CHAPTER 4 SOLO RIVER ESTUARY

4.1 Background

At the estuary of Bengawan Solo River, sand bar development and sedimentation in the navigation channel across the sand shelf of Madura Strait are ongoing under the great sediment inflow from the Bengawan Solo River. The navigation channel, which is the main shipping approach for deep-sea freight carries to the Surabaya and Gresik ports, is being maintained by periodic dredging. Further, ongoing sand bar development and possibility of river mouth clogging are overriding concerns to the government authorities. The location map of the estuary of the Bengawan Solo River is presented in Figure 4.1.1.

The impact of the sediment release from the Wonogiri dam to the Solo River estuary was preliminary examined in this study. The study items were i) geometrical assessment for sand bar development by using available aerial photos and satellite images, ii) field investigation, iii) grain size analysis of the bed materials in the Solo River estuary and iv) quantitative estimation of sediment inflow into the estuary applying sediment rating curves in Lower Solo River. Based on the obtained data, it can be said that the sediment release from the Wonogiri dam have less impact to the development of sand bar at Solo river estuary.

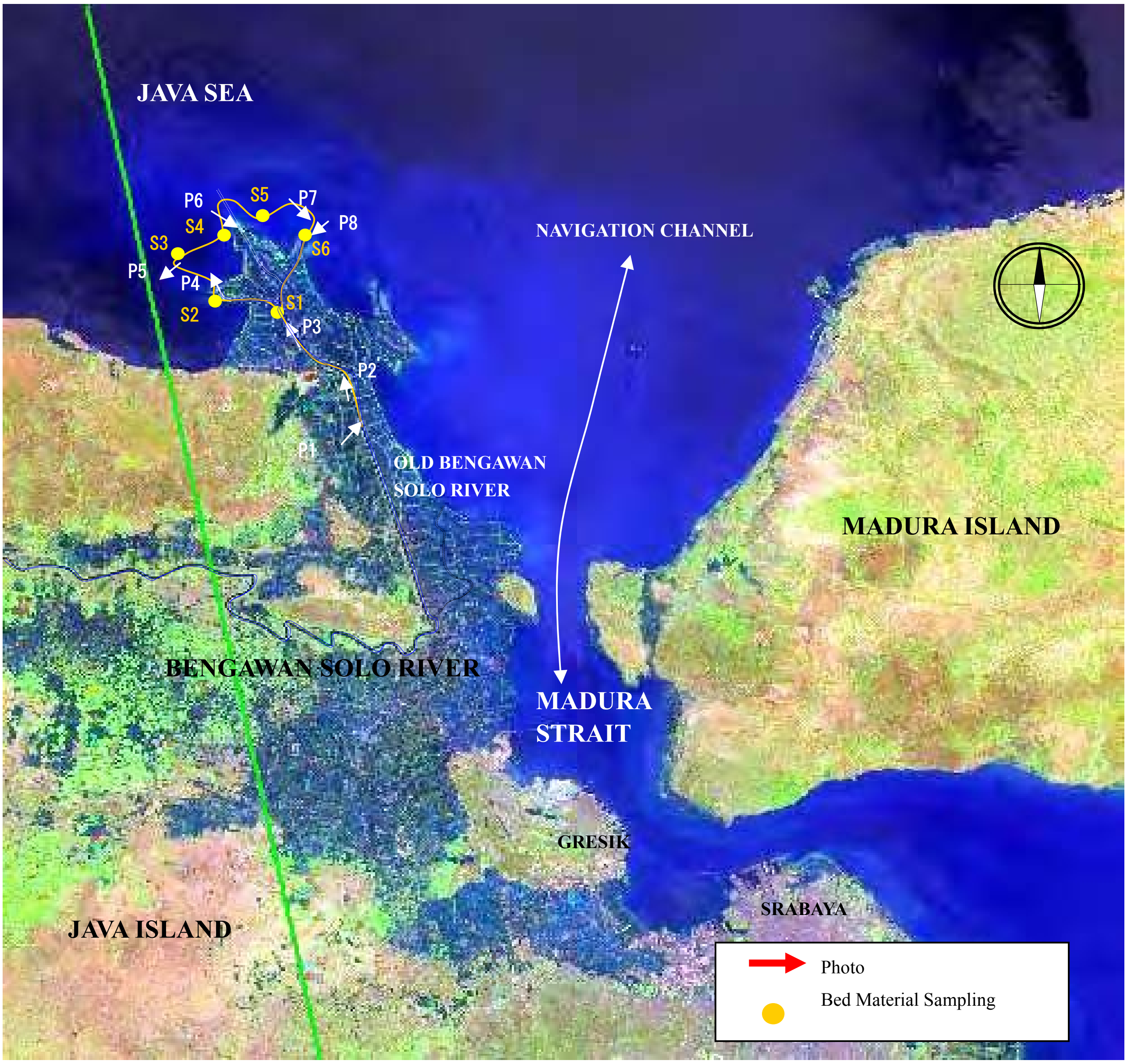
4.2 Origin and Growth

The Bengawan Solo River receives much of its water and high sediment load from numerous tributaries which drain the slopes of four volcanoes, Mt Lawu, Mt Melapi, Mt Merbabu and Mt Wills. The volcanoes contribute large quantities of fine materials which transport mainly as wash load and much of its delivered directly to the estuary.

Before 1893, the Bengawan Solo River flew out in the west shore of the Madura Strait, in an easterly direction across the estuary. It was assumed that sediments from the Bengawan Solo River made it difficult keeping the channel clear. As a solution of this problem, a canal was dredged northward straightly through swampy low-land to the Java Sea. The canal had persisted in its original alignment in 13 km long and 100 m wide to the present day, but has developed an extensive estuary.

Little else was done on the river that would affect the estuary until the creation of PBS in 1967. After that, completion of the Wonogiri dam and its irrigation project, Upper Solo River Improvement project, etc. have impacted on the flows and sediment transport entering the lower river. However, it is considered that above projects have had little impact compared with that of the total inflow and sediment transport at the river mouth.

For the data of the development of sand bar at estuary, available topographic maps, aerial photos and satellite photos were collected. Topographic map indicating the shoreline and river course is shown in Figure 4.2.1 and aerial photos and satellite images are shown in Figure 4.2.2. The data sources are shown below:



Source :Satellite Image from Centre for Remote Imaging, Sensing and Processing (CRISP), The National University of Singapore in August 2000.

Figure 4.1.1 Location Map of Estuary of Bengawan Solo River

Table 4.2.1 Past Main Works for River Improvement in Bengawan Solo River

Year	Solo River Improvement Work
1893	River mouth diversion under the Dutch Administration
1980	Completion of Wonogiri dam
1984	Wonogiri Irrigation Project (completion of Colo Weir)
1994	Upper Solo River Improvement Project
1995	Madiun River Urgent Flood Control Project
2003	Lower Solo River Improvement Project (Completion of Babat Barrage and Flood Way)

Source : JICA Study team.

Table 4.2.2 Collected Map, Aerial Photographs and Satellite Images of Bengawan Solo River Estuary

Year	Type	Source
1922 (Map)	Map	1:50,000 topographic mapping [USAMS, 1963] with topography based on 1922 dutch mapping and hydrography based on USHO mapping of 1959
1972.09	Satellite Image	Satellite
1977	Aerial Photo	1:5,000 topographic mapping [Exsa, undated] based on 1:15,000 scale 1977 aerial photographs
1989.03	Satellite Image	Satellite
1993	Map	1:25,000 digital mapping [BAKOSURTANAL, 1998] from 1993/94 aerial photographs
2000.08	Satellite Image	Source : Centre for Remote Imaging, Sensing and Processing (CRISP), The National University of Singapore Satellite : SPOT 4 Date and Time : Aug. 21, 2000, 03:01:43

Source: JICA Study Team

Superimposed with the shore line maps of 1922, 1977, 1993 and 2000, the variation of the location of the mouth of the Bengawan Solo River and development of sand bars in each main canal were analyzed. (see Figure 4.2.3)

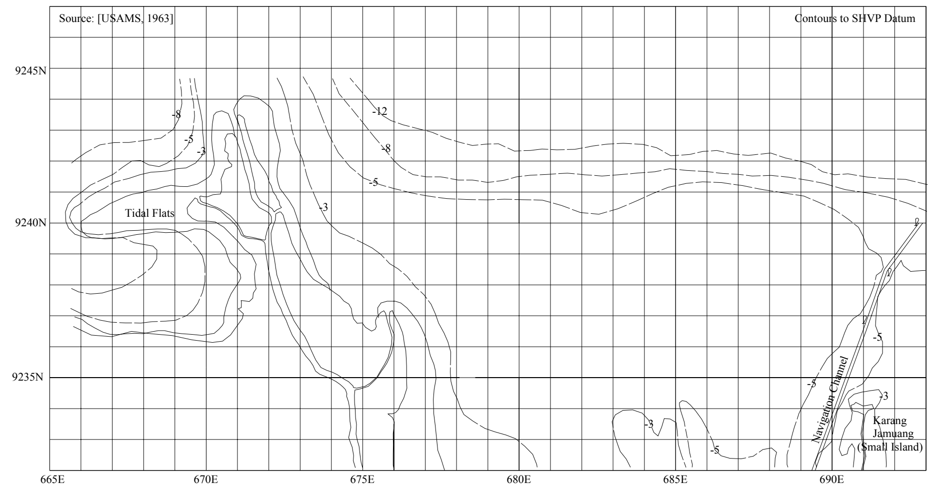
By 1922 : Though the accuracy of the shoreline in the map of 1922 is lower, the river had extended its estuary 9 km northward. Main channel about 100 m wide and three side-channels about 50 m wide had been already identified.

1922 – 1977 : Though it is difficult to determine the variation of sand bars in this 55 years due to low accuracy of 1922 mapping, developing of sandbars at the main channel, side-channels 1 and 3 and the retiring of side-channel 2 should be remarked.

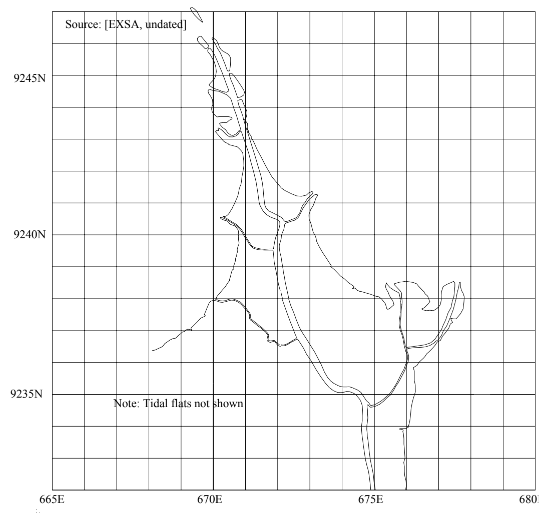
1977 – 1993 : In this 16 years, the main channel had become closed off and the length of the estuary had retreated by 1800 m. Side-channel 1 had moved from north to southeast and its sand bar had extended by 1600 m. Previous retirement of the sand bar at side-channel 2 had changed to development and it had extended by 500 m west. Sand bar at side-channel 3 had further extended by 600 m northwest. .

1993-2000 : In this 7 years, main channel retirement had continued by 700 m inland. Along two sub channels in side-channel 1, the sand bar had extended by 2000 m north and by 400 m southeast. The sand bars had extended by 1300 m west in side-channel 2 and by 1100 m northwest in side-channel 3.

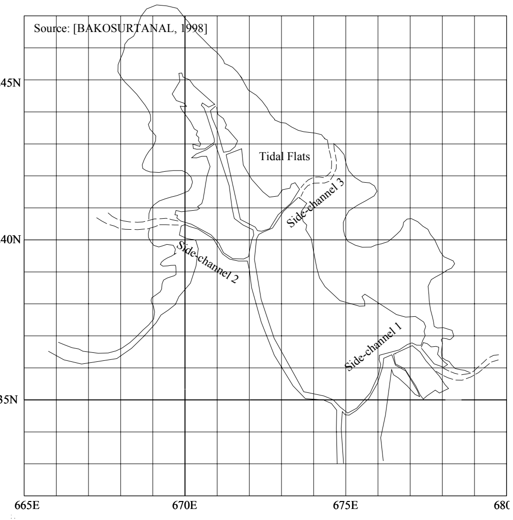
The sand bar is entirely still developing. The main growth of the estuary has occurred at the mouths of three main side-channels. The northern tip of the estuary where main channel was previously most active had retreated by 2.5 km from 1977 to 2000. The Bengawan Solo River estuary can be said to be in infancy, including the developing and retiring of sand bar and the diverting and converging of small channels.



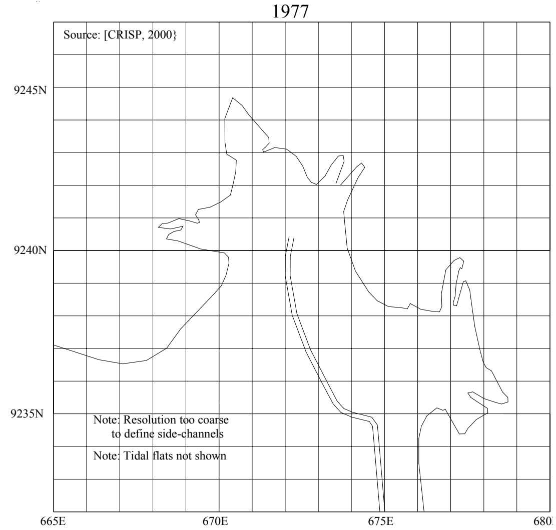
1:50,000 topographic mapping [USAMS, 1963] with topography based on 1922 Dutch mapping and hydrography based on USHO mapping of 1959



1977



1993/94



August 2000

Source : CDMP

Figure 4.2.1 Topographic Mapping of Bengawan Solo River Estuary

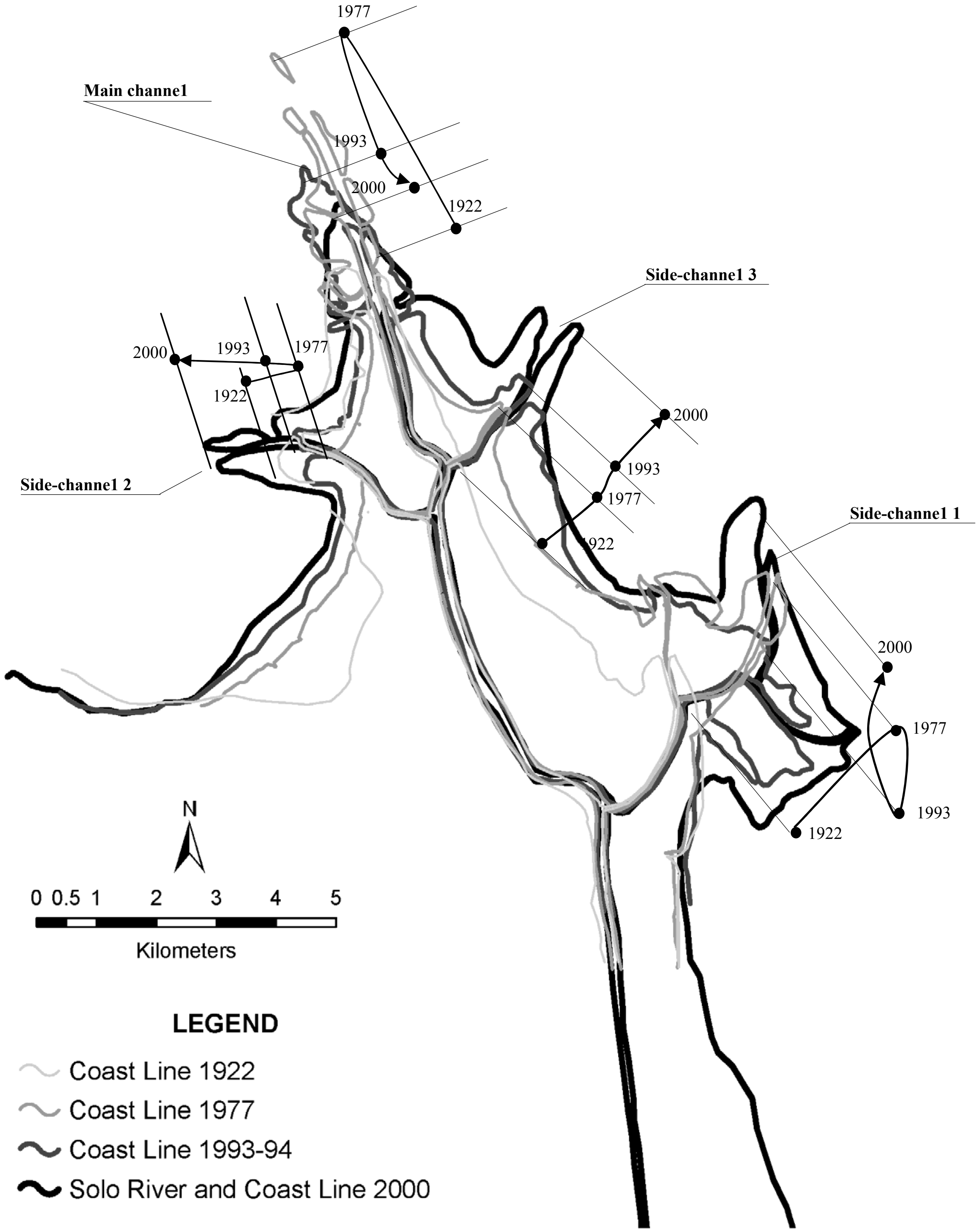
Satellite Image-19720927

Satellite Image-19890328

Source : Centre for Remote Imaging, Sensing and Processing (CRISP), The National University of Singapore, Satellite :SPOT 4, Date and Time :Aug. 21, 2000, 03:01:43

1:15,000 scale 1977 aerial photographs

Figure 4.2.2 Aerial Photograph and Satellite Image of Bengawan Solo River Estuary



Source : JICA Study Team

Figure 4.2.3 Variations of Bengawan Solo River Estuary from 1992 to 2000

4.3 Filed Investigation on Bengawan Solo River Estuary

The present development of Solo River estuary has characteristics as below:

- Large retiring of sand bar in main channel in northern part,
- Development of sand bar at the mouth of three side-channels.

The status of the estuary mentioned above was inspected by the field investigation in September 2005. The location map of field investigation in estuary is shown in Figure 4.1.1. The investigation started from fisher port at Ujungpangka using fisher boat, driving down to the main channel in northward and passing through the west coast through the side-channel 2, and navigating around the chersonese and back to main channel through the side channel 3.

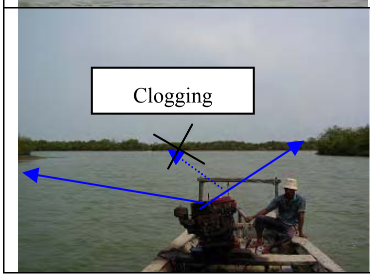
At 7 locations along the shipping route, the global positioning, DO, temperature and turbidity were observed as shown in Figure 4.1.1. The results of observation are presented as follows:

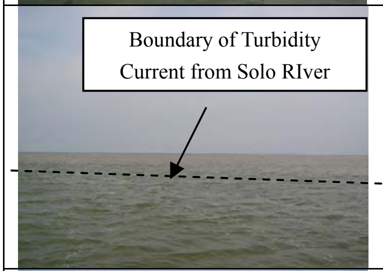
Table 4.3.1 Location of Site and Result of Observation of DO, Temperature and Turbidity

No.	Location	Time	NS	EW	DO (mg)	Temp (℃)	Turbidity (NTU)
1	Boat Port	12:18	06.54'38.7"	112.34'01.6"	5.71	30.8	17.6
2	River 1	12:55	06.52'39.1""	112.33'21.7"	5.91	32.1	11.9
3	River Mouth (left)	13:24	06.51'58.2"	112.31'54.8"	7.44	31.8	12.2
4	Estuary (left)	13:45	06.51'15.2"	112.31'14.6"	6.87	31.0	11.9
5	Cherosones	14:10	06.50'29.0"	112.32'32.4"	8.41	30.6	14.4
6	Estuary (right)	14:27	06.50'16.3"	112.33'01.8"	8.08	31.6	20.4
7	River Mouth (right)	15:05	06.50'35.9"	112.34'32.6"	5.84	31.3	<10

Source: JICA Study Team

The preset status of channels, estuary and characteristics of grain size distribution are summarized as in Figure 4.3.1 with photos.

	(P1) Fisher port at Ujungpangka The fisher port is about 3 km far from mouth of the Bengawan Solo River. As show in photo , the bed deposition is fine sand and there are many garbage.
	(P2) Main channel before diverting section Main channel flows straightly north ward. The river is about 100 m wide. In deeper section, water depth is more than 5 m. Many fisher boats drive through the channels to the sea. On both sides of river bank, many plants grow with 5 to 10 m high. Banks are considered in stable.
	(P3) Diverting point in Main channel (S1) The side-channel 1, ex-main channel, had been already closed and is preventing fisher boat from navigation. It is assumed that the clogging of Side-channel 1 was caused by the following circumstances: i) one canals become longer ⇒ ii) slow down the flow velocity due to extra friction ⇒ iii) deposition increase ⇒ ii) ⇒ iii). The clogging of side-channel 1 has caused the retirement of sand bar in the

	northern tip of chersonese. The bed material sampled at S1 is composed mostly sand at 56% of total.
	(P4) River mouth of side-channel 2 in the west shore (S2) Bed sediments appeared when the tidal level is low. Presently same condition can be seen in Side-channels 1 and 3. Sand bars are developing in the mouth of side-channels. The bed material sampled at S2 was composed at 14% sand, 47% silt and 39% clay and classified as silty clay.
	(P5) Tidal flat in west of estuary(S3) High sediment concentration water flows into the sea from the Bengawan Solo River and the boundary of turbidity current was observed. The bed material sampled at S3 was composed of mostly fine materials at 25% sand, 47% silt and 29% clay and classified as silty clay.
	(P6) Northern tip of chersonese (S4) Shallow tidal flat are spreading in the Bengawan Solo River estuary. Previously sand bar at this location had been developing, but currently large retirement are progressing due to clogging of main channel. The bed material sampled at S4 was composed mostly fine materials about 44% sand, 38% silt and 18% clay and classified as silty sand.
	(P7) Tidal flat in east of estuary.(S5) There are many wooden piles standing in the tidal flat for fish nets and navigation sign. Water depth is approximately 1 to 2 m for MSWL. The bed material sampled at S5 was composed of mostly fine materials at 15% sand, 47% silt and 37% clay and defined as silty clay.
	(P8) River mouth of side-channel 3 in the east shore (S6) Photo shows the bed materials at S6 in the mouth of Side-channel 3 flowing out to east shore of the sand bar. The bed material sampled at S6 is composed at 51% sand. Less silt and clay is contained than those at S2 and S3, and grain size distribution is similar to those at S1 and S4.

Source: JICA Study Team

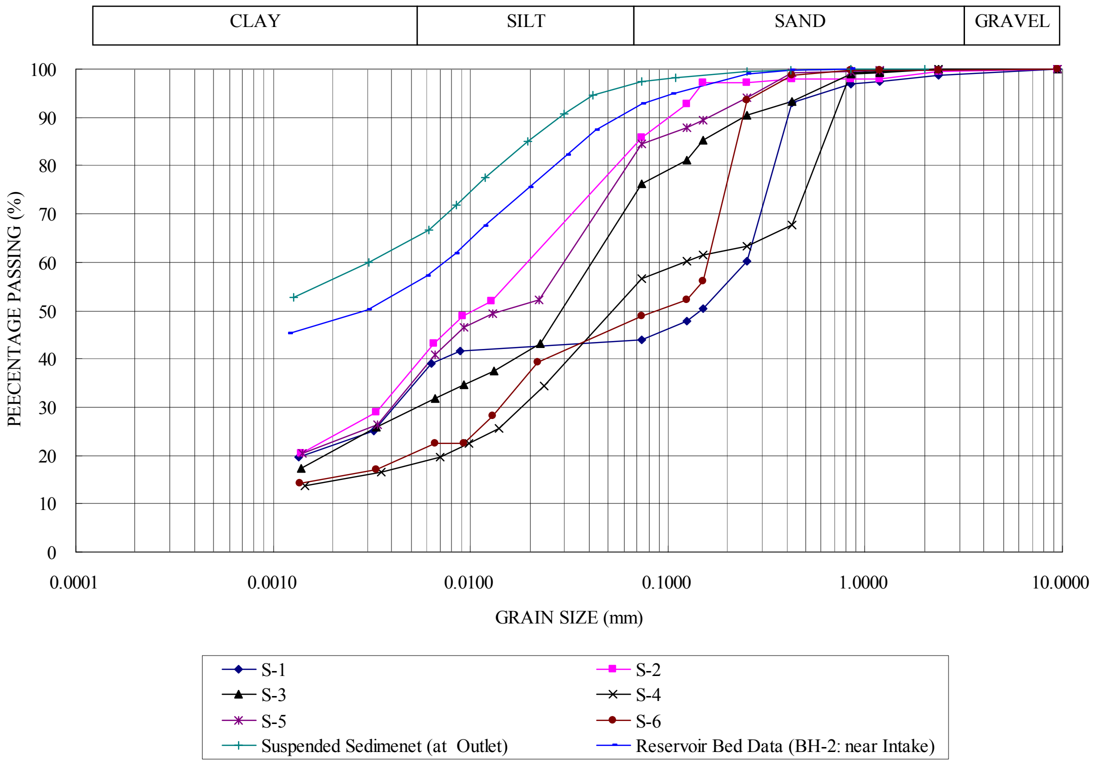
Figure 4.3.1 Present Condition and Photos in Bengawan Solo River

At 6 locations, the bed materials in the channels and in the coastal zone were sampled by bed sampler and analyzed for grain size distribution. The grain size distributions are presented in Table 4.3.2 and Figure 4.3.2 comparing to the grain size distribution of deposited sediment in Wonogiri reservoir and suspended solid of the outflow from the Wonogiri power station. The bed materials of S1, S4 and S6 taken from the side-channels are composed of mainly sand. The bed materials of S2, S3 and S5 taken from tidal flat are mainly composed of very fine materials as silt and clay. The difference of these grain size distributions shows that the fine materials tend to deposit in the coastal zone. It is thus considered that slow velocity of tidal current is causing the deposition of finer materials.

Table 4.3.2 Specific Gravity and Grain Size Composition of Sediment Deposit at Estuary of Bengawan Solo River

No	Name of Sample	Gs	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
S1	River 1	2.50	0.58	55.60	7.81	36.01
S2	River Mouth (left)	2.38	0.25	13.83	46.60	39.32
S3	Estuary (left)	2.39	0.00	23.75	47.18	29.07
S4	Chersonese	2.29	0.00	43.50	38.19	18.31
S5	Estuary (right)	2.35	0.08	15.42	47.37	37.13
S6	River Mouth (right)	2.47	0.08	51.10	27.77	21.05

Source : JICA Study Team



Source: JICA Study Team

Figure 4.3.2 Grain Size Distribution of Sediment Deposit at Estuary of Bengawan Solo River

4.4 Analysis of Sediment Load in Solo River Estuary

The sediment load of Bengawan Solo River is composed of mainly wash loads which can be transported to the river mouth. For monitoring of suspended load in the Lower Solo River, the periodic samplings of suspended load were commenced in 1975. The survey results were plotted to log-log scale with sediment load in ton/day against discharge in m^3/s and applying of following equation constant a and b were determined.

$Qs = a \times Q^b$

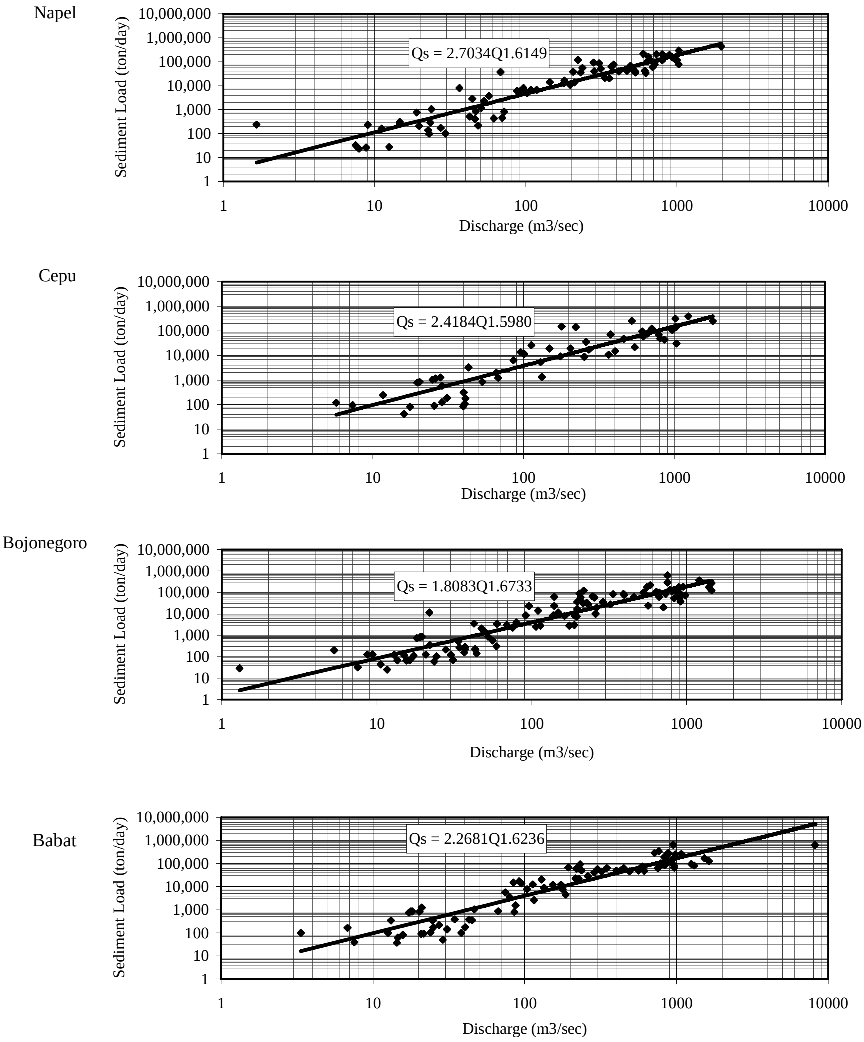
where, Qs : suspended sediment load (ton/day)

Q : dairy discharge (m^3/s)

a, b : constant

The equations at Napel, Cepu, Bojonegoro and Babat stations with its catchment area are shown in Table 4.4.1 below. Available survey data are potted to log-log scale with a strait line fitted to the data using the least square method in Figure 4.4.1.

The daily sediment load at each station can be estimated from the observed daily discharge. The daily hydrograph at each station is presented in Figures 4.4.2 to 4.4.5. Based on daily data, mean monthly and mean annual sediment load were estimated as summarized in Table 4.4.1 and Figure 4.4.6.



Source: CDMP

Figure 4.4.1 Sediment rating Curves at Major Stations in Lower Solo River

Table 4.4.1 Catchment Area and Equation of Sediment Rating Curve at Each Station in Lower Solo River

Station	Catchment Area (km^2)	Equation
Napel	9,880	$Qs = 2.4184 \times Q^{1.5980}$
Cepu	10,922	$Qs = 2.7034 \times Q^{1.6149}$
Bojonegoro	12,804	$Qs = 1.8083 \times Q^{1.6733}$
Babat	14,247	$Qs = 2.2681 \times Q^{1.6236}$

Source : CDMP

A longitudinal variation of mean annual sediment load along the Lower Solo River is presented in Figure 4.4.7. The mean annual sediment load is 15.9 million ton for Napel, 13.3 million ton for Cepu, 22.1 million ton for Bojonegoro and 22.8 million ton for Babat. Mean annual sediment load in 1975 to 1999 at Solo River mouth is determined 23.0 million ton referring to the lower stations of Bojonegoro and Babat because less sediment supplies from tributaries in the downstream of the Lower Solo River basin.

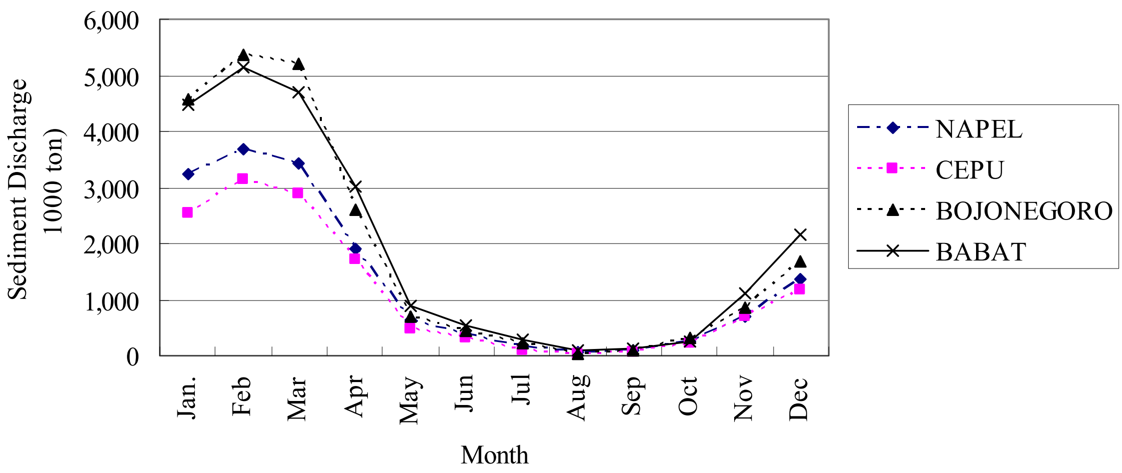
Table 4.4.2 Mean Monthly Sediment Discharge in Lower Solo River

(unit :thousands ton)

STATION	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
NAPEL	3,236	3,697	3,424	1,894	650	376	169	49	94	261	699	1,379	15,929
CEPU	2,542	3,138	2,890	1,718	462	307	111	24	74	228	714	1,163	13,372
BOJONEGORO	4,567	5,360	5,218	2,617	701	440	232	42	111	332	847	1,681	22,148
BABAT	4,467	5,145	4,704	3,001	890	549	274	87	122	250	1,121	2,156	22,767

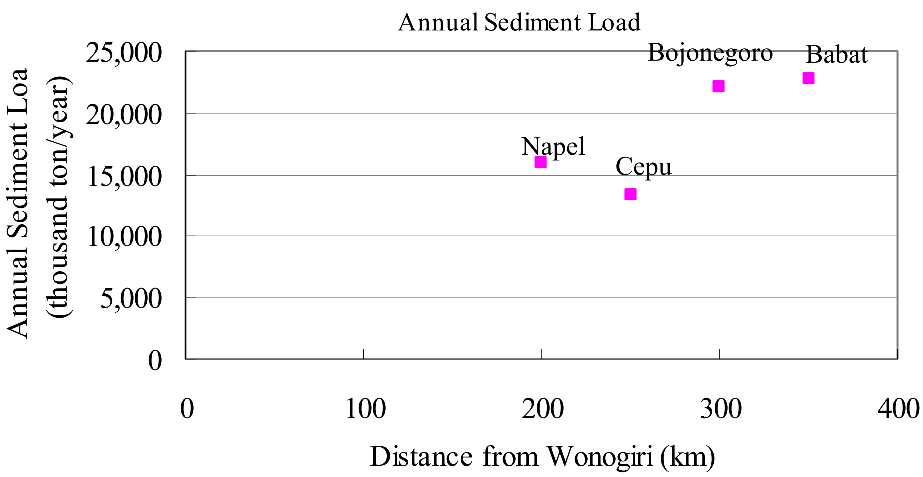
Note) Above calculation are based on daily discharge and Q-Qs relation in 1975 to 1999 referring to CDMP[2000].

Source : JICA Study Team



Source: JICA Study Team

Figure 4.4.6 Comparison of Mean Monthly Sediment Loads in Lower Solo River in 1975 - 1999



Source: JICA Study Team

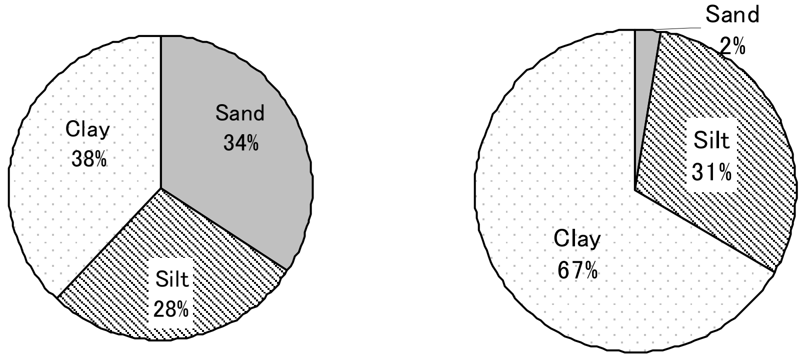
Figure 4.4.7 Longitudinal Variation of Mean Annual Sediment Load in Lower Solo River

4.5 Impact of Sediment Release from Wonogiri Dam

4.5.1 Characteristics of Sediment Released from Wonogiri Dam

Comparison of grain size distributions between bed materials in Solo River Estuary and sediment released from the Wonogiri dam was presented in Figure 4.5.1.

The bed materials in the Wonogiri dam is composed 98% clay and silt (smaller than 74 μ m), while that in the Solo River estuary is 66%. Because of the tidal flow at the estuary, some of finer sediments from the Wonogiri dam would not deposit in the estuary and directly wash out to the sea.



Solo River Estuary **Sediment released from Wonogiri Dam**

Source: JICA Study Team

Figure 4.5.1 Comparison of Composition Ratio of Each Grain Size between in Solo River Estuary and Wonogiri Dam Sediment

4.5.2 Impact of Sediment Load

The mean annual sediment load at Solo River estuary is estimated as 23.0 million ton, while annual sediment released from the Wonogiri dam is to be around1.0 million ton after implementation of measures. Even if all sediments from the Dam would be transported to the estuary, it is only 2.4% of the total sediment load into the estuary. It can be said that present development of the sand bar is caused by sediment produced from the whole watershed.

4.5.3 Conclusion

The Bengawan Solo River estuary is still developing and can be said to be in infancy, including the developing and retiring of sand bar and the diverting and converging of small channels.

Sediment released from the Wonogiri dam will mainly contain wash loads. Therefore, these wash load will be delivered into the Solo Rive estuary, but some of finer sediments would not deposit in the estuary and directly wash out to the sea due to the tidal flow at the estuary. Further, even if all sediments released from the Wonogiri dam would be delivered into the estuary, it is only 2.4% of the total sediment load produced from the whole watershed. In conclusion, it is indicated that the sediment release from the Wonogiri dam have less impact to the development of sand bar at Solo river estuary. It shall be discussed in the basin-wide sediment management system.

There would be a slight impact from the side-channel 1 to the navigation channel in the Madura Strait. Though the river mouth of the side-channel l is around 15 km far from the navigation channel and sediment released from there wound not be directly conveyed to the navigation channel, one of idea to minimize the impact would divert the side-channel

1 to the adverse direction of the Madura Strait.

The development of sand bars has not only negative impacts but positive impacts. Over the developing sand bars in the Solo River estuary, new fish ponds are created and expanding. Profits from the fish pond become an important source of income for local people. As well as the management of sediment in the Bengawan Solo River estuary, the management of land use shall be considered.

CHAPTER 5 COLO WEIR

5.1 Objective of Study

The Colo intake weir is one of most important river structure in the Upper Solo River mainstream located at 14 km downstream of the Wonogiri dam.

Since the completion of the Wonogiri Irrigation Project in 1986, the supplied water to the Wonogiri irrigation system has been taking from the Colo intake weir. The Wonogiri irrigation system comprises 94 km long main canal and 105 km long secondary canal. Water released from the Wonogiri dam is taken and fed into the west and east main canals at the Colo intake weir. At present, the irrigation area has been extended from 24,000 ha in the original plan to 29,330 ha where farming with triple or double cropping is being practiced.

In the future, however, in case of large sediments will be released from the Wonogiri dam to the downstream, there is a threat that sediments issues will be taken over to the Colo weir from the Wonogiri dam. Candidate issues concerning the sediments at the Colo weir are i) clogging of intake , ii) decrease of flow capacity by development of the back sand in upper stretch and iii) sediment deposition in the canal. In this Study, aiming at evaluation the impacts of sediment releasing from the Wonogiri dam to the Colo weir, present status of the Colo weir sedimentation was investigated by cross section survey, interview survey and analysis of grain size distribution of bed materials. Subsequently, a case study by using the turbidity analysis model was conducted to quantitatively estimate the sedimentation in the Colo weir.

Colo Weir

5.2 Structural Feature and Operation and Maintenance

5.2.1 Basic Feature

Longitudinal and cross sections of the Colo weir are presented in Figure 5.2.1 and outline of structure is presented in Table 5.2.1. The Colo weir is fixed weir type with the crest elevation of El.108.0 m and design intake water level of El.107.0 m to supply water to the irrigation area of 28,000 ha through the intake canals on both sides of river.

The basic function of the Colo weir is summarized as below;

1) To draw water from the intake to east and west canal,
2) To run out a flood safety to the downstream of the weir,

3) Removal sediments over the upstream of the weir by operation of sediment flushing gates,
4) To secure a river maintenance flow to the downstream of the weir.

In accordance with the Feasibility Report of Wonogiri dam projects in 1975, the Colo weir has an equalizing storage of 1.2 million m^3 between El.107 m and El.108.m. This storage is corresponded to the necessary volume to regulate the maximum outflow discharge of 60 $m^{3/}s$ from the Wonogiri hydropower to 30 m^3/s in 6 hours peak operation.

5.2.2 Structural Feature of Intake

The Colo weir has six intakes to take water to the east main canal and the west main canal. The structural feature of the intakes is summarized below;

(1) Intakes for East Main Canal
- Three (3) intake gates at right side of the weir,
- The average intake discharge for the east canal is 15.7 m^3/s from 1986 to 2005.

(2) Intakes for West Main Canal
- One intake gate at right side of the weir connects to a small regulation tank and separates into a siphon to the west main canal passing under the crest and another pipe for releasing the river maintenance flow.
- One intake gate at the left side of a sediment flushing canal connects to the West main canal passing through a pipe located immediately upstream of the crest and.
- One intake gate located at 50 m upstream and left of the weir had lost its function because of sedimentation.
- The average intake discharge for the west canal is 2.9 m^3/s from 1986 to 2005.

5.2.3 Operation and Maintenance

(1) Operation and Maintenance of Intake

PJT-1 is the responsible agency for the operation and maintenance of the Colo weir. Water level record and intake water both for the east canal and the west canal from 2000 to 2005 are presented in Figure 5.2.2. In non-flood period, water level of the Colo keeps at EL. 108.0 m and annual average discharge of the intake is 23 m^3/s.

Basic concept of the intake operation is presented as below;

1) Five (5) water level gauges are installed in the adjacent area of the intake. Each canal has a water level gauge inside of the channel.
2) Depend on the demand of irrigation usage, intake gates are operated and control the drawn discharge. After reconfirmation of the discharge in the canal by the WL gauge, the difference would be fine adjusted.
3) Intake gate operation is independent from the operation of sediment flushing gates. Basically, while sediment flushing gate open, intake gate is no need to be close.
4) River maintenance flow is controlled at a small regulation tank with the valves. In dry season, required river maintenance flow is set as $2m^3/s$ for downstream.

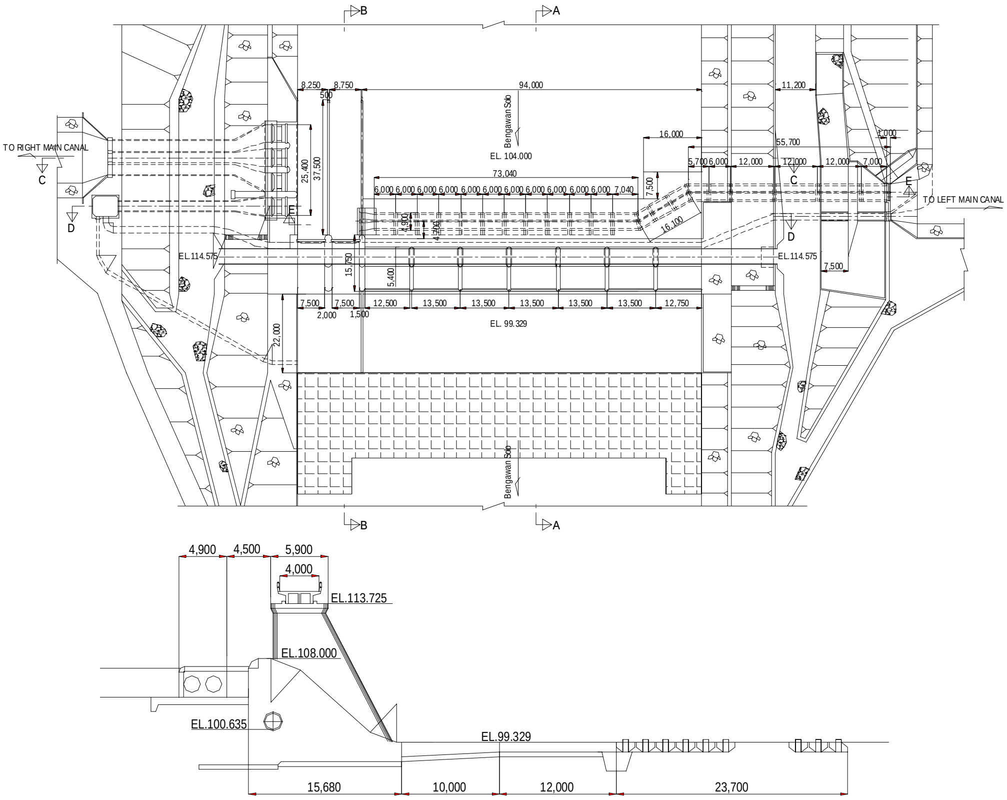
Regarding to the operation manual, the weir, the bed protection and banks shall be periodical inspected every year. Especially from October 2002 to January 2003 and from September 2004 to November 2004, special inspection and large maintenance works were conducted to maintain the canals.

5.2.4 Operation of Sediment Flushing

A sediment flushing channel is installed at the right side of the weir to release the sediments deposited in front of the intakes. The channel is 17.5 m wide and its slope is 1/16. The bottom elevation of intake channels is 1.5 m higher than that of sediment flushing channel to protect from inflowing of bed loads. Basic concept of the sediment flashing operation is presented as below;

1) Two (2) sediment flushing gates are operated simultaneously,
2) The channel has a function as a part of a spillway when water level is above El.109.0 m,
3) In dry season, sediment flushing is never operated and all sediment gates are closed,
4) In wet season, sediment flushing is operated in the beginning and end of wet season, if enough water are available to draw to the canals.

East Canal of Colo Weir (Right: During Wet Season, Left : During Improvement Works in 2004)



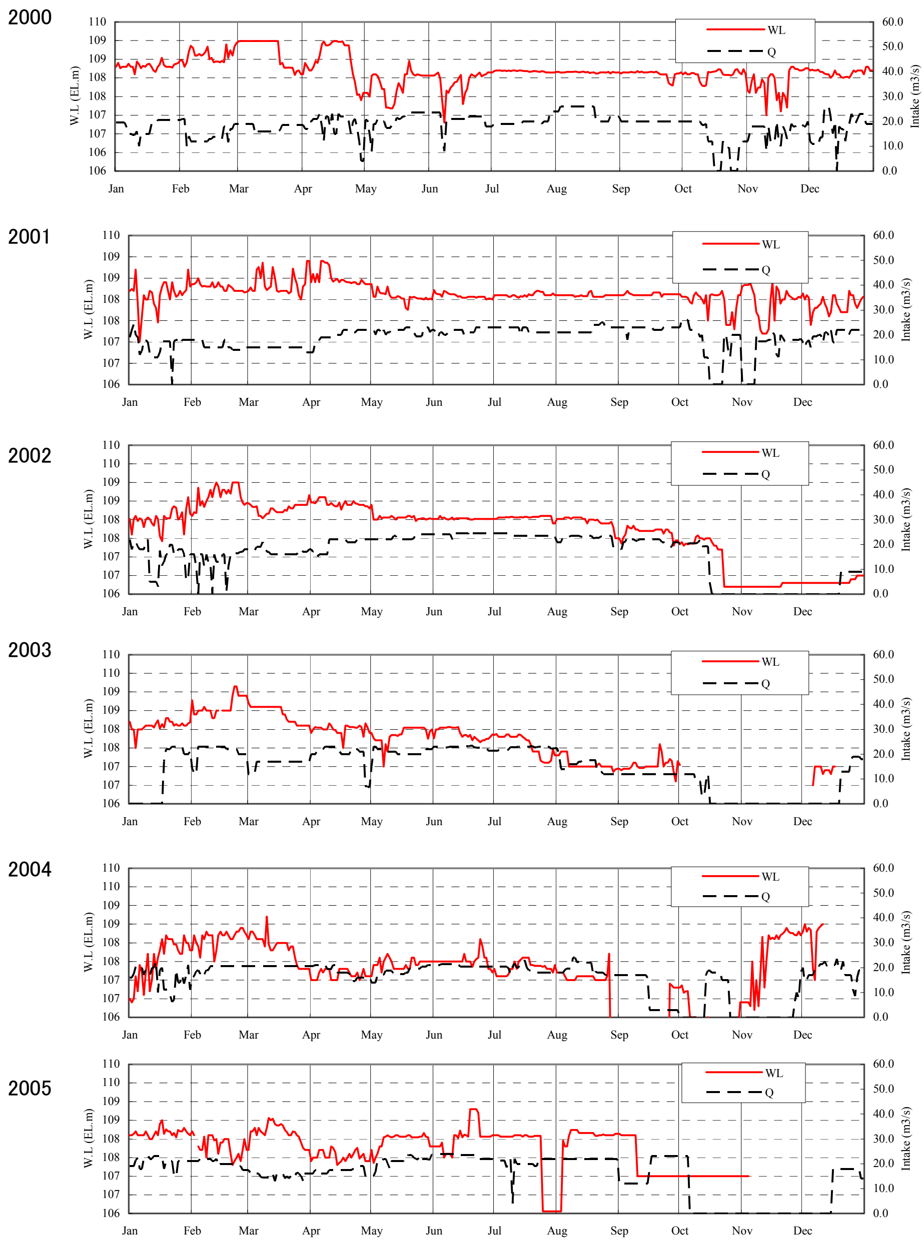
Source : PBS

Figure 5.2.1 Plan, Longitudinal and Cross Section of Colo Weir

Table 5.2.1 Structural Feature of Colo Weir

Colo Weir	
- Weir Type	Fixed Concrete Weir
- Weir Length	111.75 m
- Weir Height	8.68 m
- Elevation of Crest Weir	+ 108.00 m
- Intake Water Level	+ 107.00 m
- Sediment Gate	7.5 x 7.5 m x 2 nos
- Intake Gate	5.2 x 2.6 m x 4 nos
- Max. Intake Discharge	31.59 m^3/sec
- Flood Design Discharge	2,000 m^3/sec

Source : COLO Operation and Maintenance Manual



Source : JICA Study Team

Figure 5.2.2 Water Level, Intake Volume at Colo Weir (2000-2005)

5.3 Present Status of Colo Weir Sedimentation

5.3.1 Sedimentation Profile and Cross Section

A longitudinal section between Wonogiri dam and confluence of the Denken River, and cross sections of the Colo weir and its upstream are presented in Figures 5.3.1 and 5.3.2 respectively. Upstream of the weir is already filled with the sediment deposits, so called “back sand”. The back sand reaches to downstream of the Wonogiri dam with the length of 14 km and the slope of 1/3,170. It is preliminary estimated that the total volume of sediment deposits in the stretch between the Wonogiri dam and the Colo weir is 3.10 million m^3 since completion of the Colo weir.

The riverbed level in front of the weir is El.106.6 m on the center and El.108.0 m on the left side of the weir. They almost reach to the elevation of the crest. On the other hand, the riverbed level is 103.5m on the right because of effects of sediment flushing gates.

5.3.2 Field Investigation

A field investigation with interview survey was carried out in the dry season in 2005. The photos of the Colo weir in the dry season are presented below. As described above, sediment level rose to the top of the crest and storage of the weir were almost fully deposited. On the other hand, sediment flushing channel was well maintained and free from sedimentation as a stream line was formulated from the upstream to the sediment flushing channel.

5.3.3 Bed Material

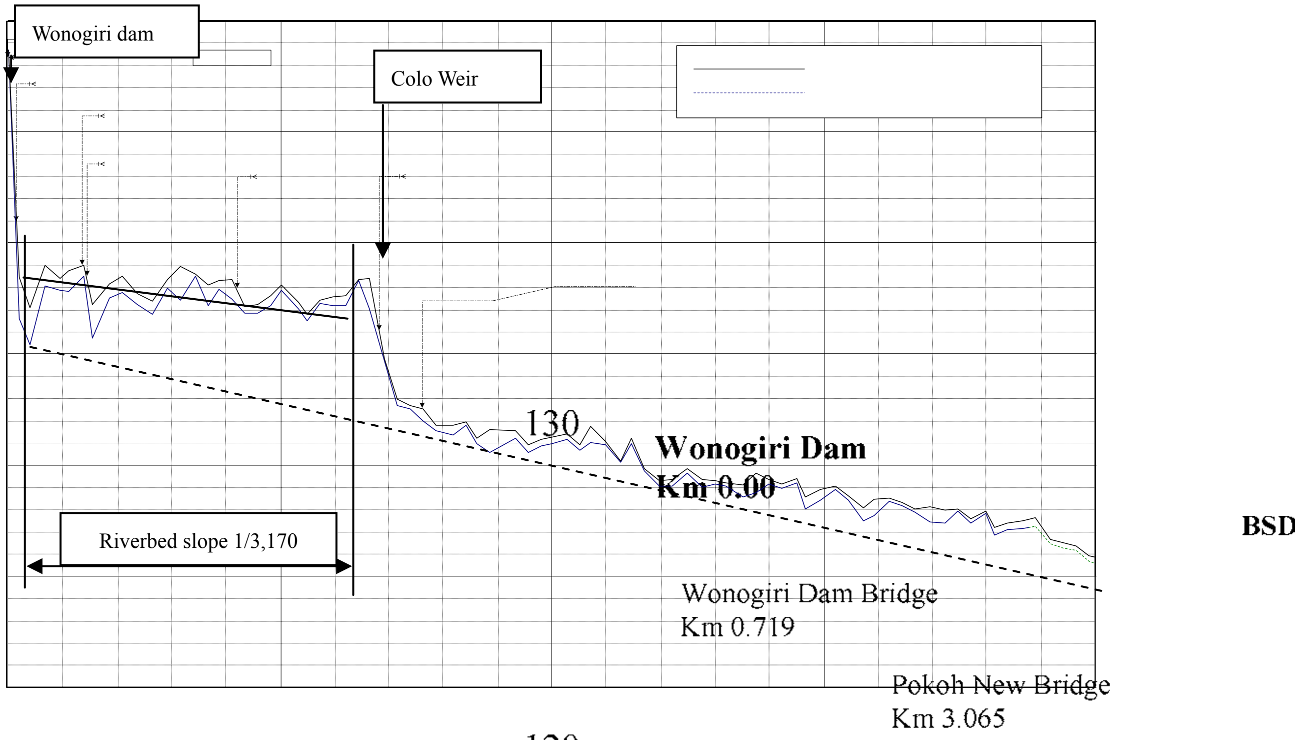
Bed materials were sampled at six locations in the upstream stretch of the weir and two locations inside of the main canals. Location map and the grain size distributions are presented in Figures 5.3.3 and 5.3.4 respectively.

The bed materials taken from the upstream stretch of the Colo weir are composed of 74% - 100% of clay and silt with the specific weight is 2.62 -2.65. The bed materials in the canals were composed of 63% of sand. The difference of grain size distribution between them is caused by a difference of flow velocity.

The comparison of the grain size distributions of the sediment deposits between the Colo weir and the Wonogiri reservoir is presented in Figure 5.3.4. The sediments in the Colo weir was composed of fine materials and its grain size distribution was similar to that of the Wonogiri dam. The grain size distribution of the sediments in the Colo weir is a little coarser than that of the Wonogiri reservoir.

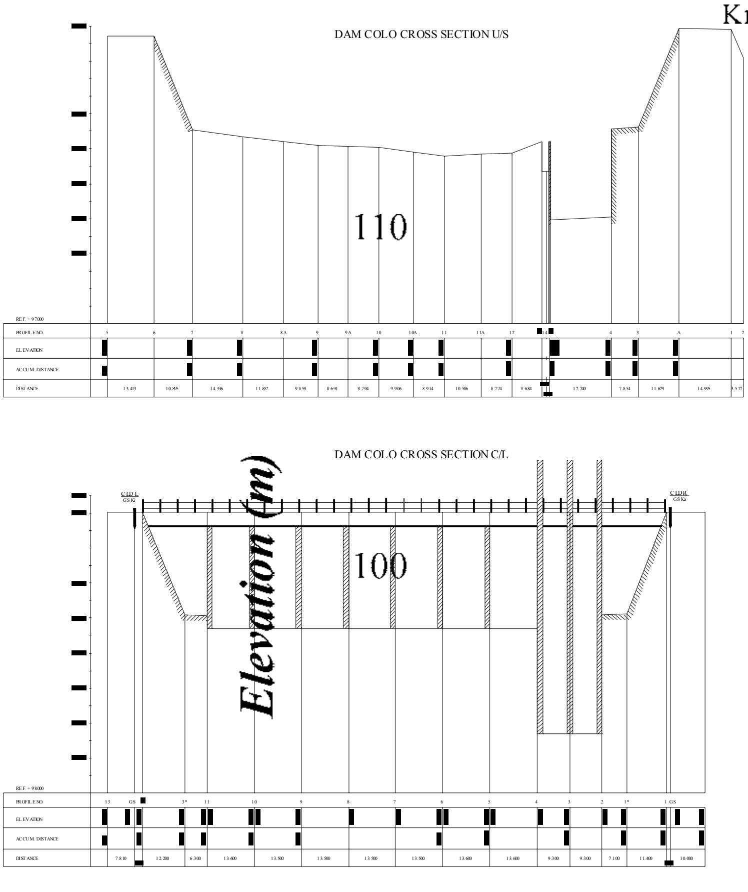
At the sediment flushing channel, the composition of clay is only 16%. Bed materials in adjacent area of the sediment flushing channel are notably coarser than those in upstream of the Colo weir.

Overall view of the grain size of sediment deposits in the Colo weir, it was clarified that clay and silt were tend to be deposited in the storage of the Colo weir as well as in the Wonogiri reservoir, however they were continuously flushed out to the downstream by the effect of the sediment flushing gates.



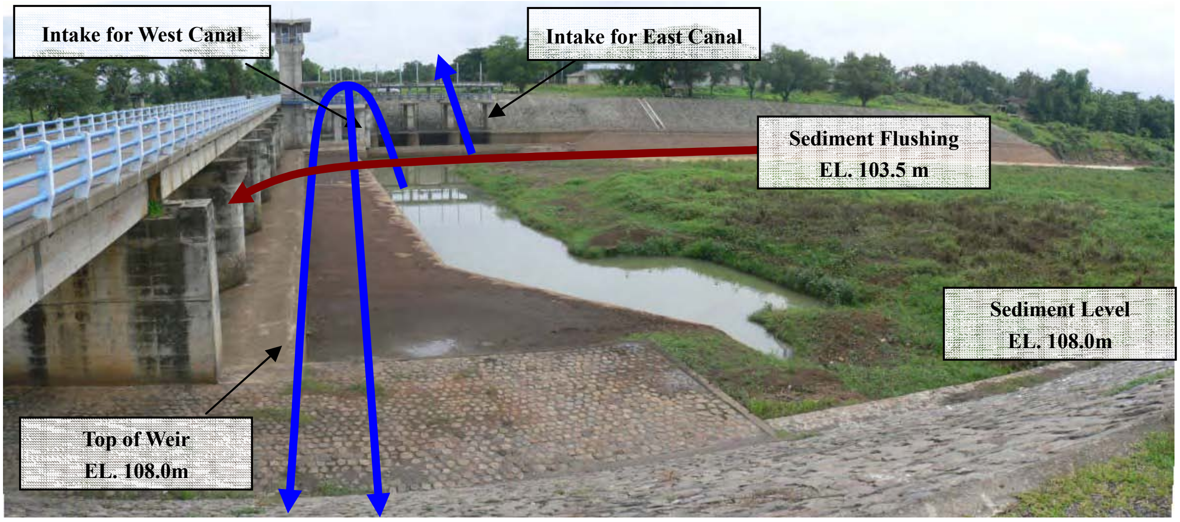
Source : JICA Study Team

Figure 5.3.1 Sedimentation Profile in the Upstream of Colo Weir

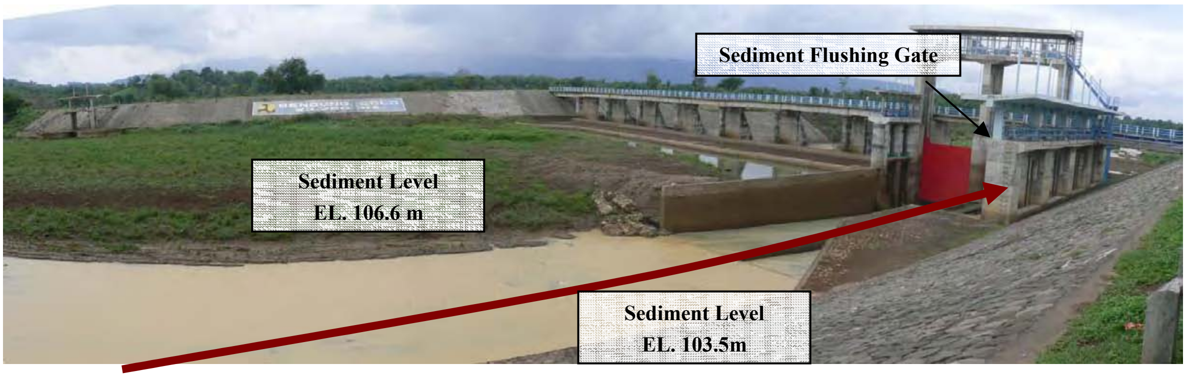


Source : WREFER & CIP

Figure 5.3.2 Cross Section of Colo Weir

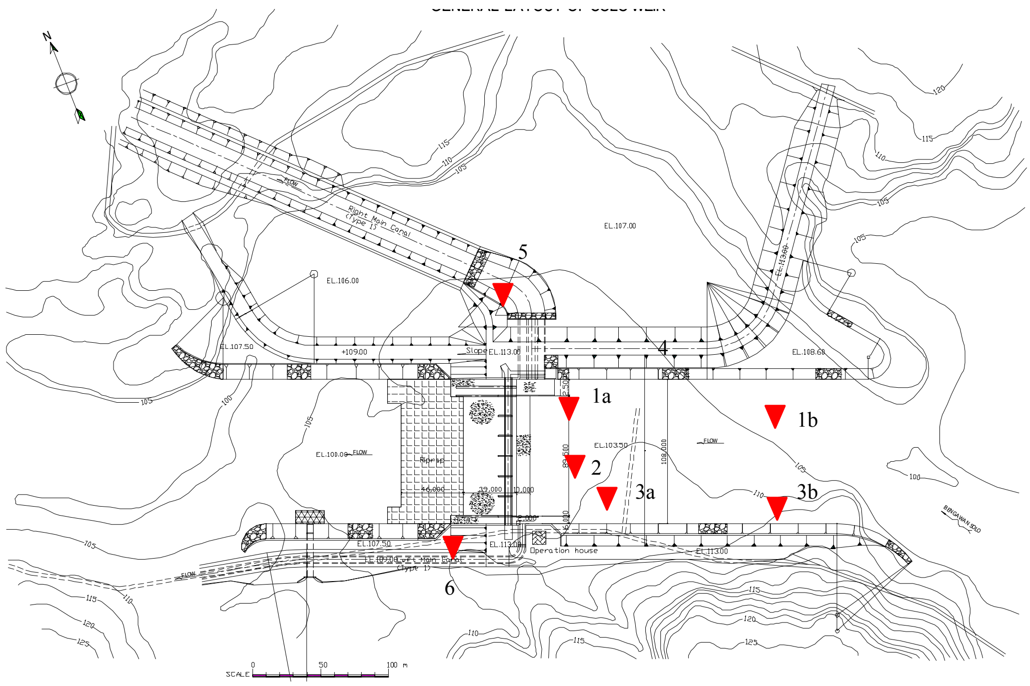


Upstream and Left Side of Colo Weir



Upstream and Right Side of Colo Weir

Intake Gate (Left : Wet Season, Right: Dry Season)



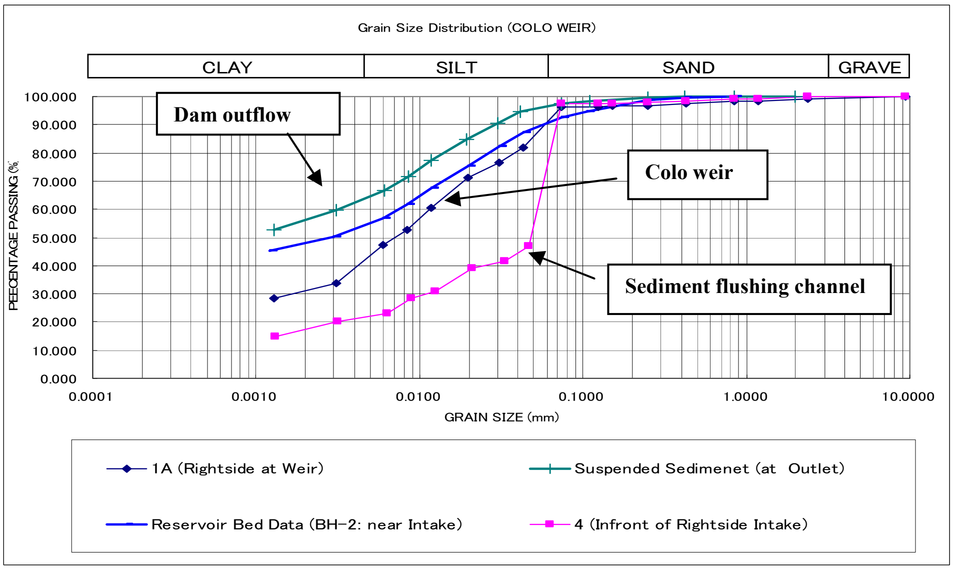
Source : JICA Study Team

Figure 5.3.3 Location Map of Sediment Sampling at Colo Weir

Table 5.3.1 Grain Size Distribution of Colo Weir Sediment

Sample	Location	Gs	Gravel(%)	Sand(%)	Silt(%)	Clay(%)
1a	Weir (East)	2.63	0.50	3.04	51.57	44.90
1b	u/s of Weir (East)	2.62	0.17	26.38	33.64	39.81
2	Weir (Center)	2.63	0.25	23.65	39.10	37.00
3a	Weir (West)	2.62	0.17	14.18	50.60	35.05
3b	u/s of Weir (Left)	2.62	0.00	0.00	47.66	52.34
4	In front of Intake (East)	2.64	0.00	2.32	75.93	21.75
5	Canal (East)	2.65	3.82	63.45	16.01	16.72
6	Canal (West)	2.63	0.00	3.98	45.70	50.75

Source : JICA Study Team



Source : JICA Study Team

Figure 5.3.4 Comparison of Grain Size Distribution of Sediment between Colo Weir and Wonogiri Dam

5.3.4 Interview Survey

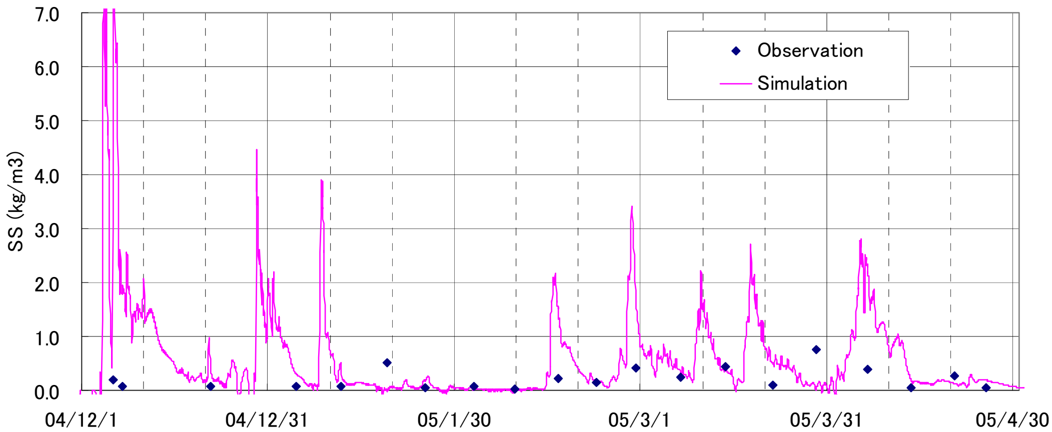
According to the interview survey to Balai PSDA, an operation agency of the main canals, it was reported that the main canal was rehabilitated in 2.5 km stretch with the budget source of Rp. 12 billion from PJT-1 in the end of 2004. As shown in the left photos, the canal was completely dried up and reformed its lining. In the several stretches, the lining of the canal were improve to concrete lining from soil. It was reported that majority of deposit materials in the canal was the bank soils which eroded or collapsed from the lining but not sediments inflowing from the river. In the wet season, irrigation water looked like a chocolate color including much amount of sediments, but almost no sediment would deposit in the canal.

Canal Improvement Work in 2004 (Source: Balai PSDA)

5.4 Analysis of Sediment Load at Colo Weir

The current condition of sediment load between Wonogiri dam and Colo weir was analyzed by using of in the turbidity analysis model as mentioned in Chapter 3. The result of analysis gathered with the result of SS monitoring in this period is shown in Figure 5.4.1 below. As shown in the result, average of SS concentration at Colo weir was 0.2 – 0.3 kg/m^3 in non-flood period but in the flood period SS concentration was increased to around 2.0 - 4.0 kg/m^3.

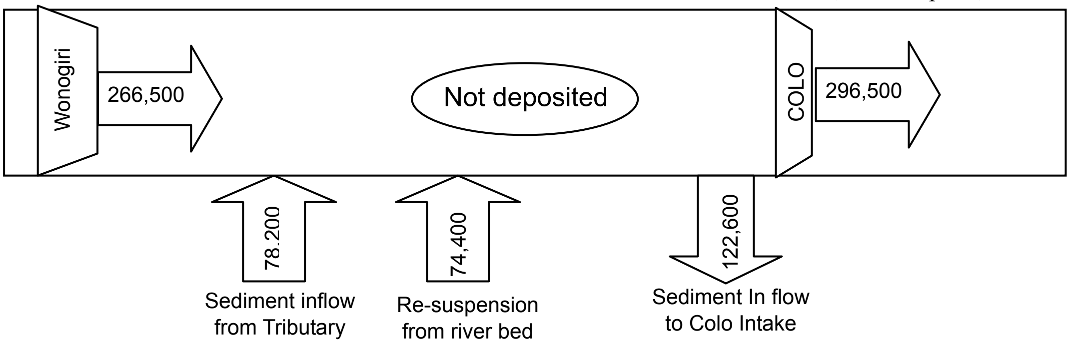
By using this analysis results, sediment balance between the Wonogiri dam and the Colo weir and are created as presented in Figure 5.4.2 assuming that no suspended sediments deposited in the stretch because the upstream of the Colo was already fully deposited.



Source : JICA Study Team

Figure 5.4.1 SS Concentration at Colo Weir in December 2004 to May 2005

Unit: m^3
Nov.1,2004 – Apr.30,2005



Source : JICA Study Team

Figure 5.4.2 Sediment Balance between Wonogiri Dam and Colo Weir

In the stretch between the Wonogiri dam and the Colo, suspended load is supplied from the Wonogiri dam of 266,500 m^3 and from tributaries of 78,200 m^3, in total 344,700 m^3. In addition, re-suspension volume in the stretch was estimated 74,400 m^3. Concerning the volume out to the stretch, suspended load was drawn into the Colo intake of 122,600 m^3 and released to the downstream of 296,500 m^3.

5.5 Impact of Sediment Release from Wonogiri Dam

5.5.1 Assessment of Clogging of Intake

As the result of the field investigation, it was revealed that sediment flushing channel was well maintained and the intake of Colo weir is free from sedimentation due to the effect of sediment flushing gate.

Even if a large amount of sediments will be released from the Wonogiri reservoir to the downstream river, timely operation of the sediment flushing gate will keep the proper function of the intake of Colo weir. Therefore, the possibility of the clogging of intake is considered as very small under proper operation of the flushing gate.

5.5.2 Assessment of Decrease of Flow Capacity by Back Sand

The design discharge between the Wonogiri dam and the Colo weir was 400m^3/s as same as the regulated maximum outflow discharge from the Dam. In practice the upstream of the Colo weir was already fully deposited by sediments. However, a flow capacity in this stretch was secured the design discharge of 400 m^3/s, (see .Sub section 1.2.3). In the future the volume of sediment released from the Wonogiri reservoir will increase, however, the river bed aggradation would not be predicted because the majority of sediments released from the Wonogiri reservoir will mainly compose of wash load. It is predicted that the deterioration of flow capacity in the upstream of the Colo was will be very small after implementation of the project.

5.5.3 Sediment Deposition in the Canal

As the result of the interview survey, it was reported that majority of deposit materials in the canal was the bank soils which eroded or collapsed from the lining but not sediments inflowing from the river. From the view of transportation of a bed material, the sheer stress in the main canal is enough to transport a sediment material with the diameter of 2.0 mm applying the design velocity of the Colo canal of 0.8 m/s. It is indicated that wash load would not deposit in the main canal. The impact of sediment releasing from the

Wonogiri reservoir to the Colo main canal would be small because a majority of released sediments from the Wonogiri reservoir is wash load.

5.6 Monitoring Plan

In present high turbid water are often observed in the Colo weir as well as the mainstream of Solo River. However, there is a threat that significantly high turbid water will be flow into the Colo weir while the sediment releasing operation of the Wonogiri dam after implementation of the project.

To cope with this affect, following measures and monitoring plan shall be proposed as below:

- Preparation of the operation rule to control of sediment releasing from the Wonogiri reservoir,
- Establishment of criteria for allowable maximum limit of SS concentration in the Solo River basin during sediment releasing operation,
- Establishment of criteria for allowable maximum duration of sediment releasing operation.,
- Prohibition of the sediment releasing operation during dry season,
- Periodical monitoring in the mainstream and tributaries of teh Solo River
- Combined sediment flushing operation between the Wonogiri dam and the Colo weir.

It is recommended that above sediment management plans will be studied and established under a trial operation of sediment releasing of the Wonogiri reservoir after implementation of the project.