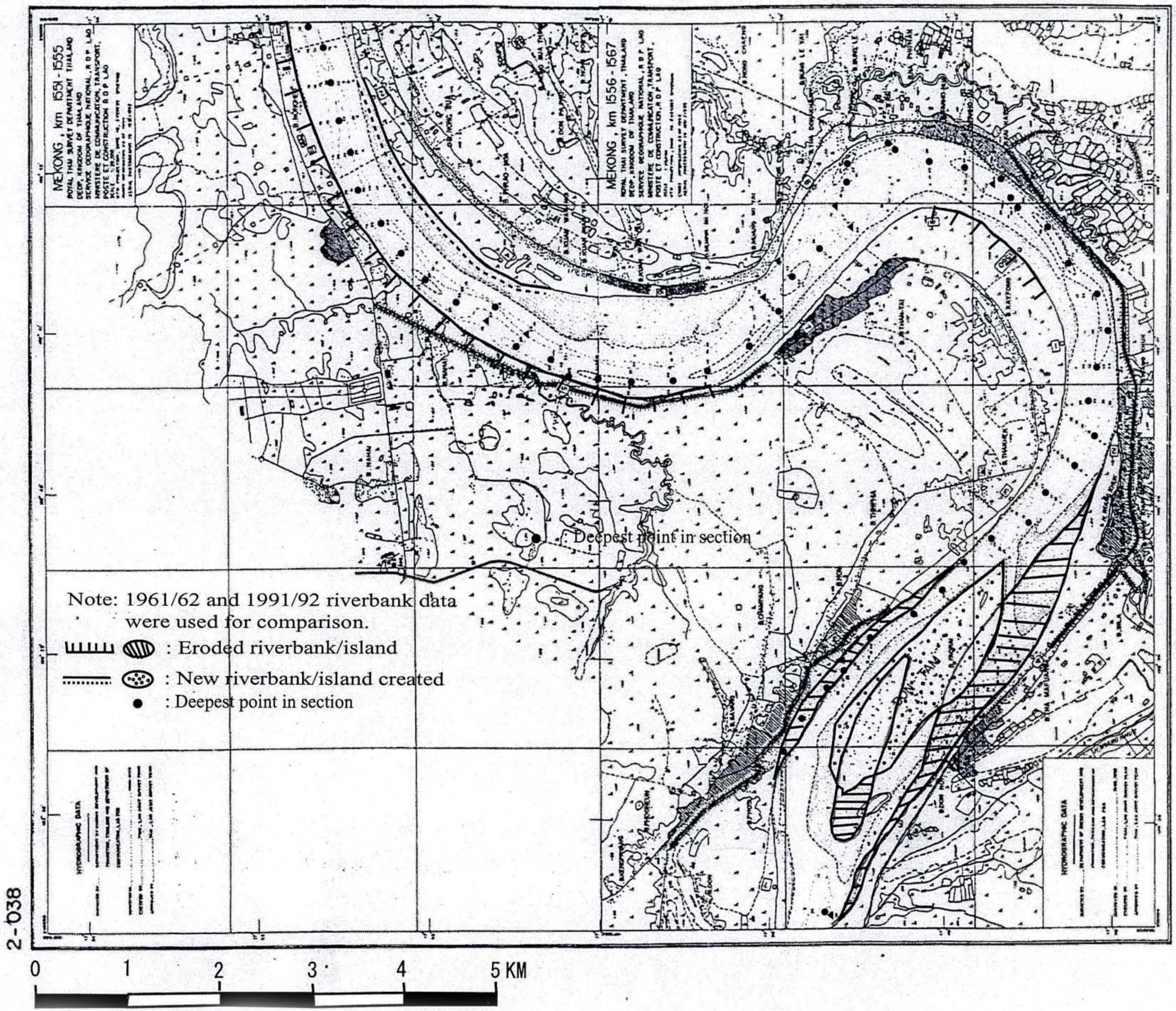


Figure 2.6 (3/4) Historical Changes of Riverbanks and Islands

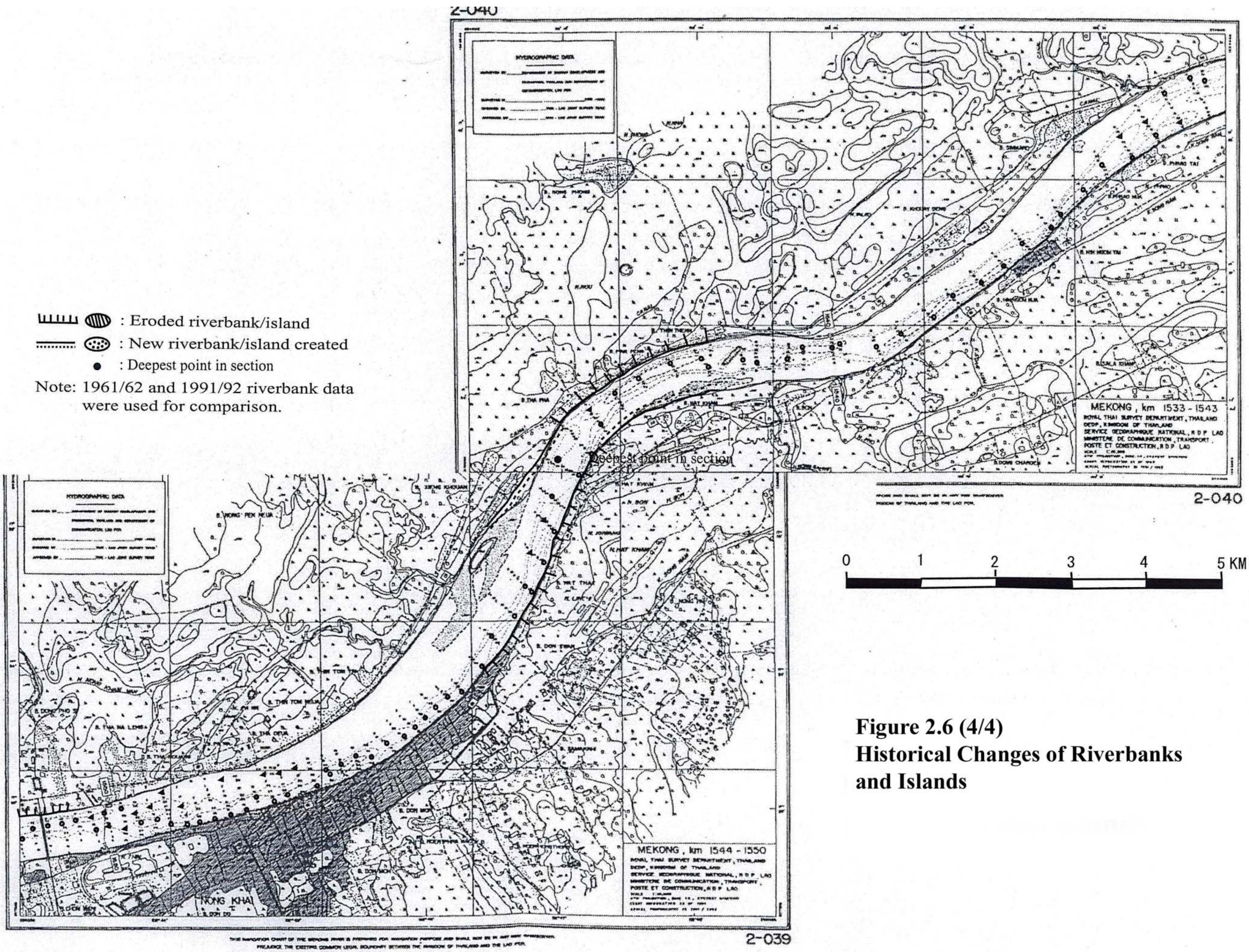


Figure 2.6 (4/4)
Historical Changes of Riverbanks and Islands

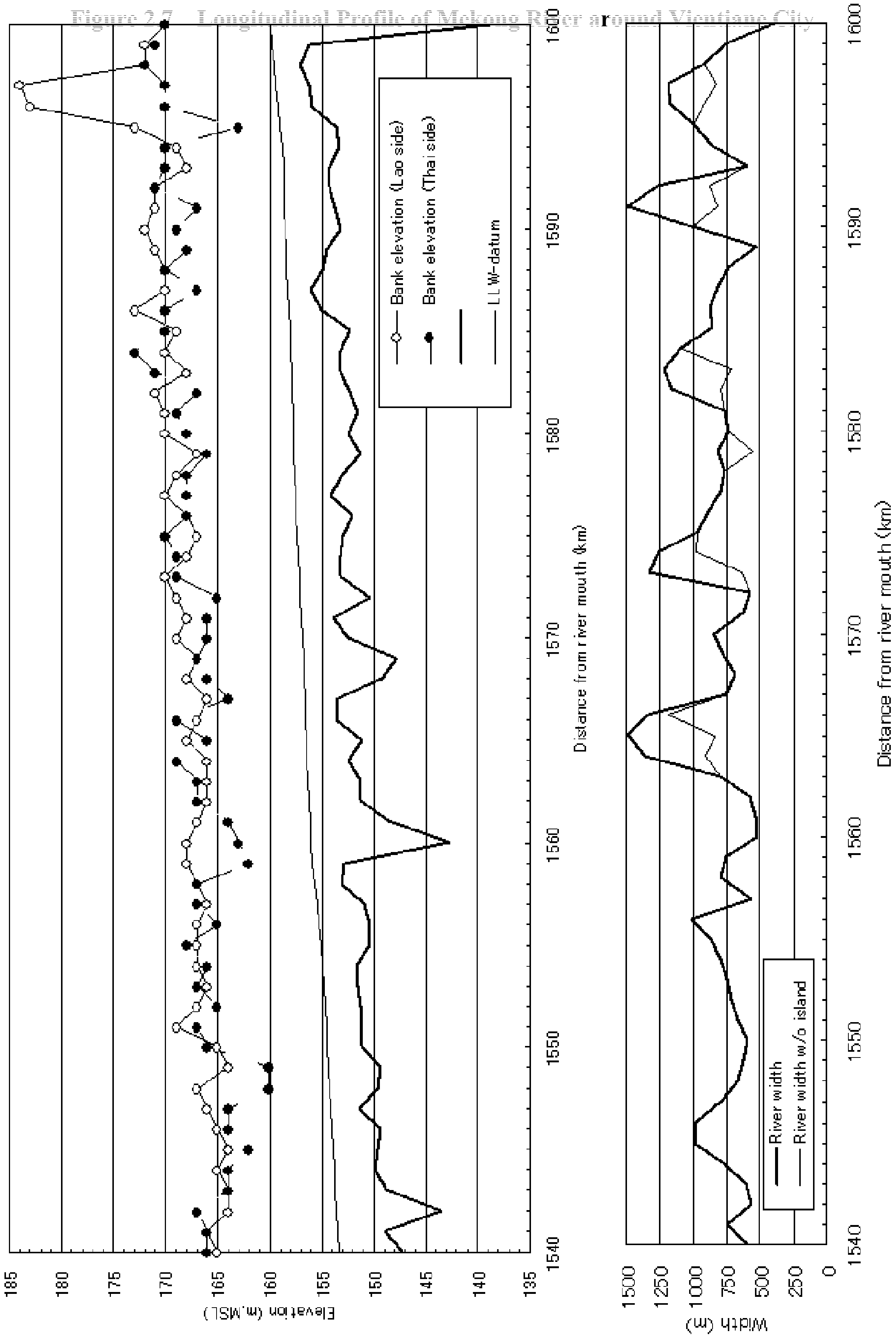


Figure 2.7 Longitudinal Profile of Mekong River around Vientiane City

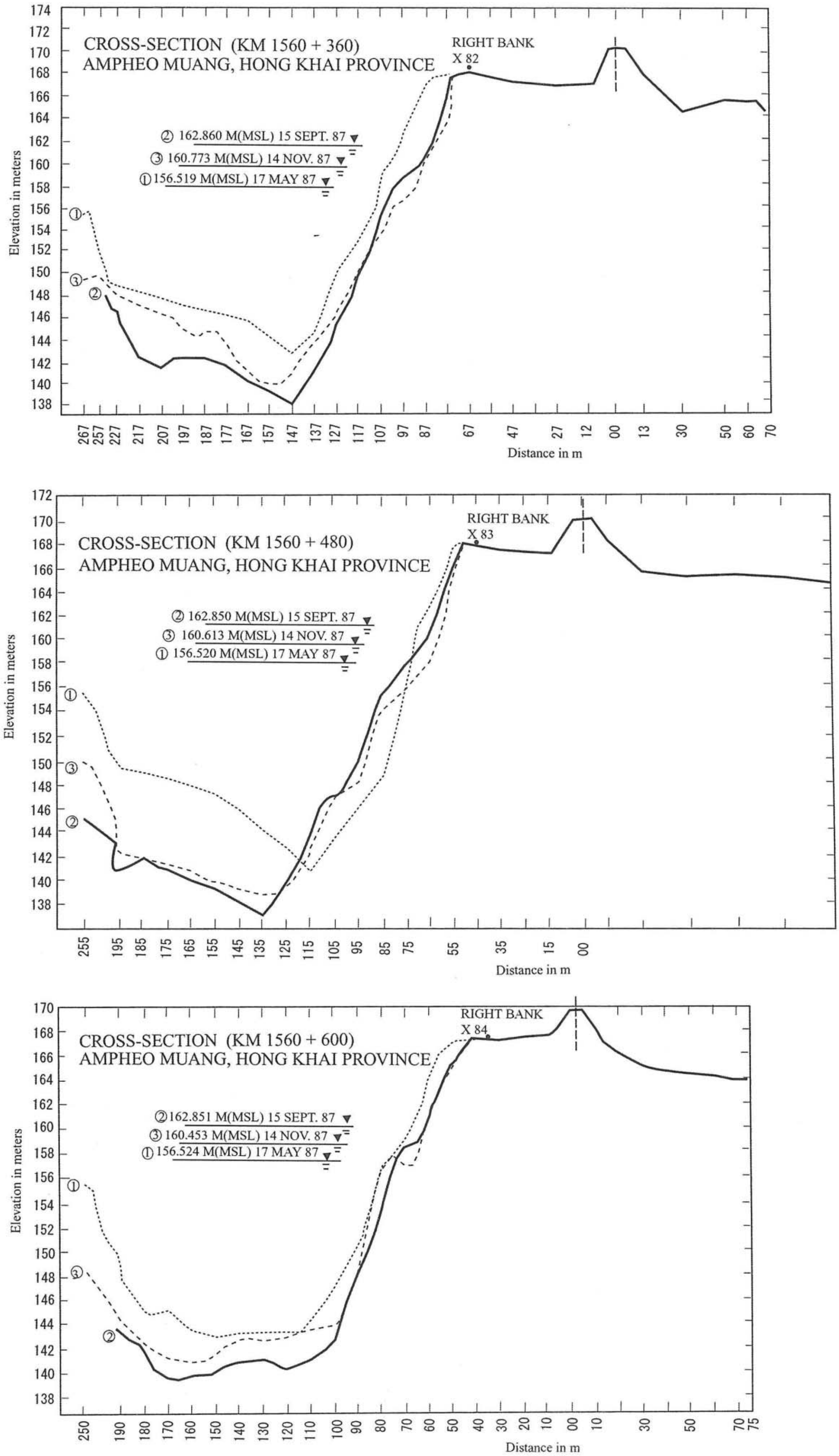


Figure 2.8 Changes in Riverbed throughout a Flood Season

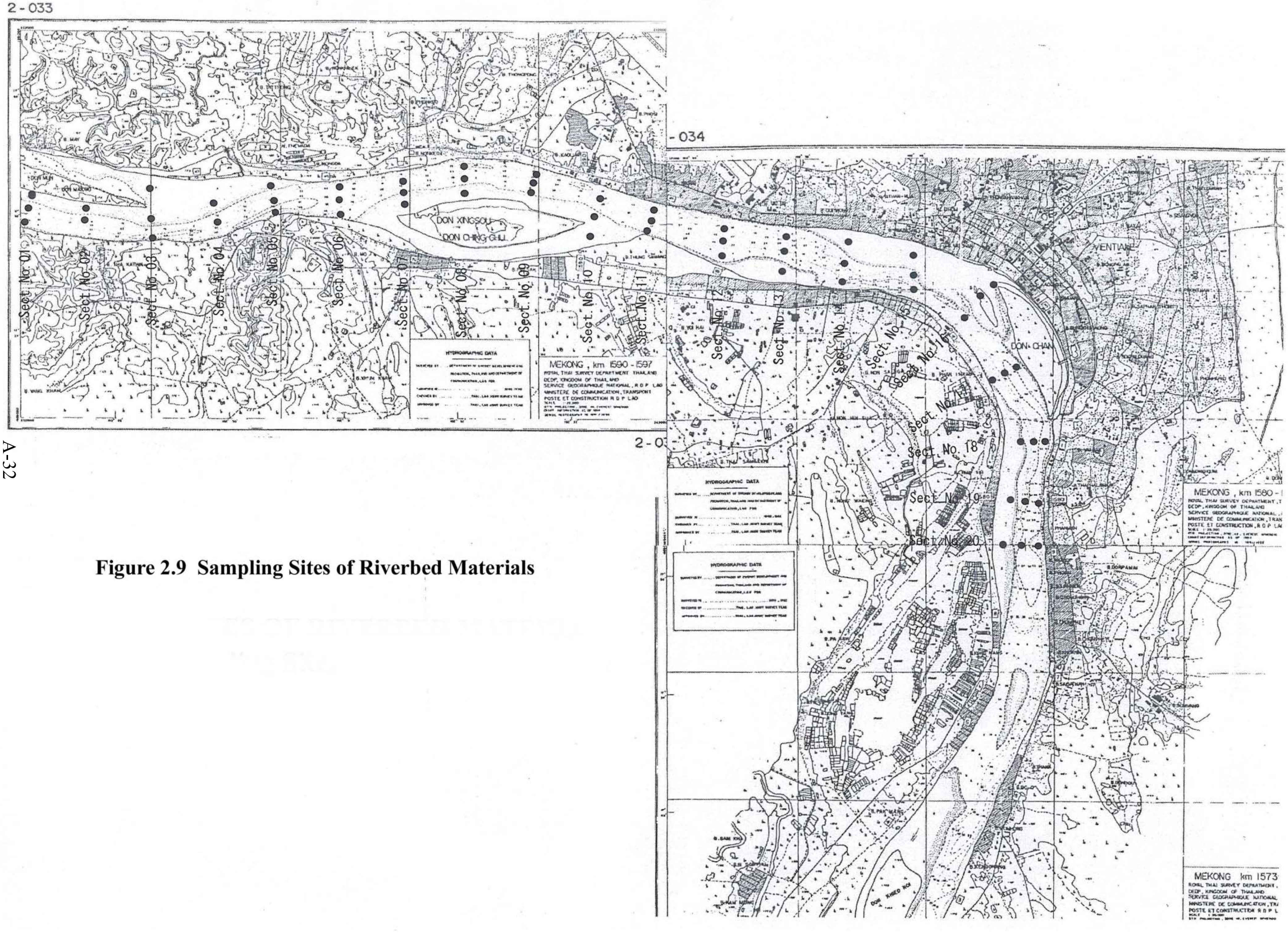


Figure 2.9 Sampling Sites of Riverbed Materials

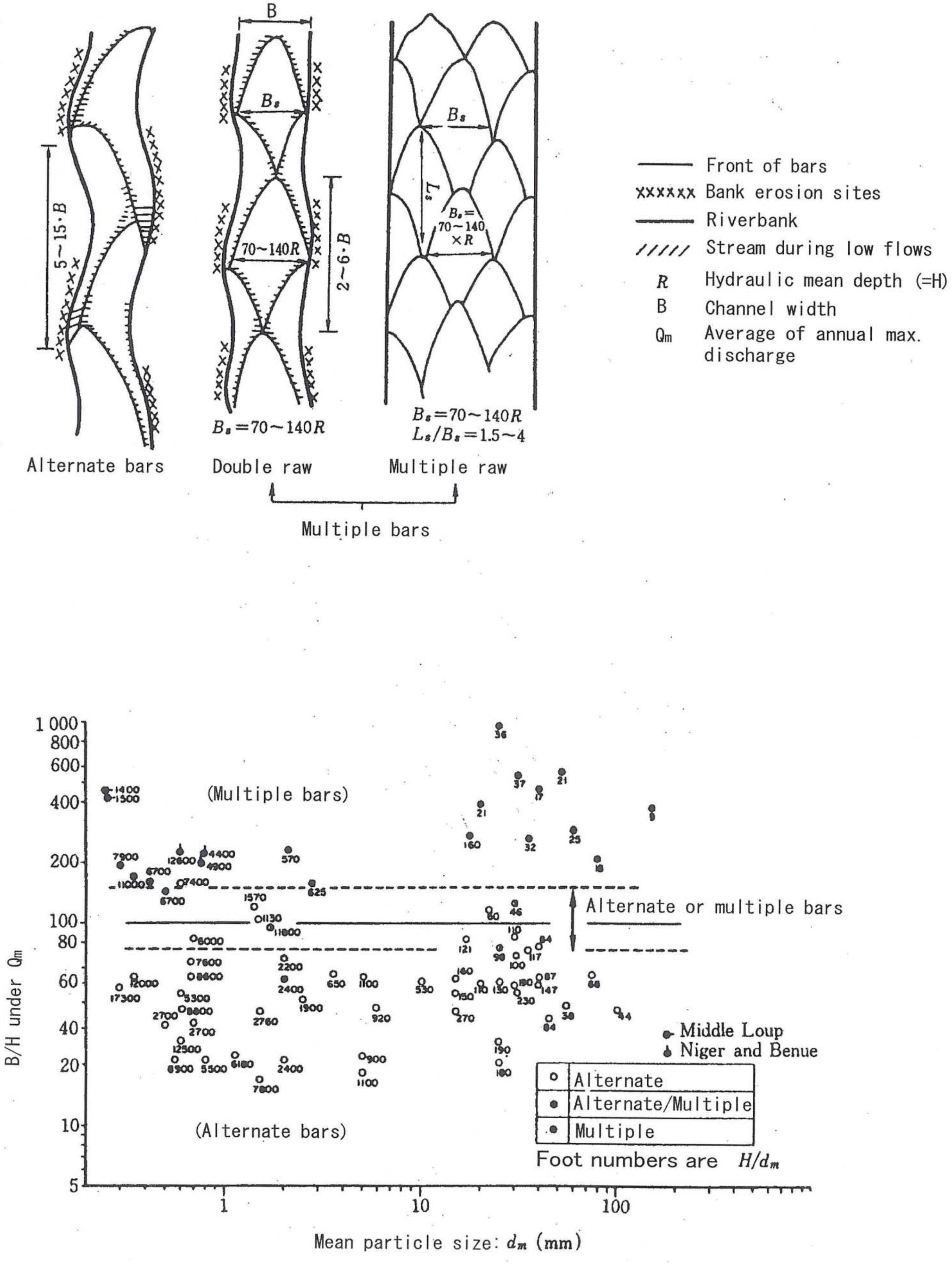


Figure 2.10 Types of Bars

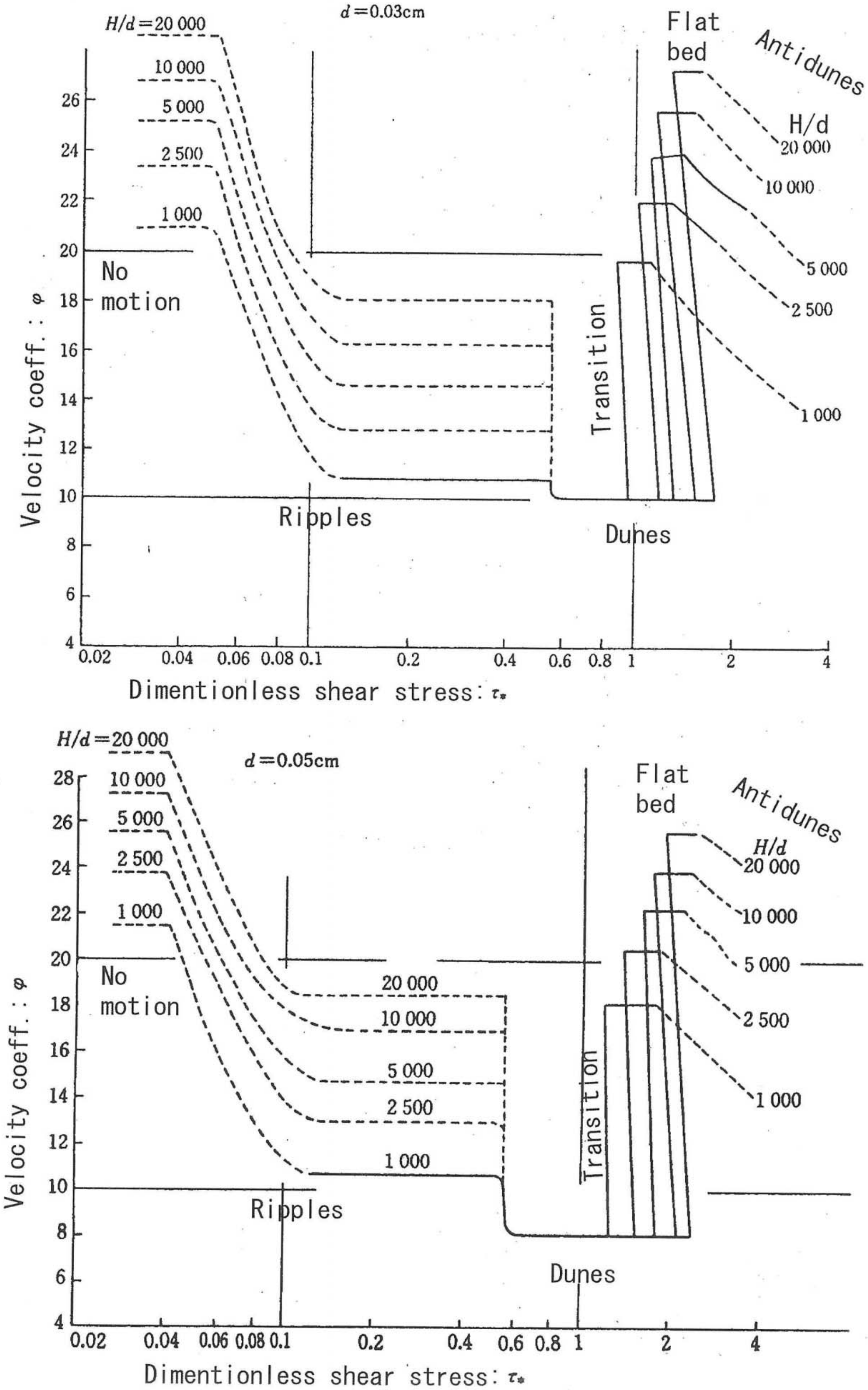


Figure 2.11 Riverbed Form and Resistance to Flow