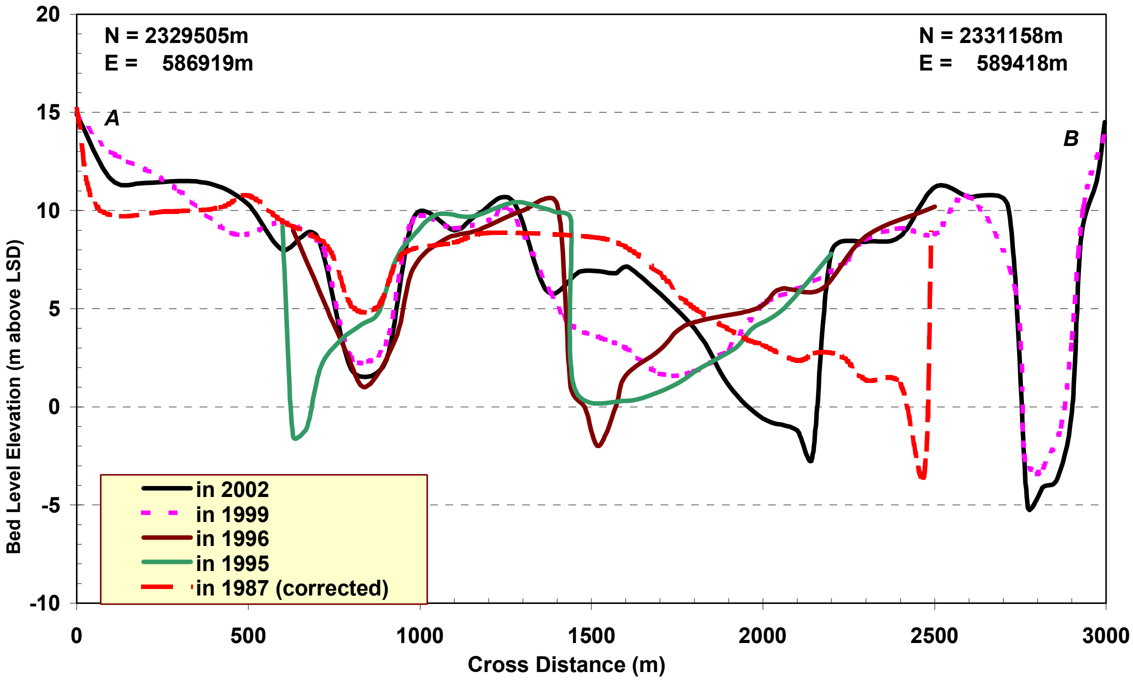

Figure 14.4.9 Evolution of (Dynamic) Cross-Section 4 Bai Tu Lien

14.5 Characteristics of flow and sediment of the Red River

14.5.1 General features of flow and sediment

As explained in Chapter 14.1 the Red River Basin can be hydrologically separated in two major subbasins:

(1) Upstream part (upstream Viet Tri)

Hydrological basin with 4 main tributaries, being the Da River, the Thao River (or Red River) and the Lo River.

(2) Downstream part

Braided river system in the alluvial and coastal plain with various meandering affluents and estuaries into the Gulf of Bac Bo.

Regarding the flow and sediment distribution, the following hydro-sedimentological information can be presented (see **Table 14.5.1**):

Table 14.5.1 General Flow and Sediment-Transport Characteristics of the Major Tributaries of the Red River

River	Gauging Station	Average Annual Discharge (m^3/sec)	Flood Season Discharge (m^3/sec)	Peak Month in Flood Season)	Dray Season Discharge (m^3/sec)	Trough Month in Dry Season	Maximum Discharge (m^3/sec)	Minimum Discharge (m^3/sec)	Sediment Transport (suspension) (Mtons d.s./year)
Thao (Red)	Yen Bai	782	1,830	August	273	March			41.9
Da	Hoa Binh	1,692	4,685	August	218	June			65.3
Lo	Phu Ninh	1,010	2,382	August	154	June			12.0
Hong	Son Tay	3,560	9,246	August	914	March	34,200 (21/8/'71)	368 (7/5/'61)	120
Hong	Hanoi	2,710					22,200 (20/8/'71)	350 (9/5/'61)	72
Duong	Thung Cat	880					9,000 (22/8/'71)	38 (28/4/'58)	26

Source) MOT-TEDI PF/S, 2001, ADB-Haskoning, 1998)

From the above-mentioned figures and detailed hydrologic information, the following rough figures about the hydrological balance can be given:

- Upstream Basin:
  - Flood Season:
    - 51% of the overall discharge is coming from the Da River basin;
    - 26% of the overall discharge is coming from the Lo River Basin;
    - 15% of the overall discharge is coming from the Thao River basin;
  - Dry Season:
    - 38% of the overall discharge is coming from the Da River basin;
    - 33% of the overall discharge is coming from the Lo River basin;
    - 30% of the overall discharge is coming from the Thao River basin;
- Downstream Subbasin:
    - Flood diversion via the Day River only occurs with extreme floods;
    - 24% of Red River Flood discharge is evacuated via the Duong River;
    - 10% of Red River Flood discharge is evacuated via the Luoc River;
    - 9% of Red River Food discharge is evacuated via the Tra Ly River;
    - 23% of Red River Flood discharge is evacuated via the Nam Dinh River;
    - 8% of Red River Flood discharge is evacuated via the Ninh Co River;
    - 25% of Red River Flood discharge is evacuated via the very downstream part of the Red River;

The overall sediment-transport (suspension-load) of the Red River is to be considered as very high, compared to other similar river systems in the world, with an overall annual average suspension-load of approx. 1 g d.s./l. Causes for such high suspension-loads are probably to be sought in high soil-erosion rates within the upstream catchment area, with special attention to be given on the Da River basin.

The overall morphology and its associated sediment-dynamics in the dynamic 'Hanoi' section however, is also to be put in relation to the bed-load transport which involves coarser sediment fractions (coarse silts, fine sand, medium sand,..). This is also reflected by the sedimentology of the riverbed, where mixtures of sand, silt and clay are encountered in various proportions. Little data of bed-load transport can be found in the literature about measured transport intensities. Generally it is accepted that bed-load transport – in terms of instantaneous sediment transport – is a fraction of the suspension-load transports, and very highly dependent upon the overall current velocity and its vertical profile over the water-column (see further section 14.5.3).

TEDI Port is reporting some current-velocity survey data in the 'Hanoi' section, which might illustrate the current intensity, its associated shear-stress on the riverbed and the seasonal fluctuations (see **Table 14.5.2**):

Table 14.5.2 Some Indicative Average Current Velocity Values in the Hanoi Section of the Red River (MOT TEDIPort, 2001)

Survey Date	Section	Water Level (m)	Average Current Velocity (m/sec)
3 Oct 1999	Than Long Bridge	5.83	0.66
11 Oct 1999	Than Long Bridge	6.51	0.78
11 Oct 1999	Chuong Duong Bridge	5.50	0.84
22 Oct 1999	Chuong Duong Bridge	4.22	0.72
24 Oct 1996	Hanoi Port	5.67	0.58
1 Nov 1996	Hanoi Port	4.96	0.62
1 Nov 1996	Single Channel Section downstream Hanoi Port	3.92	1.02
25 Oct 1996		4.45	1.11

Source) MOT TEDI Port, 2001

14.5.2 Characteristics of the Flow and Sediments in Hanoi Segment

(1) Hydraulic grade line

The longitudinal profile along the Talweg of the Red River in Hanoi, which was measured in January 2002, is shown in **Figure 14.5.1 (1)**. The average hydraulic gradient is appr. 1/17,000. The steepest gradient appeared between Hanoi

Gauging Station and Hanoi Port. It is characteristic that at a short segment of downstream of Hanoi Port, the water surface is almost flat for about 1km. It suggests that here is a critical section, occurring a phenomenon similar to a jump. The downstream portion from there to Khuyen Luong Port has a very gentle slope, which imply rather stable river flow accompanied by meandering.

It is noted that the water level in the Hanoi section is affected by the tides in the sea during the dry season. It is confirmed that amplitude of about 10cm varies at the lower portion of the Hanoi segment in January 2002.

The riverbed has the deepest depth at the Thang Long Bridge and the shallowest depth at between the mouth of the Duong River and the Chuong Duong Bridge.

(2) Water depth datum

The water depth of inland waterways is defined based on Water Depth Datum, which is LSD plus 95% Occurrence Depth, H95%. At Hanoi Gauging Station, H95% is 2.70m. Then, based on the measured water level in January, the Study Team constructed the water depth map, referring to the Water Depth Datum, which is parallel to the water level as shown in **Figure 14.5.1 (2)**.

(3) Riverbed material

The riverbed consists of silt (5 to 75 μm), fine sand (75 to 250 μm), and medium sand (250 to 850 μm). The median diameter (d_{50}) of the sediments is mostly distributed between 74 μm and 200 μm as shown in **Figure 14.5.2**. The bed material at a depth of 50 cm below the riverbed has quite similar median diameters to those at the bottom surface with only few exceptions as shown in **Figure 14.5.2**.

(4) Water discharge

Water discharge , water velocities, turbulence,...and other related hydraulic forces are the driving parameters governing the interaction with the riverbed-sediments and will determine the sediment-transport and erosion/sedimentation features which, in the end, will determine the morphological evolution of the river. Hence a good comprehension first, supported by correct hydraulic simulations of water discharge, discharge distribution between confluents and affluents are the key to correct sedimento-logical/morphological predictions.

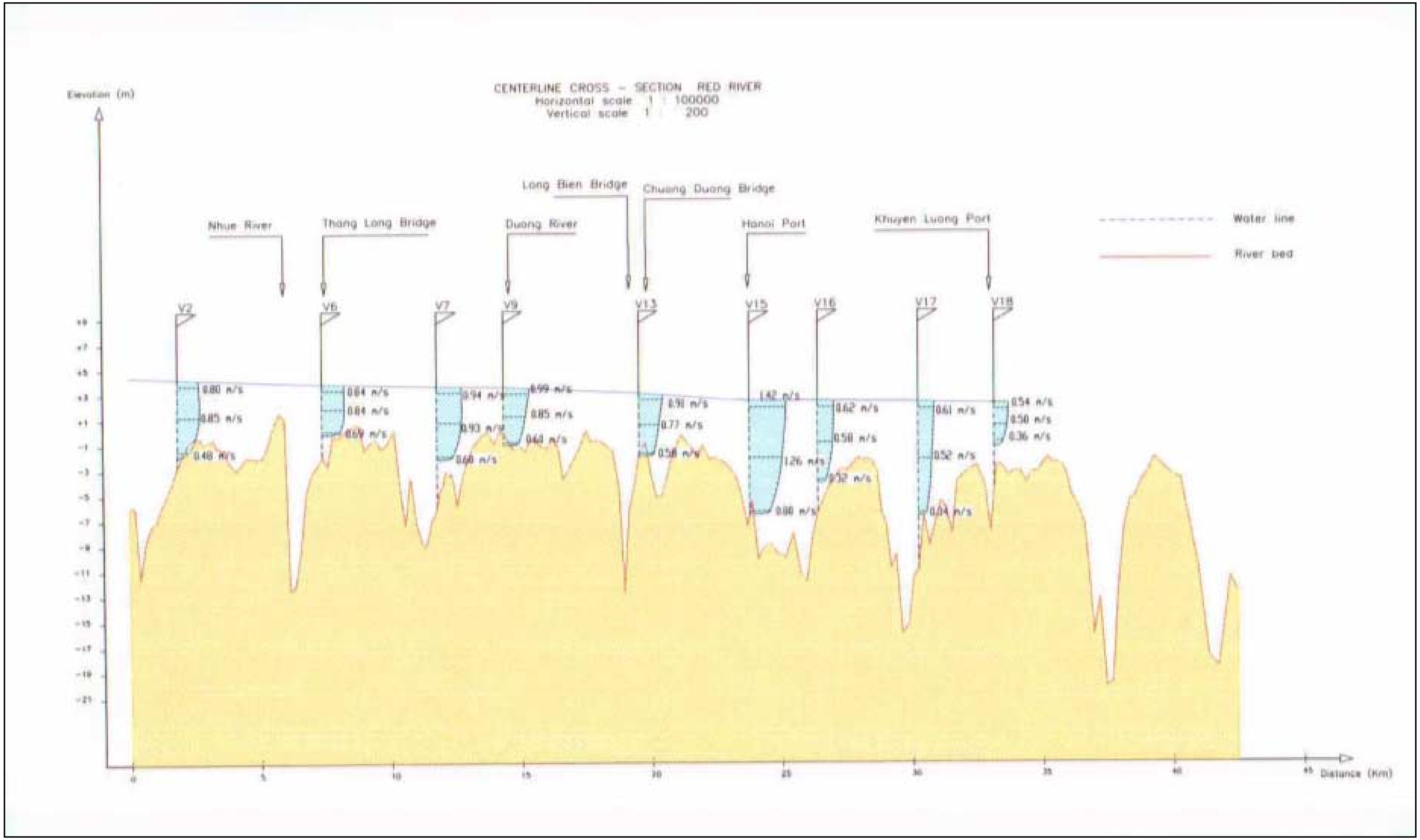

Figure 14.5.1 (1) Longitudinal Cross Section along Red River Talweg through Hanoi City (January 2002)

Source) JICA Study Team

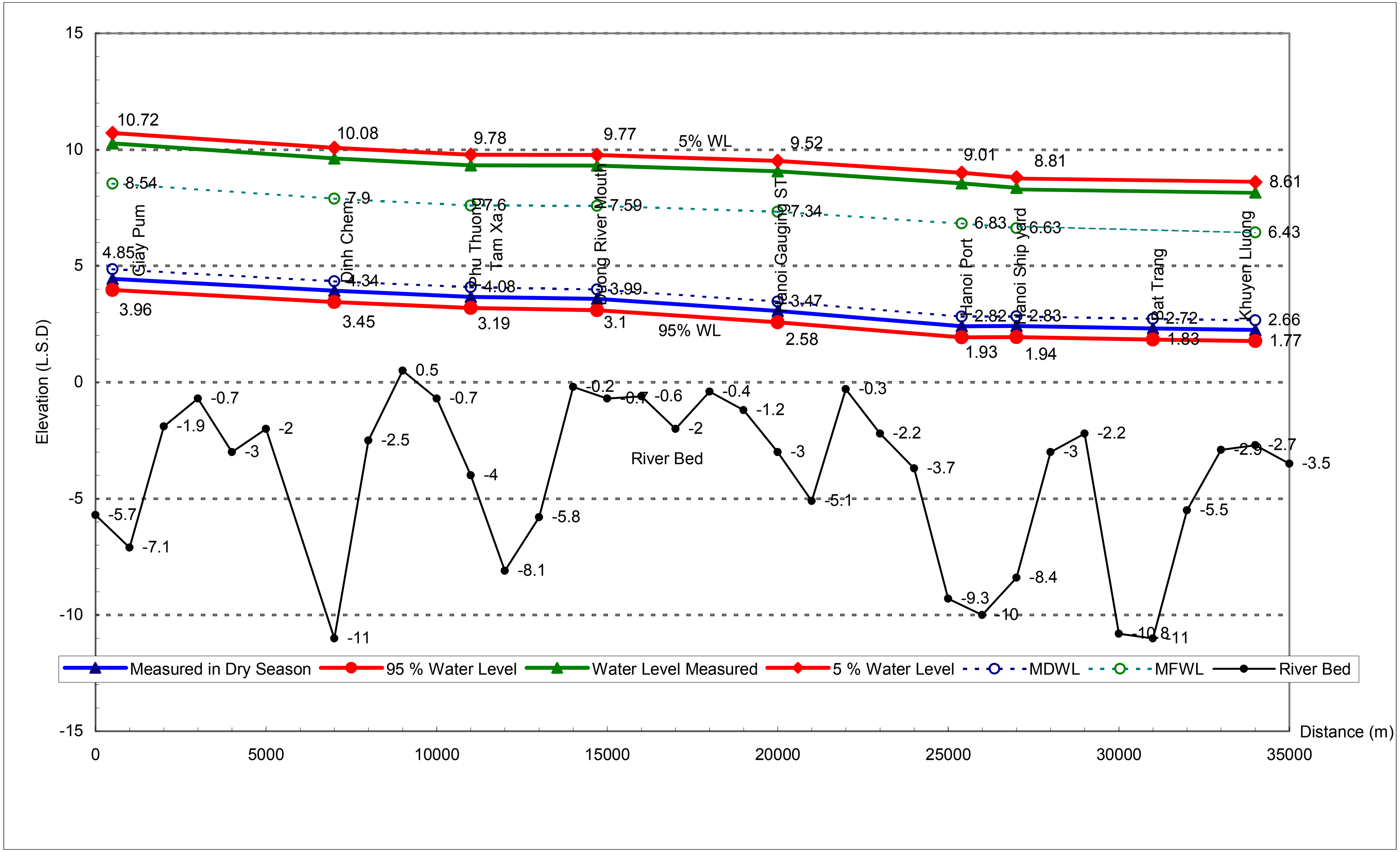

Figure 14.5.1(2) Water Depth Datum along the Talweg in the Red River

Source) JICA Study Team

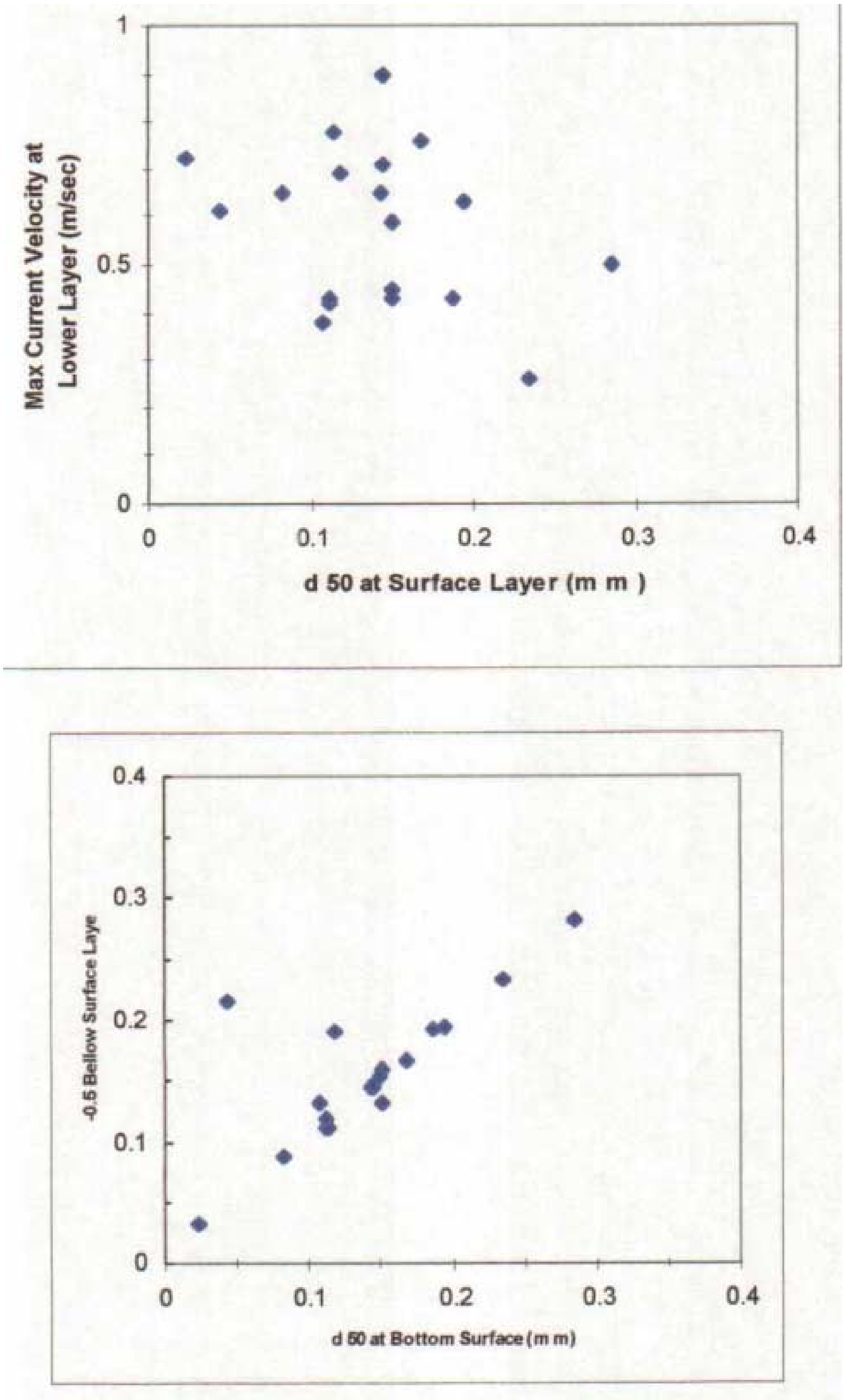

Figure 14.5.2 Co-relation between d_{50} on Riverbed and 50cm below the Bottom

Source) JICA Study Team

Figure 14.5.3 below gives the time series for average daily river discharge since 1956 showing the peaks of August 1971 and suggests some kind of cyclicity in river discharge.

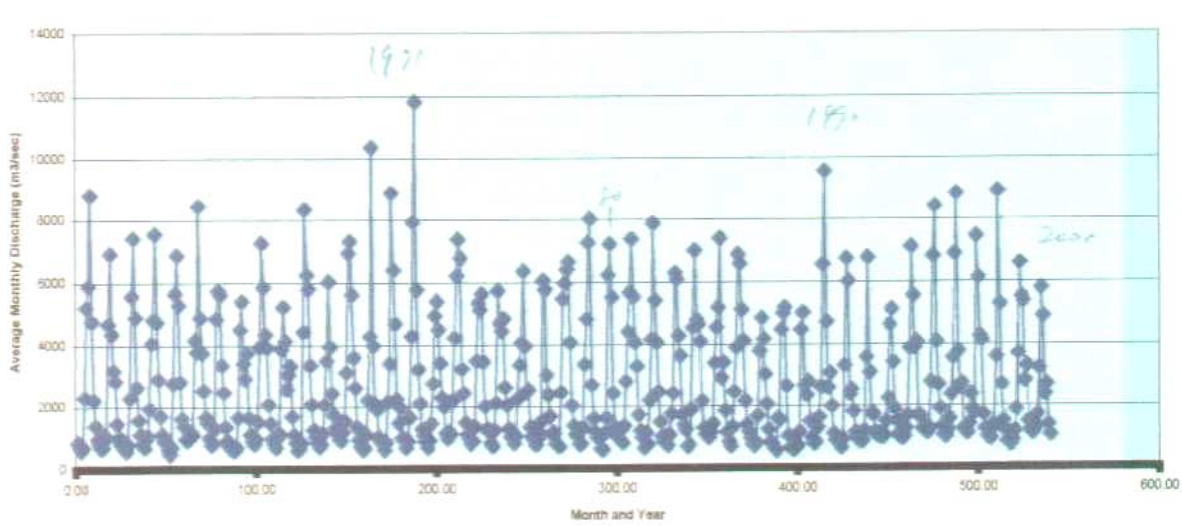

Figure 14.5.3 Average Daily Discharge at Hanoi Station since 1956

Out of TEDIPort's July 2001 PF/S Study Report and from HYDROMET's data of 2001, data were extracted and presented on one single H =f (Q) hydrological Rating Curve (see Figure 14.5.4), which must be considered as a first approximation. From this comparative H = f(Q) graph, the importance of the river discharge of the Duong River can clearly be seen: between 30 and 50 % of the Red River Discharge at Hanoi Station is deviated via the small Duong River.

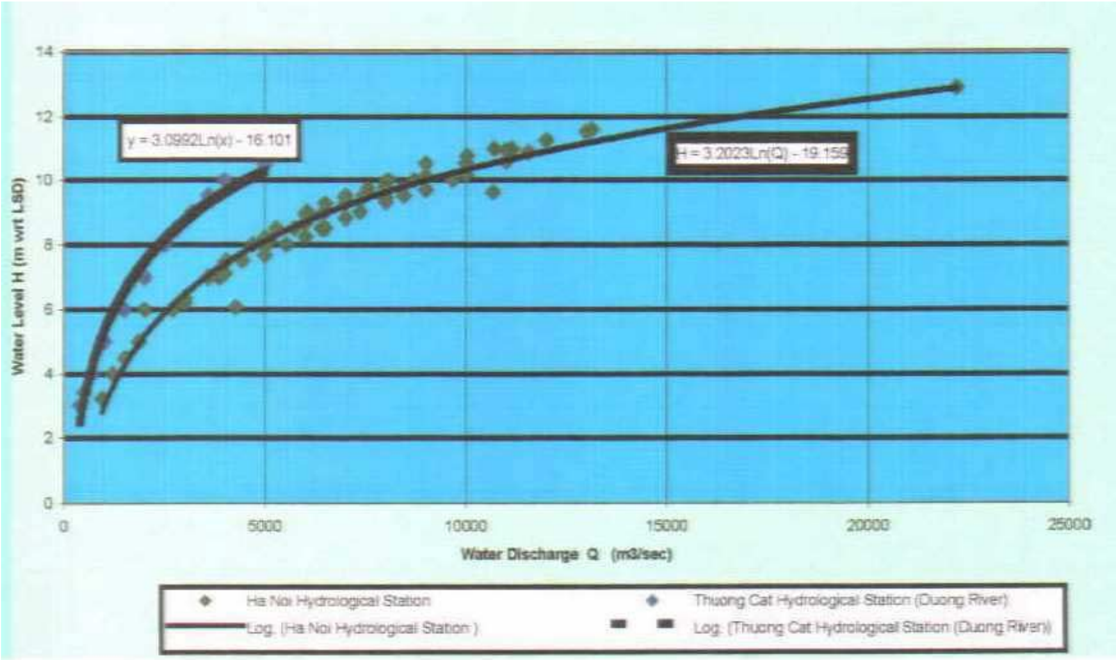

Figure 14.5.4 Hydrological Rating Curve H=f(Q) for the Hanoi Station (period 1991-1995 + Extreme Historic Values and the Thuong Cat station on the Duong River ,2001 (ref TEDIPort and Hydromet)

At present, no similar hydrologic rating curves are yet available to the project for the following stations:

- Son Tay (on the Red River);
- Thuong Cat Song Duong (on the Duong River);
- Khuyen Luong Port (downstream end of the 'Hanoi Section')

It is to be mentioned that there are indications that the Hoa Binh Dam seriously affected the hydrological regime. According to Hydromet's operators the water level is said to be more 'stable', with average low-water levels higher than previously, and with unpredictable regimes. This means that one should essentially rely on the situation after 1995, regarding hydrology/hydraulics.

For the Steady-State hydraulic modelling, it is proposed to pay attention to the current-flow field and to make the comparison with the initial (actual) situation, and to evaluate long-term morphological effect by keeping the Sh/Q (Sh = hydraulic section ; Q = discharge ratio) as constant as possible and as close as possible to the value in the stable upstream sections (e.g. 1 + 2).

Once, these computations are done, the study team will initiate more detailed hydraulic/sedimentological simulations with associated morphological computations.

14.5.3 Stability of the sediments

Suspension loads are reported to be quite high in the Red River: since 1957 daily water samples are taken in the cross-section at the Hanoi Hydromet Station (averaged over the cross-section and over the waterdepth)

– Before Hoa Binh dam construction:
  Flood Season : 1,080 mg/l (max 4,990 mg/l) ;
  Dry Season : 322 mg/l (min 19 mg/l) ;
  Annual average : 940 mg/l

– Hanoi National Hydrological Station (Statistics 1957-2000) :
  Average Ssconc = 801 mgds/l (1957-1994) ;
  Average Ssconc = 775 mgds/l (1995-2000) ;
  Extreme Value Flood Season Ssconc=12,500 mgds/l (12/10/86) ;
  Extreme Value Dry Season Ssconc= 3.7 mgds/l (6/4/77)

– Thuong Cat National Hydrological Station (Statistics 1957-2000)
  Average Ssconc = 1210 mgds/l (1959-1994) ;
  Average Ssconc = 938 mgds/l (1995-2000) ;
  Extreme Value Flood Season Ssconc=15,100 mgds/l (13/10/86) ;
  Extreme Value Dry Season Ssconc= 0.5 mgds/l (24/1/85)

– Red River Segment Dry Season Survey (Dec 2001/Jan 2002, JICA ; see also Figure 14.4.12) :
  At 0.5m below Water Surface :
  Ssconc = 119 mgd.s/l (median value;var 202-33) ;
  At Middle Depth
  Ssconc = 156 mgds/l (median value;var 300-74) ;
  At 0.25m Above River Bed
  Ssconc = 197 mgds/l (median value;var 380-96) ;

– Suspension-sediments have typical contents of 30 to 40 % of fine sand , with d50= 0.022mm to 0.037mm (ref ADB Haskoning,1998, TEDIPort 2001).

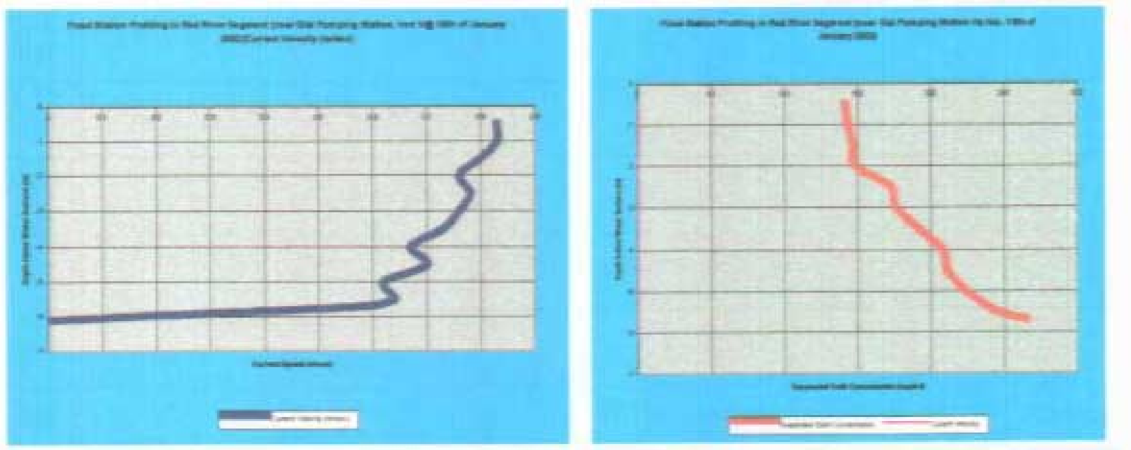

Figure 14.5.5 Example of a Fixed Station Profiling in Upstream Part of Red River Segment 'Hanoi Section' (Vert V2 on 15th of January 2002)

– Suspension load (Ssconc in mgds/l) is apparently related to the water discharge (Q in m3/sec) as illustrated in Figure 14.5.6 below (Data set for daily averages between 1957 and 2000)

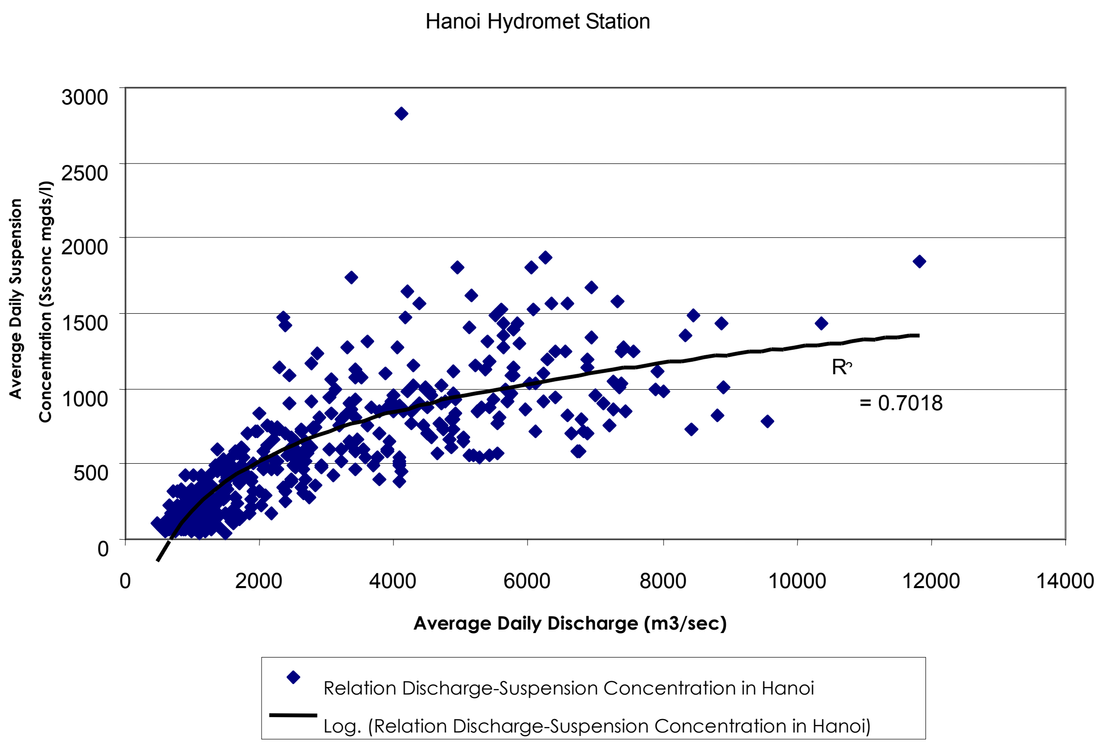

Figure 14.5.6 Relationship between River Discharge (Q in m3/sec) and Suspension Concentration (Ssconc in mgds/l) at Hanoi Station (1957-2000) ref Hydromet

Apparently, the average suspension-load is ceiled off at some value around 1800 mgds/l and above Q = 4,000 m3/sec suspension concentrations are very little affected by the discharge intensity. This may indicate that the beginning of the flood season is characterised by high suspension loads due to run-off of fine-grained soil particles and resuspension of young deposits ; this wash-load is supposedly advected and transferred to the sea.

Accordingly, are sediment transport rates – suspension load and probably bed-load as well – quite high (qs= 120 Mtds/yr on average; calculated qb= 15 to 37 Mtds/yr) in the Red River system upstream Hanoi (see Progress report (I) Chapter 14 for more details on sediment budget). In this part of the Red River two river-portions with enlarged hydraulic sections (braided river sections) occur:

A 20 km section downstream Phu Tho (some 25 km upstream Hanoi; km28 to km 48) with;

- Upstream km 28:
  Average Width ca 1,000m;
- Enlarged Section km 28-km 48
  Average Width: ca 2,000 m;

A 40 km section in Hanoi (km58 to ca km 95 with:
  Average Width ca 1,500m;

Both sections are susceptible to trap bedload sediments and , to a certain extent also suspension sediments, due to current slackening; such sedimentation is, in turn, likely to induce morphological changes of both river bed and river banks; most likely, fine sediments – silts and clays – will decant and settle , together with sand deposits in the widened sections during Flood and preferably on the shoals and banks; these shoals are, in turn hydraulic obstacles to the flow, and will react via erosion/sedimentation patterns in both riverbed morphology and river banks;

The advection-terms- for both suspension-load and bed-load transport in the modelling set-up are therefore of primary importance in order to ascertain valid simulations and sustainable solutions; this advection towards the 'Hanoi Section' (transit?) must also be considered against :

- The evacuation via the Duong River: figures indicate water-discharge evacuation –rates of ca 25 to 30 % of the total flood discharge; question is, if this figure is also applicable towards sediment-load:

- It can be assumed that the suspension-load will, more or less, follow the water-flow;

- Bed-load is generally likely to migrate to the inner-sides of riverbends, which should mean that the right-sides of the channels are most likely to trap the coarser sediments of the bed-load: this is, to some extent, confirmed by the survey-results, in which a tendency to preferential accretion is observed on the right sides of the channels (comparison 2002-1999) and in which coarser sediments are encountered; this should be verified, however, over multianual cross-sectional analysis;

- The extraction of river-sand for landfilling and construction : very few reliable data are available regarding annual extraction volumes, extraction-depths, etc…; hence, this extraction is evaluated from the inventory of the sand-mining pits as they were surveyed in March 2002 which estimate the amount as 2.82 million per year.

A realistic figure is estimated at about 3 to 5 Mm3/year extraction of sand out of the riverbed in the 'Hanoi Section', which would represent almost 20% of the theoretical bed-load supply to this section, and which is to be considered as significant; however, more data are to be collected in order to ascertain the above-mentioned figures ;

As the riverbed material consists of mostly clayey sand and fine sand, the material can be suspended, floated, and re-settled depending on action of bottom currents.

The critical current speed governing erosion or sedimentation of the riverbed has been formulated empirically by several researchers. Diagrams are available, which show and are useful to judge the relationship between the median diameter and the maximum current speed above the riverbed. The data obtained in the survey in January 2002 are plotted on the empirical diagrams proposed by Gilluly (1968), as well as by Nakata and Hirono. The result is presented in **Figures 14.5.7.**

It is apparent that most of the sediments belong to the domain of intermediate and scoring under the present current speed of less than 1m/sec during the dry season, implying an easy state of re-suspension during the other season.

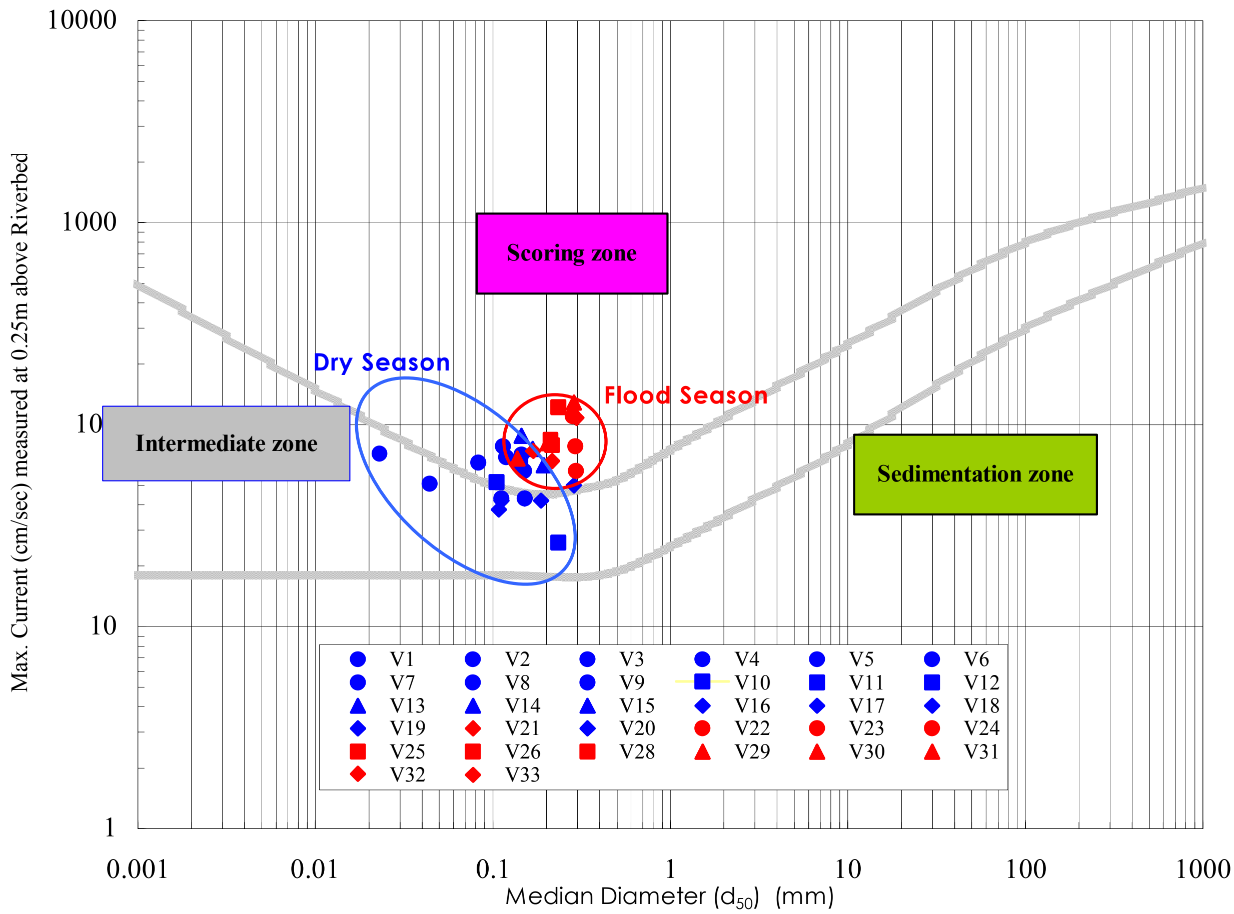

Figure 14.5.7 Current vs. Particle Size after Gilluly's Curve

Source) JICA Study Team

14.5.4 Results and analysis of the hydro-sedimentological survey

During the wet season a hydro-sedimentological survey was executed along the Red River. This survey included a bed-load transport survey and a suspension load and grain size distribution survey. **Appendix 14.4** presents the methodology, used equipment and results of both surveys.

(1) Bed-load transport survey

Cross-section V1, V2, V3 (08-08-02)
V2 - profile
current speed Vc = 1.6 m/sec (surface)

water depth d = 8 m
bed-load transport Sb = 20 kg d.s./m・hr
material : fine sand d50 = 0.210 mm
V3 - profile
current speed Vc = 1.8 m/sec (surface)
water depth d = 9.5 m
bed-load transport Sb = 190 kg d.s./ m・hr
material : fine sand

Cross-section V11, V12, V13 (30-08-02 Hanoi, Chuong Duong)
V11 profile
bed-load transport Sb = 210 kg d.s./ m・hr
V12 profile
bed-load transport Sb = 21 kg d.s./ m・hr
V13 profile
bed-load transport Sb = 60 kg d.s./ m・hr

Taking into account the average hydraulic width and bed-load transport rates, it appears that bed-load discharge in this Hanoi Red River Section could be of the order of 100-200 t.d.s./hr which is considerable (Wet Season). Moreover, is it to be specified that the highest bed-load transport rates occur in the channels, which is logical.
It is believed that this bed-load is the main agent governing the morpohological dynamics in this section (suspension load is mainly wash-load and has little or no contribution to the morphodynamics).

(2) Suspension load + grain-size distribution

The result determining the size of suspended solid is as follows:

Name of sample	Date	Weight > 0.063mm (g)	Weight < 0.063mm (g)	Suspension load con kg/ds/m^3
V1	2002/8/8	4.40	10.00	0.96
V2	2002/8/8	5.85	9.61	1.031
V3	2002/8/8	9.94	12.84	1.519
V11	2002/8/8	3.73	9.61	0.889
V12	2002/8/8	15.53	11.54	1.805

It should be noted hereby that the results of V12 and V13 show exceptional high sand (W > 0.063 m) contents.

14.5.5 Hydraulic analysis

(1) Analysis of the different cross-sections

This analysis starts from the basic knowledge on the cross-section development that the river is stable during the past 15 years in cross-section 2 and dynamic considering the same time period in section 4 (as described in chapter 14.4.5). The basic idea to control morphological processes in the studied river reach is to aim at a constant uniform flow along a single-channel river. This uniform flow will not induce any gradient in sediment transport. So, no drastic local deposition or erosion phenomena occur in the main river channel. Therefore, to obtain this constant flow conditions (assuming a known discharge variation along the Red River) the hydraulic section should be kept as constant as possible along the river reach. This basic assumption of "constant hydraulic section" leads to an initial design of the river regulation works. However, associated narrowing or guiding constructions (to realize these nearly constant hydraulic flow sections), placed in a moveable riverbed, could on their turn induce local erosion or sedimentation processes.

Due to the limited available data, only calculations of the actual discrete hydraulic sections along the studied river reach can be executed for different water levels in the respective cross sections. Actually, no further spatial information on the overall river bed morphology (and its time evolution) is available.

The results can be seen in **Figure 14.5.8** and **Figure 14.5.9** for the years 1999 and 2002.

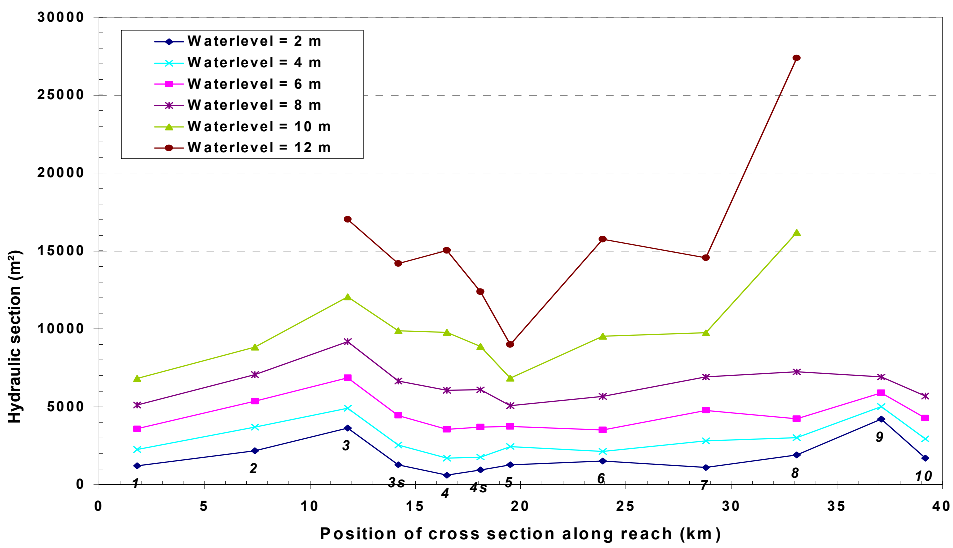

Figure 14.5.8 Hydraulic Section for Different Water Levels (m above LSD) at the Different Cross-Sections for the Year 1999

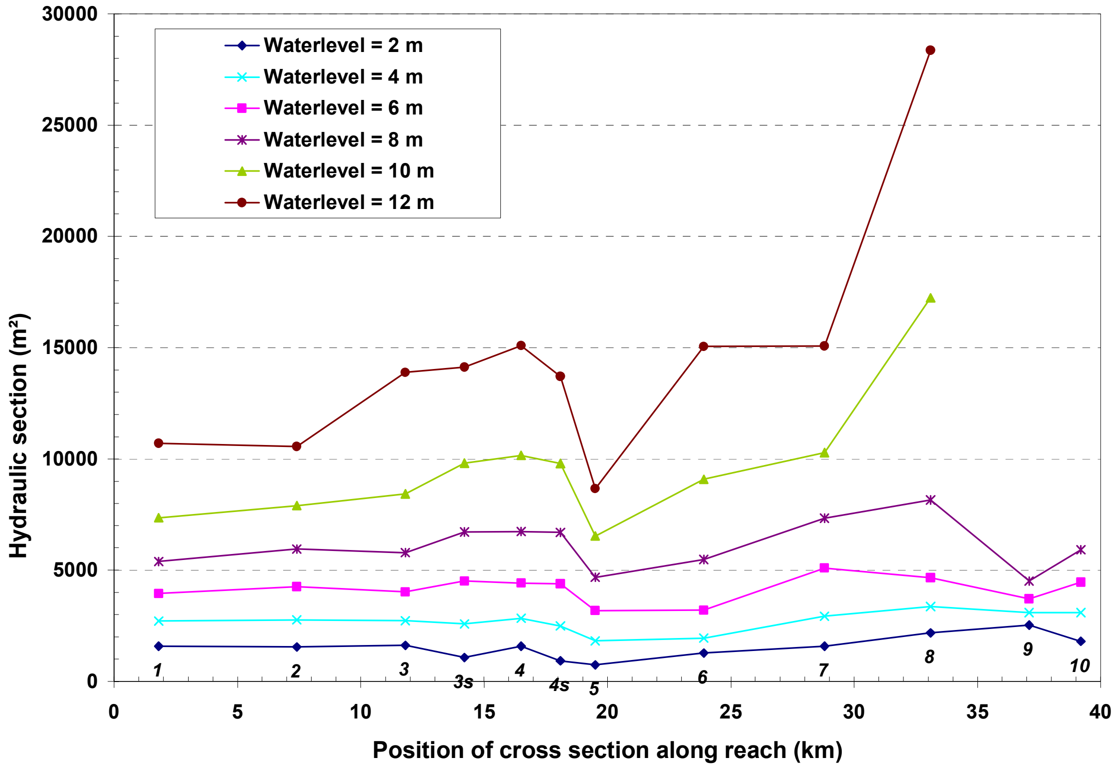

Figure 14.5.9 Hydraulic Section for Different Water Levels (m above LSD) at the Different Cross Sections for the Year 2002

The actual hydraulic sections show a rather smooth longitudinal variation for water levels below 6 m. At this water stage, the flow is mainly concentrated in a single main channel along the river reach. For higher water levels (and according flow conditions), a more pronounced local discrepancy in the consecutive hydraulic sections is noticed. The total hydraulic flow section at this water level is locally composed of lateral flood areas and side channels. Some specific features can already be identified:

- The dual channel system at cross-section 3 becomes a single river channel just upstream the bifurcation of the Duong River.

- Cross-section 5, between the upstream Long Bien Bridge and downstream Chuong Duong Bridge, forms a quite narrow flow passage in the Red River, reflecting a significant drop in the actual hydraulic section.

(2) Stage-discharge relationship

Regular water level and discharge measurements are available at two locations: Hanoi Gauging Station on the Red River near Long Bien Bridge and Thuong Cat

Gauging Station on the Duong River some 2.5 km downstream the bifurcation with the Red River. Daily measurements are available for the period from 1957 till 2000. Based on these data, rating curves giving Q (m^3/s) as a function of local water level H (m above LSD) are formulated.

1) For Hanoi station

Based on the local river cross-section topography (section 5), a split up in two areas refers to the bankfull-discharge identification at a water level H = 8.2 m.

$$\text{for } H \le 8.2\,\text{m} : Q = \left(\frac{H}{0.0502}\right)^{\frac{1}{0.5921}}$$

$$\text{for } H > 8.2\,\text{m} : Q = \left(\frac{H}{0.3192}\right)^{\frac{1}{0.3772}}$$

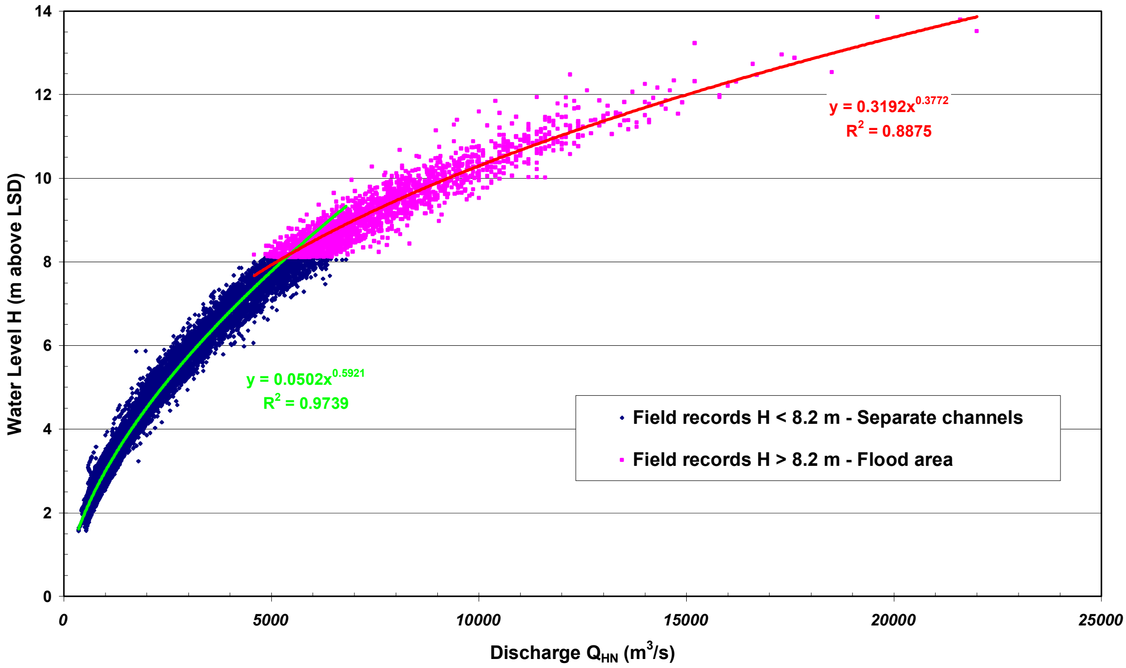

Figure 14.5.10 Double Rating Curve at Hanoi station (data from 1956 till 2002)

(2) For Thuong Cat station

$$\text{for } Q < 5000 \text{ m}^3/\text{s}: \; Q = \left(\frac{H}{0.3834}\right)^{\frac{1}{0.3945}}$$

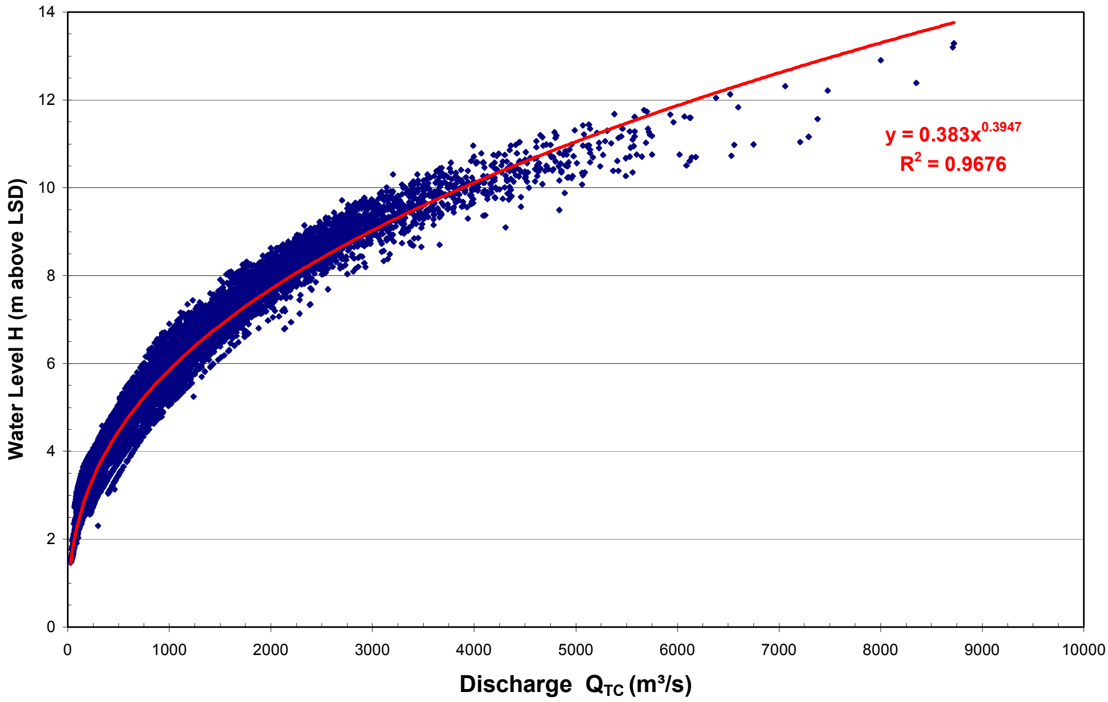

Figure 14.5.11 Rating curve at Thuong Cat Station (data from 1957 till 2000)

Upstream the bifurcation of Duong River and Red River, no specific flow discharge measurements are available in the study area. Therefore a virtual data set has been generated:

- The upstream (input)discharge at section 1 (Q_{input}) is calculated as a sum of discharges in Thuong Cat (Q_{TC}) and Hanoi station (Q_{HN}).
- Doing so, the uptake of water through Liem Mac pumping station is not taken into account.
- The corresponding water levels are determined by a systematic increase of the water level at Hai Noi station with 1.66 m, based on the calculated (nearly linear) water surface profile (cfr. Asian Development Bank-Vietnam Inland Waterway Administration, "Final report Red River Waterway Project Vietnam TA no. 2615-VIE", 1998, Haskoning – Delft Hydraulics).

As a result, the generated Q-h relation in cross section 1 (**Figure 14.5.8**) is given by

$$\text{for } Q < 15\,000 \text{ m}^3/\text{s}: \; Q_{input} = \left(\frac{H}{0.2793}\right)^{\frac{1}{0.3959}}$$