6 Impact Assessment of Hydraulics, Sediment and Water Quality

6.1 Introduction

Based on the *Annex* 6 *Criteria for Evaluating Water Pollution*, and the *Annex* 14 *Guidelines for Assessment of Water Pollution*, *of the Technical Memorandum on Environmental Impact Assessment Process* (TM-EIA, HK), this chapter is devoted to discussing the present status of hydraulic condition, sedimentation and water quality in the Shenzhen River, evaluating the potential impacts of Stage III Project construction and subsequent maintenance on hydraulic condition, sedimentation and water quality, proposing measures to mitigate the negative impacts, and evaluating the residual impacts and their acceptability.

According to *North District Development Programme* made by the Territory Development Department of the HKSAR Goverment, there is no development programme in the affected area on the Hong Kong side. The nearest one to the Project Area is *Fanling, Sheung Shui Development Program.* Implementation of this programme will involve construction of water supply systems and houses, the latter of which is based on *Home Ownership Program.* There will be basically no wastewater discharge from the construction activities associated with this programme, even if there is some, it will be discharged into the existing Hong Kong wastewater collection system, but not into the Shenzhen River. Therefore, there is no need for this EIA to consider any superposition of water quality impact of any other project on Stage Ⅲ Project.

On the Shenzhen side, the area along Stage Ⅲ Project has been well developed. During construction of the Project, there is no other large-scale development and construction plan in the adjacent area.

Therefore, the superimposed impact on water quality caused by other projects will not be considered in the EIA.

6.1.1 *Assessment Purpose*

The Shenzhen River Regulation Project aims mainly at eliminating the downstream flood hazard. Construction of the Project will have potential impact on the river dynamics, sediment transport and water quality. This chapter aims at evaluating the magnitude of the impacts on the river dynamics, sediment transport and water quality in different phases of the Project construction and proposing mitigation measures by means of mathematical modeling simulation and integrated contrast analyses. In addition, the basis for evaluating the Project impacts on other environmental elements will be provided.

6.1.2 *Methodology*

The survey on the water quality was carried out in the Stage Ⅲ Project Area, which has revealed the water pollution status of the Shenzhen River. By using mathematical modeling simulation, integrated contrast and inductive method, the potential impacts of the Project construction on hydraulics, bed sediment and water quality in the Shenzhen River in different phases have been evaluated.

6.2 Regulations and Standards

6.2.1 *National Relevant Regulations and Standards*

On the Shenzhen side, *Water Pollution Prevention and Control Law of P.R.C.* must be followed. Accordingly, *Environmental Quality Standard for Surface Waters* (*GB*3838-88) is followed in the assessment of water quality. The Standard is subdivided into five classes according to different water utilization purposes. In accordance with the requirement of water functional zoning planning of Shenzhen City, the standard specified for the Shenzhen River is Grade V (only suitable for landscape). Part of the parameters and water quality targets for Grade V are listed in Table 6.1.

Table 6.1 Targets for the Shenzhen River Water Quality on the Shenzhen Side Unit: mg/L

Parameter	NH_3-N	NO_2-N	NO_3-N	Total N	Total P	DO
Standard	1.0	1.0	25	1.0	0.2	2.0
Parameter	COD_{Mn}	BOD_5	SS	Total Cu	Total Hg	Total Cd
Standard	10.0	10	150	1.0	0.001	0.01

Note: 1. The criterion for NH_3-N is extracted from the recommended values by China Environmental Monitoring General Station for evaluating river water quality in urban area;

2. The standards for total nitrogen (TN) and suspended substances (SS) are quoted from reference standards, due to GB3838-88 not including these two parameters;

3. The rests are quoted from GB3838-88.

6.2.2 *Hong Kong's Regulations and Standards*

On the Hong Kong side, *Water Pollution Control Ordinance* (*Chapter* 358) and its technical memorandum issued by Hong Kong government, and the wastewater discharge regulations (for aqua-culture purpose) enacted by Hong Kong government in 1988 according to *Wastewater Discharge Ordinance* (*Chapter* 354), are applied in assessing water quality. The selected water quality targets are listed in Table 6.2.

Table 6.2 Standard for the Shenzhen River Water Quality on the Hong Kong Side

Parameters for Water Quality	Standard of Water Quality	Applied Water Body
Bacteria	1) No detection of the *Escherichia* coliform (with the interval of 7-21 days, the latest average of 5 successive samples) 2) Not more than 1000 individuals of total coliform in 100 ml sample with the interval of 7-21 days, the average of the latest 5 consecutive samples)	* Surface Water
DO	Not less than 4 mg/L due to pollution	Surface Water
SS	The annual average not more than 20 mg/L due to pollution.	Surface Water
NH_3-N	The annual average must not exceed 0.02 mg/L.	All waters
Nutritious Salt	Not cause aquatic biota blooming, such as algae No special standard	Marine waters Inland waters
BOD_5	No more than 3 mg/L due to pollution No more than 5 mg/L due to pollution	* Other inland waters
COD	No more than 15 mg/L due to pollution No more than 30 mg/L due to pollution	* Other inland waters

* Yuen Long and Jingtian (upper) sub-districts, Shuangyu sub-district, Ng Tung sub-district, River Ganges sub-district and catchment area

6.2.3 *Coordination of Standards*

The Shenzhen River is the boundary between Hong Kong and Shenzhen. Therefore, the impact on water quality should be assessed according to the respective standards. Many water quality parameters significantly exceed the relevant standards of both sides. The national environmental quality standard is adopted to assess the water quality baseline of the Shenzhen River, while the impact of the Project on the water quality is assessed by using Hong Kong's standard.

6.3 Current Status of Water Quality

6.3.1 *Water Quality Baseline Survey*

Both Shenzhen and Hong Kong have not conducted routine water quality monitoring in the Project area. According to the requirement of water quality evaluation, the water quality baseline monitoring was carried out. Three cross-sections for monitoring water quality were set up, which are located at downstream of the mouths of River Ganges and the San Pan River and upstream of the Ng Tung River mouth, respectively (see Figure 6.1). Sample for each cross-section was taken from the midstream at the depth of 0.5 m. If the river depth is less than 0.5 m, the sample will be taken at half of the water depth.

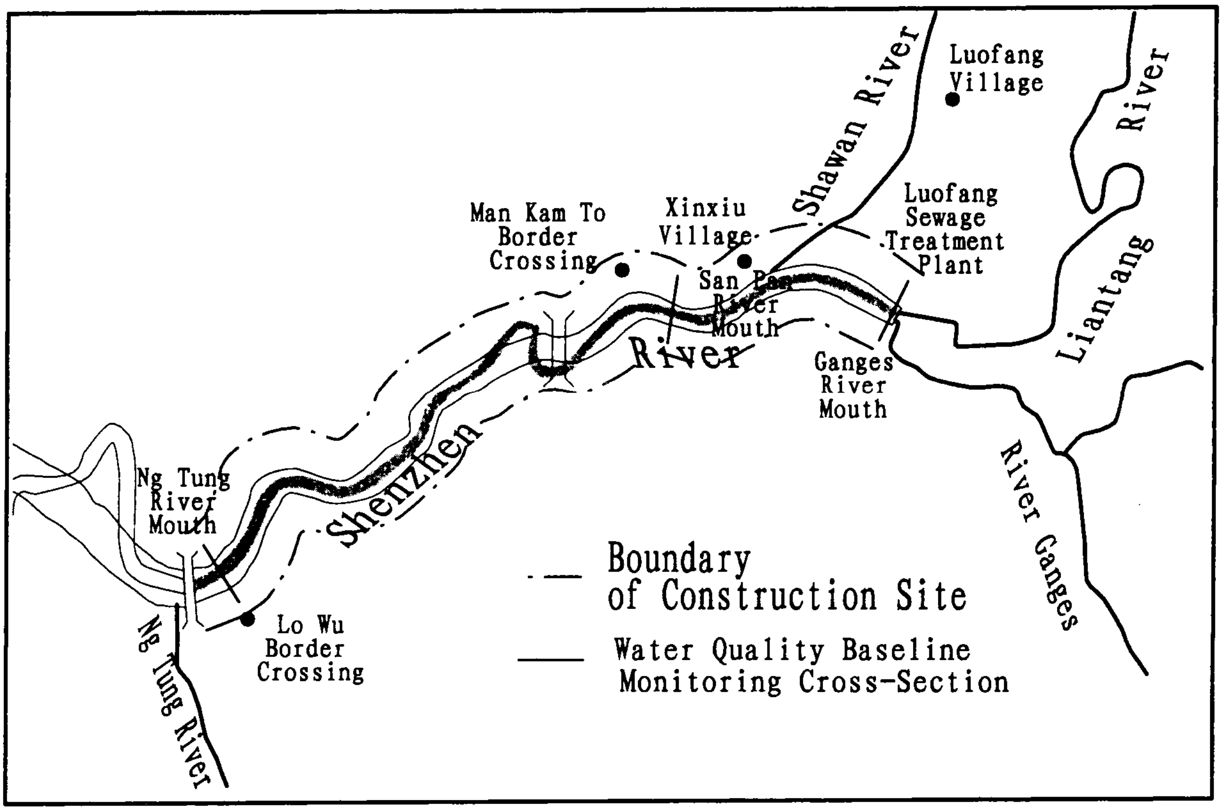


Figure 6.1 Location of Water Quality Baseline Monitoring Cross-sections

The water quality baseline monitoring was carried out on August 18th ~20th (flood season), October 19th ~ 21th (normal season) and December 21th ~ 23th (dry season) 1998. The sampling time in each season lasted for 3 days, and sample was taken twice in flood tide and ebb tide, every day.

Water quality baseline monitoring parameters include water temperature, pH, conductivity (COND), suspended solid (SS), chloride ion (Cl^-), dissolved oxygen

(DO), chemical oxygen demands measured with permanganate method (COD_{Mn}) and dichromate method (COD_{Cr}), biochemical oxygen demand (BOD_5), NH_3-N, NO_2-N, NO_3-N, total nitrogen(TN), total phosphorus(TP), soluble phosphorus(DP), total copper(TCu), total lead(TPb), total zinc(TZn), total cadmium(TCd), total mercury (THg), total arsenic(TAs), total nickel(Tni), total chromium(TCr), Cr^{6+}, phenols(Ar-OH), cyanide(TCN), anionic surfactants(LAS), grease & oils(OIL) and total coliform(COLI) etc..

The adopted water quality analytical methods of the water quality baseline are recommended by National Environmental Protection Agency (see Table 6. 3).

The monitoring results of water quality baseline for the three seasons in 1998 are listed in Table A6. 1 to A6. 3 of Appendix 6

Table 6. 3 The Analytical Methods for Water Quality Parameters

No	Item	Analytical Method	Detected Range (mg/L)
1	Water Temperature	Thermometer method	
2	pH	pH Meter with a glass electrode	
3	Conductivity	Platinum-electrode	
4	SS	Weight measurement	
5	Cl^-	Nitrate salt method	>10
		Mercuric nitrate method	Less then 10 mg/L can be
6	DO	Iodometric method	0. 2 - 20
7	COD_{Mn}	Titration and oxidation method by acidic potassium permanganate	0. 5 - 4. 5
		Titration and oxidation method by basic potassium permanganate	0. 5 - 4. 5
8	COD_{Cr}	Open reflux method	10 - 800
9	BOD_5	5-Day BOD test	>3
10	NH_3-N	Nesslerization method	0. 05 - 2
11	NO_2-N	Colorimetric method	0. 003 - 0. 02
12	NO_3-N	Colorimetric Method	0. 02 - 1
13	Total N	Ultraviolet spectrophotometric method with oxidation of potassium persulfate	0. 05 - 4
14	Total P	Molybdenum blue spectrophotometer	0. 01 - 0. 6
15	Soluble P	Molybdenum blue spectrophotometer	0. 01 - 0. 6
16	Total Cu	Atomic absorption spectrometric method	
17	Total Pb	Atomic absorption spectrometric method	
18	Total Zn	Atomic absorption spectrometric method	

No	Item	Analytical Method	Detected Range (mg/L)
19	Total Cd	Atomic absorption spectrometric method	
20	Total Hg	Cold vapor atomic absorption method	
21	Total As	Cold vapor atomic absorption method	
22	Total Ni	Atomic absorption spectrometric method	
23	Total Cr	Colorimetric method by reaction with diphenylcarbazide	0.004 - 1
24	Cr^{6+}	Colorimetric method by reaction with diphenylcarbazide	0.004 - 1
25	Phenols	Chloroform extraction method	0.002 - 6
26	Cyanide	Colorimetric method	0.004 - 0.25
		Colorimetric method by reaction with pyridine-barbituric Acid	0.002 - 0.45
27	Anionic Surfactants	Methylene blue active substances method	0.05 - 2.0
28	Grease & Oils	Ultraviolet spectrophotometric method	0.05 - 50
29	Total Coliform	Multiple-tube fermentation technique or membrane filter technique	

6.3.2 *Assessment Methodologies for Water Quality Baseline*

In order to evaluate the overall pollution situation, the integrated pollution index method, which is widely used in mainland, is applied to assess the water quality in the reach involved in Stage Ⅲ Project. In addition, the contribution from single pollutant to the total pollution loading is evaluated. The methods used for the assessment are as follows:

(1) Single-parameter water quality index

$$P_{ij}=C_{ij}/S_i \qquad (6-1)$$

Where

P_{ij} is the pollution index for a pollutant, and i refers to the type of pollutant, while j indicates the location from where the sample is taken.

C_{ij} is the measured concentration of the pollutant, mg/L

S_{ij} is the assessment standard for the pollutant, mg/L.

(2) Integrated pollution index

$$P_j = \sum_{i=1}^{n} P_{ij} \qquad (6-2)$$

Where

Pj is the integrated pollution index, and j indicates the sampling location;

n is the pollutant number.

(3) **Pollution contribution**

$$K_{ij} = P_{ij}/P_j \times 100\% \qquad (6-3)$$

Where

K_{ij} is the contribution of pollutant i to water body j.

6.3.3 *Assessment on Current Water Quality Status*

The Shenzhen River water quality had been kept in quite a good condition until 1960s. Since then, however, with the rapid economic development on both sides of the River, the discharge of industrial wastewater and domestic sewage increased sharply, which polluted the River seriously and made the River water quality significantly degraded. Because rainwater is the main water source of the Shenzhen River, the river flow would become small without rainfall and the wastewater quantity discharged into the River might be more than the river runoff. Because of the flat slope in the middle and lower reaches and the narrow river channels with the tide effect, the wastewater could often stay in the river channels for 2 - 7 days, which greatly aggravate the pollution of the River.

Upon the monitored data for water quality baseline study listed in Appendix 6, the statistical results calculated for different seasons and tidal levels are listed in Table 6.4 and Table 6.5.

Figure 6.2 and Figure 6.3 show the concentration variations of the main pollutants in the Stage Ⅲ Project reach in different seasons and for different tidal levels.

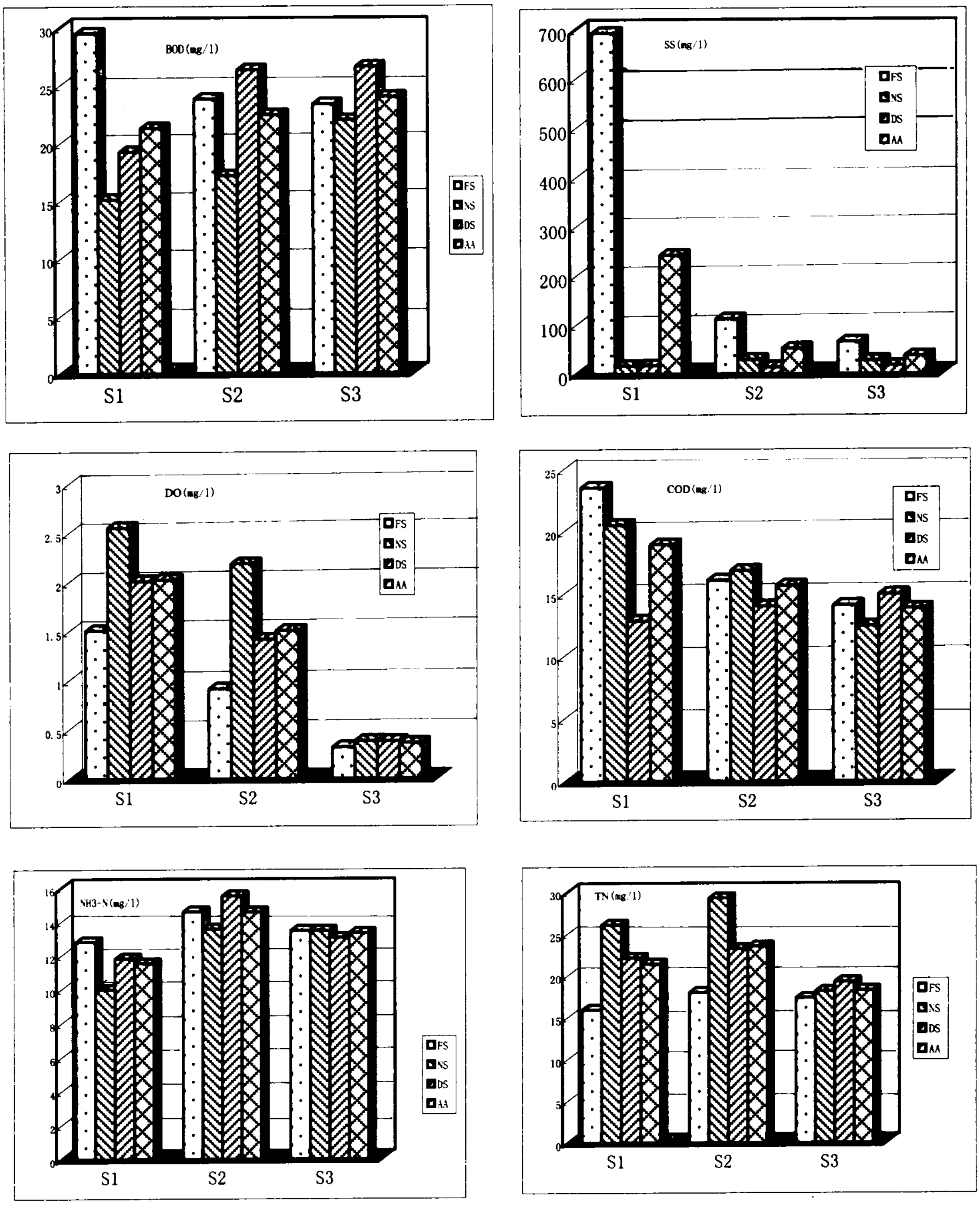
Figure 6.4 shows the annual pollution loading contributions of the main pollutants at different sampling points in the Stage Ⅲ Project.

Table 6.4 Statistic Results of Baseline Monitoring (by Seasons)

Sampling Spots	Mouth of River Ganges			San Pan River Mouth			Ng Tung River Mouth		
Period	Flood Season	Normal Season	Dry Season	Flood Season	Normal Season	Dry Season	Flood Season	Normal Season	Dry Season
Water Temperature(℃)	31.0	27.2	21.6	30.9	26.9	22.3	30.6	26.6	21.2
pH	7.7	7.3	7.2	7.6	7.4	7.3	7.5	7.2	7.3
SS(mg/L)	694	16.7	17.5	112	29.3	14.0	65.3	27.3	17.2
Conductivity(μS/cm)	658	699	730	623	644	757	584	630	658
DO(mg/L)	1.5	2.6	2.0	0.9	2.2	1.4	0.3	0.4	0.4
BOD$_5$(mg/L)	29.5	15.1	19.3	23.8	17.2	26.3	23.4	22.0	26.6
COD(mg/L)	23.5	20.5	12.8	16.1	16.9	14.0	14.1	12.4	14.9
NH$_3$-N(mg/L)	12.8	10.0	11.8	14.6	13.6	15.5	13.5	13.5	13.0
NO$_2$-N(mg/L)	0.093	0.327	0.193	0.066	0.352	0.500	0.024	0.514	0.105
NO$_3$-N(mg/L)	0.04	2.49	4.43	0.02	1.07	2.93	0.02	0.21	0.35
Total N(mg/L)	15.9	26.1	22.1	18.0	29.3	23.2	17.3	18.1	19.3
Total P(mg/L)	3.39	4.26	3.58	2.22	5.14	3.32	1.97	2.46	3.41
Soluble P(mg/L)	0.95	1.74	2.72	1.22	1.75	2.74	1.17	1.61	1.94
Anionic Surfactants(mg/L)	0.51	0.52	0.88	0.49	0.64	1.27	0.77	0.86	1.43
Cr^{6+}(mg/L)	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Phenols(mg/L)	0.004	0.040	0.009	0.005	0.021	0.011	0.008	0.038	0.011
Cyanide(mg/L)	0.002	0.002	0.001	0.002	0.003	0.001	0.001	0.002	0.001
Grease & oils(mg/L)	2.34	1.37	0.62	1.83	1.19	0.84	2.18	1.70	0.95
Total Coliforms (10^{4}cell/L)	14200	8630	2080	12030	7870	3480	14300	6500	3500
Cl$^-$(mg/L)	78.5	87.5	91.5	68.1	72.9	92.5	66.5	72.7	82.5
Total As(mg/L)	0.016	0.005	0.004	0.007	0.005	0.002	0.006	0.003	0.004
Total Hg(mg/L)	0.00021	0.00013	0.00010	0.00017	0.00009	0.00011	0.00015	0.00007	0.00014
Total Cu(mg/L)	0.059	0.035	0.056	0.022	0.027	0.023	0.022	0.016	0.036
Total Zn(mg/L)	0.316	0.168	0.163	0.125	0.151	0.119	0.223	0.109	0.176
Total Pb(mg/L)	0.145	0.011	0.020	0.025	0.016	0.015	0.016	0.010	0.031
Tota Cd(mg/L)	0.001	0.001	0.000	0.001	0.001	0.000	0.001	0.001	0.000
Total Ni(mg/L)	0.013	0.015	0.010	0.008	0.009	0.009	0.012	0.007	0.017
Total Cr(mg/L)	0.061	0.043	0.018	0.025	0.015	0.004	0.025	0.020	0.026

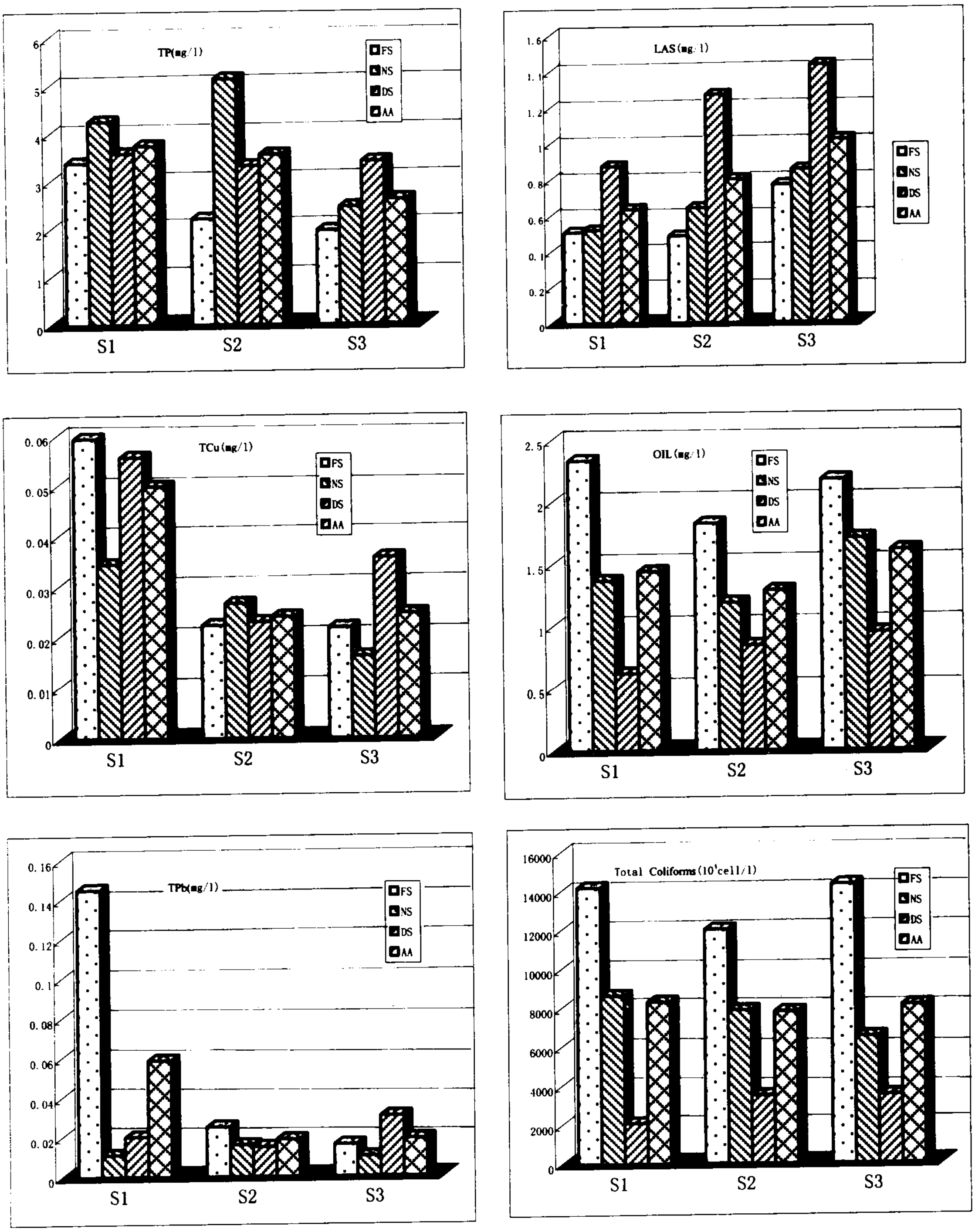
Table 6.5 Statistic Results of Baseline Monitoring (by Tidal Phases)

Sampling Spots	Downstream of River Gange		San Pan River Mouth		Ng Tung River Mouth	
Tidal Period	Spring Tide	Ebb Tide	Spring Tide	Ebb Tide	Spring Tide	Ebb Tide
Water Temperature(℃)	26.1	27.1	26.6	27.1	26.1	26.1
pH	7.4	7.4	7.4	7.5	7.3	7.4
SS(mg/L)	345	140	45.7	63.7	24.2	48.9
Conductivity(μS/cm)	693	699	719	665	608	640
DO(mg/L)	2.2	1.9	1.5	1.8	0.3	0.4
BOD_5(mg/L)	20.9	21.7	20.3	24.3	25.1	22.9
COD(mg/L)	18.5	19.4	16.5	17.5	12.7	14.9
NH_3-N(mg/L)	11.6	11.5	14.8	14.3	13.2	13.4
NO_2-N(mg/L)	0.174	0.234	0.195	0.364	0.019	0.409
NO_3-N(mg/L)	2.27	2.36	1.05	1.48	0.07	0.31
Total N(mg/L)	20.7	22.0	24.8	24.2	17.8	18.7
Total P(mg/L)	4.02	3.47	3.45	4.16	2.32	2.91
Soluble P(mg/L)	1.84	1.77	2.06	1.88	1.55	1.60
Anionic Surfactants(mg/L)	0.58	0.69	0.77	0.90	1.08	0.96
Cr^{6+}(mg/L)	0.003	0.003	0.003	0.003	0.002	0.003
Phenols(mg/L)	0.014	0.021	0.014	0.011	0.025	0.013
Cyanide(mg/L)	0.001	0.002	0.002	0.002	0.001	0.001
Grease & Oils(mg/L)	1.14	1.74	1.23	1.53	1.73	1.48
Total Coliforms (10^4cell/L)	10400	6220	7920	9230	8320	7900
Cl^-(mg/L)	82.1	89.7	89.7	75.9	71.6	76.1
Total As(mg/L)	0.008	0.008	0.005	0.005	0.003	0.005
Total Hg(mg/L)	0.00013	0.00020	0.00012	0.00015	0.00008	0.00016
Total Cu(mg/L)	0.046	0.054	0.032	0.027	0.018	0.031
Total Zn(mg/L)	0.199	0.232	0.130	0.160	0.182	0.156
Total Pb(mg/L)	0.060	0.058	0.020	0.021	0.008	0.029
Total Cd(mg/L)	0.001	0.001	0.001	0.001	0.001	0.001
Total Ni(mg/L)	0.014	0.012	0.009	0.010	0.013	0.011
Total Cr(mg/L)	0.041	0.041	0.023	0.016	0.015	0.032



S1: Mouth of river ganges	FS: Flood Season
S2: San Pan River Mouth	NS: Normal Season
S3: Ng Tung River Mouth	DS: Dry Season
	AA: Annual Average

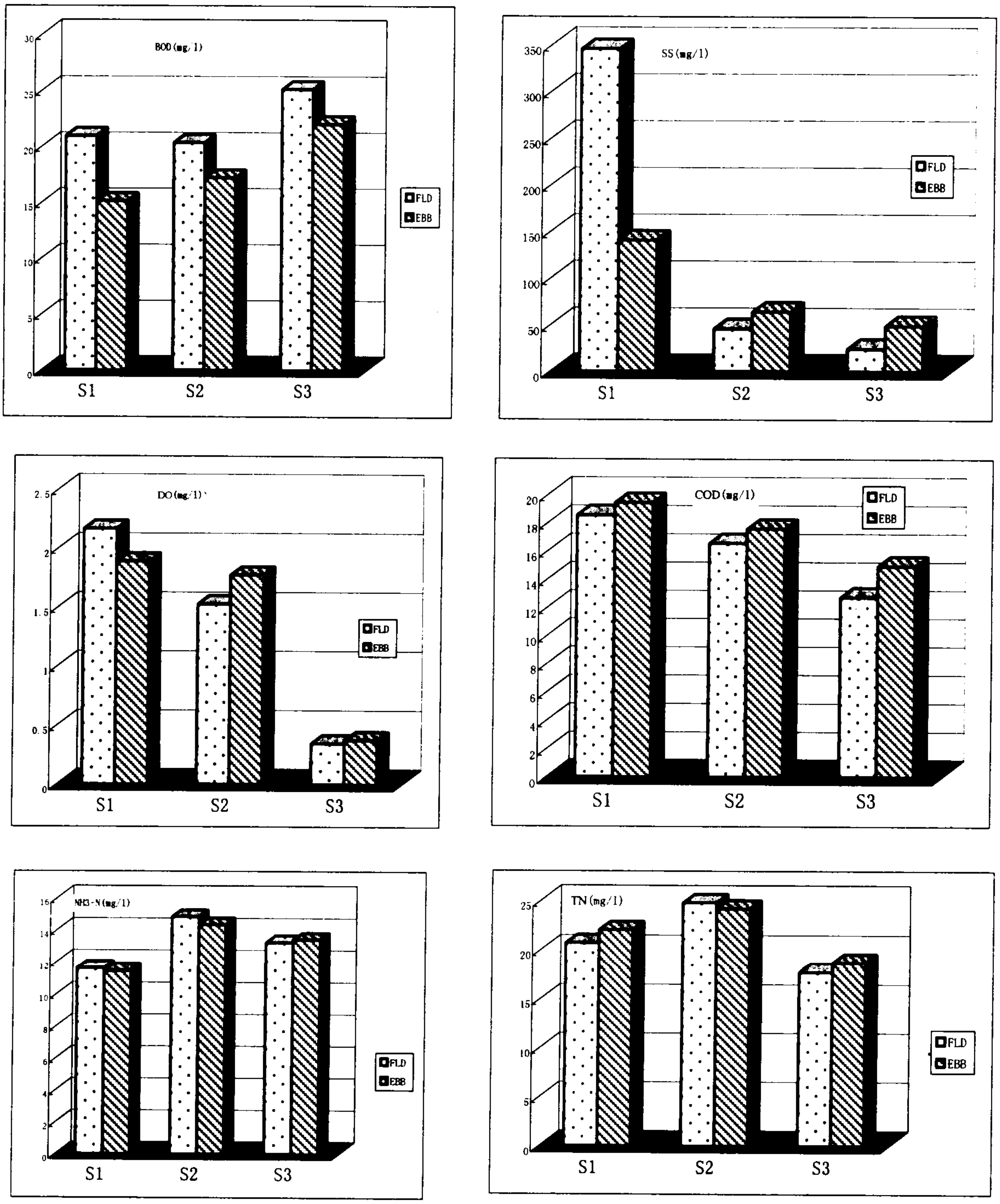
Figure 6.2 Concentrations Of Main Pollutants in Different Seasons Along The Project Involved Rivers



S1: Mouth of river ganges
S2: San Pan River Mouth
S3: Ng Tung River Mouth

FS: Flood Season
NS: Normal Season
DS: Dry Season
AA: Annual Average

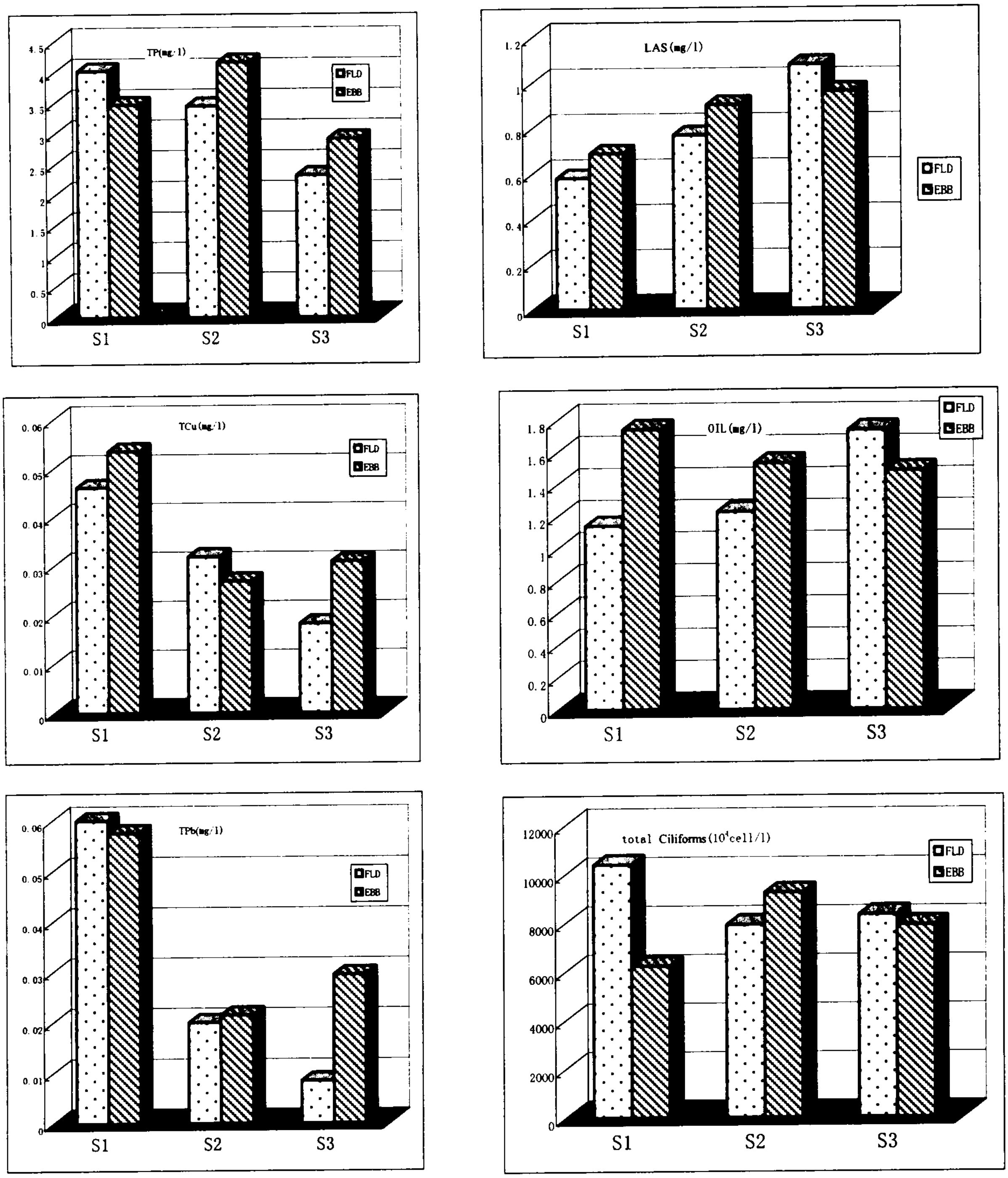
Figure 6.2 (Cont'd) Concentrations Of Main Pollutants in Different Seasons Along the Project Involved Rivers



S1: Mouth of river ganges
S2: San Pan River Mouth
S3: Ng Tung River Mouth

FLD: Flood Tide
EBB: Ebb Tide

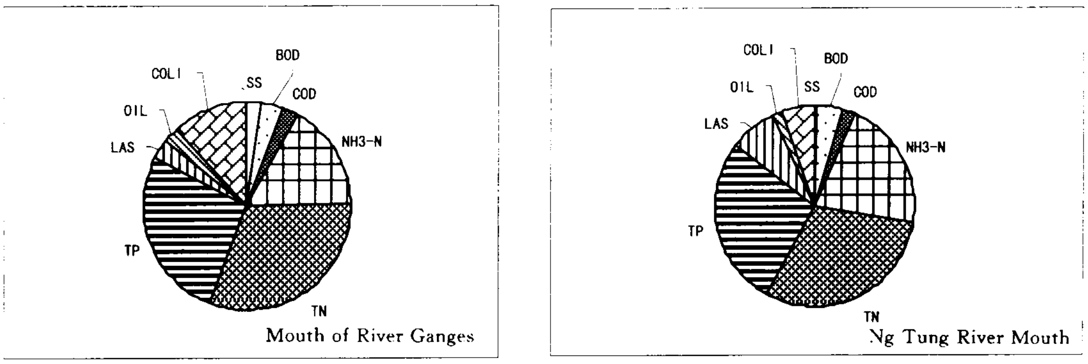
Figure 6. 3 Concentrations of Main Pollutants at Different Tidal Levels along the Project Involved Rivers (by Tide)



S1: Mouth of river ganges
S2: San Pan River Mouth
S3: Ng Tung River Mouth

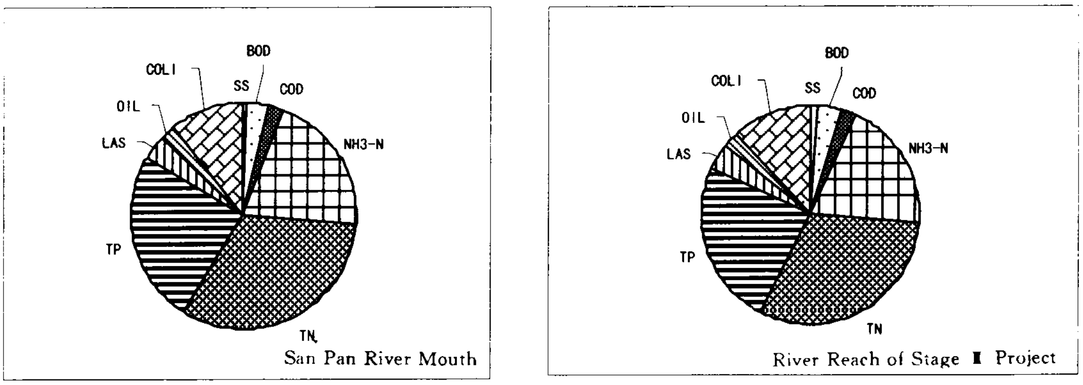
FLD: Flood Tide
EBB: Ebb Tide

Figure 6.3(Cont'd) Concentrations Of Main Pollutants in Different Tidal Levels Along the Project Involved Rivers



Mouth of River Ganges

Ng Tung River Mouth



San Pan River Mouth

River Reach of Stage I Project

Figure 6.4 Annual Pollution Loading Contribution from Main Pollutants in the Project Involved Section

It can be obviously seen that the Shenzhen River has been severely polluted from Table 6.4, Table 6.5, Figure 6.2 and Figure 6.3. Concentrations of quite a number of water quality parameters are much higher than the permitted levels listed in Table 6.2, and most of the monitored DO concentrations are lower than 2 mg/L. The annual concentration averages of which exceed relevant standards, and the corresponding times of excess for different cross-sections are given in Table 6.6. The main pollutants in this reach are total nitrogen, total phosphorus, BOD_5, COD, grease & oils, anionic surfactants, total coliform and SS, etc., most of which are organic pollutants. The contributions of different pollutants are presented in Figure 6.4, among which the total nitrogen and total phosphorus are the largest two contributors whose concentrations are more than 10 times, even 30 times, of the permitted values. The results in different seasons indicate that the pollutants discharged into the River are much larger than the dilution and self-purification capacity. Therefore the variation of runoff has little effect on river water quality.

Table 6. 6 Parameters Exceeding Water Quality Standards and Their Times of Excess in Baseline Survey (Annual Average)

Parameters	Times of Exceeding Standard			
	Downstream of River Gange	San Pan River Mouth	Ng Tung River Mouth	All Reaches
SS	0. 6	No-excess	No-excess	No-excess
DO	No-excess	Excess	Excess	Excess
BOD_5	1. 1	1. 2	1. 4	1. 3
COD	0. 9	0. 6	0. 4	0. 6
NH_3-N	10. 5	13. 6	12. 3	12. 1
Total N	20. 4	22. 5	17. 2	20. 0
Total P	17. 7	16. 8	12. 1	15. 5

6. 4 Hydraulics, Sediment and Water Quality Models

6. 4. 1 *Introduction*

By simulating the characteristics of hydraulics, sedimentation and water quality etc. of the Shenzhen River, mathematical models are applied to evaluate the impact of Stage Ⅲ Project on these factors.

(1) Aim of the model simulation

The model simulation aims at quantitatively describing the effect of the Project on the hydrologic condition, sedimentation and water quality in the Shenzhen River, which will provide the basis for comprehensively evaluating the environmental impacts caused by the Project. The relevant models are applied to simulate and calculate the following elements:

1) The hydraulic characteristics of the Shenzhen River, including the characteristics of the water current and tide process before and after the Project construction;

2) Variation of sedimentation in the Shenzhen River before and after the Project construction;

3) Modification of water quality in the Shenzhen River before and after the Project construction.

(2) Model selection

1) Hydraulic model

Saint-Venant equations are selected as the hydrodynamic model and the one-dimensional non-steady flow mathematical model is set up by means of Preissmann implicit difference scheme. By feeding the model with the hydrologic and physical data before and after the Project, the hydraulic characteristics of the Shenzhen River are simulated. The model can describe the mixing movement of runoff and tide current in the whole tidal reach.

2) Sedimentation model

The non-steady flow suspended sedimentation model is adopted to predict the sediment transportation, siltation and scouring in the Shenzhen River. From the suspended sediment grading data of the Shenzhen River, it is known that there is no much difference among the sediment grading data collected at different hydrological stations along the River. Moreover, as the Shenzhen River belongs to a silt bed type river, no bed load data could be acquired. So the selection of the non-steady flow suspended sediment model is proper for the simulation. Due to the little effect of the sediment on the current, it is unnecessary to solve the sediment equation and current equation by using the coupled method. Therefore, uncoupled method is applied, which will not only be convenient for calculation and simulation, but also meet the requirement for the Project.

The sediment transport model has a higher requirement for the arithmetic and the basic data. With the popularity and development of computer technology, similar models, such as the Pearl River estuary sediment model, have been successfully applied to many domestic rivers. The limited sediment data of the Shenzhen River basin cannot meet the demand of the sediment transport model. Whereas the Shenzhen River is adjacent to the Pearl River with similar riverbed, therefore part of the research findings of the sediment model of the Pearl River estuary is adopted to set up the sediment model for the Shenzhen River.

3) Water quality model

The one-dimensional steady estuary model is adopted to study the average water quality of the Shenzhen River during tide cycles. There have been many water quality models available for simulating the process of pollutant transfer and conversion in tidal river. The selection of water quality model depends on the characteristics of water quality and current and the aim of simulation. Because the Shenzhen River is a tidal river with narrow riverbed, the pollutants discharged into the River will meet the joint action of runoff from upstream and tide from estuary and wander in the River for 2 - 7 days, when the pollutants are continuously mixed, diluted, transferred and decomposed. According to water quality monitoring result, the pollutant concentration is horizontally and vertically well mixed in the Shenzhen River. The pollutant concentration fluctuates regularly in the period of a tide cycle, which could be simulated by one-dimensional model. Moreover, from the present water resource planning for Shenzhen City, it is impossible for the Shenzhen River to become a drinking water source. So it is unnecessary to know the detailed variation of water quality during the tide cycle. But the difference of water quality between different tide cycles needs to be studied. Therefore, the target values of some water quality parameters are selected as control parameters, and the hydraulic elements during different tide cycles and different seasons could be generalized into corresponding steady conditions to analyze and compare the variation of water quality.

The practicality of different water quality models have been compared by South China Environment Protection Scientific Research Institute. The results show that the Thomann Model is suitable for studying the variation of water quality in the Shenzhen River and Shenzhen Bay. It can simplify the tide river model. At first, an independent dispersion term is used to represent inverse runoff dispersion of the river mouth in the model, which is remained in model calculation. Next, the estuarine storage is introduced to deal with pollutant degradation (comprehensive reaction including biochemical reaction), which is different from one-dimensional model and will keep the river mouth characteristics in the calculation no matter what conditions it is used for, the steady condition or the averaged tidal cycle condition. Finally, the model is used to simulate the temporal variation of water quality (tide cycle).

Except for BOD and DO, which are calculated by the coupled model, the other pollution parameters (COD, total coliform, total nitrogen, total phosphorus, Cu and Pb etc.) are simulated and predicted by single factor model. In the model, the integrated attenuation coefficient is introduced to represent the total effect of the various factors on the simulated pollutants. The main aspects of the pollutant transfer and conversion in tidal river have been considered in these models. Therefore, they are suitable for the Shenzhen River.

6.4.2 *Model Description*

(1) Hydraulic model

Preissmann difference scheme is applied to model the Saint-Venant equations in the hydraulic model. The derivation and calculation method of the model is elaborated in Appendix 6. The study covers the area from downstream of River Ganges to the Shenzhen estuary (The former 17.866 km long channel will become 13.466 km after the Project.), which includes the effects of the tributaries such as Liantang River, Ng Tung River, Buji River and Huanggang River, and the effect of discharge from the upstream Shenzhen reservoir during a extra-large flood.

According to the aim of study and existing data, the model only provides the comparison between the highest water level and dyke height along the river. The inflow from the tributaries is considered as conflux.

The topographic information applied in the model is the channel topographic maps from the mouth of River Ganges to the Shenzhen estuary with the scale of 1:500, which were made in 1985, 1994 and 1998 and provided by Shenzhen government. The flow data of the River and its tributaries are quoted from the results of the preliminary design of Phase II of Stage Ⅲ Project.

(2) Sediment transport model

The sediment model adopts non-equilibrium mode of homogeneous suspended sediment. This mode has been widely used in China for studying alluvial river. In the model, the suspended sediment transport capacity formula is a common semi-empirical formula, which supposes the sediment-carrying capacity is the function of the current velocity, depth and sedimentation velocity under the condition of the river keeping in balance. Because there is no enough data of the Shenzhen River for the sediment transport capacity formula, the research results of the Pearl River sediment transport model similar to that of the Shenzhen River is used for reference in the sediment simulation and calculation of the Shenzhen River. The analysis of the model sensitivity and calculation results has proved that the method is suitable.

The sediment model applies the same topography and inflow data as the hydrodynamic model. The designed sediment inflow is determined by the hydrologic sediment data measured in 1995 - 1996. For the detailed description of the sediment transport model and its mathematical derivation, see Appendix 6.

(3) Water quality model

One-dimensional finite-volume estuary model is adopted for this study. The studied reach is divided into a certain number of elements with finite length. These elements link end by end to represent the river mouth. It is supposed that each element is a zero-dimensional model and the river mouth is a discrete one-dimensional model. The finite-interval model selects the average value during one tide cycle as basis and the net flow as the input flow. The pollutant transfer and conversion, such as transport, diffusion and degradation etc., are considered in the model. With the boundary condition and the pollution source data along the River, the water quality of all elements during the designed tide cycle could be simulated and figured out. This model has been adopted to simulate and predict the water quality in many estuaries and the results are very good. For the detailed introduction about the model, see Appendix 6.

The pollution source adopted by the model is provided by Shenzhen Environmental Protection Bureau. The hydrologic data for the model establishment and verification are the data of the Shenzhen River monitored in 1994. The pollution source data in the operation period are determined according to *Shenzhen River Pollution Control Plan.*

6.4.3 *Model Establishment and Prediction*

(1) Hydraulic model

1) Hydraulic parameters and basic information

① Determination of hydraulic parameters

The model covers the area from the mouth of River Ganges to the Shenzhen estuary. There is only one parameter in the hydrodynamic model, that is roughness. According to the research objective, the value recommended in the Project planning and design report is adopted. To the present channel, based on the flood level mark records on May 20, 1989 and September 26, 1993, Guangdong Hydro and Power Planning and Designing Institute and Shenzhen Water Affairs Bureau have successively derived the roughness values. The later roughness value is input into the model. The roughness of the reach from San Pan River mouth to downstream of River Ganges adopts the value recommended in the Liantang River regulation planning. To the designed channel, the roughness value is 0.0225 listed in Table 6.7, which is re-commended by the Project designer. The analysis result of roughness sensitivity (see Figure 6.5 and Figure 6.6) shows that the above selection is suitable.

Table 6. 7 **Roughness of the Truck Channel of the Shenzhen River**

Reach		Shenzhen Estrary-Yunong Village	Yunong Village - Lo Wu	Lo Wu - San Pan River	San Pan River to River Ganges
Present Channel	Trunk Channel	0. 020	0. 025	0. 0285	0. 032
	Shoal	0. 033			
Designed Channel		0. 0225			

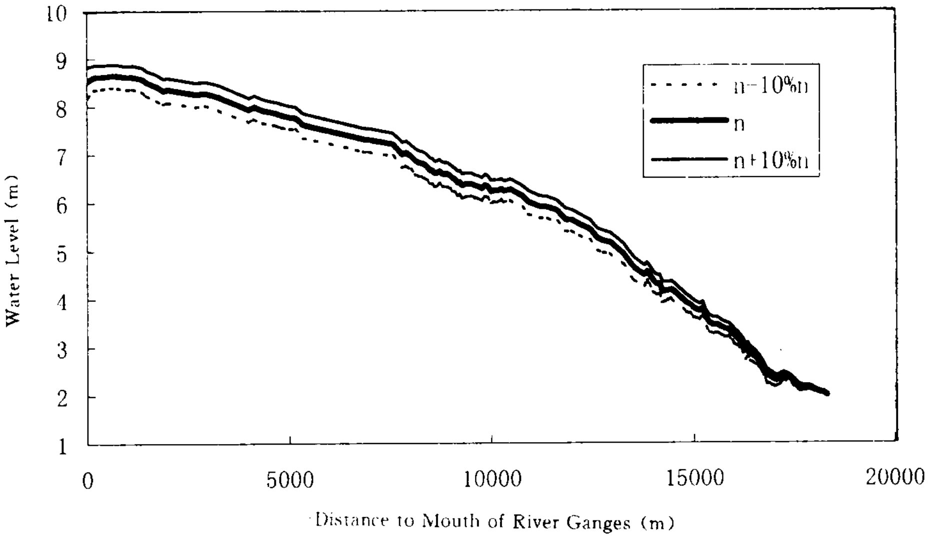


Figure 6. 5 Impact of River Bed Roughness on Water Surface Profile (before the Project)

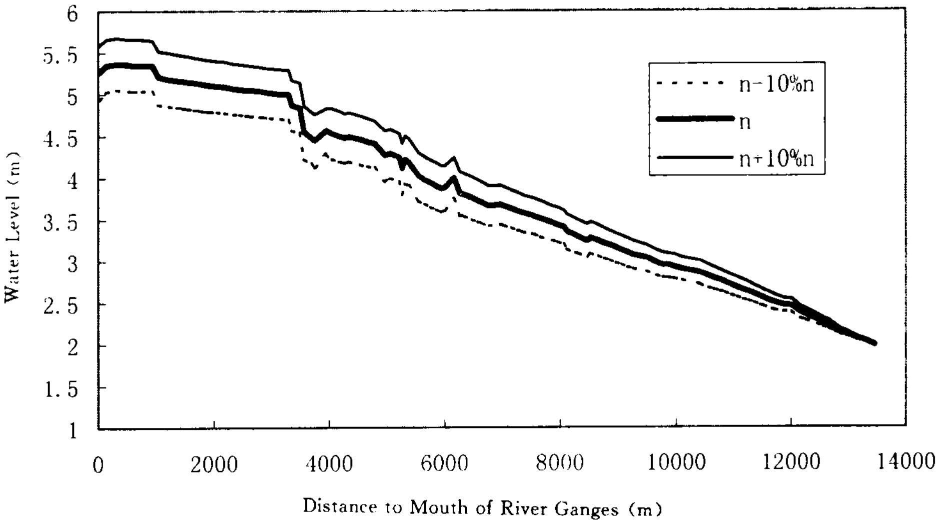


Figure 6. 6 Impact of Riverbed Roughness on Water Surface Profile (after the Project)

② Designed discharge

The total catchment of the Shenzhen River is 312. 5 km², of which 125 km² is in Hong

Kong and 187.5 km^2 is in Shenzhen. The length of river channel from the mouth of River Ganges to the Shenzhen estuary is 17.866 km, which will become 13.466 km after completion of the Project. The main tributaries are Liantang River, Sha Wan River, Shangshui River, Buji River and Futian River, etc.

There is no regular hydrological station in the Shenzhen River basin, so the hydrological data is insufficient. In 1982, the designed flood hydrograph under natural condition was derived by Hydropower Survey and Design Institution of Guangdong Province through rational method during the preliminary design for flood control of Shenzhen City. In 1994, it was recalculated by Flood Control Planning Office of Shenzhen City through integrated unit graph. In 1998, it is audited by Changjiang Institution for Survey, Planning and Design during the preliminary design for Phase II of Stage Ⅲ Project. In this EIS, the designed flood hydrograph is adopted for computation of hydraulics and sedimentation.

The designed flood hydrographs for the main cross-sections with 50-year return period and 10-year return period are shown in Figure A6.2 and Figure A6.3 of Appendix 6.

③ Designed tidal level at river mouth

The designed tidal hydrographs are obtained from the typical tidal hydrographs at Jianbizui station, which are given in Figure A6.4 of Appendix 6.

④ River topography

The map of the existing river topography is obtained from the information surveyed in 1985 and in Stage Ⅱ as well as in Stage Ⅲ Project. The information of the river topography after construction can be acquired from the design reports for Stage Ⅰ, Stage Ⅱ, and Stage Ⅲ Project. The original Shenzhen River reach is 17.866 km long with 135 cross-sections, which will be 13.466 km long with 118 cross-sections after completion of the Project.

2) Computational conditions and results

In the present channel from the mouth of River Ganges to the Shenzhen estuary, 135 sections are selected with length of 50 - 300 m, 118 sections with length of 50 - 204 m are selected in the designed channel for computation. The time interval applied is from 60 seconds to 3,600 seconds.

The topographic data for original channel is obtained from the original channel topographic map, while that for new channel is extracted from the designed report, including that from the finished Stage Ⅰ Project, the in-construction Stage Ⅱ Project and the in-design Stage Ⅲ Project. Therefore, the computation reflects the condition before and after the construction of the Project.

The key hydraulic elements in the Shenzhen River before and after the construction as well as after 1 and 2 years' operation of the Project are simulated under different conditions. The main computation results are:

Flood surface profiles for 50-year return period flood and 10-year return period flood plus 10-year return period tide before construction (Figure 6.7);

Flood surface profiles for 50-year return period flood and 10-year return period flood plus 50-year return period tide before construction (Figure 6.8);

Flood surface profile for 50-year return period flood plus 10-year return period tide after 1 year' operation (Figure 6.9);

Flood surface profile for 50-year return period flood plus 10-year return period tide after 2 years' operation (Figure 6.10);

Flood surface profiles for 10-year return period flood plus 50-year return period tide after 1 year's operation (Figure 6.11);

Flood surface profiles for 10-year return period flood plus 50-year return period tide after 2 years' operation (Figure 6.12).

(2) Sediment transport model

1) Model parameter and basic data

The sediment model adopts non-equilibrium mode of homogeneous suspended sediment. This mode has been widely used in China for studying alluvial river. In the model, the suspended sediment transport capacity formula is a common semi-empirical formula, which assumes that the sediment-carrying capacity is the function of the

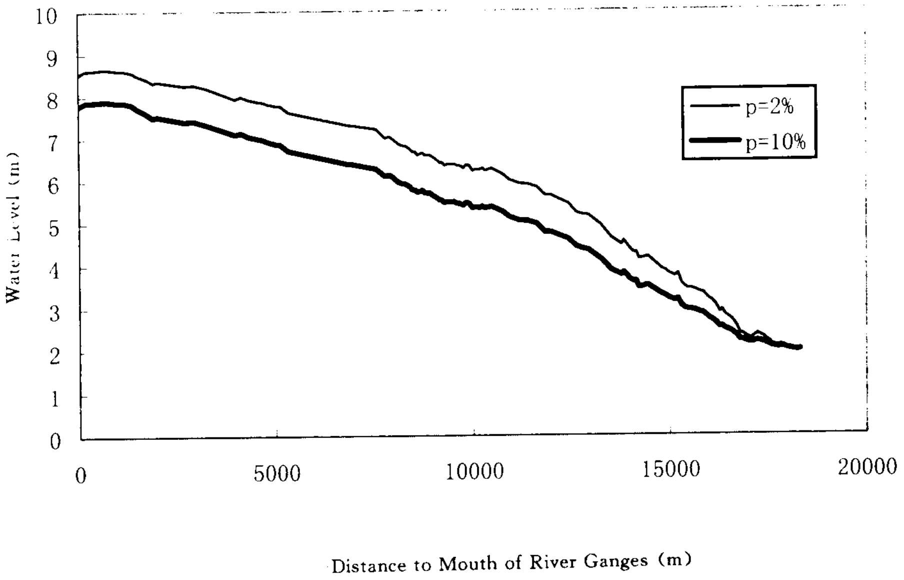


Figure 6.7 **Water Surface Profile for Different Frequency Flood Plus 10-year Recurrence Tidal Level before Construction**

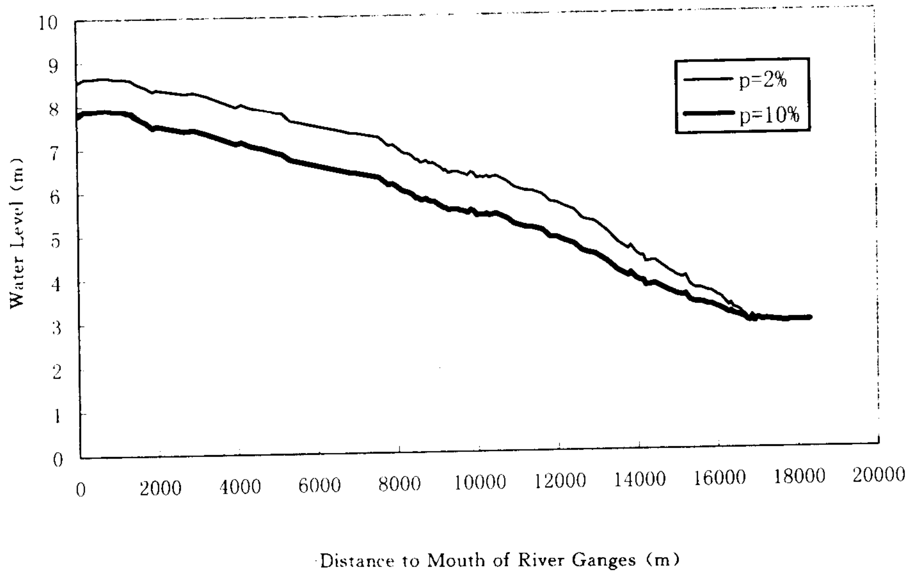


Figure 6.8 **Water Surface Profile for Different Frequency Flood Plus 50-year Recurrence Tidal Level before Construction**

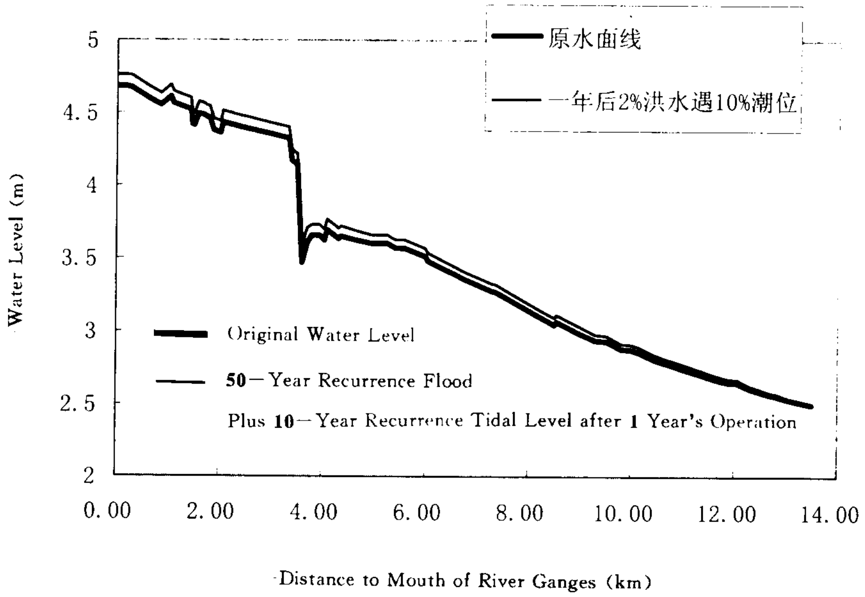


Figure 6.9 Water Surface Profile for 50-year Recurrence Flood Plus 10-year Recurrence Tidal Level after 1 Year's Operation

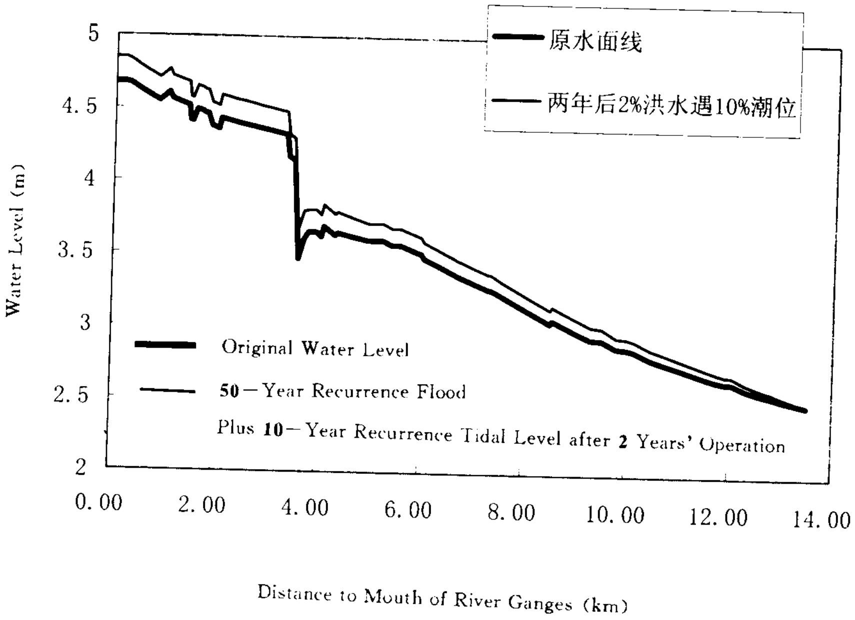


Figure 6.10 Water Surface Profile for 50-year Recurrence Flood Plus 10-year Recurrence Tidal Level after 2 Years' Operation

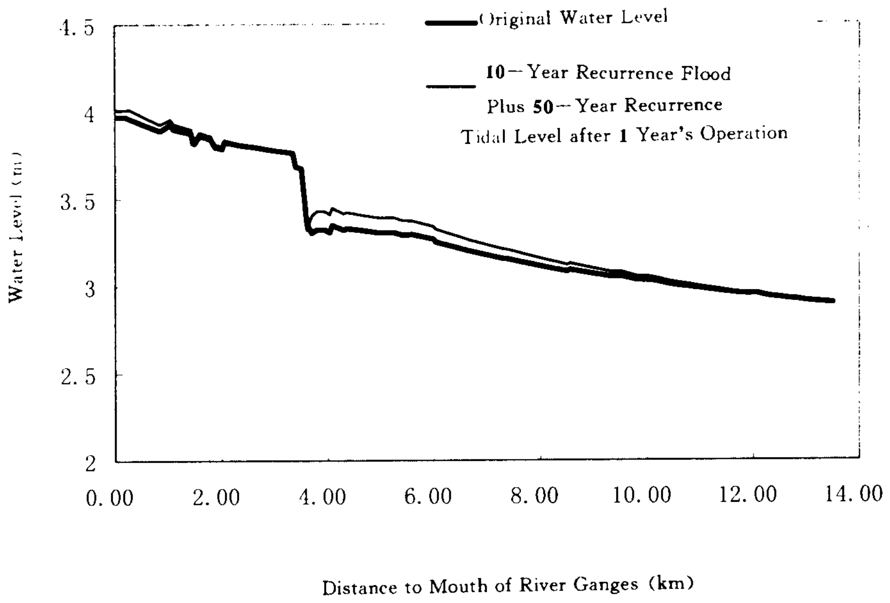


Figure 6. 11 Water Surface Profile for 10-year Recurrence Flood Plus 50-year Recurrence Tidal Level after 1 Year's Operation

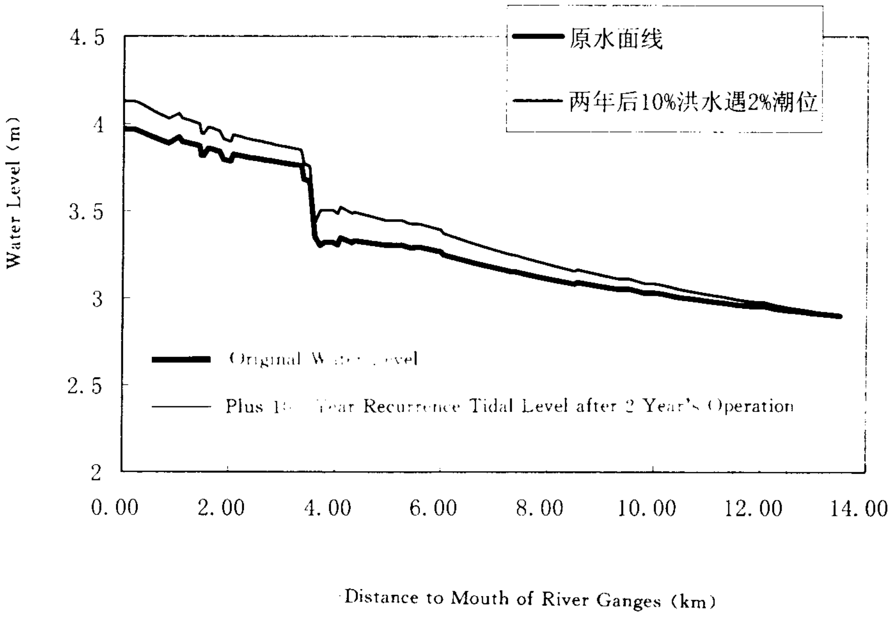


Figure 6. 12 Water Surface Profile for 10-year Recurrence Flood Plus 50-year Recurrence Tidal Level after 2 Years' Operation

current velocity, depth and sedimentation velocity under the condition of the river keeping in balance. Because there is no enough data of the Shenzhen River for the sediment transport capacity formula, the study results of the Pearl River sediment transport model similar to that of the Shenzhen River is used for reference in the sediment simulation and calculation of the Shenzhen River.

The sediment prediction computation model for Stage Ⅰ and Ⅱ environmental assessment and Stage Ⅲ Project design all adopt the above method. This treatment has been proved to be valid.

① Determination of model parameters

Besides river roughness n, sand carrying capacity m and recovery saturation coefficient α should be determined for one-dimensionalal sediment transportation model. The value of roughness n in the sediment transport model is the same as that in the hydrodynamic model.

Due to insufficient long-term data for sediment transportation, the values of coefficients m and α used here are quoted from the tidal model for the Pearl Riverestuary (*People's Pearl River, February* 1988). This model has been used in the Modao Channel of Pearl River near the Shenzhen River, which can well describe the interactions among hydraulic elements, riverbed deformation and suspended sediment transportation.

Formulas for sand carrying capacity

$$S_* = k_e (U^3/g\omega h)^{0.603} \qquad \textit{ebb tide}(U > 0) \qquad (6-4)$$

$$S_* = k_f S_e (U^3/g\omega h)^{0.104} \qquad \textit{ebb tide}(U < 0)$$

Where:

S_e is the mean sand content during ebb tide, obtained from model calculation.

k_e and k_f describe the flow regime such as high-flow, even-flow and low-flow. Normally the mean value of the three flow regimes is adopted, namely $k_e = 0.25$, $k_f = 0.1$

The recovery saturation coefficient for sand continuity equation is determined by

$$\alpha = 2.14 - 0.28 lg(U^3/g\omega H) \qquad (6-5)$$

When $U^3/g\omega h$ is less than 0.1, $\alpha = 2.8$.

② Basic information

1 year series of data about hydrology and sand transportation

There is no daily record along the River for discharge and sand content except for Buji River Hydrological Station. The one-year daily data used in the study are interpolated from the available data. The tidal levels in the river mouth are the control levels for two low tides and two high tides every day, while the sand contents in the river mouth are derived from the sediment contents at the river mouth and Yunong station.

Designed flood profiles under different frequencies and designed tidal profile in river mouth

It is the same as that for hydrodynamic model.

Sand profiles under different designed frequencies

Due to insufficient sand transportation data, the widely used empirical formula is used in this study. The designed sand profile is obtained from the designed discharge profile.

$$Q_s = kQ^{\alpha} \qquad (6-6)$$

Where Q_s is sand flux (kg/s);

Q is river flow (m^3/s);

k and α are coefficients.

Then the relation between the discharge and sand flux is built up based on the data acquired from the Sha Wan River, the Ng Tung River and the Buji River from November 1995 to October 1996. As the Ng Tung River is affected by the sand by carried tides, three typical flood profiles are selected for setting up the relationship between water and sand transportation, namely the flood on 15 - 16 July 1997, the flood on 22 - 24 July 1997 and the flood on 14 - 15 September 1996, to eliminate the effects. The following gives the relations between sand transport ratio and discharge for the three rivers:

For the Sha Wan River, $Q_s = 0.0804Q^{1.6817}$

For the Ng Tung River, $Q_s = 0.0127Q^{1.6259}$

For the Buji River, $Q_s = 0.0663Q^{2.3844}$

Grain-size distribution

Based on the monitored grain-size distribution curve for suspended sand, the medium size of suspended sand adopted in this study is $d_{50} = 0.02 \sim 0.03$ mm.

River topography

It is the same as that used in the hydrodynamic model.

2) Computational conditions and results

Upon the river topography before and after Stage Ⅲ Project, and combination of different discharge and sand transportation process and boundary conditions, eight situations are computed in this study, which describe the phenomena of sediment transportation, scouring and siltation after completion of the Project. The eight schemes are presented as follows:

Scheme 1: After completion of Stage Ⅰ Project and before Stage Ⅲ Project, 1 year's operation under 1 year's discharge and sand profiles;

Scheme 2: After completion of Stage Ⅲ Project, 1 year's operation under 1 year's discharge and sand profiles;

Scheme 3: After completion of Stage Ⅲ Project, two years' consecutive operation under 1 year's discharge and sand profiles;

Scheme 4: After completion of Stage Ⅲ Project, three years' consecutive operation under 1 year's discharge and sand profiles;

Scheme 5: After completion of Stage Ⅲ Project, four years' consecutive operation under 1 year's discharge and sand profiles;

Scheme 6: After completion of Stage Ⅲ Project, five years' consecutive operation under 1 year's discharge and sand profiles;

Scheme 7: After completion of Stage Ⅲ Project, 1 year's operation under 1 year's discharge and sand profiles with 50% enlargement;

Scheme 8: After completion of Stage Ⅲ Project, 50-year return period discharge and sand profiles plus 10-year return period tidal profile.

Based on the hydrological and sediment analysis, the result from the physical model and the calculation in this study, it was concluded that Stage Ⅲ Project cannot meet the design requirement after 2 - 3 years' operation due to siltation. Therefore maintenance dredging is necessary at some serious siltation sections. It is considered that no equilibrium situation can be reached after the construction. No calculation is thus conducted for sediment equilibrium. The accumulated deposition after 5 years' operation is computed to evaluate the sediment behaviors after completion of the Project.

Table 6. 8 shows the calculation results of the quantity and thickness of sediment under different schemes.

Figure 6. 13 to Figure 6. 16 show the sedimentation situation along the mainstream under four different conditions.

Table 6. 8 shows that, after completion of the Project, there will be about 160,000 m^3 sediment deposited in the river channel, of which 143,000 m^3 sediment in the reach downstream from Lo Wu Bridge. It is reported by the EIA of Stage Ⅱ Project that, after completion of Stage Ⅱ Project, the total siltation amount is about 50,000 m^3 in the whole channel. There are 60, 000 m^3 of silt scouring from upstream of Lo Wu Bridge, and 110,000 m^3 of silt depositing in the downstream of Lo Wu Bridge. Both calculating ways have a similar result on the scouring and depositing of the Shenzhen River sediment. But they have different results on the total siltation due to the different data applied. The EIA of Stage Ⅱ Project was finished in the end of 1994, which is based on Hong Kong's sand-yielding data and the Shenzhen River suspended substance data before 1992. At that time, the Hong Kong side along the Shenzhen River kept in natural condition and good vegetation, and the Shenzhen side was just developed with little vegetation destroyed. So soil erosion was limited by then. In this EIA, the hydrologic and sedimentation data of 1996 are selected. By 1996, both sides of the Shenzhen River have been rapidly developed with vegetation having been destroyed and severe water and soil erosion on the Shenzhen side. It causes sharp increase of sediment and siltation in the channel. It is predicted that the sand production and sedimentation

Table 6.8 Statistics of Quantity and Thickness of Scouring and Depositing for All Schemes

River Reach	1 Year's Operation before Stage III Project		After 1 Year's Operation of Stage III Project		After 2 Year's Operation of Stage III Project		After 3 Year's Operation of Stage III Project		After 4 Year's Operation of Stage III Project		After 5 Year's Operation of Stage III Project		Sand and In flow Increasing 50% for a Year		50-Year Recurrence Flood Plus 10-Year Recurrence Tide	
	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS
Downstream of River Ganges～San Pan River Mouth	-0.36	-	0.779	0.23	1.61	0.47	2.16	0.62	2.91	0.83	3.66	1.03	0.830	0.224	-0.63	-0.18
San Pan River Mouth～ Man Kam To	-0.78	-	0.228	0.11	0.483	0.23	0.715	0.34	0.979	0.47	1.26	0.59	0.403	0.188	0.017	0.008
Man Kam To～Lo Wu	-1.26	-	0.673	0.07	1.45	0.16	2.28	0.21	3.07	0.29	3.86	0.38	1.63	0.162	-0.14	-0.02
Lo Wu～ Yumin Village	1.97	0.54	0.331	0.09	0.710	0.19	1.65	0.15	2.03	0.23	2.28	0.30	0.577	0.134	-1.96	-0.47
Yumin Village ～ Buji River Mouth	2.17	0.52	0.766	0.19	1.59	0.39	2.25	0.55	3.03	0.74	3.84	0.92	1.11	0.306	0.083	0.023

River Reach	1 Year's Operation before Stage III Project		After 1 Year's Operation of Stage III Project		After 2 Year's Operation of Stage III Project		After 3 Year's Operation of Stage III Project		After 4 Year's Operation of Stage III Project		After 5 Year's Operation of Stage III Project		Sand and In flow Increasing 50% for a Year		50-Year Recurrence Flood Plus 10-Year Recurrence Tide	
	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS	QS	HS
Buji River Mouth～ Futian River Mouth	3.97	0.15	3.34	0.12	7.05	0.24	10.6	0.36	14.4	0.49	18.4	0.63	5.71	0.224	2.41	0.095
Futian River Mouth～ Yunong Village	1.14	0.06	0.916	0.05	2.05	0.12	3.10	0.18	4.34	0.25	5.70	0.33	2.39	0.141	1.19	0.070
Yunong Village～ Shenzhen Estuary	9.25	0.21	9.02	0.20	18.7	0.40	25.3	0.55	34.3	0.55	43.4	0.92	9.95	0.226	3.87	0.088
Total of Scouring and Depositing	16.1		16.0		33.7		48.1		65.1		82.4		22.6		4.85	

Note: QS is the quantity of sediment scouring and depositing; HS is the mean thickness of sediment scouring and depositing.

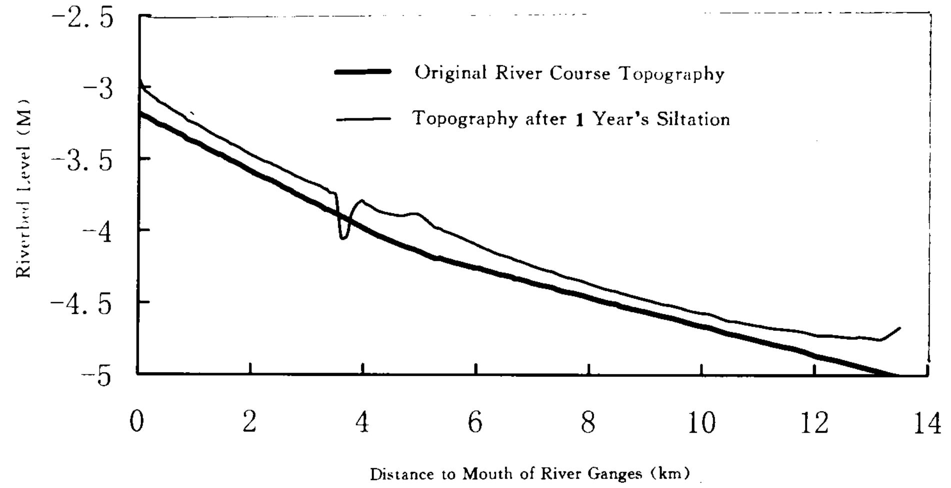


Figure 6. 13 Scouring and Depositing Status along the River after 1 Year's Operation

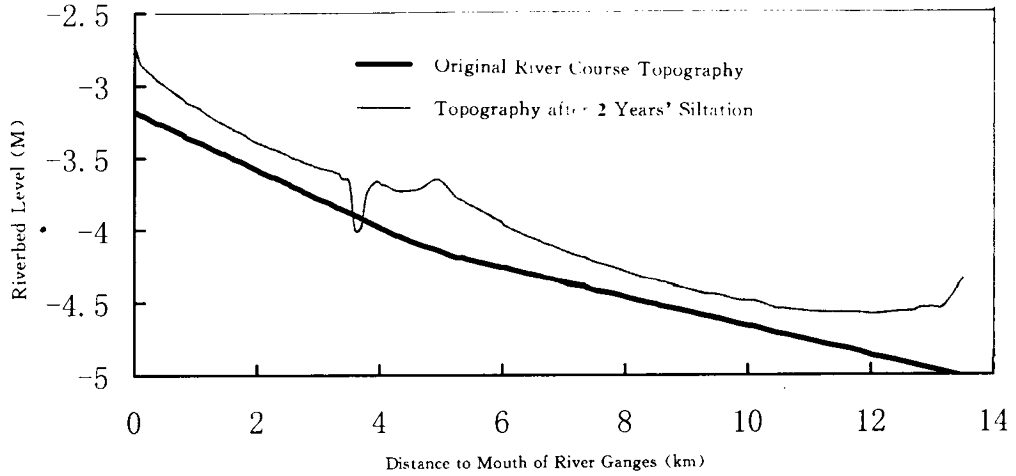


Figure 6. 14 Scouring and Depositing Status along the River after 2 Years' Operation

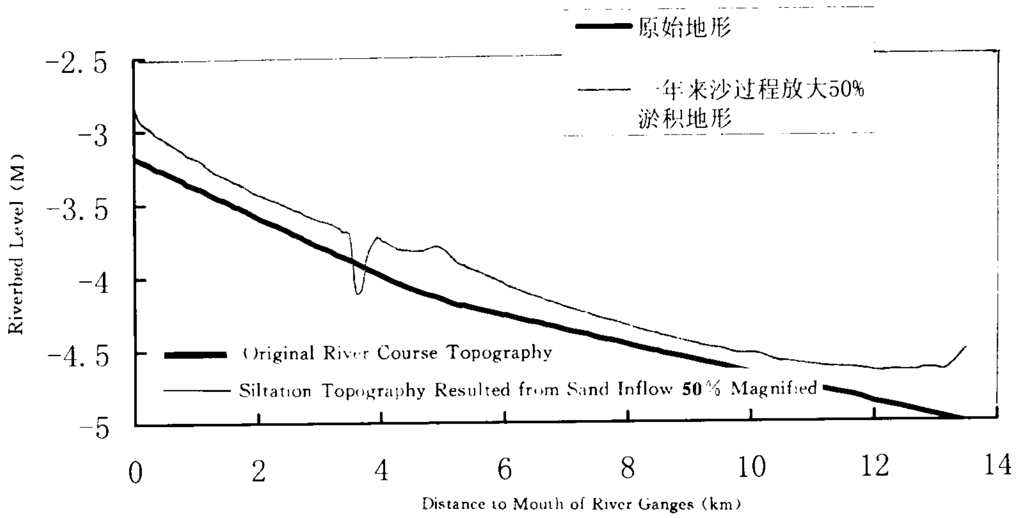


Figure 6. 15 Scouring and Depositing Status along the River with Sand Inflow 50% Magnified, after 1 Year's Operation

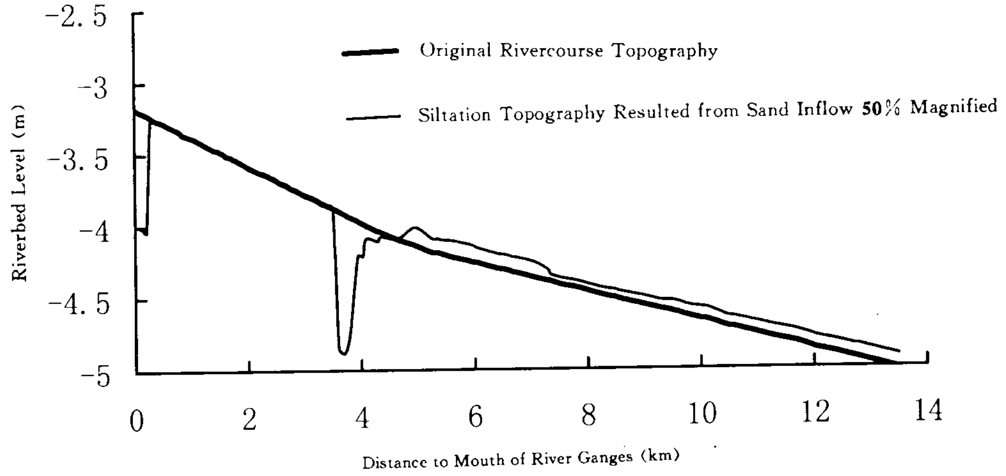


Figure 6.16 Scouring and Depositing Status along the River with 50-year Recurrence Flood Plus 10-year Recurrence Tidal Level

will decrease remarkably with the completion of projects and restoration of vegetation on both sides of the Shenzhen River.

3) Sediment impact from construction

After completion of the Project, the sediment is easy to settle down as the River is widened and deepened. At the same hydrological regime, the sand content in the Shenzhen River is much lower than before. However, the re-suspension will happen due to dredging disturbance, which will increase sand content locally.

No model is available so far to simulate the impact from the silt leakage during construction, and it is impossible for this study to carry out field experiment. Therefore, Mott MacDonald (1990) experiment results are introduced to simulate the impact of construction on sand content. According to the experiment, it is estimated that 20 kg and 25 kg sediment will be re-suspended if 1 m^3 silt is dredged by a clamshell dredger and open clamshell dredger, respectively. Upon the construction arrangement, the maximum monthly wet excavation is about 40,400 m^3. If calculated at 25 workdays every month and 12 workhours every day, the re-suspension ratios are 748 g/s and 935 g/s for the clamshell dredger and open clamshell dredger, respectively.

Stage Ⅲ Project is in the 4 km reach between the mouth of River Ganges and the Ng Tung River mouth with no large inflow from tributaries, so the sediment are mainly from the Liantang River in upstream. The effect of construction activities on sediment re-suspended in the Shenzhen River is evaluated in flood season and dry season. The monitored data about discharge and sand content in June 1996 and January 1996 are chosen for computation of flood season and dry season, respectively. The minimum and the maximum daily discharges are 0.41 m^3/s and 14.0 m^3/s, respectively, at Sha Wan station, which is responsible for monitoring the inflow from the Liantang River. In January 1996, the monthly mean discharge of 0.26 m^3/s is selected owing to little change of its daily mean discharge. They are taken as inputs at the Sha Wan River mouth, the reach between the Sha Wan River mouth and Ng Tung River mouth, and Ng Tung River mouth for model simulation. The monthly mean sand contents at all cross-sections are calculated.

Table 6.9 shows the result of sediment increasing rate caused by construction activities at 500 m upstream and 1,000 m downstream of the construction reach during the flood season and dry season.

Table 6.9 Sediment Increase Ratio Caused by the Project Construction in the Shenzhen River (%)

Construction Spots		Sha Wan River Mouth		Sha Wan River Mouth — Ng Tung River Mouth		Ng Tung River Mouth	
Distance from the Construction Spot		500 m Upstream	1 km Downstream	500 m Upstream	1 km Downstream	500 m Upstream	1 km Downstream
In the flood season	Open clamshell dredger	12.9	39.6	34.7	41.5	39.0	25.3
	Clamshell dredger	10.6	28.8	28.9	29.8	29.7	19.9
In the dry season	Open clamshell dredger	381.2	34.8	207.5	77.8	161.5	140.3
	Clamshell dredger	303.7	27.7	174.3	62.2	130.1	111.6
In the dry season	Clamshell dredger and mud-proof curtain	27.1	12.3	28.9	20.3	24.1	22.3

For the change of sediment content along the Shenzhen River caused by construction during the flood season, see Figure 6.17 to Figure 6.19.

For the change of sediment content along the Shenzhen River caused by construction during the dry season, see Figure 6.20 to Figure 6.22.

during the dry season, see Figure 6. 20 to Figure 6. 22.

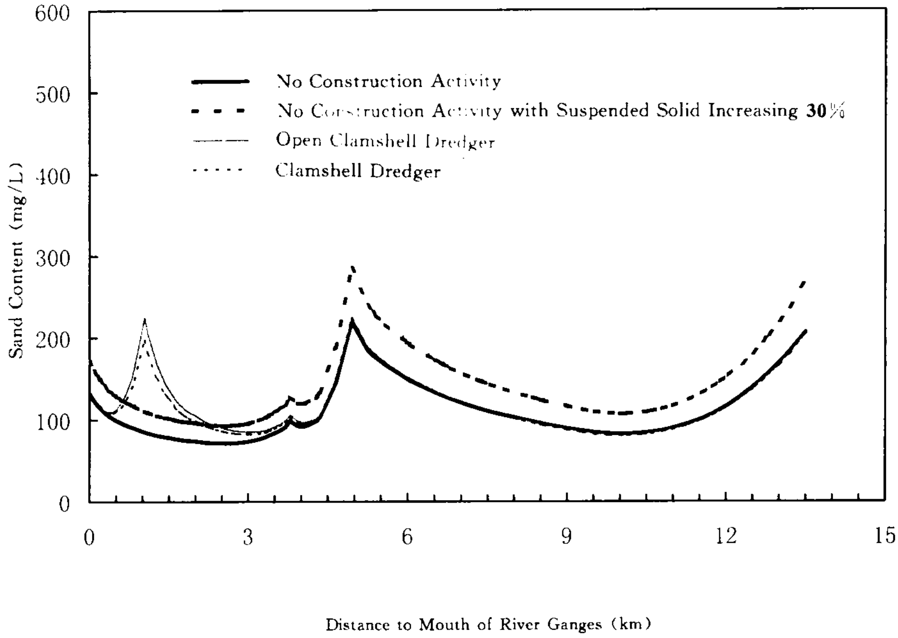


Figure 6. 17 Impact of Wetted Excavation on Sand Content in the Shenzhen River during Flood Season (Sha Wan River Mouth)

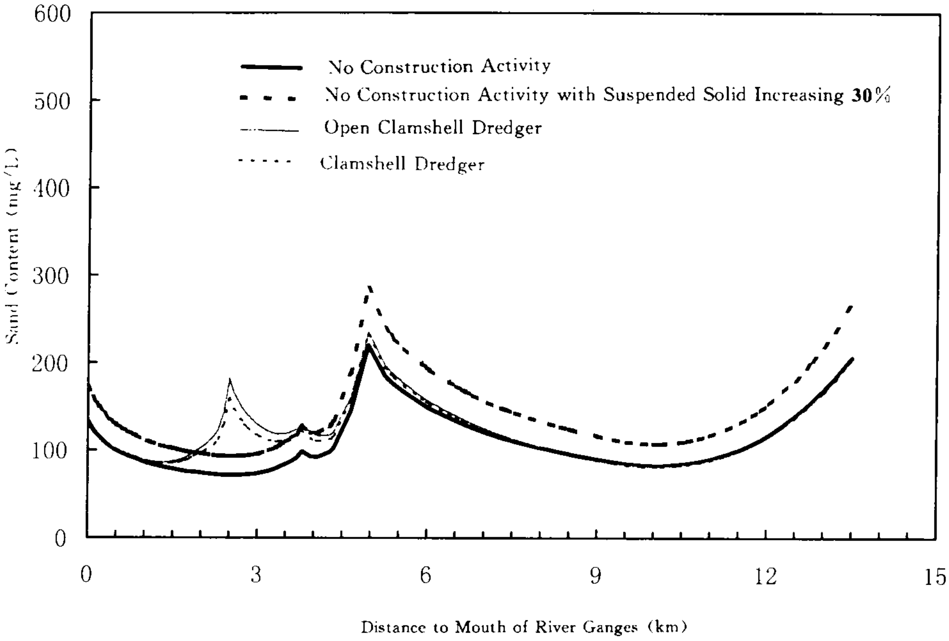


Figure 6. 18 Impact of Wetted Excavation on Sand Content in the Shenzhen River during Flood Season (from Sha Wan River Mouth to Ng Tung River Mouth)

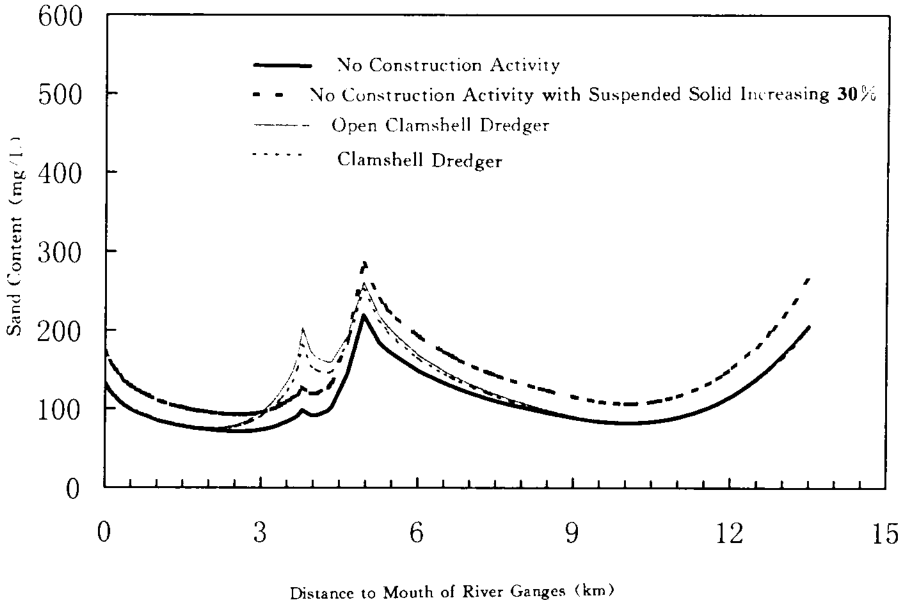


Figure 6. 19 Impact of Wetted Excavation on Sand Content in the Shenzhen River during Flood Season (Ng Tung River Mouth)

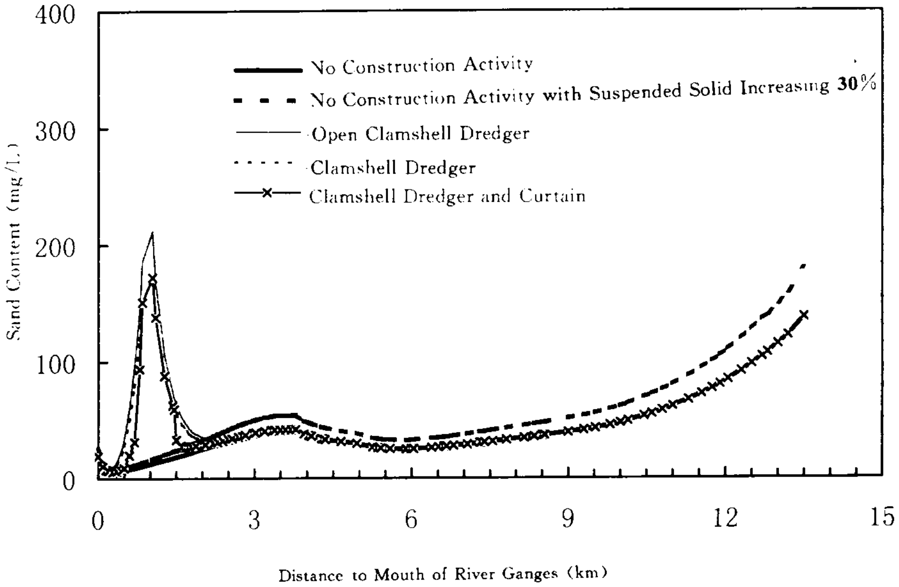


Figure 6. 20 Impact of Wetted Excavation on Sand Content in the Shenzhen River during Dry Season (Sha Wan River Mouth)

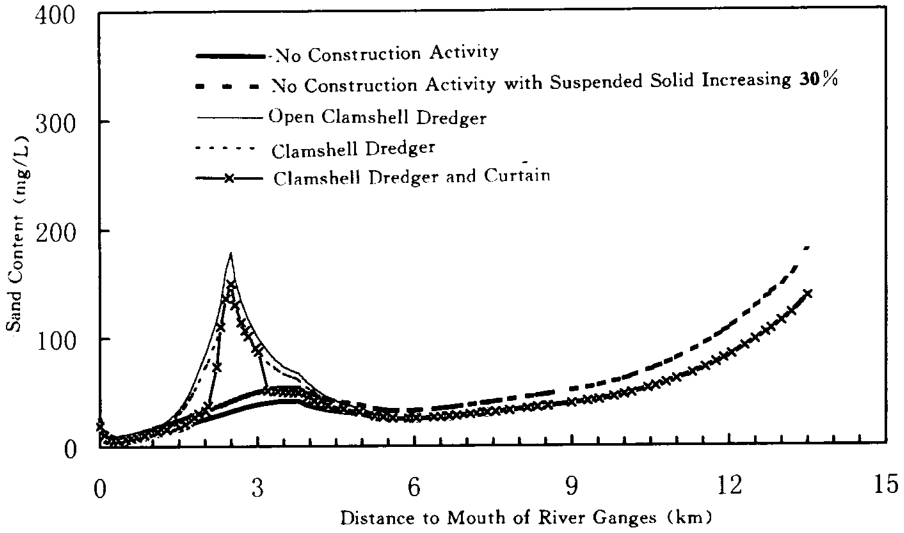


Figure 6. 21 Impact of Wetted Excavation on Sand Content in the Shenzhen River during Dry Season (from Sha Wan River Mouth to Ng Tung River Mouth)

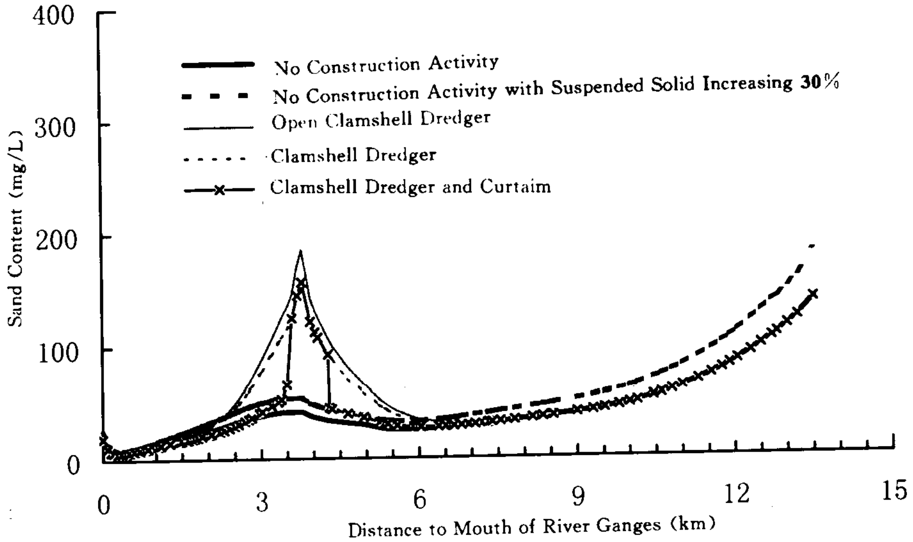


Figure 6. 22 Impact of Wetted Excavation on Sand Content in the Shenzhen River during Dry Season (Ng Tung River Mouth)

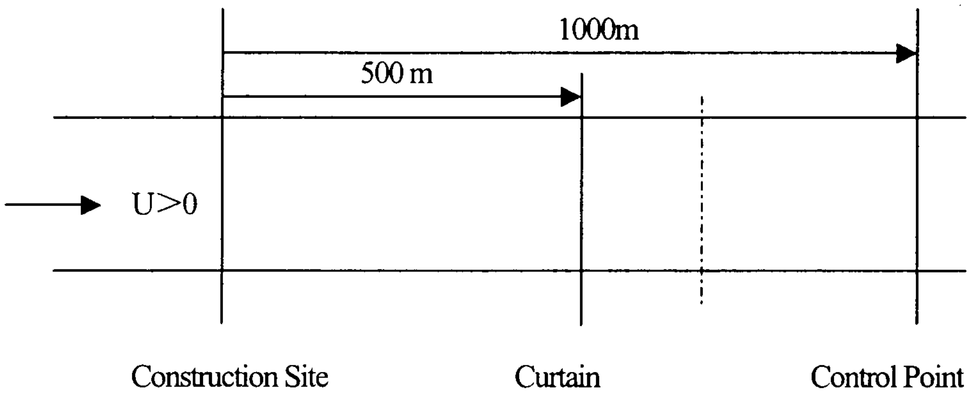


Figure 6.22A Conceptual Model for Sediment Transport with Sediment-proof Curtain

The computational results show that the sand content will increase sharply near the construction spots by using the two kinds of dredger mentioned above. However, the sand content will reduce soon due to deposition effect. With the common action of runoff and tide, the re-suspended sediment transportation distance to downstream is longer than that to upstream.

During the flood season, if the open clamshell dredger is used, the suspended sediment content will increase by 12.9 - 39.0% at 500 m upstream from dredging spot, and that will increase by 25.3 - 41.5% at 1000 m downstream from dredging spot. If the clamshell dredger is used, the increase of suspended sediment will be less than 30% at both spots. Generally, 30% can be used as the criteria to judge whether the impact of re-suspended sediment on water quality is acceptable. This shows the clamshell dredger is the suitable machine for most reaches of the Project and the open clamshell dredger is not suitable.

During dry season, the Shenzhen River is controlled by tides due to very small runoff. At the Sha Wan River mouth and its upstream, due to the action of tides, water velocity is very slow and the re-suspended sediments deposit quickly. In the other reaches greatly affected by the tides, the tide velocity increase will be helpful for the re-suspended sediment transporting up and down. Therefore, if dredging during the dry season, except relative little effects at the Sha Wan River mouth, the sediment increase by much more than 30% will be caused by the construction activities at 500 m upstream and 1000 m downstream from dredging spots if construction is carried in other sections. The mitigation measures should be taken to alleviate the effect of construction activities.

The original channel is very narrow in the reach of Stage Ⅲ Project. After completion of the Project, the width of the channel will be no more than 50 m, and no navigation will be demanded in this channel. It will be an effective measure to alleviate the effect of construction in the River that the mud-proof curtain at the place is established to surround the construction spots. Upon the data acquired by the EIA in Hong Kong and recommended by Environmental Protection Department of the HKSAR Government, the silt curtain could reduce 60% of the re-suspended sediment. It appears that the distance from the silt curtain to the construction spot is shorter. It is more favorable to control the sediment transportation, but it is against to dredging construction. After calculation and comparison of different location of the silt curtain time after time, it's showed that, during the dry season, when the clamshell dredger is put into operation, the silt curtain is better to set up at 200 m upstream and 500 m downstream from the construction spot. Thus, not only the effect of the re-suspended sediment could reach the allowable level, but also it can satisfy the requirement of the dredging construction. After set up the silt curtain, the sediment transportation calculate model is showed in figure 6. 22A (the silt curtain is at downstream from the construction spot, ebb tide). When ebb tide ($U>0$), it is calculated normally with the sediment transportation calculate model in the section up the silt curtain (considering the re-suspended sediment in construction), at the place of the mud-proof curtain, the sediment content at the upstream calculated with the sediment transportation calculate model is Ci (include the baseline C0 and re-suspended sediment), the sediment content at the downstream is $(C_i-C_0)\times 40\%+C_0$. And it is calculated normally with the sediment transportation calculate model at the downstream. During flood tide, the sediment content at the place of the mud-proof curtain is controlled with the first calculation cross section (showed as broken line) at the downstream, and here the mud-proof curtain at the downstream does not function. They calculated normally with the sediment transportation calculate model both at the upstream and the downstream (considering the re-suspended sediment in construction). The calculation of setting up the mud-proof curtain at the upstream of the construction spot is similar, but the treatment process with the flood tide and ebb tide is just the other way round. They are considered at one time to set up mud-proof curtain at upstream and downstream in model calculation.

The results calculated show that, during dry season, when the clamshell dredger is put into operation, the effect of the re-suspended sediment could reach the allowable level if the mud-proof curtain is set up at 200 m up stream and 500 m downstream from the construction spot. For the sediment load in the Shenzhen River with the mud-proof curtain, see Figure 6. 20 to Figure 6. 22. The effect of construction activities on the Shenzhen River sediment content at 500 m upstream and 1000 m downstream from construction spots is listed in Table 6. 9.

(3) Water quality model

1) Basic information

In 1994, 50 hours in-phase measurements and monitoring of water quantity and quality for the EIA of Stage Ⅰ and Stage Ⅱ Project was carried out jointly by Shenzhen Environmental Monitoring Station and South China Environmental Research Institute. For this EIA study, measurement and monitoring were also carried out on 29 July 1998 and 7 August 1998 respectively. The first time encountered the construction of Stage Ⅱ Project. Considering the potential effect caused by the dredging operation, the data collected in 1994 is used for model calibration.

The pollution sources information is quoted from Shenzhen Environmental Protection Monitoring Station. It is point sources along the Shenzhen River and has been used in EIA for Stage Ⅰ and Stage Ⅱ Project.

The river channel information is taken from the morphological map made in 1985 and the data measured during Stage Ⅱ and Stage Ⅲ Project.

The simulation area is from downstream of River Ganges to the Shenzhen River mouth. Based on the inflow and pollution sources locations, the reach is divided into seven units for model calculation, which are downstream of River Ganges-San Pan River mouth-Lo Wu Bridge-Yumin village-Buji River mouth-Futian River mouth-Yunong village-Shenzhen River mouth. The location of the pollution sources and the monitoring cross-sections, as well as the division of units are shown in Figure 6. 23.

The mean values within the tide period used in the model are arithmetic average of the date in continuous monitoring, and the hydraulic parameters take these mean values.

$$C_j=\frac{1}{n}\sum_{i=1}^{n}C_{ij} \qquad (6-7)$$

Where

C_{ij} is the measured concentration of pollutant j for the ith monitoring (mg/L);

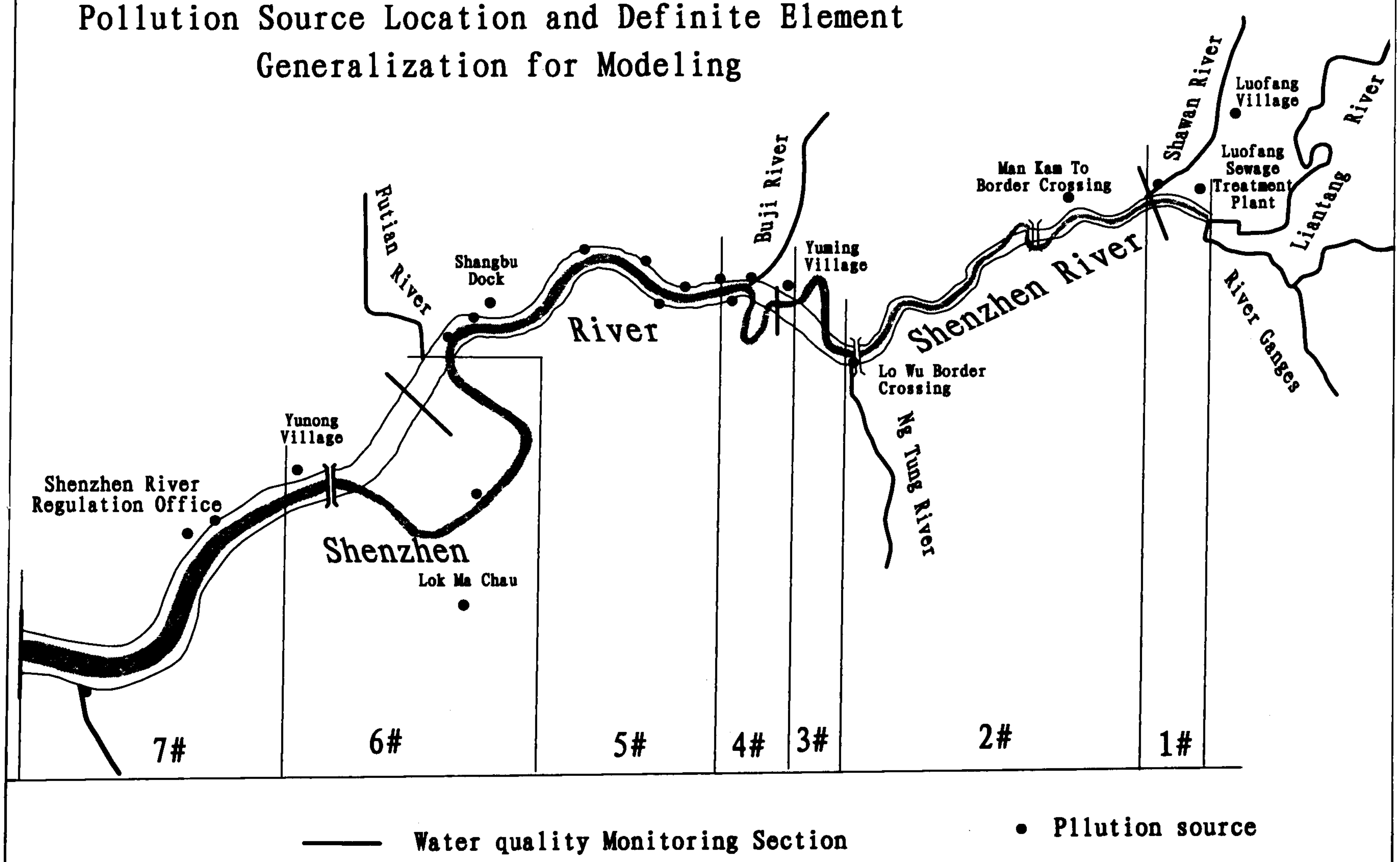
C_j is average cross-section concentration within the tide period for pollutant j (mg/L);

n is monitoring times.

The average water depth and discharge are obtained from the water depth and discharge profiles at the subject cross-section.

$$H=\frac{1}{\sum_{i=1}^{n}\triangle t_i}\sum_{i=1}^{n}H_i\triangle t_i \qquad (6-8)$$

Figure 6.23 Sketch Map for WAter Quality Monitoring, Pollution Source Location and Definite Element Generalization for Modeling



$$Q=\frac{1}{\sum_{i=1}^{n}\triangle t_i}\sum_{i=1}^{n}Q_i\triangle t_i \qquad (6-9)$$

Where:

H is average water depth within the tide period (m);

H_i is the average depth for the ith monitoring (m);

Q is the average discharge within the tide period (m^3/s);

Q_i is the average discharge for the ith monitoring (m^3/s);

Δt_i is the monitoring interval (s);

n is the number of monitoring.

The data to the model for the simulations before and after the Project are listed in Table A6. 1 and Table A6. 2 of Appendix 6.

2) Parameter calibration and verification

The longitudinal dispersion coefficient and other coefficients are determined based on literatures review and site measurements, which not only guarantee the physical meaning, but also ensure the accuracy requirement.

About the coupling model for BOD DO, the objective function is

$$J_i(D_{xi},K_{di},K_{ai})=\sum_{j=1}^{n}[\lambda(L_{ij}-L_{ij}^{o})+(1-\lambda)(D_{ij}-D_{ij}^{o})] \qquad (6-10)$$

Where:

L_{ij}^{0} is the baselined concentration of BOD$_5$;

L_{ij} is the computed value of BOD$_5$;

D_{ij}^{0} is the baselined concentration of DO;

D_{ij} is the computed value of DO.

λ is the relative weight coefficient for BOD$_5$ and DO, which can be adjusted in line with the accuracy and precision of the data.

Through optimization, the minimum value of the objective function can be obtained, which is

$$J_i(DL^o_{xi}, K^o_{di}, K^o_{ai}) = \min\left\{\sum_{j=1}^{n}\left[\lambda(L_{ij}-L^o_{ij})+(1-\lambda)(D_{ij}-D^o_{ij})\right]\right\} \quad (6-11)$$

Where DL^0_{xi}, K^0_{di} and K^0_{ai} are the estimated values of Kd, Ka and DL.

The constraints for optimization are

$0.38 \leqslant Kd < 1.0$

$0.302 \leqslant Ka < 1.0$

$DL \geqslant 38.8$.

Other single-parameters in water quality model are determined in similar way.

Based on the data about hydrology and water quality measured in June 1994, the model parameters are obtained through comprehensive search, which are presented in Table 6.10 and Table 6.11. The parameter calibration and verification are provided in Table 6.12, and Figure A6.8 to Figure A6.15 in Appendix 6.

Table 6.10　　BOD-DO Coupled Model Parameter Estimation

River Reach Number	1	2	3	4	5	6	7
K_d(1/d)	0.246	0.246	0.204	0.143	0.146	0.184	0.56
K_a(1/d)	0.302	0.302	0.671	0.62	0.624	0.3	0.302
D_L(m^2/s)	172	172	47.2	250	210	230	160

Table 6.11　　Attenuation Coefficient for Other Pollutants (1/d)

River Reach Number	1	2	3	4	5	6	7
COD	0.08	0.08	0.08	0.08	0.08	0.05	0.05
Total N	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total P	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Total Coliforms	2550	2550	2474	2420	3000	2817	22400
Total Cu	2.1	2.1	2.828	1.19	0.407	0.154	0.15
Total Pb	0.545	0.545	0.227	0.479	0.73	0.82	0.14

Table 6.12 **Comparison of Estimated Value with Monitoring Result**

River Reach		San Pan River			Yunong Village			Shenzhen Estrary		
Parameter	Unit	Base-lined	Calcu-lated	Error (%)	Base-lined	Calcu-lated	Error (%)	Base-lined	Calcu-lated	Error (%)
BOD	mg/L	36.99	35.4	−4.3	24.41	25.72	5.37	17.52	17.51	−0.06
DO	mg/L	0.16	0.16	0.0	0.25	0.29	16.00	0.25	0.19	−24.00
COD	mg/L	19.92	20.68	3.8	21.87	18.37	−16.00	17.24	16.89	−2.03
Total N	mg/L	12.93	12.17	−5.9	12.59	10.11	−19.70	11.91	9.63	−19.14
Total P	mg/L	1.96	1.72	−12.2	2.19	1.62	−26.03	2.19	1.6	−26.94
Total Coliforms	10^4/cell/L	13985	14017	0.2	26385	26384	0.00	8631	8626	−0.06
Total Cu	mg/L	0.0199	0.0248	24.6	0.02187	0.0193	−11.75	0.0172	0.0144	−16.28
Total Pb	mg/L	0.0074	0.0073	−1.4	0.00978	0.0103	5.32	0.0108	0.0074	31.48

It should be pointed out that the degradation coefficient of total coliform in the Shenzhen River is high, especially near the estuary. The possible reason is that the Shenzhen River is affected by tide, which is not suitable for coliform to live in due to high salinity.

For nitrogen and phosphorus, only total nitrogen and total phosphorus are studied in the water quality model. Absorption, desorption and deposition are not considered for the heavy metal, in the study, which are lumped into the comprehensive degradation coefficient. It is a rough estimate, but is suitable to such a severely polluted the Shenzhen River.

Table 6.13 is the verification results by using the data measured from 13:00 on 30 June to 13:00 on 1 July 1994. The results are shown in Figure A6.16 to Figure A6.23 of Appendix 6. The results show that most of the errors are less than 30%. So the accuracy of the model is acceptable.

Table 6.13 **Water Quality Model Pridiction Result**

Section		San Pan River			Yunong Village			Shenzhen Estuary		
Parameter	Unit	Base-lined	Calcu-lated	Error (%)	Base-lined	Calcu-lated	Error (%)	Base-lined	Calcu-lated	Error (%)
BOD	mg/L	38.45	35.96	6.5	21.59	26.02	−20.52	15.06	17.71	−17.60
DO	mg/L	0.18	0.13	27.8	0.27	0.27	0.00	0.26	0.21	19.23
COD	mg/L	20.37	21.4	−5.1	20.4	18.2	10.78	16.1	15	6.83
Total N	mg/L	14.24	12.6	11.5	13.15	10.35	21.29	11.83	9.79	17.24
Total P	mg/L	2.13	1.72	19.2	2.24	1.62	27.68	2.18	1.60	26.61
Total Coliforms	10^4/cell/L	14000	14017	−0.1	28667	26384	7.96	7133	8626	−20.93
Total Cu	mg/L	0.0204	0.024	−17.6	0.0204	0.0199	2.45	0.0161	0.0182	−13.04
Total Pb	mg/L	0.0069	0.0066	4.3	0.0094	0.0104	−10.64	0.0114	0.009	21.05

3) Water quality impact prediction

Table 6. 14 gives the computed results of different pollutants under the current pollution sources before and after completion of the Project using the model described above. Figure A6. 24 to Figure A6. 31 of Appendix 6 show the comparison of the pollutant concentrations along the River before and after the Project under the existing pollution situation.

Table 6. 14 Simulated Results before and after Completion of the Project under Existing Condition

Parameter	River Reach	1#	2#	3#	4#	5#	6#	7#
BOD (mg/L)	Before	22. 12	19. 21	34. 70	31. 15	29. 94	25. 35	17. 27
	After	19. 67	17. 78	23. 39	19. 58	16. 98	12. 94	8. 83
DO (mg/L)	Before	1. 13	0. 99	0. 29	0. 17	0. 22	0. 03	0. 1
	After	1. 31	1. 70	1. 10	0. 56	0. 36	0. 38	1. 9
COD (mg/L)	Before	17. 99	19. 79	20. 83	19. 66	19. 37	17. 70	14. 49
	After	14. 27	16. 15	16. 89	15. 07	13. 93	12. 11	10. 19
Total N (mg/L)	Before	13. 883	10. 771	12. 963	11. 950	11. 523	10. 060	8. 043
	After	13. 440	11. 585	11. 509	9. 853	8. 647	7. 041	5. 563
Total P (mg/L)	Before	1. 961	1. 561	1. 746	1. 663	1. 656	1. 537	1. 225
	After	1. 976	1. 758	1. 693	1. 509	1. 368	1. 143	0. 892
Total Coliforms (10^4/cell/L)	Before	98544	7031	14017	5350	29484	26384	8626
	After	7642	847	9733	2218	6697	14942	1929
Total Cu (mg/L)	Before	0. 0255	0. 0253	0. 0239	0. 0213	0. 0221	0. 0194	0. 0145
	After	0. 0232	0. 0135	0. 0150	0. 0121	0. 0111	0. 0089	0. 0064
Total Pb (mg/L)	Before	0. 0088	0. 0085	0. 0071	0. 0069	0. 0081	0. 0102	0. 0074
	After	0. 0087	0. 0066	0. 0062	0. 0056	0. 0055	0. 0058	0. 0044

The water quality in 2010 is predicted with the assumption that the pollution load increases by 50% based on the current situation. The results are given in Table 6. 15. Figure A6. 32 to Figure A6. 39 of Appendix 6 give the comparison of the pollutant concentration along the River before and after the construction, with 50% increase of pollution load based on the current pollution situation.

After the Project, the watercourse will be straightened, beneficial to water flowing. According to the simulation result, the water quality will be improved greatly in the reach downstream from the mouth of River Ganges. As the discharge and channel storage are increased greatly due to watercourse widened and deepened, the tide volume will also increase greatly, which will benefit water quality of the Shenzhen River.

Table 6.15 Prediction Water Quality before and after Completion of the Project (Pollution Source in 2010)

Parameter	River Reach	1#	2#	3#	4#	5#	6#	7#
BOD (mg/L)	Before	30.17	26.77	51.19	46.01	44.29	37.44	25.11
	After	26.48	23.75	33.14	27.75	24.06	18.10	11.91
DO (mg/L)	Before	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	After	0.01	0.01	0.01	0.01	0.01	0.01	0.01
COD (mg/L)	Before	23.84	28.01	30.54	28.86	28.49	25.97	20.82
	After	18.08	22.02	23.76	21.11	19.40	16.51	13.33
Total N (mg/L)	Before	17.327	14.218	18.633	17.238	16.706	14.577	11.508
	After	16.740	15.151	15.768	13.531	11.882	9.553	7.344
Total P (mg/L)	Before	2.424	2.050	2.497	2.390	2.395	2.228	1.760
	After	2.454	2.290	2.305	2.065	1.878	1.558	1.190
Total Coliforms (10^4/cell/L)	Before	147797	10547	21026	8025	44226	39575	12938
	After	11453	1270	14600	3327	10046	22413	2894
Total Cu (mg/L)	Before	0.0314	0.0352	0.0348	0.0310	0.0325	0.0285	0.0213
	After	0.0283	0.0181	0.0213	0.0172	0.0160	0.0127	0.0091
Total Pb (mg/L)	Before	0.0108	0.0115	0.0101	0.0099	0.0119	0.0150	0.0107
	After	0.0107	0.0087	0.0084	0.0078	0.0078	0.0081	0.0059

Upon the simulation results, the Project will be beneficial to the water quality improvement in the Shenzhen River. But the improvement is relative and limited since the River is already severely polluted by the pollutants discharged along the bank, which is the main cause for the water quality deterioration. Therefore, the improvement for water quality will be limited and the water quality still fails to meet the functional demands after completion of the Project. If it is necessary for the Shenzhen River pollution problem to be solved once and for all, fundamental measures must be taken to strengthen the water pollution control and enforce the wastewater treatment.

In association with the economic development on both sides, the positive effects from the Project will disappear if pollution control and wastewater treatment are not enhanced. According to the simulation results in the planning year of 2010, the water quality will deteriorate quickly if the pollution load increases by 50%. DO in all river reaches will decrease to the lowest level, and the concentrations of other contaminants will increase greatly. In recent years, the water pollution control is enforced gradually by both sides. For examples, Luofang wastewater plants has be put into operation, Binhe wastewater plants has been reconstructed and enlarged. A project of intercepting wastewater for marine discharge has been planned in Shenzhen. A water pollution control regulation, a livestock wastes control and the north area integral wastewater control planning will be implemented in Hong Kong. All these programs have great significance on water quality improvement in the Shenzhen River. It can be proved by the fact that the water quality did not deteriorate recently even though the economy has been developed rapidly on both sides. Therefore, the simulations in this study are relatively conservative, which give the water quality impact upon the worst situation.

4) Impact prediction for construction activities

In order to assess the worst effect of construction on the water quality of the Shenzhen River, the pollution load released from the bed sediment is estimated based on the data from elutriation test (listed in Table A6. 6 of Appendix 6). Because the elutriated amount of other pollutants is very small except for total nitrogen, the impact prediction for construction activities is conducted only on total nitrogen.

Using the test result after 72-hour elutriation, the following empirical relation equation can be built up upon the water-soil ratio and the elutriation concentration of total nitrogen.

$$Y=89.57X+8.45\ (R=0.938) \qquad (6-12)$$

Where

Y is the elutriation concentration of total nitrogen (mg/L);

X is the water-soil ratio;

R is the correlation coefficient.

According to the design of Stage Ⅲ Project, the maximum monthly wet excavation quantity is 40,400 m^3. The results of Mott MacDonald experiment (1990) show that the suspended sediment caused by dredging will amount to 25 kg/m^3. Upon this estimation, the monthly maximum of re-suspended sediment will amount to 1,010 tons during the wet excavation of Stage Ⅲ Project. Due to small amount of the resuspended sediment, the weight ratio between re-suspended sediment and runoff will change little if the river flow changes slightly. Accordingly, the elutriated concentration of total nitrogen will change little. Suppose the runoff of the Shenzhen River is 0.5 - 5 m^3/s, the elutriated concentration of total nitrogen will amount to 8.53 - 8.62 mg/L computed from the above empirical equation. Taking the larger value into the model stated in Section 6.4.3(3)2), the simulated results and the comparisons with existing status are shown in Table 6.16.

Table 6.16 Impact of Construction Activity on Total Nitrogen (mg/L)

Number of the Reach	1#	2#	3#	4#	5#	6#	7#
Without construction impact	13.44	11.58	11.51	9.85	8.65	7.04	5.56
With construction impact	13.78	13.47	12.73	10.78	9.36	7.55	5.89
Impact ratio(%)	2.53	16.32	10.60	9.44	8.21	7.24	5.94

From Table 6.16, the impacts on water quality caused by construction activities mainly occur at downstream and the reach involved in Stage Ⅲ Project, especially from the San Pan River mouth to the Buji River mouth. The impact is less than 20%.

6.5 Project Impact Assessment

6.5.1 *Modification to Hydrodynamic Conditions*

After the Project is completed, the river course will be straightened and the mean width of the Shenzhen River will reach 80 m. The water level will lower obviously under various design frequency ($p=2\%$, $p=10\%$). The level for flood passing will be 1- 2 m lower than the embankment level. In the downstream from River Ganges, the maximum flood level will be decreased by more than 3 m and the water level in the Shenzhen estuary will decrease remarkably. The 50-year return period flood could safely pass through the Shenzhen River. The frequency of flood disaster will decrease significantly. After completion of the Project, the exchange of tide and river water will increase by about 90%. The channel storage capacity will also increase by 3.2 times due to the wider and deeper channels.

After the two-year operation of the Project, due to siltation in the channel, the water level in the reach of Stage Ⅲ Project and 3 - 4 km downstream from Lo Wu bridge will rise.

6.5.2 *Impact on Sediment Transportation*

1) Construction impact

When Stage Ⅲ Project starts, Stage Ⅰ and Ⅱ Project will have been completed and put into operation. At that time, the average river width of the reaches from Lo Wu to the river mouth will be 50~140 m. The siltation is dominant in this reach except during the flood season. Upon the design, the total excavation amount is 2.02 million m^3 for Stage Ⅲ Project, and the estimated leakage is 18,000 m^3. It is simulated that the leaked sediment will deposit mostly in the reach involved in Stage Ⅲ Project and the reach 2 km downstream from Lo Wu Bridge, with a average siltation depth of 0.08 m.

The results computed from sediment transport model show that the main reaches affected by the re-suspended sediment of the Project are the mouth of River Ganges and the 6 km long reach downstream from the river mouth. The effects of the re-suspended sediment in part reaches of Stage Ⅲ Project will vary greatly during different seasons.

Different dredgers could cause different effects in different seasons. During flood season, if the open clamshell dredger is used for wet excavation, the sediment content will increase by 10.60 - 39.0% at 500 m upstream from the construction spot, and monthly mean sediment content will increase by 25.3 - 41.5% at 1000 m downstream, which will lead to SS exceeding the permitted limit. If the clamshell dredger is used for wet excavation, the sediment content will increase by 10.6 - 29.7% at 500 m upstream from the construction spot, and monthly mean sediment content will increase by19.9 - 29.8% at 1000 m downstream, which is acceptable. It shows the open clamshell dredger has a greater effect on the re-suspended sediment if no mitigation measures are taken. But the clamshell dredger is the recommended machine for wet excavation of Stage Ⅲ Project with no unacceptable effect.

During dry season, the Shenzhen River is controlled by tides due to very small runoff. The sediment concentration will increase with the wet excavation by 130.1 - 381.2% at 500 m upstream, and 27.7 - 140.3% at 1000 m downstream from when the dredging takes place without mitigation measure. The operation of the clamshell dredger has greater impact. Thus, the rational mitigation measures should be taken to alleviate the effect of construction activities. The simulated and calculated results of dredging effect show that, during dry season, when clamshell dredger is used, the effect of the re-suspended sediment could meet the allowable level if a mud-proof curtain is set up at 200 m upstream and 500 m downstream from the construction spot.

(2) Operation impact

1) Sediment transport impact

The computed results of sediment scouring and depositing (see Table 6.8) show that, before Stage Ⅲ Project, the strongly scoured sediment from the reach of the Project all deposit in the channel of the finished Stage Ⅰ and Ⅱ Project and form a sand ridge in downstream from Lo Wu Bridge, which will affect the flood control capacity of Stage Ⅰ and Ⅱ Project. After completion of the Project, most of the sediment from upstream of Lo Wu Bridge will be deposited in the widened and deepened channel of Stage Ⅲ Project so that the sediment siltation will reduce in the reaches of Stage Ⅰ and Ⅱ Project. Stage Ⅲ Project will benefit by reducing downstream sedimentation and have the benefits of flood control of the Project.

After the Project is put into operation, the sand from tributaries will deposit in the downstream reach of the Shenzhen River due to the channel being widened and deepened and water velocity being slower in normal year. Except for slightly scouring in the narrow reach of Lo Wu Bridge, the annual siltation amount in the Shenzhen River is 160,000 m^3 in normal year. The main siltation places are the reaches downstream from the mouth of River Ganges, 2 km upstream and down-stream from Lo Wu Bridge, and 3 km upstream of the river mouth. The thickness of siltation in the other reaches is rather even with a range of 0.07 - 0.23 m. After two-year operation of the Project, the maximum siltation thickness caused by sediment from tributaries could exceed 0.5 m in the reach 1-2 km downstream from Lo Wu Bridge. When encountering severe flood ($P=2\%$), with the action of flood, the strong scouring will take place in the reach downstream from the mouth of River Ganges and the narrow reach near Lo Wu Bridge. The large quantities of sediment carried by flood will deposit in the downstream of Lo Wu Bridge and the original sediment deposited there will be transported to further downstream.

The interannual sediment deposition of the Shenzhen River is basically one-directional.

After two years consecutive siltation, parts of the Shenzhen River will not satisfy the design demand. Due to the randomness of upstream flood, maintenance dredging for the Shenzhen River will be necessary to guarantee the safety of flood passage during operation of the Project.

Since souring will happen locally at downstream of the mouth of River Ganges and the narrow part of Lo Wu reach during the flood season, the protection of the corresponding embankment and Lo Wu footbridge should be enhanced.

2) Dredging measure

The computed results of sediment transport show that, after completion of the Project, the sediment from the tributaries will deposit in the regulated channel, which will cause the riverbed ascending, the cross-section for flood passage shrinking and thus the flood level lifting. As a result, the designed conditions of the Project could not be met and the aim of flood control could not be reached. Thus dredging channel is necessary. During flood season, although scouring will only occur in part reaches of the Shenzhen River, it will not change the siltation status. Even if 50-year return period flood encounters 10-year return period flood, the obvious result is to transport the sediment from upstream to downstream gradually, which could not be washed effectively. Thus, dredging is the most effective measure to remove sediments.

According to the computed result of sediment transport simulation, the sediment deposited in the Shenzhen River amounted to 160,000 m^3 after one year's operation, and 337,000 m^3 after two years' consecutive operation. For the siltation situation after 3 - 5 years' operation of the Project, see Table 6. 8. The main siltation takes place at the reach below the mouth of River Ganges, the reach 2 km upstream and downstream of Lo Wu Bridge, and in the vicinity of the Shenzhen estuary, where dredging sediment should be conducted. The best dredging period is in the flood season.

The interval for dredging is depended on the inflow of sand from upstream and downstream of the Shenzhen River, and siltation status. It is suggested that the main siltation location should be monitored every year. The rational siltation levels should be: silted thickness not more than 0. 5 in the upstream reach of Lo Wu Bridge; the bed elevation no more than -3 m below Lo Wu Bridge or -4 m at the river mouth. The completed dredging plan should be made after a detailed study and included in the project operation manual. It is suggested that the bed sediment should be monitored and tested before dredging. The dredged sediment should be dumped to marine area as much as possible. If necessary, environment impact analysis should be done for the dredging work.

(3) The potential impact of maintenance dredging

From the calculation, there will be a lot of sediment settled in the regulated channel after construction of the Project. The sediment of the upper reach is mainly from the Buji River, the Ng Tung River and the Liantang River. The sediment of the lower reach is mainly from the estuary. After two years' operation, the designed condition will not be reached owing to siltation. So it is necessary to dredge the channels regularly. Since most of the re-suspended sediment from dredging will settle in the channel, increase of sand content from dredging is less than 30% at the places 1 km upstream and downstream away from the operation site if proper dredgers and mitigation measures are selected.

6.5.3 *Potential Impact on Water Quality*

1) Construction period

The Project will not deteriorate the water quality since no pollution load is added by the Project itself.

The bottom mud of the Shenzhen River has been severely polluted by inorganic and organic pollutants. Under the usual condition, the sediment re-suspension and pollutant release arising from the dredging operation will locally affect the water quality. The extent is determined by the type and number of construction plant and the season of construction, especially the size and site of construction. Because when Stage Ⅲ Project starts, Stage Ⅰ and Ⅱ of the Project will have been completed and put into operation, the transport distance of the sediment will be limited. On the other hand, the Shenzhen River is polluted seriously, and the leached amount of the sediment pollutants will not be large, so the dredging will not affect the water quality of the River remarkably.

Table A6.4 of Appendix 6 gives the experimental results of pollutant elutriation in pure water, with the state *Standards for Toxicity Experiment Method of Waste Solid Elutriation of Non-ferrous Metal Industry* (*GB*5086-85). It is found that the total nitrogen in polluted spoil has the largest elutriation capability in pure water, while the others are very limited. Also found from the elutriation of total nitrogen is that, the longer it is elutriated in the fresh water, the more it will be released. However the equilibrium state will be reached after 240 hours, when the concentration is almost the same as that in the Shenzhen River. The estimated results of the total nitrogen in the Shenzhen River are listed in Table 6.16, which show that the increase of total nitrogen caused by construction activities will be less than 20%.

Table 6.17 presents the results of pollutant release experiment using the water from the Shenzhen River (quoted from *Research for Environment Impact Assessment of the Shenzhen River Regulation Project* made jointly by Shenzhen and Hong Kong). It can be seen that pollutant with maximum increase of concentration is COD, which is however less than 10% when water-soil ratio is 1000 : 1.

The results of these two experiments show that the leached pollutant from re-suspended sediment is very limited. The heavy metal content has a decreasing tendency due to sediment absorption and the current organic pollutants are at a stable condition in the River. Therefore the soluble contaminants will not increase greatly and water quality will not be deteriorated in the process of dredging.

Table 6.17 Pollutant Leaching Procedure for Testing Toxicity of Solid Waste (mg/L)

Water and Soil Ratio	Total N	Total P	COD	Total Cu	Total Pb
No sediment added	26.97	2.82	19.39	0.018	0.048
1 : 100	24.50(—)	0.55(—)	20.13(3.8%)	0.014(—)	0.048(0%)
1 : 1000	28.48(5.6%)	1.87(—)	21.06(8.6%)	0.014(—)	0.048(0%)

Note: The reduction (—) is caused by adsorption of sediment.

(2) Operation period

From the results, the water quality of the River will be better than the existing condition together with the improvement of dilution and transport condition.

(3) Maintenance dredging

The maintenance dredging during operation period will not increase the pollution load. So the water quality will not be degraded as predicted for the construction period.

6.5.4 *Potential Impact on the Liantang River and the River Ganges*

1) Hydraulic condition

After Stage Ⅲ Project has been implemented, the 50-year return period flood will be controlled below the mouth of River Ganges. The water level there will decline due to smoother discharge. The flood-carrying condition in upper reaches will be improved and the loss from flooding will be reduced.

2) Sedimentation

With the improvement of water flowing condition, the local reverse scouring will occur in the reach above the mouth of River Ganges. As a result, the channel will be deeper and wider. The extent of scouring will gradually decrease towards the upstream direction. The scoured sediment will settle in the Stage Ⅲ Project reach below the mouth of River Ganges. After operation of the Project for a certain period, the bed formation will be balanced, and the river channel will become stable.

3) Water quality

The water flowing condition improvement will benefit the pollutants transport downward and increase the environmental capacity of the River Ganges. Thus Stage Ⅲ Project will benefit the water quality improvement in the reaches above the mouth of the River Ganges.

6.5.5 *Impact from Tidal Intrusion*

According to the hydrologic observation data of the Shenzhen River, the tide will move up to the mouth of San Pan River when the river current is low. The tide can reach further during extremely large tide. The results of hydrodynamic model show that the exchange amount of tide and tidal current will increase to a large extent due to the wider and deeper channel. But the distance of tidal intrusion will not change significantly. The living conditions for aquatic biota in the Shenzhen River would not be greatly changed due to tidal intrusion after completion of the Project.

6.5.6 *Impact on Water Quality from Bridge Reconstruction*

Affected by Stage Ⅲ Project, five bridges must be reconstructed, which are Lo Wu Railway Bridge, Lo Wu Old Footbridge, Lo Wu New Footbridge, Man Kam To Old Bridge and Man Kam To New Bridge. The impacts mainly come from two aspects. One is the sediment re-suspension due to base excavation, and the other is sand and pollutants from the water used for concrete mixing. For the first one, as bridge reconstruction work will be conducted before the river channel work. The impact will not be large enough to affect water quality since the excavation volume is already included in the total volume of the Project, and its effect on water quality has been evaluated in the assessment of construction activities for the whole Project. As for the second one, the water quality will not be affected as commercial concrete is used. Therefore, the bridge reconstruction will not cause unacceptable impacts on water quality.

6.6 Mitigation Measures

6.6.1 *Construction Method*

The water pollution load will not increase during dredging operation, while sediment re-suspension is the main problem. In the dredging work, the sediment re-suspension should be avoided as much as possible to reduce the transport distance effectively.

With a view to the Stage Ⅲ Project features and the analysis to sediment re-suspension and transportation, the clamshell dredger should be used during flood season since it is suitable for shallow water dredging and its impact is acceptable. During dry season, the silt curtain should be used at upstream and downstream of dredging spot in order to prevent the re-suspended sediment from moving upward and downward effectively. The silt curtain must cross-over the river, unless allowing passage of ship. Otherwise, the curtain is closed. If the curtain is set up 200 m upstream and 500 m downstream of dredging region, the impact of construction on the sediment re-suspension is acceptable upon the computed results in Section 6.3.4. The environmental supervision should be executed in the process of construction. If exceeding standard is found, the dredging intensity should be reduced to make the water quality nearby satisfying the relevant standard.

Because no navigation requirement is imposed on Stage Ⅲ Project and the width of the channel is not more than 50 m after the Project, it is feasible to use silt curtain 200 m upstream and 500 m downstream of the construction site.

The construction method separating and isolating the excavating channel from the existing flowing channel will reduce the impact on water environment effectively.

Attention should be paid to reducing the lifting speed of the dredger to minimize the sediment loss.

Part of the spoil produced in Stage Ⅲ Project will be barged to the marine dumping area. In order to avoid mud leakage, the mud should be loaded steadily, with screen covering on the mud if necessary. Besides, fuel leakage should be prevented during barging.

6.6.2 *Construction Arrangement*

Regarding to the impact on water quality, it is very important to properly schedule the construction activities. If the amount of re-suspended sediment and the transport distance decreases, the impact of the Project on water quality will be reduced greatly.

In addition, wet excavation should be reduced as much as possible. The necessary wet excavation should be arranged in the period of relatively high flow so that the extreme sediment re-suspension could be avoided.

Due to the characteristics of narrow width and small water flow of the original channel, the earth excavation could be conducted first on both sides of the channel. The original river channel will be retained as a temporary water diversion channel. After the excavation and embankment on one side is finished, the excavated channel can be used for river water discharging. In this way, the quantity of wet excavation can be decreased and the impact of sediment re-suspension can be reduced.

If in stage Ⅱ of the Ng Tung River project, when underwater construction is put up at the entrance of the Ng Tung River and the Shuangyu River and in the section 400 m upstream from it, underwater construction should not be arranged at the river mouth of the Ng Tung River and in the section 2000 m upstream from it. Thus the cumulative effect on water quality of the Shenzhen River and stage Ⅱ of the Ng Tung River project can be avoided.

6.6.3 *Mitigation Measures for Maintenance Dredging*

In order to prevent the impact on water quality from re-suspended sediment, the mitigation measures used during the construction period are also necessary and effective in maintenance dredging.

6.7 Residual Impact

6.7.1 *Construction Period and Maintenance Dredging Period*

During construction and maintenance dredging, the dominant impact on the water quality in some reaches of the Shenzhen River is the sediment re-suspension. But when the mitigation measures as described in Section 6.6 are adopted, the impact on water quality from the re-suspended sediment caused by channel excavation, including maintenance dredging, could satisfy the requirements of Annex 6 of *Technical Memorandum on Environmental Impact Assessment Process.*

6.7.2 *Operation Period*

The Project will have a positive impact on water quality of the Shenzhen River.

6.8 Conclusion

6.8.1 *Hydrodynamic Condition*

After the Project has beem completed, the river course will be straightened, which can greatly improve the channel condition for flood passage. In the downstream from the mouth of River Ganges, the highest flood level will lower by more than 3 m and the water level of the Shenzhen estuary will also decrease remarkably. The 50-year return period flood could safely pass through the Shenzhen River. As a result, the frequency of flood disaster will decrease. After completion of the Project, the exchange volume between the tide and the river water, and the river channel storage capacity will increase greatly with the wider and deeper channel.

After two years operation of the Project, the water level in the Stage III Project reach and the 3 - 4 km reach downstream of Lo Wu Bridge will rise due to siltation in the channel.

6.8.2 *Sediment Transportation*

(1) Construction impact

When Stage Ⅲ Project is started, Stage Ⅰ and Ⅱ Project will have been completed and put into operation. At that time, the average river width of the reach from Lo Wu to the river mouth will be 50~140 m. The siltation is dominant in this reach except for flood season. During the construction of Stage Ⅲ Project, the estimated leakage of sediment is about 18,000 m^3, which will mainly deposit in the river mouth area and the downstream 6 km reach.

During dry season, when the clamshell dredger is used, the effect of the re-suspended sediment could satisfy the requirements of Annex 6 of *Technical Memorandum on Environmental Impact Assessment Process* if the mud-proof curtain is used.

(2) Operation impact

1) Impact on sediment transport

After the Project is put into operation, sand from tributaries will deposit in the downstream reach of the Shenzhen River due to the channel being widened and deepened and flow velocity being reduced. Except for slight scouring in the narrow reach of Lo Wu Bridge, the annual siltation amount in the Shenzhen River is 160,000 m^3 for normal years. The main siltation location are the reach below the mouth of River

Ganges, the reach 2 km upstream and downstream, of Lo Wu Bridge, and the 3 km reach above the Shenzhen River mouth. After two years operation of the Project, the maximum siltation thickness caused by sediment from tributaries could exceed 0.5 m in the 1-2 km reach below Lo Wu Bridge.

Scouring and depositing in the channel will reach a balance.

After two years sustained siltation, parts of the Shenzhen River channel will not satisfy the designed demand. Dredging for the Shenzhen River will be necessary.

2) Dredging measure

The effective measure is to remove the bed mud. The main siltation locations are the reach below the mouth of River Ganges, the reach 2 km upstream and downstream of Lo Wu Bridge, and the reach near the Shenzhen River mouth, which are the main areas to be dredged. The best dredging period is in the flood season with larger flow.

The dredging interval and quantity should be depended upon inflow of sand coming from the upstream and downstream of the Shenzhen River, as well as siltation status of the River. It is suggested that the main siltation location should be monitored every year and the dredging work depends on siltation status. A completed dredging plan should be made after a detailed study and be included into the Project operation manual. It is also suggested that the bed sediment should be monitored and tested before dredging.. The dredged sediment should be disposed of to the marine dumping area as much as possible. If necessary, EIA should be done for the dredging work.

Because scouring will happen below the mouth of River Ganges and in the narrow Lo Wu reach during the flood season, attention needs to be paid to protection of the associated river embankment, especially to the Lo Wu bridges.

(3) Maintenance dredging impact

Since most of the re-suspended sediment from dredging will settle in the channel, increase of sand content from dredging could be controlled at an acceptable level at the places 500 m upstream and 1000 m downstream from the dredging area if dredgers and preventive measures recommended in Section 6.6 are applied. It could satisfy the requirements of Annex 6 of *Technical Memorandum on Environmental Impact Assessment Process*.

6.8.3 *Water Quality*

(1) Construction period

The Project will not deteriorate the water quality since no pollution load is added by the Project itself.

The sediment re-suspension and pollutants re-release arising from the dredging will indirectly locally affect the water quality of the Shenzhen River.

The dredging will not cause any unacceptable effect on the water quality if the mitigation measures recommended in Section 6. 6 are taken.

The research results show that the increase of total nitrogen caused by construction activities will be less than 20%. Thus, the dredging will have no obvious effect on water quality of the River.

(2) Operation period

From the calculation the water quality will be better than that in current condition as the dilution and transport condition are improved. The pollution in the Shenzhen River will be slightly alleviated.

(3) Maintenance dredging

The dredging itself will not increase the pollution load, and the water quality will not be degraded due to dredging during maintenance period. It could satisfy the requirements of Annex 6 of *Technical Memorandum on Environmental Impact Assessment Process*.

6. 8. 4 *Potential Impacts on Liantang River and River Ganges*

After Stage Ⅲ Project is implemented, the 50-year return period flood will be controlled below the mouth of River Ganges. The flood-carrying capacity of the upper reach will be improved and the loss from flooding will be reduced.

With the improvement of water flowing condition, local reverse scouring will occur in the reach above the mouth of River Ganges. As a result, the channel will be deeper and wider. The degreet of scouring will gradually decrease towards the upstream direction. The scoured sediment will settle in the Stage Ⅲ Project reach below the mouth of River Ganges. After operating for some time, the bed formation will be balanced, and the channel will become stable.

The water flowing condition will improve the pollutants transport downward and increase the environmental capacity of River Ganges. Thus Stage Ⅲ Project will benefit the water quality in the reaches above the mouth of River Ganges.

6.8.5 *Impact from Tidal Intrusion*

The exchange volume of tide and tidal current will increase to a large extent due to the wider and deeper channel, but the distance of tidal intrusion will not change significantly. The living conditions for aquatic biota would not be changed by the tidal intrusion after completion of the Project.

6.8.6 *Impact on Water Quality from Bridge Reconstruction*

Reconstruction of bridges, such as Man Kam To Bridge, will not cause any unacceptable impact on water quality. It could satisfy the requirements of Annex 6 of *Technical Memorandum on Environmental Impact Assessment Process*.