Appendix 26 Stabilizing Measures of the Navigation Channel

Appendix 26.1 Unsteady flow riverbed change analysis using Two-Dimensional Flow Model

In this Study, the Study Team proposes to predict changes in the unsteady flow riverbed using numerical simulations as a means of evaluating appropriate measures for navigable waterway maintenance and sedimentation control in the Red River, an inland waterway artery through the metropolitan area of Hanoi City, capital of the People's Republic of Vietnam.
For the river sections covered by the predictions, computations will be made for unsteady flow riverbed changes using a two-dimensional flow model to evaluate the impacts of low water channel dike improvement, pier construction and dredging of navigable waterways on the riverbed.

1. Outline of prediction model

1.1 Basic equation for Two-dimensional Unsteady Flow Model (Cylindrical Coordinates System)

The basic equations for flow regime and sediment transport have been obtained.

(1) Basic equation for two-dimensional shallow water flow model (flow regime)

The basic equation for two-dimensional shallow water flow model in the cylindrical coordinates system is given as indicated below.

<Equation of motion>

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial s}+v\frac{\partial u}{\partial n}+\frac{uv}{r}=-\frac{1}{r}\bullet\frac{\partial p}{\partial s}-\frac{ts}{rh}+2\frac{\partial}{\partial s}\left(e\frac{\partial u}{\partial s}\right)+\frac{\partial}{\partial n}\left(e\frac{\partial u}{\partial n}\right)-\frac{g}{Ks^2}u\sqrt{u^2+v^2} \quad ....(1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial s}+v\frac{\partial v}{\partial n}+\frac{u^2}{r}=-\frac{1}{r}\bullet\frac{\partial p}{\partial h}-\frac{tn}{rh}+\frac{\partial}{\partial s}\left(e\frac{\partial v}{\partial s}\right)+2\frac{\partial}{\partial n}\left(e\frac{\partial v}{\partial n}\right)-\frac{g}{Ks^2}v\sqrt{u^2+v^2} \quad .....(2)$$

<Equation of continuity>

$$\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial s}+\frac{1}{r}\bullet\frac{\partial(rvh)}{\partial n}=0 \quad ....(3)$$

where;

s, n: distances in downstream direction and transverse direction, respectively,

u,v: average flow velocity in directions of s and n, respectively,
h: water depth,
p: water pressure,
ρ: density of fluid,
r: radius of curvature,
τ s, τ n: riverbed shear force in directions of s and n, respectively; the Manning formula is used,
ε: turbulent eddy viscosity,
g: gravitational acceleration,
κ: Karman's constant (=0.4),
u_*: frictional velocity,
Ks: permeability coefficient of trees,
n_m: Manning roughness coefficient

$$\frac{ts}{rh} = \frac{gn_m^{\ 2}}{h^{4/3}} u\sqrt{u^2 + v^2} \text{ ....(4)}$$

$$\frac{tn}{rh} = \frac{gn_m^{\ 2}}{h^{4/3}} v\sqrt{u^2 + v^2} \text{ ....(5)}$$

$$e = \frac{k}{1} u_* h \text{ ....(6)}$$

(2) Basic equation for sediment transport

<Equation of motion for bed load>

- Equation for sediment transport in downstream direction (Meyer-Peter-Muller equation)

$$q_{BS} = 8\sqrt{(r_s / r - 1)gd^3} \bullet (t_*' - t_{*c})^{1.5} \text{ ....(7)}$$

- Equation for sediment transport in transverse direction (Hasegawa's equation)

$$q_{Bn} = q_{BS}\left(v_b / u_b - \sqrt{t_{*C} / (m_s m_k t_*)}\right) \bullet \partial z / \partial n \text{ ....(8)}$$

where;
q_{BS}: sediment transport per unit width in direction of axis s
ρ_s: density of gravel
ρ: density of running water
d: particle size of riverbed material
τ ?: dimensionless effective shear force

τ_{*c}: dimensionless critical shear force

q_{Bn}: sediment transport per unit width in direction of axis n

v_b/u_b: flow direction on riverbed

τ_*: dimensionless shear force

μ_s:static friction coefficient

μ_k: dynamic friction coefficient

<Equation of motion for suspended sediment>

- Equation of continuity for suspended particles

$$h\frac{\partial C}{\partial t}+\frac{\partial u}{\partial s}(huC)+\frac{1}{r}\bullet\frac{\partial}{\partial n}(rhvC)=\frac{\partial}{\partial s}\left(D_s h\frac{\partial C}{\partial s}\right)+\frac{\partial}{\partial n}\left(D_n h\frac{\partial C}{\partial n}\right)+\left(q_{su}-w_f C_b\right)h \quad ....(9)$$

- Equation for amount of floating suspended particles (Itakura-Kishi equation)

$$\frac{q_{su}}{\sqrt{(r_s/r-1)gd}}=K\left(a_*\frac{r}{r_s}\bullet\frac{\Omega}{\sqrt{t_*'}}-\frac{W_f}{\sqrt{(r_s/r-1)gd}}\right) \quad ....(10)$$

$$\Omega=\frac{t_*'}{B_*}\frac{\int_{a'}^{\infty}x\frac{1}{\sqrt{p}}\exp\left(-x^2\right)ax}{\int_{a'}^{\infty}\frac{1}{\sqrt{p}}\exp\left(-x^2\right)ax}+\frac{t_*'}{B_*h_0}-1 \quad , \quad a'=\frac{B_*}{t_*'}-\frac{1}{h_0} \quad ....(11)$$

where C: density of suspended sediment

D_s: diffusion coefficient in direction of axis s

D_n: diffusion coefficient in direction of axis n

q_{su}: amount of floating suspended particles from riverbed

W_f: sedimentation velocity of suspended particles

C_b: density of suspended particles near riverbed

η_0: 0.5

B_*:= 0.143

α_*:=0.14

K: =0.008

<Equation of continuity>

$$\frac{\partial Z}{\partial t}+\frac{1}{(1-l)}\left(\frac{\partial q_{Bs}}{\partial s}+\frac{1}{r}\bullet\frac{\partial q_{Bn}}{\partial n}+q_{su}-W_f C_b\right)=0 \quad ....(12)$$

where Z: height of riverbed

t: time

λ: void ratio of riverbed material

2. Flow chart for simulation analysis of unsteady flow riverbed changes

Figure A26.1.1 shows the flowchart of steps in simulation analysis of unsteady flow riverbed changes. Brief descriptions for the individual steps are given below.

2-1 Objective and description of computations

The basic policy for the simulation analysis will be drawn up on the basis of examination of the computation conditions and outputs and will be established after discussions with the Vietnamese authorities. The basic policy will also be confirmed by consultation with the Vietnamese side after the preliminary computations using simplified topographic model referred to later have been made.

All the materials and data necessary for establishing the basic policy for simulation analysis are as listed below.

(1) Data relating to building topographic model

• Plan, longitudinal profile and lateral profile of the area covered by computations
• Plan and lateral profile of improvement plan
• Data on riverbed height
• Data on trees and vegetation inside river channel

(2) Data on boundary conditions for water levels and discharge

• Water levels (downstream end) and discharge data (upstream end and lateral inflow) during past floods and longitudinal flood mark water level data (for model verification)
• Water level data (downstream end) and discharge data (upstream end and lateral inflow) during other floods considered

(3) Other data

• Survey data on riverbed material
• Field measurements of suspended sediment density and data on relations with river discharge
• Survey data on riverbed roughness

2-2 Computation output

• Calculated water level (values and contour map)
• Flow velocity (vector diagram)
• Riverbed height (values and contour map)

2-3 Analysis with Simplified Topographic Model (preliminary computation)

Numerical simulations of unsteady flow riverbed changes normally involve a great deal of computations and thus it does not always prove efficient to undertake computations using full-scale topographic model (detailed model) from the outset.

For this reason, the Study Team proposes to make preliminary computations using a simplified topographic model and to study the conditions for use in the computations with the detailed topographic model. After this process the analytical method and policy will be verified.

2-4 Production of topographic model

The area covered by the analytical computations will be divided into appropriate mesh grids and X-Y coordinate values will be determined. The division into mesh grids will be made on the basis of the data listed below.

- Configuration of low water channel and high water channel alignment
- Survey lines for lateral profile of river
- Planning of river structures

The next step is to determine the ground levels for the topographic model. When a lateral profile of the river is available, the dividing positions in the transverse direction will be projected on the lateral profile and their elevations will be taken as the ground levels. When the lateral profile is not available, the ground levels will be determined using a topographic plan.

2-5 Establishment of boundary conditions

The necessary boundary conditions will be established in the manners described below.

(1) Boundary conditions for water level and discharge

The boundary conditions for discharge and water level will be established at the upstream end and downstream end, respectively, on the basis of actual measurements.

(2) Roughness and resistance coefficients

The roughness coefficient for the riverbed will be established taking account of the river channel conditions and previous relevant studies, while the resistance coefficient will be established where the river channel is clustered with trees and other plants. The values of these coefficients will be determined after the model reproducibility of the actual flow regime is verified.

(3) Boundary conditions for particle size of riverbed material

The boundary conditions for the particle size of riverbed material will be established on the basis of the survey data on riverbed material.

(4) Boundary conditions for inflow material at upstream end

The boundary conditions for inflow material at the upstream end will be established after
performing sediment load capacity computations for one-dimensional non-uniform flow or unsteady flow on the basis of field suspended sediment measurements and riverbed material survey data. These conditions will be corroborated by the outcome of riverbed change computations for movable beds.

2-6 Reproducibility computations for actual flow regime

Under the fixed bed conditions which do not consider changes in the riverbed, reproducibility computations for flood marks will be undertaken using the water level and discharge data pertaining to previous floods to evaluate the appropriateness of necessary parameters such as the model topography and roughness and resistance coefficients.

2-7 Reproducibility computations for actualities with movable bed

Computations for riverbed changes will be performed with a movable bed taken into consideration to evaluate the model reproducibility of actualities. Where these computations indicate stability of the actual river channel or changes with time in the longitudinal and lateral profiles, analysis will be undertaken to determine if the computation results agree with the trends of the actual changes.

2-8 Computations for prediction of future flow regime and riverbed change

Simulations of riverbed changes will be carried out using a combination of discharge conditions and structural conditions of the plan.

2-9 Collation of computation results

The computation results will be collated and compiled into charts and diagrams. The computation results for the actual conditions and those for predicting future conditions will be compared to evaluate the changes in riverbed height and effectiveness of proposed improvement measures. The outputs will include comparison tables and charts, flow velocity vector diagrams, and water level contour maps.

3. Grid Arrangement

The Grid s for simulation calculations are arranged as shown in **Figure A26.1.2.**

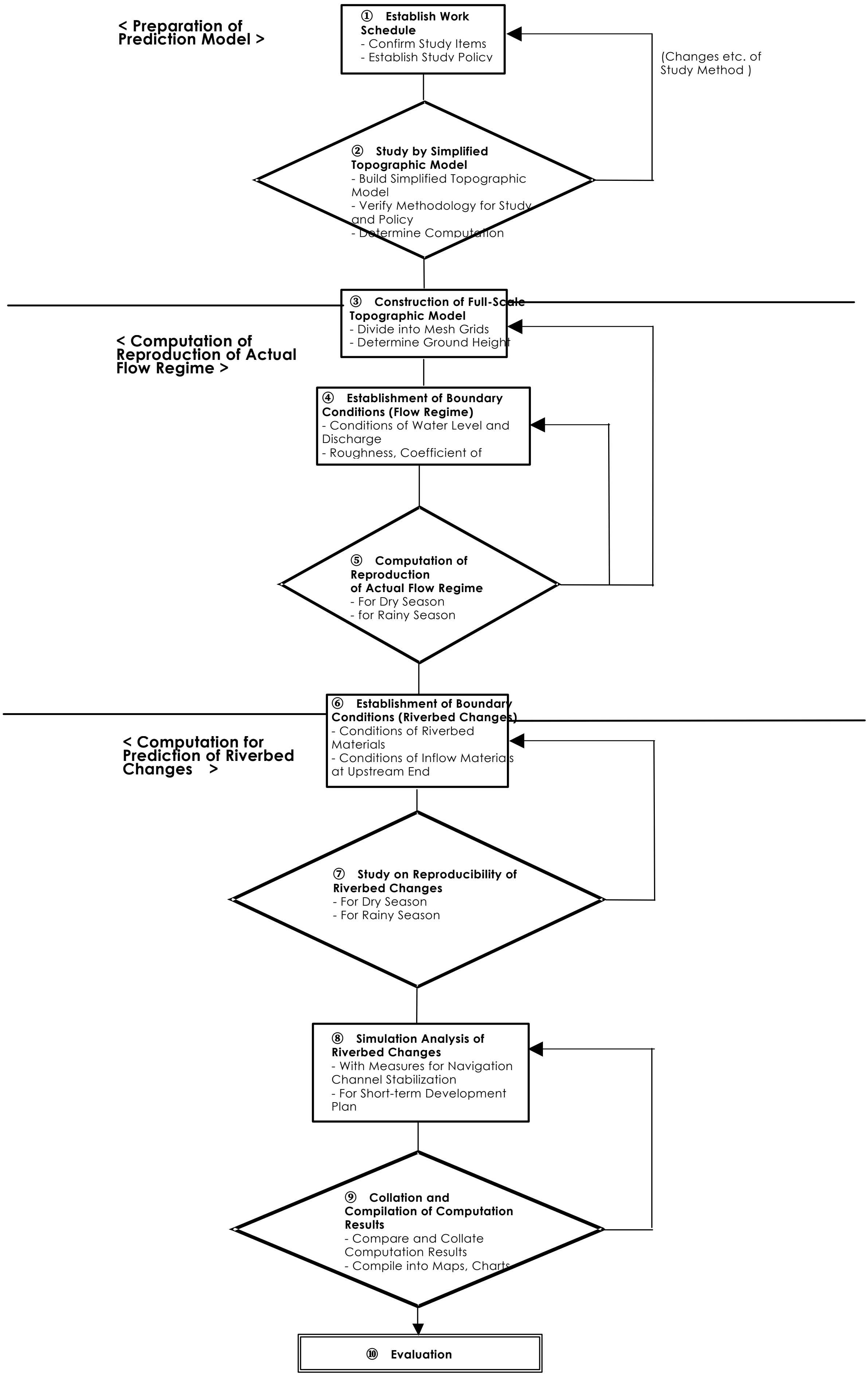

Figure A26.1.1 Flowchart of Steps in Prediction of Riverbed Changes in the Red

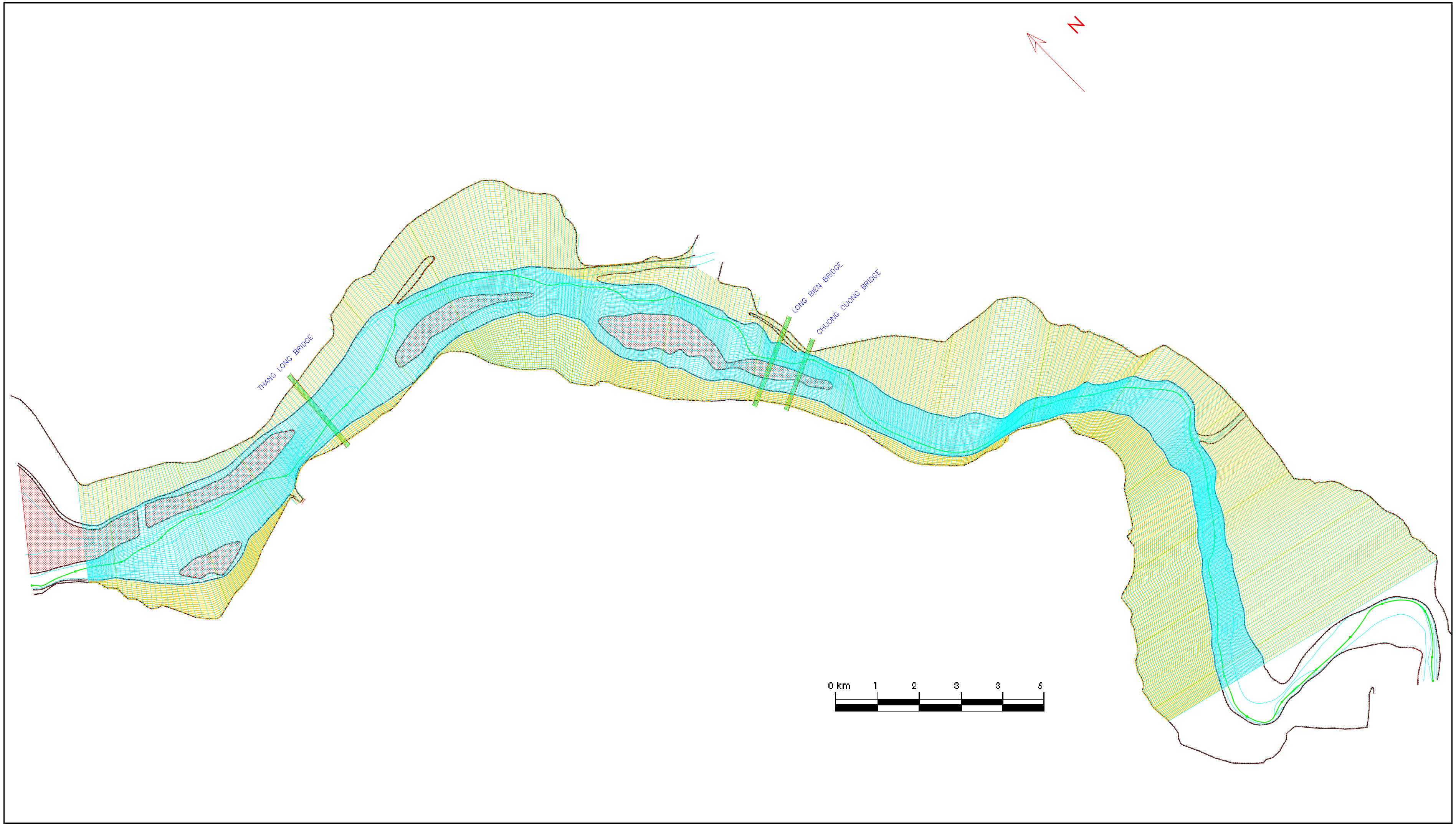

Figure A26.1.2 Grids Arrangements

Appendix 26.2

Table A26.2.1 Dredging Fleet of Viet Nam Waterway Construction Cooperation (VINAWACO)

Type	Ship Name	Year built	Country maid	L (m)	B (m)	H (m)	T (m)	Engine Capa-city (PS)	Pump-ing capa-city (m^3/hr)	Hopper Capa-city (m^3)	Dredg-ing Depth (m)	Pumping Distance (m) Max	Pumping Distance (m) Min	Speed (knot/hr)	Dredg-ing per year (10^3.m^3)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Suction Dredger	Long	1969	Germany	95	16	6	5.3	5810	3500	3,200	16			10	3500
	Chan	1969	Germany	95	16	6	5.38	6650	3500	3,500..	16			10	3500
	Tran H	1989	Vietnam	53.7	10	4	1.6	1590	400	400	7			7	500
	Dao														
	HB 38														
Sea Backhoe Dredger	TC81	1981	France	69.8	12.6	4	2.4	2060	800		16			10	1000
	TC82	1982	France	69.8	12.6	4	2.4	2060	800		16			10	1000
	TC54	1954	Germany	52.5	9.73	3.3	1.85	665	300		14				300
	TC91	1989	Russia					920	600		14			4-5	300
River Dredger	TC 82	1983	Russia	52.6	9.6	2.8	1.8	490	275		12				250
Cutter Section Dredger	H 01	1961	America	39	11	2.8	2.1	1950	500		10	2000	200		300
	H 02	1965	America	21	8.	2.5	1.0	1185	480		10	1500	200		200
	H 03	1965	America	21	8	1.5	1.0	1185	480		10	1500	200		300
	H 04	1965	America	21	8	1.8	1.0	1185	480		10	1500	200		300
	H 19/5	1982	Vietnam	25	8.33	2.2	1.2	1065	480		10	1500	200		
	Pe Ka 6	1975	H.L	24	7.08	1.8	1.2	1700	500		10	5000	300		550
	H 06	1965	America	23	7.4	3.2	1.2	910	300		9.5	1200	200		
Southern Cutter Section Dredger	H 06	1986	Vietnam					525	250						
	H 07	1985	Vietnam	19	6.6	1.8	1.0	545	300		8	800	200		
	H 08	1963	America	16	6.5	1.6	0.85	574	300		8	800	200		
	H 09	1964	America	15	5.5	1.6	1.05	574	300		8	800	200		
	H 10	1965	America	15	5.5	1.6	1.05	574	300		8	1000	200		
	H 11	1965	America	15	5.6	1.25	1.0	290	100		5	500	100		
	H 12	1979	Vietnam	15	6.2	1.5	0.9	375	200		8	500	150		
	H 22/12	1984	Vietnam	16.5	3.75	1.2	0.8	215	100		5	300	100		
	H 30/4	1985	Vietnam	16.5	3.75	1.2	0.8	215	100		5	300	100		

Type	Ship Name	Year built	Country maid	L (m)	B (m)	H (m)	T (m)	Engine Capa-city (PS)	Pump-ing capa-city (m^3/hr)	Hopper Capa-city (m^3)	Dredg-ing Depth (m)	Pumping Distance (m)		Speed (knot/ hr)	Dredg-ing per year ($10^3.m^3$)
												Max	Min		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Northern	HQ 30	1985	Vietnam	27.5	9.2	2.8	1.4		180		10		250		
Cutter	HS 19	1968	Russia	15	5.8	2.06	0.47	300	160		5		150		
Suction	HS 20	1968	Russia	15	5.8	2.06	0.47	300	160		5	500	150		
Dredger	HS 21	1968	Russia	15	5.8	2.06	0.47	300	160		5	500	150		
	HS 23	1970	Russia	15	5.8	2.06	0.47	300	180		5	500	150		
	HS 24	1970	Russia	15	5.8	2.06	0.47	300	180		5	500	150		
	HS 27	1978	Vietnam	15	5.8	2.06	0.47	300	160		5	500	150		
	HS 28	1970	Russia	15	5.8	2.06	0.47	300	160		5	500	150		
	HS 29	1970	Russia	15	5.8	2.06	0.47	300	180		5	500	150		
	HS 30	1976	Russia	25	5.8	2.06	0.47	300	180		5	500	150		
	HS 31	1976	Russia	15	5.8	2.06	0.47	300	180		5	500	150		
Large	HA 97	1997	America	34.7	9.15		1.68	4170	2300		17.7	7000			4000
Cutter	VNAmeri	1997	America	34.7	9.15		1.68	4170	2300		17.7	7000			4000
Suction	ca	1996	Poland	35		2.97	1.65	3300	2100		16	5000	100		2000
Dredger	12-9	1995	Poland	36.5	1.07		1.7	2400	1450		16	5000	0		1200
	HP 01												100		
													0		

Notes) Design capacities are :

- For Sea Dredger, calculated capacity is liquid volume (m^3). Actual capacity equal to 15 % liquid volume.
- River Dreder, actual capacity is taken 65%.
- River Backhoe Dredger, actual capacity has a full grab coefficient of 0.65.

Appendix 26.3 Conditions of Numerical Simulations

A26.3.1 Boundary Conditions related to Currents

1.1 Dry Season

Results of the surveys in January 2002 are applied to the calculations. Water level at Hanoi Station is set as 3.11m. Water levels at the lower boundary (No. 10) and the Duong River (No.5) are first given based on the measured levels. Then, the water discharge at the upper boundary(No.1) is assumed based on Statistical Analysis Results on Hydrological Data.

Table A26.3.1 Boundary Conditions (Dry Season)

Location	Water level (m)	Discharge (m^3/s)	Remarks
No.1	(4.44)	1,750	Upper end
No.5	3.39	(510)	Duong River
No.10	2.34	(1,240)	Lower end

1.2 Flood Season

Results of the surveys in August 2002 are applied to the calculations. Water level at Hanoi Station is set as 9.33m. Water levels at the lower boundary and the Duong River are given based on the measured levels. Then, the water discharge at the upper boundary is assumed based on Statistical Analysis Results on Hydrological Data.

Table A26.3.2 Boundary Conditions (Flood Season)

Location	Water level (m)	Discharge (m^3/s)	Remarks
No.1	(10.30)	10,445	Upper end
No.5	9.33	(3,265)	Duong River
No.10	8.18	(7,180)	Lower end

1.3 Very High Flood

Data at Hanoi and Truong Cat Stations in August 2002 are applied to the calculations. Water level at Hanoi Station is set as 12.50m.

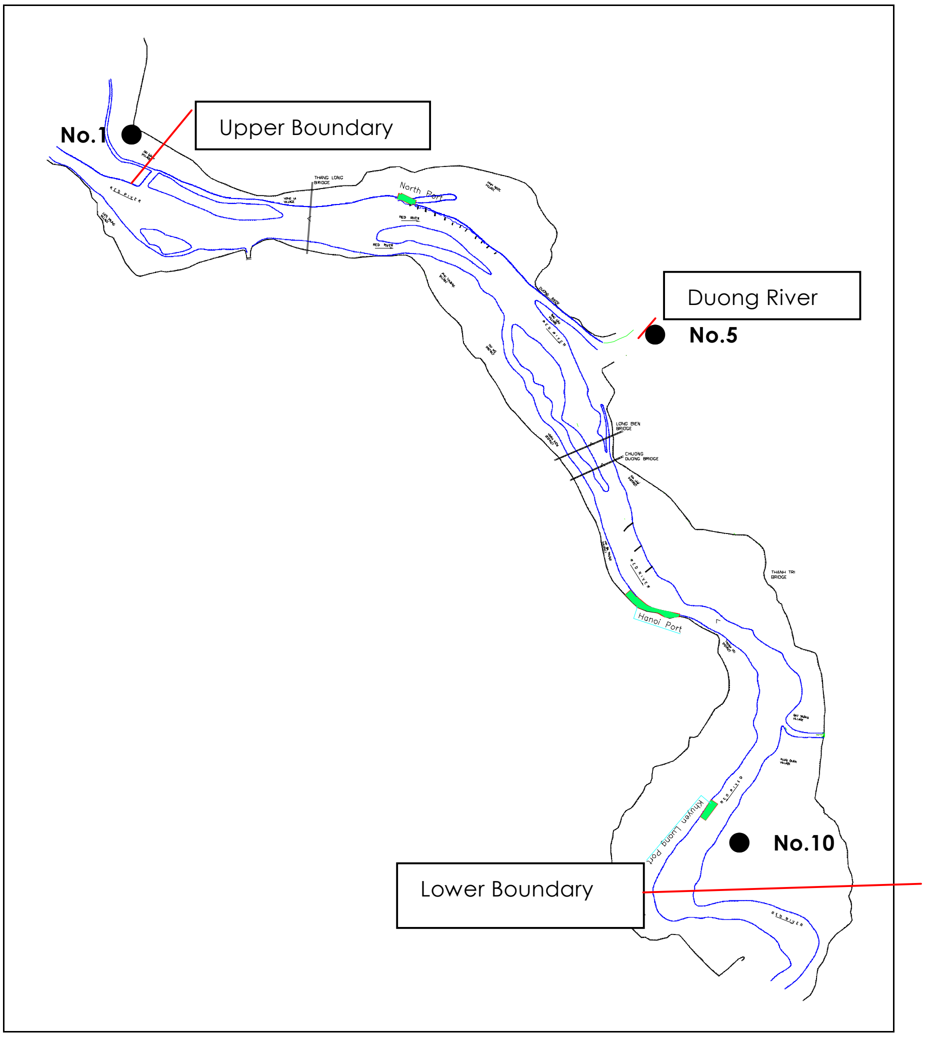

Figure A26.3.1 Locations of Boundaries

Water levels at the lower boundary (No. 10) and the Duong River (No.5) are first assumed based on the above analysis for the Flood Season. Then, the water discharge at the upper boundary is assumed based on Statistical Analysis Results on Hydrological Data.

Table A26.3.3 Boundary Conditions (Very High Flood)

Location	Water level (m)	Discharge (m^3/s)	Remarks
No.1	(14.08)	22,715	Upper end
No.5	13.05	(7,254)	Duong River
No.10	11.50	(15,461)	Lower end

1.4 Extremely High Flood

Water level is assumed as 13.4m at Hanoi Station. Referring to the H-Q diagram based on observed data from 1957 to2000, water levels at the Duong River and the lower boundary are estimated. Water discharge at the upper boundary is calculated by adding water discharges at the Duong River and the lower boundary. It is assumed that there is no breakdown of the dikes.

Table A26.3.4 Boundary Conditions (Extremely High Flood)

Location	Water level (m)	Discharge (m^3/s)	Remarks
No.1	(14.8)	32,381	Upper end
No.5	13.5	(10,381),	Duong River
No.10	12.5	(22,000)	Lower end

A26.3.2 Conditions on Riverbed Materials

2.1 Roughness Coefficients

Roughness coefficients are determined referring to the LANDSAT image shown below in **Figure A26.3.1**. Basically it is considered that the roughness condition is different among lower channel, sand bar, and floodplain:

Lower channel:	0.025
Sand bar:	0.030 for bars with small grain size, bars relatively newly created, and places where color is white on the LANDSAT image.
Floodplain:	0.040 for bars with vegetation and resident areas

Figure A26.3.1 LANDSAT Image of the Red River, Hanoi Segment

2.2 Grain Size Distribution

Conditions of riverbed materials is formulated based on the results of laboratory tests of grain size distribution done in January 2002. According to the cumulative distribution curves, the grain size distribution is different between the lower river channel and the floodplain (including sand bars). Deviation of each distribution is small as shown in **Figure A26.3.2**. Therefore, the distribution is classified into two patterns. **Table A26.3.5** shows division of size, median diameter and composition of each size.

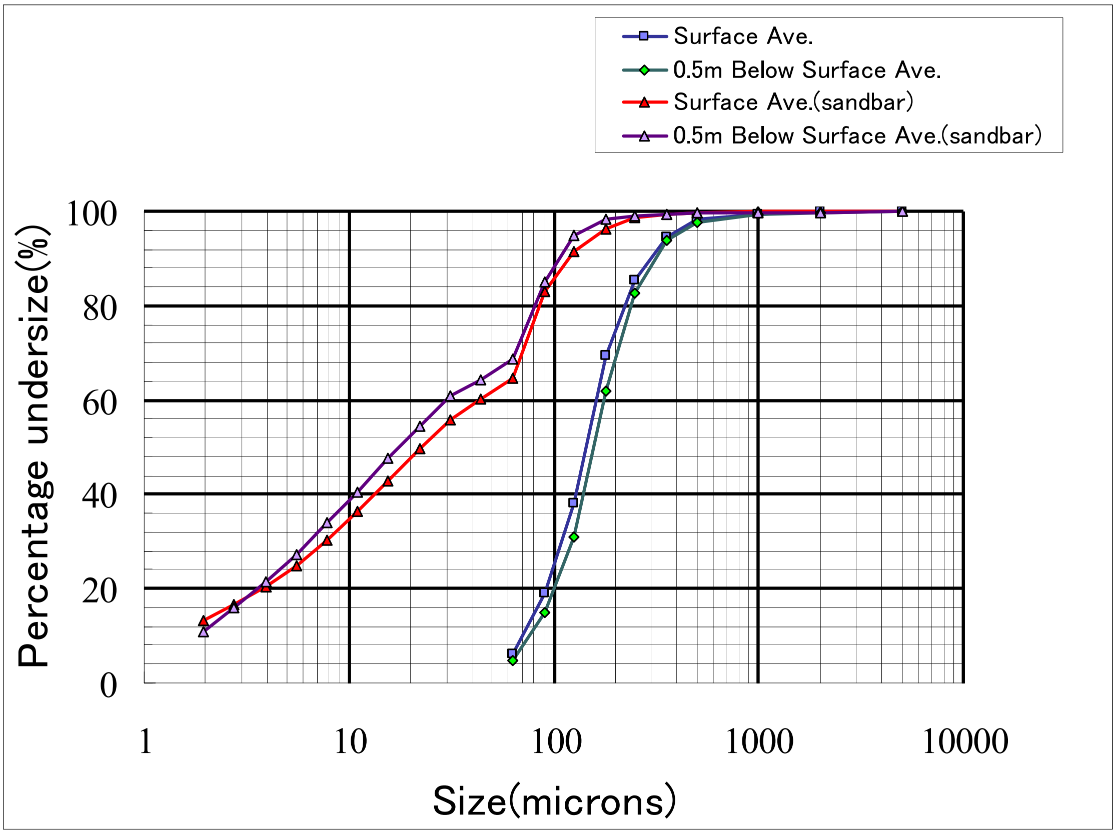

Figure A26.3.2 Grain Size Distributions of Bed Materials

Table A26.3.5 Conditions of Particle Size of Bed Materials

Code of particle size	Division of size (micron)	Median diameter (micron)	Average composition in the lower channel (Cumulative %)	Average composition in sand bars (Cumulative %)
D01	5000.0 ～ 10000.0	7500.00	100.00	100.00
D02	2000.0 ～ 5000.0	3500.00	99.88	100.00
D03	1000.0 ～ 2000.0	1500.00	99.47	99.99
D04	500.0 ～ 1000.0	750.00	98.18	99.60
D05	355.0 ～ 500.0	427.50	94.50	99.31
D06	250.0 ～ 355.0	302.50	85.26	98.53
D07	180.0 ～ 250.0	215.00	69.51	96.32
D08	125.0 ～ 180.0	152.50	38.23	91.57
D09	90.0 ～ 125.0	107.50	19.07	82.83
D10	63.0 ～ 90.0	76.50	6.17	64.60
D11	44.2 ～ 63.0	53.60		60.28
D12	31.2 ～ 44.2	37.70		55.64
D13	22.1 ～ 31.2	26.65		49.78
D14	15.6 ～ 22.1	18.85		43.02
D15	11.0 ～ 15.6	13.30		36.55
D16	7.8 ～ 11.0	9.40		30.39
D17	5.5 ～ 7.8	6.65		24.95
D18	3.9 ～ 5.5	4.70		20.47
D19	2.76 ～ 3.9	3.33		16.56
D20	～ 1.95	0.98		13.38