Annex No.6
Turbidity Analysis for Downstream Reaches, Solo River Estuary and Colo Weir

THE STUDY ON
COUNTERMEASURES FOR SEDIMENTATION
IN
THE WONOGIRI MULTIPURPOSE DAM RESERVOIR
IN
THE REPUBLIC OF INDONESIA

FINAL REPORT

SUPPRTING REPORT I

Annex No.6: Turbidity Analysis for Downstream Reaches, Solo River Estuary and Colo Weir

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CHAPTER 1 GENERAL

1.1 Outline of the Study

In the master plan, construction of a sediment storage reservoir with new gates was proposed as one of the urgent measures. This measure aims at securing the existing intake function through a sediment sluicing/flushing system on the sediment storage reservoir without using the stored water in the main reservoir. However, while the sediment sluicing/flushing system is operated, plenty of highly turbid water will be released to downstream reaches for a certain duration. There would be a threat to cause adverse impacts to social and natural environments in the downstream reaches.

For example, on the Wlingi multipurpose dam project the combined sand flushing of Wlingi multipurpose dam and Lodoyo afterbay weir located downstream of the Wlingi dam in the Brantas River basin was carried out for the period from May 7, 2004 to May 10, 2004. It was reported that the significantly high concentration of sediment load more than 10,000 mg/ltr was observed in the released water. e effects of the sand flushing operation and its impacts on downstream reach are under evaluation by the project office. Hence, it is envisaged that the operation of sediment sluicing/flushing from the Wonogiri reservoir may need to be restricted to the extent that they will not affect significantly the river conditions

Combined Sand Flushing of Wlingi Multipurpose Dam and Lodoyo Afterbay Weir

On the other hand, form the view of the concept "basin-wide sediments management system", a sustainable use of the Wonogiri reservoir and an appropriate sediment balance in the Bengawan Solo River basin may lead in the future through sediment flushing/sluicing operation.

The study on turbidity analysis for the downstream stretch from the Wonogiri reservoir aims at assisting to prepare the sediment releasing plan in the future. This supporting report presents the results and findings of the study on turbidity analysis for the downstream stretch from the Wonogiri reservoir, which involved:

- To review the present status of the Upper Solo River from the Wonogiri dam,
- To measure and assess the turbidity in the stretch of the Uppwer Solo and the dam intake and the dam outlet,,
- To develop and verify a numerical sedimentation model and analyze the present and future sediment hydraulic condition of the Upper Solo River from the Wonogiri dam
- To review and assess the impact of the Solo River estuary through sluicing/flushing system,, and
- To review and assess the impact of the Colo weir through sluicing/flushing system.

1.2 Present Condition

1.2.1 Mainstream and Tributaries

The Bengawan Solo River basin is located along the eastern and central districts of Java with a chatchment area of 16,100km^2 and a length of about 600 km. The Bengawan Solo River is largely divided into 3 basins, the Upper Solo River basin, Madiun River basin and Lower Solo River basin. The subject area of this study is the Upper Solo basin between Wonogiri dam and Ngawi located at the confluence of the Madiun River and the Solo River. The location map of Upper Solo River is presented in Figure 1.2.1. The Upper Solo mainstream flows passing through the wider plain between Mt. Lawu and Mt. Merapi/ Mt. Murbabu and crossing the ancient capital of Surakarta City from south-west to north-east and change its direction from west to east at Suragen City, then confluence with the Madiun River at Ngawi City. It is 200 km long from the Wonogiri dam to Ngawi with the drainage area of 4,750 km^2.

Before flood control projects of the Wonogiri dam construction in 1980 as well as the Upper Solo River improvement project in 1994, the Upper Solo basin was frequently suffered from the floods year after year. Especially in 1966 and in 1968, the recorded maximum floods attacked the basin sequentially which inundated around one week in the Surakarta City. These floods caused the severe damage for people, crops and many facilities. Through above projects, the river stretch of the Upper Solo had been improved to secure a safety against a 10-year probable flood. Recently, since completion of the projects no awful flood occurred in the basin. In present, the past flood plain drastically changed to the fertile irrigation area.

There are many tributaries flowing into the mainstream of the Upper Solo supplying not only water but also sediments produced in the basin. In this Study, the tributaries in the subject area were divided into 16 basins as presented in the basin diagram for turbidity analysis model in Figures 1.2.2.

1.2.2 Cross Section and Profile

In 2004, the river cross section survey was carried out by WREFER & CIP (JBIC) and by this Study in the respective stretches of the Upper Solo River between the Wonogiri dam and Ngawi. Totally 329 cross sections were surveyed with the interval of 500 m as presented in Table 1.2.1. The characteristics of Upper Solo mainstream is summarized in Table 1.2.3.

The longitudinal section between the Wonogiri dam and Ngawi was created based on the cross sections as presented in Figures 1.2.3. The riverbed slope is 1/3000 – 1/3700 in the stretch of Jurug – Ngawi and 1/1700 – 1/2200 in the stretch of Colo – Jurug. The riverbed slope is gradually gentler from the Jurug to the downstream. Especially in the stretch between the Wonogiri dam and the Colo weir, the river bed slope is almost flat because of sediment deposits in the upstream stretch of the Colo weir.

Table 1.2.1 Outline of Cross Section Survey

Year	Stretch	Interval	Section	Source
2004	Just D/S of Wonogiri dam to confluence with Sragen River (BS130)	500 m	163	WREFR&CIP(JBIC)
2004	confluence with Sragen River to confluence with Madiun River	500 m	166	JICA

Source: WREFR&CIP(JBIC) and JICA Study Team

Table 1.2.2 Characteristics of Upper Solo Mainstream

Upper Solo	Length		Average features		
	Unit (km)	*Accum. (km)*	*Bed Slope*	*Depth*	*Width*
Ngawi - Pojok	35.3	35.3	1/3,700	10	140
Pojok - Sawur	35.9	71.2	1/3,000	9	120
Sawur - Tangen	21.4	92.6	1/3,200	9	120
Tangen - Jurug	50.9	143.5	1/3,200	8	100
Jurug - Dengkeng[1)]	17.3	160.8	1/1,720 (1/2,720)	10 (7)	220 (80)
Denkeng – Nguter[1)]	21.6	182.4	1/1,720 (1/2,340)	6 (5)	200-90 (160-55)
Nguter - Colo	1.3	183.7	1/2,200	5	130
Colo - Wonogiri	16.4	200.1	-	9	150-70

Note: Data in the participation shows the value before Upper Solo River Improvement Project, Stage 1 in 1994.
Source: CDMP

1.2.3 Flow Capacity and Design Discharge

The Upper Solo River Improvement Project was completed in 1994 covering the river stretch of 53 km in length from Nguter bridge to Jurug bridge. The Nguter bridge is located downstream of the Colo Intake Weir and the Jurug brigde is located about 5 km downstream of Surakarta City. By the project, the river stretch was improved to secure a safety against a 10-year probable flood incorporating the significant flood control effect of the Wonogiri reservoir. The design flood discharge distribution along the stretch is illustrated in Figure 1.2.4 below:

The present flow capacity of the stretch between the Wonogiri dam and Ngawi was assessed by the non-uniform flow calculation using the recent cross section survey data. As illustrates in Figure 1.2.5 below, between Wonogiri and Jurug the river channel has basically enough capacity against the design discharge of 10 years probable flood. On the other hand, some parts of the river stretch downstream of the Upper Solo Improvement Project could not secure enough flow capacity against the design discharge.

There is a bottle-neck of flow capacity in the stretch from the Wonogiri dam to the Colo. Because of the bottle-neck, the outflow discharge from the Wonogiri dam shall be strictly regulated less than 400 m^3/s against inflowing of the Standard Highest Flood Discharge of 4,000 m^3/s. Although the Colo weir was almost fully deposited of sedimentation in present, the flow capacity in the stretch upstream of the Colo still keeps the design discharge of 400 m^3/s.

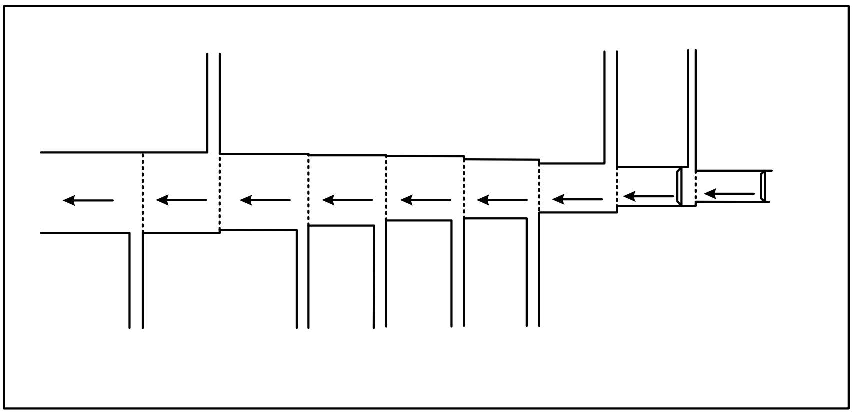
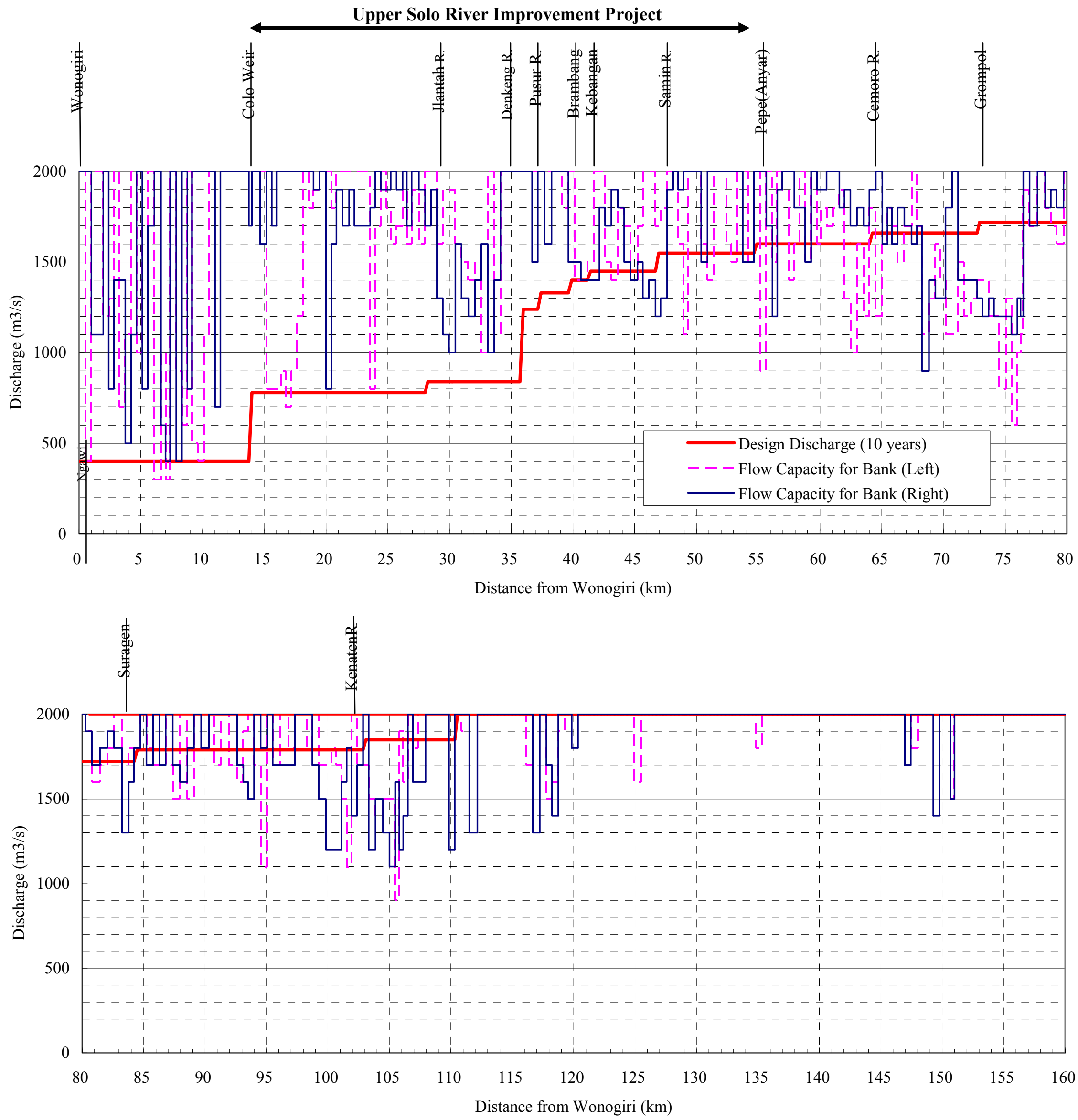


Figure 1.2.4 Design Flood Discharge Distribution in Upper Solo River Improvement Project



Source: JICA Study Team

Figure 1.2.5 Flow Capacity in Upper Solo River

1.2.4 Riverbed Material

(1) Data Availability

Grain size distribution of riverbed materials is one of the dominant factors for the sediment transportation in a river as well as a hydraulic condition. From the feasibility study stage of the Wonogiri Dam Project, available grain size distribution data were collected. Availability of the data is shown in Table 1.2.3 below.

Table 1.2.3 Availability of Grain Size Distribution of Riverbed Materials in Wonogiri Basin

No.	Year	Location	Reference	Agency
1	1975	Dam site (1) Keduang (1) Tirtomoyo (1) Solo (1)	Feasibility Study of Wonogiri Multipurpose Dam	OTCA
2	1983	Upper Solo d/s of dam	WRFER&CIP	PBS
3	1986	Keduang (8) Tirtomoyo (8) Temon (8) Solo (8) Alang (8) Wuruyantro (8)	Monitoring on Erosion and Sedimentation Consisting of Measurement, Planning and Erosion/Sedimentation Researches in Wonogiri Dam Catchment Area	PBS
4	1994	Upper Solo d/s of dam	WRFER&CIP	PBS
5	1995	Upper Solo d/s of dam	WRFER&CIP	PBS
6	2001	Dam Site (Spoil Bank) (1) Keduang (Bridge) (1) Keduang (Dam+12K) (1) Keduang (Dam+19K) (1) Keduang (Dam+24K) (1)	Basic Design Study Report on the Project for Urgent Countermeasures for Sedimentation in Wonogiri Multipurpose Dam Reservoir	JICA
7	2004	Keduang (6) Tirtomoyo (6) Temon (6) Solo (6) Alang (6)	JICA Study	JICA

Note) Number in parenthesis shows the number of samples.

Source: JICA Study Team

(1) Upstream of Wonogiri Reservoir

The comparison of grain size distribution of riverbed materials in the Wonogiri dam basin is shown in Figure 1.2.6.

1) Wonogiri Reservoir

Before the Wonogiri dam construction, riverbed composed of mainly coarse materials of 15 mm in D60. There was no material smaller than 0.3 mm in diameter. This means finer materials were completely flown out to the downstream reaches at that time. In 2001 and 2004 after the completion of the Wonogiri dam, fine materials have been completely trapped in the reservoir. The sediment deposits in the reservoir comprise fine material, that is, D60 is 0.07mm.

2) Main Tributaries

The grain size distribution is similar with each tributary. Riverbed is composed of sand and gravel and there is no fine materials smaller than 0.1 mm. As the result of site inspection in this Study, many outcrops were observed on riverbed in tributaries. In the stretch of upstream of the Wonogiri reservoir, the grain size of river bed materials in tributaries varies in wide range and thus its distribution is not uniform because i) the riverbed materials looked strongly influenced by riffles and pools of natural stream and ii) sand mining activities are very active. As shown in photo below, large rocks with 1 m diameter are deposited in upper reaches, sand and gravel are usually deposited in middle reaches and finer materials as clay and silt can not be easily deposited in river channel and finally reach down to the reservoir.

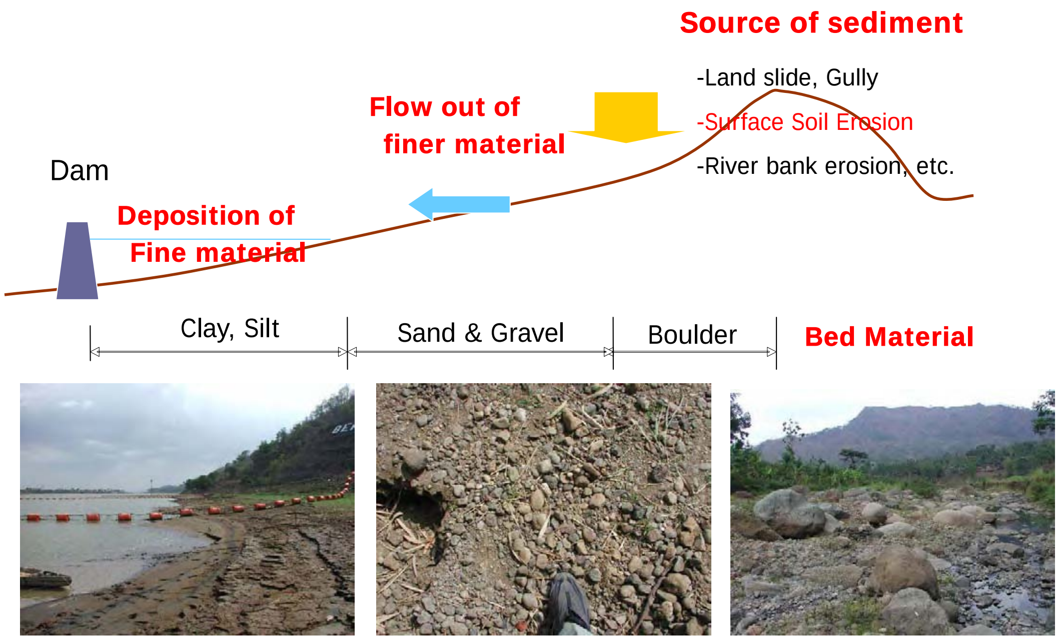
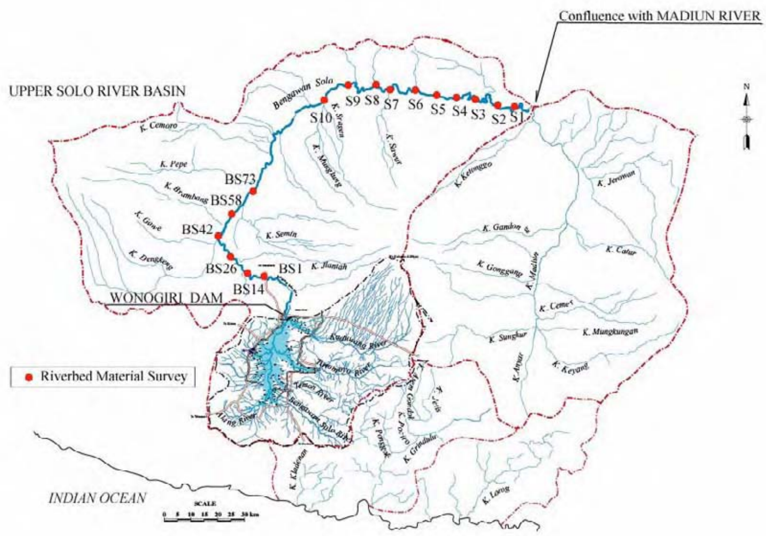


Figure 1.2.7 Characteristic of Grain Size Distribution in Tributaries

(2) Downstream of Wonogiri Dam

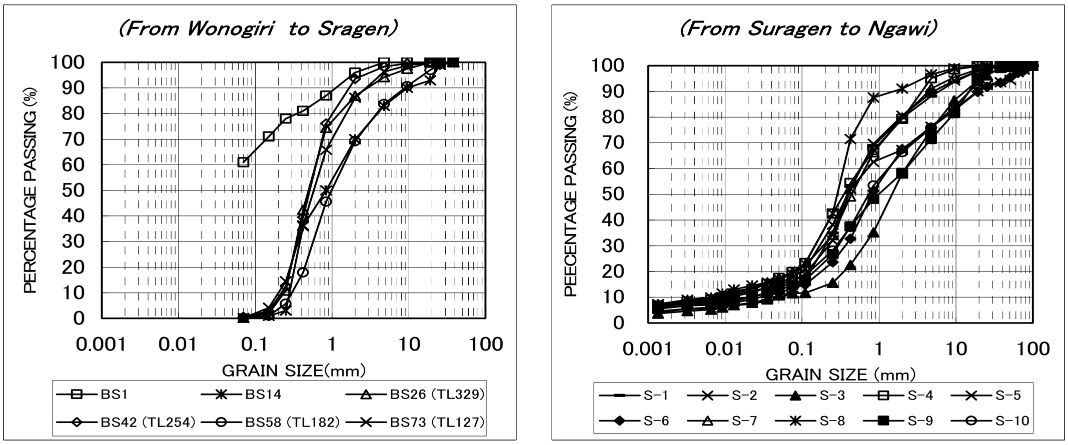
The riverbed material survey has been carried out by PBS on the stretch from the Wonogiri dam to Jurug in 1983, 1994 and 1995. In addition to the previous data to extend the survey area until Ngawi, the river bed materials were sampled at ten (10) locations between Jurug and Ngawi. Location map of river bed material survey is presented in Figure 1.2.8.

At each location, the riverbed materials deposited in 50 cm below the surface were sampled from the central part of the river channel and both side of the river banks. The grain size distribution curves of river deposit materials are shown in Figure 1.2.9 below. The maximum grain size ranges from 88.90 mm to 4.75 mm and 60% diameter of grain size ranges from 9.50 mm to 0.18 mm with an average of 1.73 mm. The river deposit materials were mainly composed of the sand and it percentage of total volume was from 65% to 98%. The composition of clay and silt was from 2% to 35%.



Source: JICA Study Team

Figure 1.2.8 Location Map of River Bed Material Sampling



Source: The data on left figure was obtained by PBS (reported in WREFR & CIP). The data on right figure was obtained by JICA Study Team.

Figure 1.2.9 Particle Size Distribution of River Sediment Materials at 10 points along the Solo River Downstream of the Wonogiri Multipurpose Dam

1.2.5 River Structure

(1) Existing River Structure

The major river structures, levees, revetments, spurs and other structures are managed by PBS and local governments. The existing river structures in mainstream and tributaries with its scale are listed in Table 1.2.4 below.

Table 1.2.4 Existing Structure in the Upper Solo River

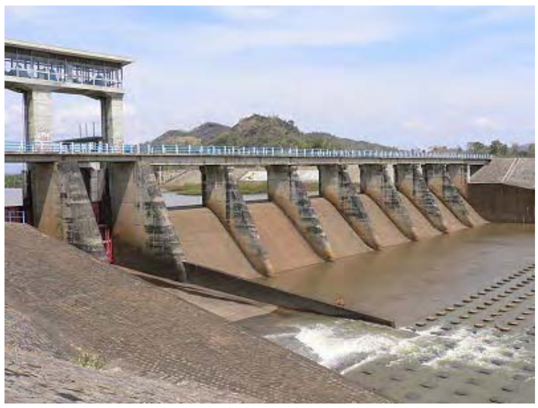
Purpose of Structure	*Structure*	*Mainstream*	*Tributaries*
Flood Control Structures	short-cut	13 km	
	levee embankment	38.7 km	36.0 km
	Groundsill	5 nos.	2 nos.
	Spur	105 nos.	16 nos.
	Revetment	3.9 km	4.9 km
	Sluice	32 nos.	74 nos.
	Pomp station	0 nos.	4 nos.
Sabo Facilities		14	
Water Resource Facilities	Weir (Colo)	1	0

Source: CDMP

(2) Colo Intake Weir

The Colo intake weir is 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



Colo Intake Weir

plan to 29,330 ha where farming with triple or double cropping is being practiced. The mean monthly discharge at the Colo Intake Weir between 1986 and 2005 are shown in Table 1.2.5 below. In case the sediment release from the Wonogiri dam, following impacts to the Colo intake weir should be considered:

- Sediment deposits upstream of the weir,
- Sediment deposits in front of the intakes,
- Sediment deposits in the irrigation canals,
- and impact on water quality of supply water for irrigation.

Table 1.2.5 Mean Monthly Discharge at Colo Intake Weir between 1986 and 2005

(Unit : m^3/sec)

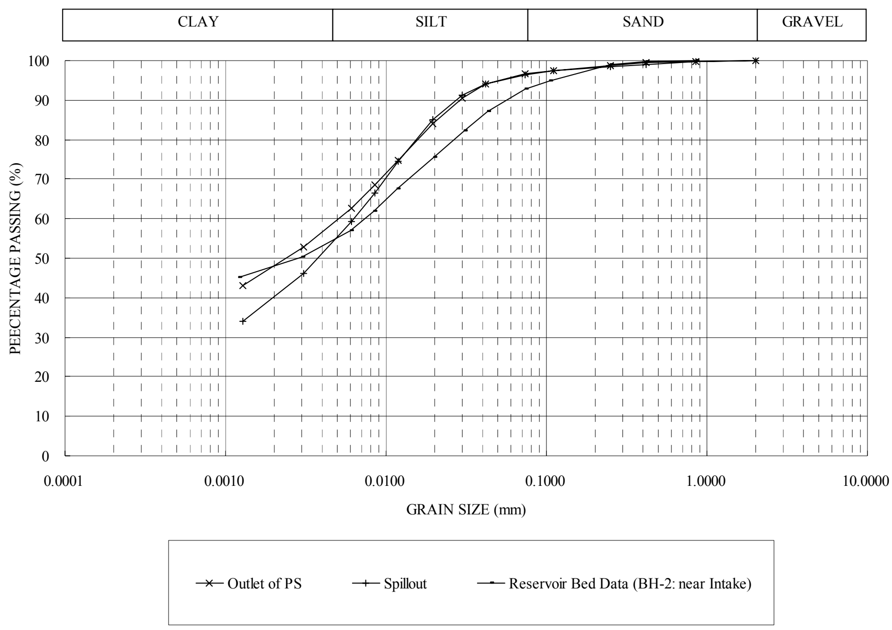
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Outflow to d/s	30.7	51.4	54.7	32.0	4.8	3.3	3.2	3.2	4.5	6.8	11.8	17.8
Left canal intake	2.4	2.8	2.5	3.1	3.3	3.5	3.4	3.2	3.4	2.7	2.3	2.7
Right canal intake	15.2	13.8	15.7	16.5	16.9	15.7	16.0	15.6	17.0	15.5	14.4	16.6
Total Inflow at Colo	**48.3**	**70.2**	**74.0**	**54.1**	**26.2**	**23.3**	**23.3**	**22.5**	**25.6**	**26.0**	**29.0**	**35.5**

Source: Balai PSDA Bengawan Solo Wilayah, Surakarta

1.2.6 Turbidity and Sediment Load

(1) Characteristics of Released Sediment from the Wonogiri dam

The grain size distributions of the suspended sediment taken from the water released from the outlet of the Wonogiri dam power station and from the spillway and sediment deposits taken from the reservoir bed near the intake are shown in Figure 1.2.10 below. They mainly contain very fine materials including 59 - 63% of clay and 33 - 37% of silt. The composition of the sand was only 4 - 7%. These fine materials are generally transported as “washload” in the river stretch downstream of the Wonogiri dam.



Source: JICA Study Team

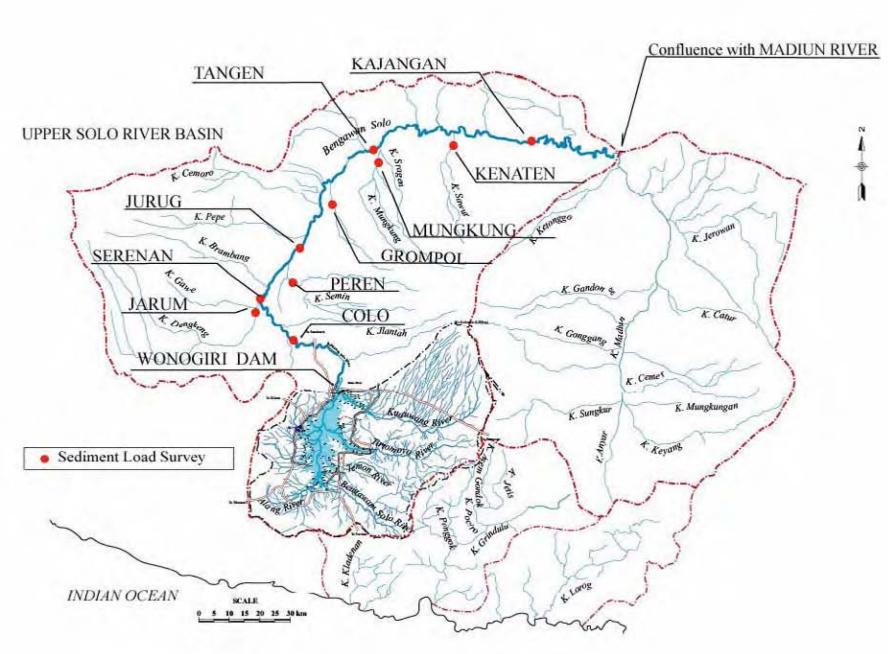
Figure 1.2.10 Grain Size Distribution of SS from Outlet of Wonogiri P/S

(2) Sediment Discharge-Rating Curve

The measurement of sediment load in the Upper Solo basin was commenced from 1980. Location map of the measurement is shown in Figure 1.2.11. Therein the measured was carried out only for suspended load. The obtained data of suspended load with its discharge was plotted on the log-log graph and correlation curve i.e. suspended load-discharge rating curve was determined for each measurement stations as presented in Figure 1.2.12.

(3) Suspended Load in Downstream Reaches

Annual suspended load in downstream reaches were estimated using the above suspended–discharge rating curves. In this estimation, the available daily discharge data of each station from 1991 – 2004 were applied. As presented in the Table 1.2.7 below, the annual suspended loads at three (3) locations on the Upper Solo mainstream, Serenan, Jurug and kajangan were 1.9 to 9.3 million with a proportion to the downstream. The annual suspended loads at five (5) locations on the main tributaries were 0.3 to 1.6 million ton.



Source: JICA Study Team

Figure 1.2.11 Location Map of Sediment Load Survey

Table 1.2.6 Annual Suspended Load in the Upper Solo Basin

No.	Location	River	Distance from the Dam (km)	Annual Sediment Load (million ton)
Main Stream				
1	Serenan	Solo River	37	1.90
2	Jurug	Solo River	52	2.60
3	Kajangan	Solo River	167	9.31
Tributaries				
4	Jarum	Denkeng River	36.2	1.61
5	Paren	Semin River	46.6	0.38
6	Grompol	Grompol River	72.8	0.31
7	Mungkung	Mungkung River(Suragen River)	89.1	1.56
8	Kenaten	Kenaten River	112.5	1.07

Source: JICA Study Team

1.2.7 Riverbed Movement

There are five (5) groundsills installed in the river stretch between the Colo weir and the downstream of the Jurug by the Upper Solo River Improvement Project in 1994. In addition to these riverbed stabilized structures, outcrops of bedrock and consolidated clays can be seen at many places over the Upper Solo mainstream as shown in the following photos. There are some sections like Lawu where a hard soil bed forms a natural groundsill. The layers of deposit materials on the river bed are basically thin due to very long term degradation in the Upper Solo River.

Besides above conditions, sand mining are very active in the river channel of the Upper Solo river. The result of the investigation by WREFR&CIP shows annual sand mining volume was approximately 62,000 m^3 per year in total in 2004. These sand mining activities cause the local scouring in the river channel. In collaboration with the operation of the sediment releasing though sediment sluicing/flushing system, sand mining activities should be strictly confined to keep from the d These sand mining activities cause the local scouring and destabilization of the river channel.

River Condition in Upper Solo River mainstram

CHAPTER 2 TURBIDITY MEASUREMENTS

2.1 Objective of Turbidity Measurement

Sediments discharge in the river cannot be measured directly, but must be calculated from stream discharge and sediment concentration. Generally while continuous monitoring of discharge presents no difficulty, no method is available to continuously measure the suspended sediment concentration. As well as in this Study, previous turbidity (suspended sediment concentration) was measured in the Upper Solo basin only at the intervals of 5-10 years and not continuously. Especially no turbidity data was available for the outflow water released from the outlet and the spillway of the Wonogiri dam. It is significantly valuable to collect the latest and actual data concerning for the turbidity and grain size distribution of the sediment discharge in the Upper Solo River basin.

In this Study, turbidity variation were periodically measured in several locations i) at five major tributaries in the Wonogiri dam basin, ii) around the intake and the outlet of the Wonogiri dam, iii) at spillway during spillout operation and iv) at four locations in the Upper Solo mainstream between the Wonogiri dam and Ngawi. The interval of measurement during the flood events was set as short as possible to observe a short time variation of turbidity both in the river stream and the released water from the dam. To obtain a continuous monitoring data, turbidity measurements was constantly and periodically carried out through the whole period of the wet season in this Study. The outline of each measurement is summarized in Table 2.1.1.

Table 2.1.1 Outline of Turbidity Measurements

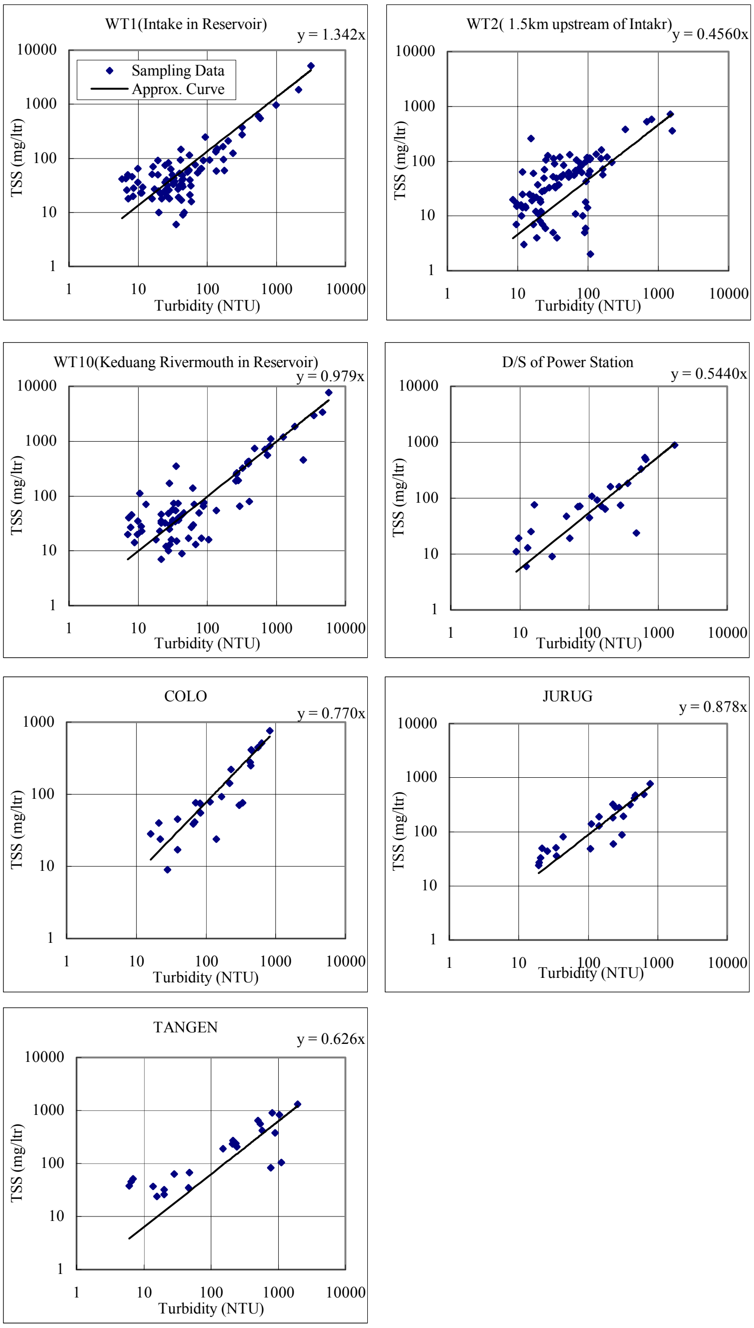
Item	1	2	3	4
Target	Inflow from 5 major tributaries	Turbidity current from the Keduang River to the intake,	Spillout (water release) from the spillway	River flow in Upper Solo River d/s of Wonogiri
Location	-Keduang -Tirtomoyo -Temon -Solo -Alang	-Keduang River mouth -Dam right side -U/S spillway gate -D/S power station	-Keduang River mouth -Dam right side -U/S spillway gate -D/S spillway gate -D/S power station -Wonogiri Bridge	-Wonogiri Bridge -Colo Weir -Jurug Bridge -Tangen Bridge
Period	2004/11 – 2006/03	2005/01 – 2005/05	2006/01/28-2006/02/03	2005/01 – 2006/05
Monitoring Interval	every hours in flood, every week in non flood period	every 3 hours in flood, every day in non flood period	every 10 minutes in beginning of spillout, every 3 hours after one hour passed from the beginning of spillout	one time per a week in wet season, one time per two weeks in dry season
Monitoring Item	SS, Grain size of SS	Turbidity (NTU) , SS	Turbidity (NTU) , SS, Grain size of SS	Turbidity (NTU) , SS
Main Usage	For estimation of reservoir sedimentation//For input condition of reservoir sedimentation analysis	For calibration of reservoir sedimentation analysis	For calibration of reservoir sedimentation analysis	For calibration of turbidity analysis in Upper Solo River downstream of the Dam

Source : JICA Study Team

2.2 Correlation between Turbidity and SS Concentration

It is well known that there is a proportional correlation between turbidity and SS (Suspended Solid) concentration. In this Study, several water samples could be directly analyzed its SS concentration with the unit of the mg/ltr (or ppm) in the laboratory.

However, other water samples were generally measured the turbidity by the turbidimeter [HACH 2100P] with the unit of NTU (Nephelometric Turbidity Units). To convert measured turbidity to SS concentration, correlation function between turbidity and SS concentration was created at each location as presented in Figure 2.2.1. Applying this functions the measured turbidity can be converted to the SS concentration.



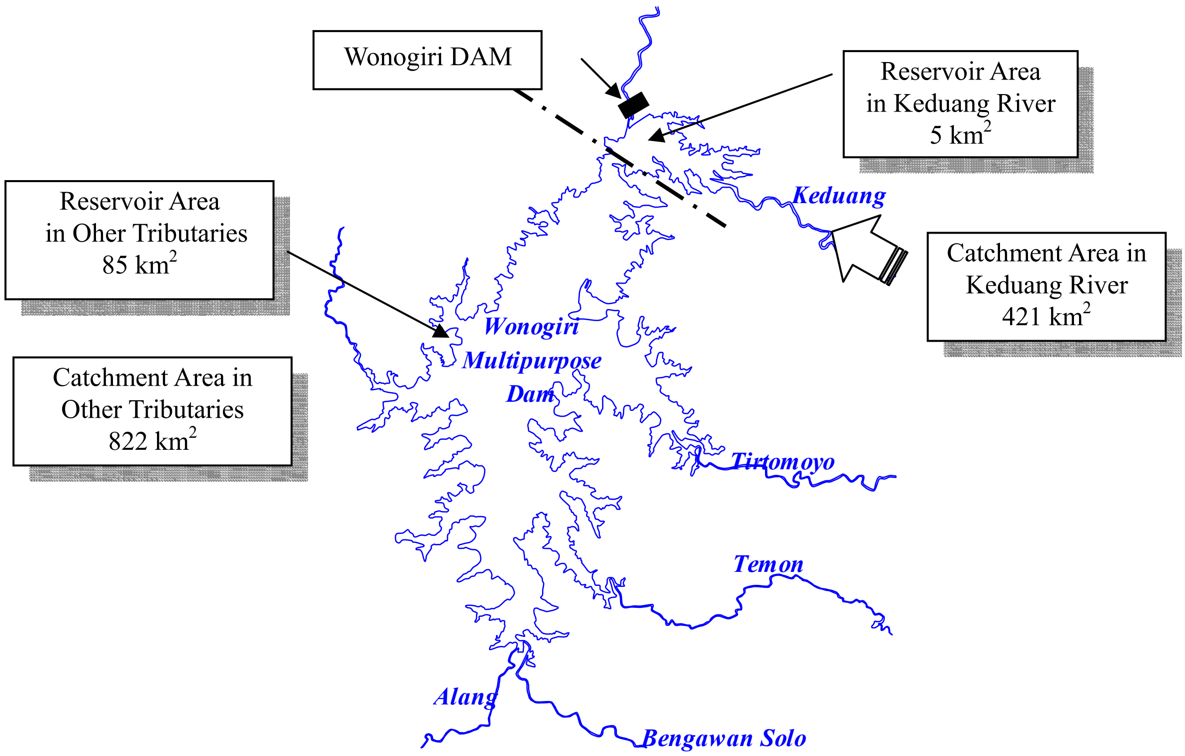
Source: JICA Study Team

Figure 2.2.1 Correlation between Turbidity and SS Concentration

2.3 Five Major Tributaries in Wonogiri Dam Basin

2.3.1 Outline of Measurement

The Wonogiri watershed is drained by five major tributaries, Keduang, Tirtomoyo, Temon, Bengawan Solo, Alang Rivers as shown in the Figure 2.3.1 in the next page. The Keduang River, which is the largest tributary in the basin, enters the reservoir immediately upstream of the dam. Although its catchment area is 421 km^2 or 34 % of the total Wonogiri catchment, the reservoir area that accommodates the sediment inflow from the Keduang river is only 5 km^2 or 6% of the total reservoir area. Because of this, progress of sedimentation in this area is much faster than those of other tributaries. On the other hand, other four tributaries enter in the middle to upstream of the reservoir. Sediments yield from these rivers may not affect the intake because of a long distance from its flange to the intake. From the view of a long term reservoir function, they continuously reduce the storage capacity of the Wonogiri dam. The sediment inflow from tributaries has local hydro-meteorological, geological, topographic characteristics. These characteristics of sediment inflow should be investigated for each tributariy.



	Keduang River	Other Tributaries
(a) Catchment Area (km^2)	421 (34%)	822 (66%)
(b) Reservoir Area (km^2) at EL.136m	5 (6%)	83 (94%)
(b) / (a) in %	***1.2***	***10.1***

Source: JICA Study Team

Figure 2.3.1 Characteristic of Wonogiri Catchment Area and Reservoir Area

The outline of turbidity measurements in five major tributaries in the Wonogiri dam basin is shown below.

Target	:	Inflow from 5 major tributaries
Location	:	(i) Keduang, (ii) Tirtomoyo, (iii) Temon, (iv) Solo, (v) Alang
Period	:	2004/11 – 2006/03
Monitoring Interval	:	every hours in flood, every week in non flood period
Monitoring Item	:	SS, Grain size of SS
Main Objective	:	For estimation of reservoir sedimentation//For input condition of reservoir sedimentation analysis

For better estimation of the sediment inflow from the tributaries, the measurements were operated based on the following principle:

- to include the large discharge events,
- to collect a large number of samples at different times over the rising and falling stage of significant runoff events,
- to collect samples continuously,
- and to collect samples simultaneously in five major tributaries.

As the results of the field measurements, the sediment rating curve of each tributary and the grain size distribution of sediment inflow were determined. Subsequently they were applied for assessment of the previous reservoir sedimentation volume and for the input and boundary condition of the reservoir sedimentation analysis.

2.3.2 Result of Measurement

(1) Sediment Rating Curve

The relationship between sediment discharge and concentration, usually plotted as a function on log-log graph, is called a "*sediment rating curve*". Observed data pairs of discharge and SS concentration in November 2004 to May 2005 were plotted on the log-log graph as presented in Figure 2.3.2. To obtain the sediment rating curve, the equation of power regression is applied:

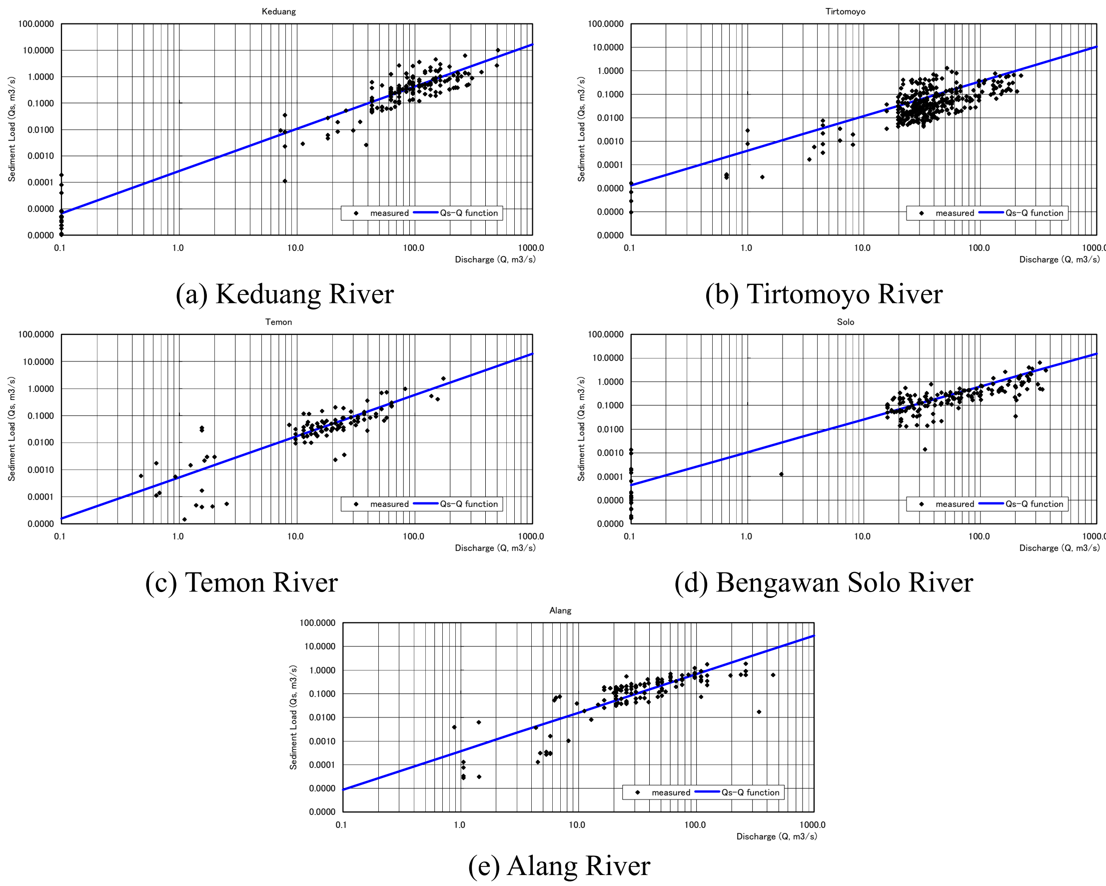
$Qs = A \times Q^B$.

Where: Qs = Sediment load (m^3/s)
Q = discharge (m^3/s)
A,B = coefficient

At first coefficient B was determined as the inclination of the correlation curve using a linear least square regression. Then coefficient A was calibrated through the reservoir sedimentation analysis and finally specified so that the volume of sediments inflow would fit to the sediment deposition volume which was measured by the two times reservoir sounding survey on October 2004 and July 2005.

(2) Gain Size Distribution of Suspended Load

In collaboration with the turbidity measurements, grain size distributions of suspended sediment, which were taken from the same location in each tributary, were analyzed as presented in Figure 2.3.3. The composition of washload (smaller than 0.074mm in diameter) of the sampled materials was 76~95% in the tributaries.



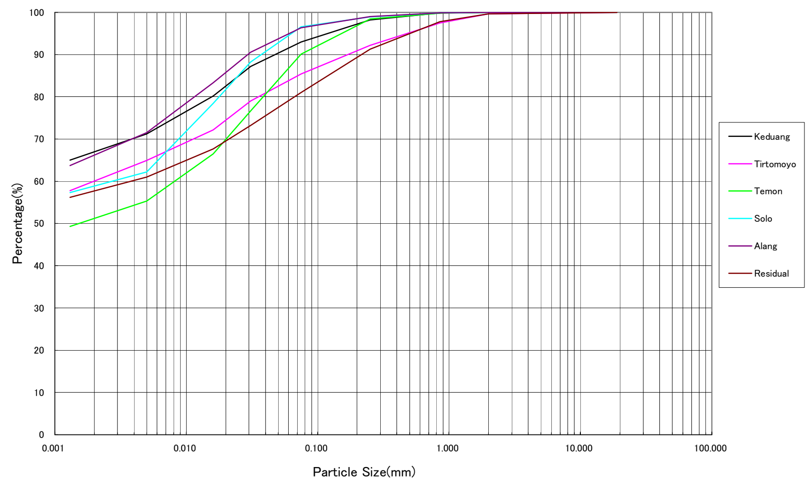
(a) Keduang River (b) Tirtomoyo River

(c) Temon River (d) Bengawan Solo River

(e) Alang River

Source: JICA Study Team

Figure 2.3.2 Sediment Rating Curves in the Rivers (2004.11~2005.5)



Source: JICA Study Team

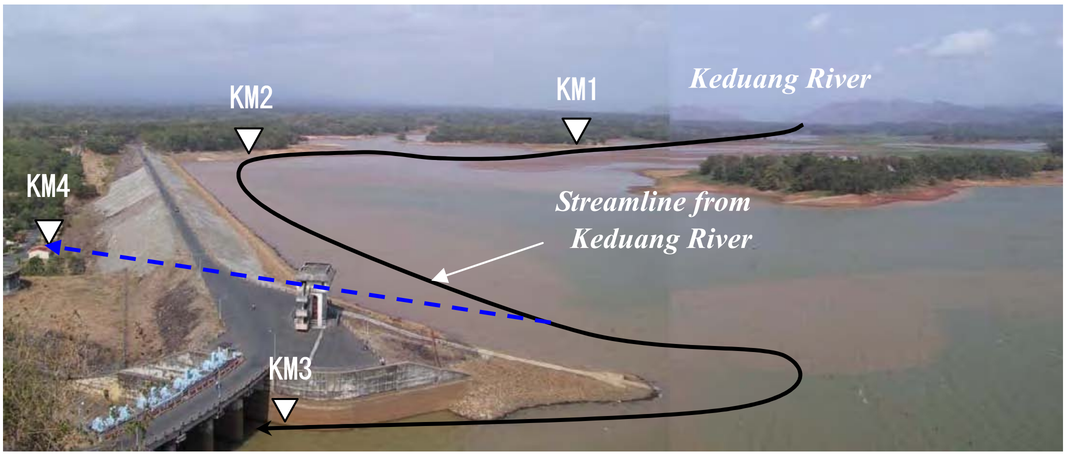
Figure 2.3.3 Grain Size Distribution of Sediment Inflow in the Rivers (2004.11~2005.5)

2.4 Turbidity Current from Keduang River

2.4.1 Outline of Measurement

Turbidity current from the Keduang River directly flows into the intake. This current has a close relation with the sedimentation in front of the intake. Turbidities of this current as well as the outflow from the power station were periodically measured from January to October in 2005. Location of measurement is presented in the photo below. Monitoring interval was every three hours in flood and everyday in non-flood period. Water was taken from the surface and analyzed of its turbidity. The outline of turbidity measurements for the turbidity current from Keduang River is shown below:

Target	:	Turbidity current from the Keduang River to the intake,
Location	:	(i) Keduang River mouth, (ii) Dam right side, (iii) U/S of spillway gate, (iv) D/S of power station
Period	:	2005/01 – 2005/05
Monitoring Interval	:	every 3 hours in flood,every day in non flood period
Monitoring Item	:	Turbidity (NTU) , SS
Main Objective	:	For calibration of reservoir sedimentation analysis



Note) KM1: Keduang River mouth, KM2: Dam right side, KM3: in front of spillway gate,KM4: outlet of power station

Source: JICA Study Team

Figure 2.4.1 Location Map of Turbidity Measurement in Keduang River Mouth

2.4.2 Results of Measurement

Totally 516 of turbidity data were obtained in each location. Measured turbidities were converted to SS concentrations using the correlation functions mentioned in Section 2.2. The relation between discharge and SS concentration of the dam outflow is presented in Figure 2.4.2. The observed SS concentration in January to October 2005 in each location is presented in Figure 2.4.3 and summarized in the table below.

Main findings of the measurements are characterized as below:

- The average SS concentration of the outflow from the Wonogiri power station (KM4) was 201 mg/ltr, which was a little higher than those in other locations measured in the reservoirs.
- Excluding at the upstream of spillway(KM3), the maximum SS concentrations rose up more than 1,500 mg/ltr. The maximum SS concentrations were 10 -30 times higher than the average in each location.

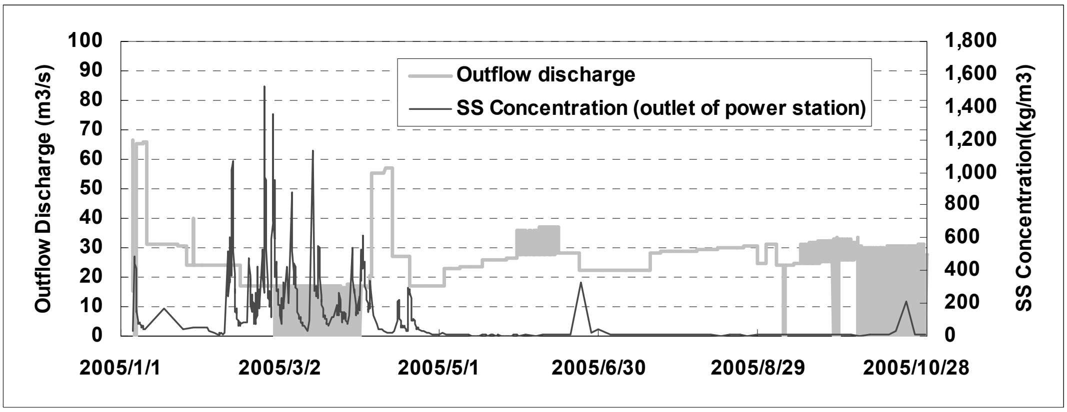
Table 2.4.1 SS concentration along Turbidity Current from Keduang River in January – October 2005

Location	SS (mg/ltr, ppm)		
	Average	Min.	Max.
(KM1) Keduang River mouth	172	6.8	1886
(KM2) Dam right side	69	4.8	2320
(KM3) In front of spillway	48	8.1	878
(KM4) Outlet of power station	201	2.7	1524

Source: JICA Study Team

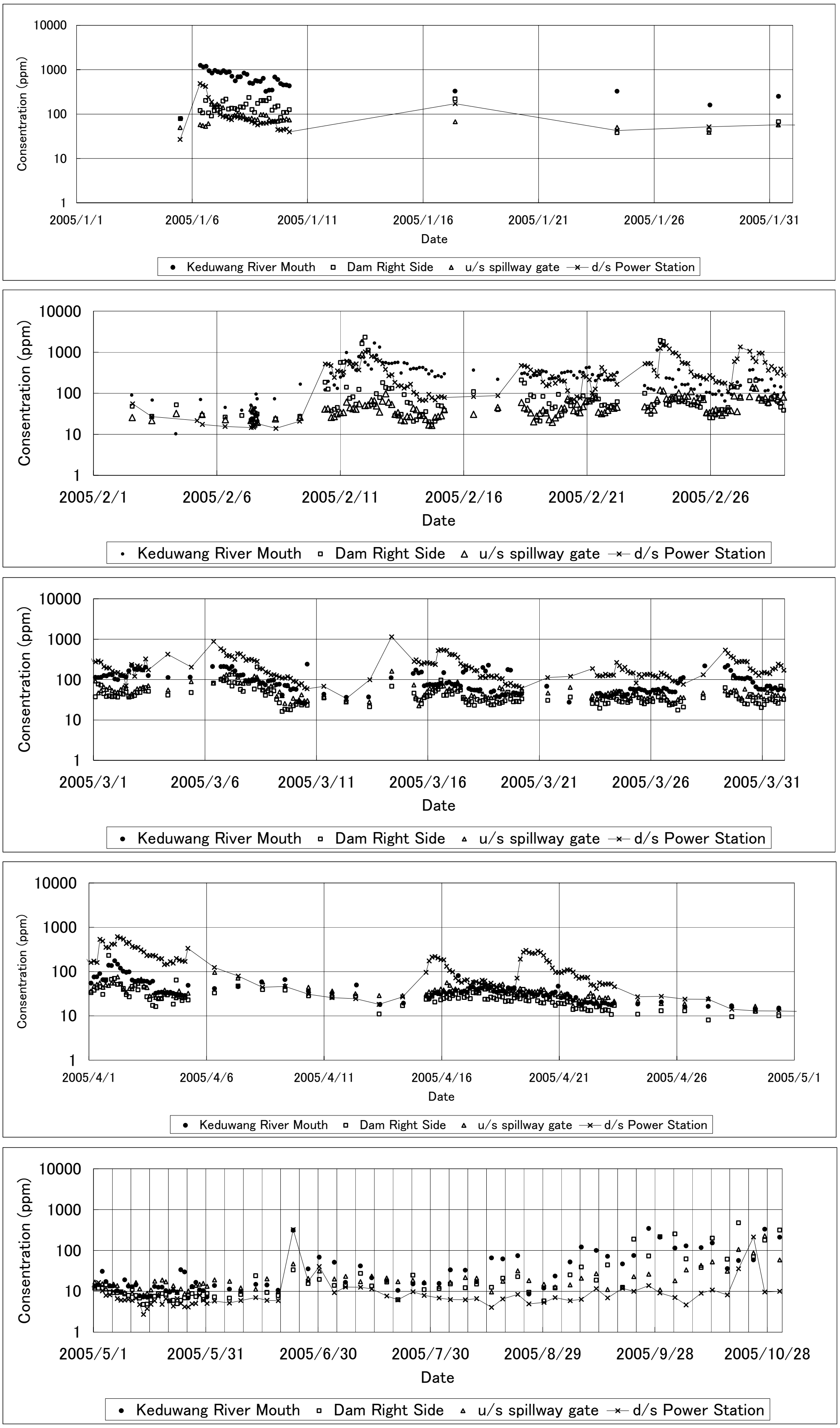
- Concentration of the upstream of the spillway gate was generally lower and more stable than those of other stations. A jetty in front of right side of spillway may block the turbidity current.
- Since the middle of February 2005, SS concentration of the outflow from the Wonogiri power station (KM4) is likely to be higher than others especially during the flood period. These results indicated that the turbidity current from Keduang River was intruded in the bottom of the reservoir and then released through the waterway of power station as shown in the vertical profile of turbidity in the reservoir measured in the Study (see Data Book No.2 Water Quality).
- Peaks of high concentration was continue around two or three days after the flood. This almost meets the settling time of fine sediments.

Sampling Work for Monitoring of Turbidity Current



Source : JICA Study Team

Figure 2.4.2 Relation between Outflow Discharge and SS Concentration in January to October 2005



Source : JICA Study Team

Figure 2.4.3 Observed SS Concentration at Keduang River Mouth, Dam in Left Front, Spillway in Front and Outlet of Power Station in January - October 2005

2.5 Spillout

2.5.1 Outline of Measurement

Before the commencement of the Study, no turbidity data was available for the outflow water released from the outlet and the spillway of the Wonogiri dam. It is significantly valuable to collect the latest and actual data of the turbidity and grain size of them. For the first year of this Study in 2004/2005, a field measurement was prepared, however, there was no spillout excluding small water release from the spillway to flush away garbage gathering into the intake on December 29 in 2004.

Subsequently in the second year of this Study in 2005/2006, the reservoir water level reached to EL.135.58 m then PJT-1 started the spillout following the Wonogiri dam operation rule on January 28, 2006,. The spillout operation continued to February 8, 2006.

While releasing water from the spillway, the turbidity of spillout water were measured at six (6) locations as presented in the Figure 2.4.1 below. Several samples was taken from the spillout water and analyzed the grain size distributions of suspended sediments.

The outline of turbidity measurements is shown below:

Target	:	Spillout (water release) from the spillway
Location	:	(i)Keduang River mouth, (ii)Dam right side, (iii)U/S spillway gate, (iv)D/S spillway gate, (v) D/S power station, (vi)Wonogiri Bridge
Period	:	2006/01/28-2006/02/08
Monitoring Interval	:	every 10 minutes in beginning of spillout, every 3 hours after one hour passed from the beginning of spillout
Monitoring Item	:	Turbidity (NTU) , SS, Grain size of SS
Main Objective	:	For calibration of reservoir sedimentation analysis

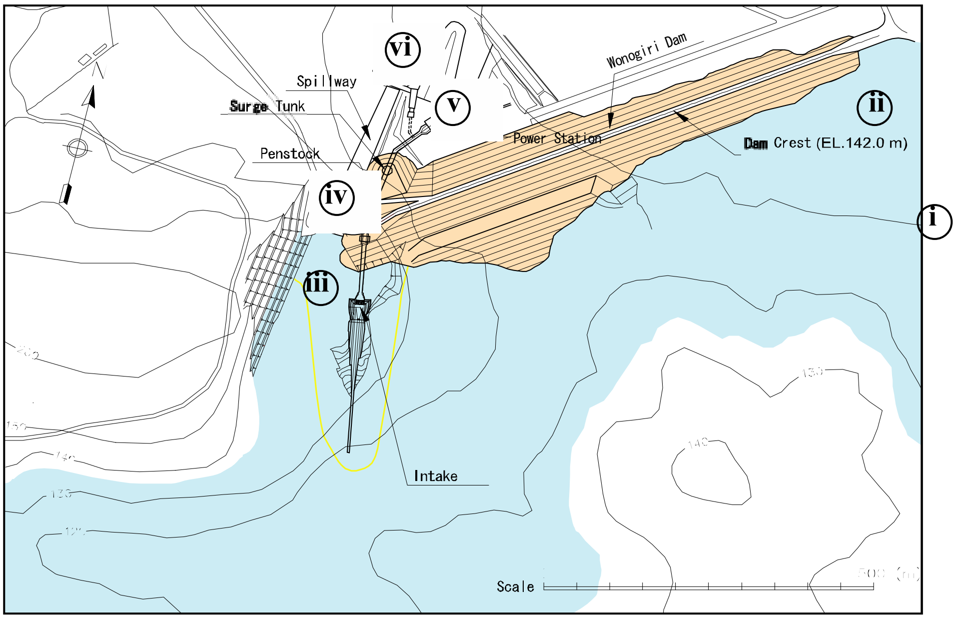
2.5.2 Spillout on December 29, 2004

(1) Condition during Spillout

PJT-1 conducted the spillout operation with a small water releasing from the spillway to flush away garbage gathering into the intake from 12:15 pm to 12:45 pm on December 29 in 2004. The conditions during spillout are described as below:

- operation of the Wonogiri power station was stopped before spillout,
- 4 (four) spillway gates were fully opened to flush away the garbage,
- water level before spillout was approximately El.133.4 m,
- water level after spillout was approximately El.133.3 m,
- outflow discharge when gate fully opened was estimated approximately 50 m3/s per gate,
- volume of the flushed garbage were estimated approximately 1,125 m^3 that was estimated 0.5 m in thickness and 2,250 m^2 in area.

During the spillout, totally 8 samples were taken form upstream and downstream of the spillway and analyze the SS concentration..



Source : JICA Study Team

Figure 2.5.1 Location Map of Turbidity Measurement during Spillout

Table 2.5.1 List of Samples during Spillout on December 29, 2004

Location	Nos. Samples.	Date	Timing of Sampling
Immediately upstream of spillway	2	Dec-2912:20	During spillout
at the bridge downstream of the spillway	1	Dec-29 12:10	Before spill out
	5	Dec-29 12:15-12:45	During spillout

Source : JICA Study Team

(2) Result of Observation

1) Before spillout

Reservoir water looked rather clean because there was no flood in a few days before December 29, 2004. The observed SS concentration was very small and less than 100 mg/ltr at both of upstream and downstream of the spillway.

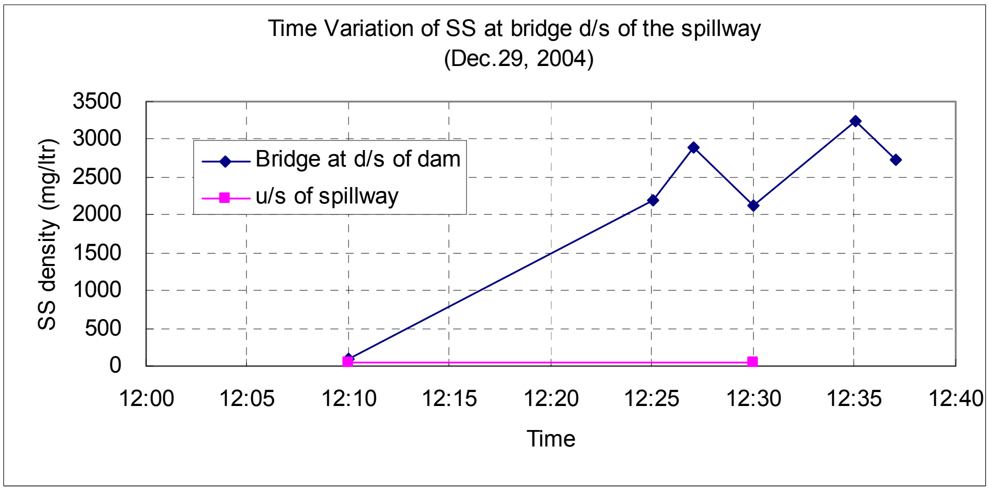
Table 2.5.2 SS concentration before Spillout on December 29, 2004

Location	SS (mg/ltr)
u/s of spillway	44
at the bridge downstream of the spillway	96

Source : JICA Study Team

2) During Spillout

SS concentration in the river at the bridge downstream of the spillway was significant increase to 2,000 to 3,000 mg/ltr during spillout. Taking into consider that the concentration at upstream of the spillway gates was still lower during spillout, it was considered that the water released from the ski-jump type outlet of the spillway caused the high concentration in the downstream river due to a strong turbulence flow in the downstream of the outlet of spill way.



Source : JICA Study Team

Figure 2.5.2 Time variation of SS concentration on December 29, 2004

2.5.3 Spillout in 2006

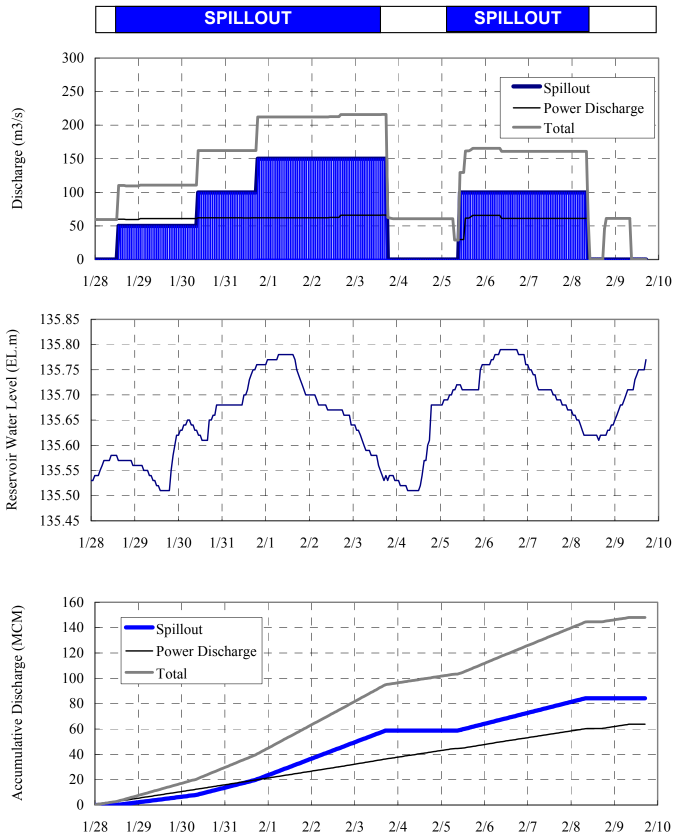
(1) Condition of Spillout

In the second year of this Study in 2005/2006, which was defined a wet year in the later study, a large number of floods occurred in the Wonogiri dam basin and then the reservoir water level rose up faster than as usual. It reached to EL.135.58 m on January 28, 2006. To secure the safety against design flood inflow, PJT-1 opened the spillway gate and started the spillout following the Wonogiri dam operation rule that the reservoir water level shall be kept lower under C.W.L.135.30 m during the flood period of December 1 to April 15. This spillout operation continued 12 days until February 8, 2006. The operation record during the spillout in 2006 is presented in Figure 2.5.3. Conditions of spillout are summarized below:

- Power station was continuously operated during the spillout with the discharge of about 50 m^3/s,
- Spillout conducted in two times. First spill out started from January 28 12:00 to February 3 17:00, second spill out started from February 5 10:00 to February 8 8:00,
- Spillout discharge varied from 50 $m^{3/}s$ to 150 m^3/s,
- Total spillout volume was around 84.2 million m^3 in 9 days,
- Nevertheless, the reservoir water level increased again after the spillout.

(2) SS Concentration during Spillout

While the first spillout from January 28 12:00 to February 3 17:00, the spillout water was taken with the interval of every ten minutes in first two hours and every three hours after first two hours passed. The SS concentration at each station is summarized in Table 2.5.3 and presented in Figure 2.5.4. The characteristics of SS concentration during the spillout are summarized below:

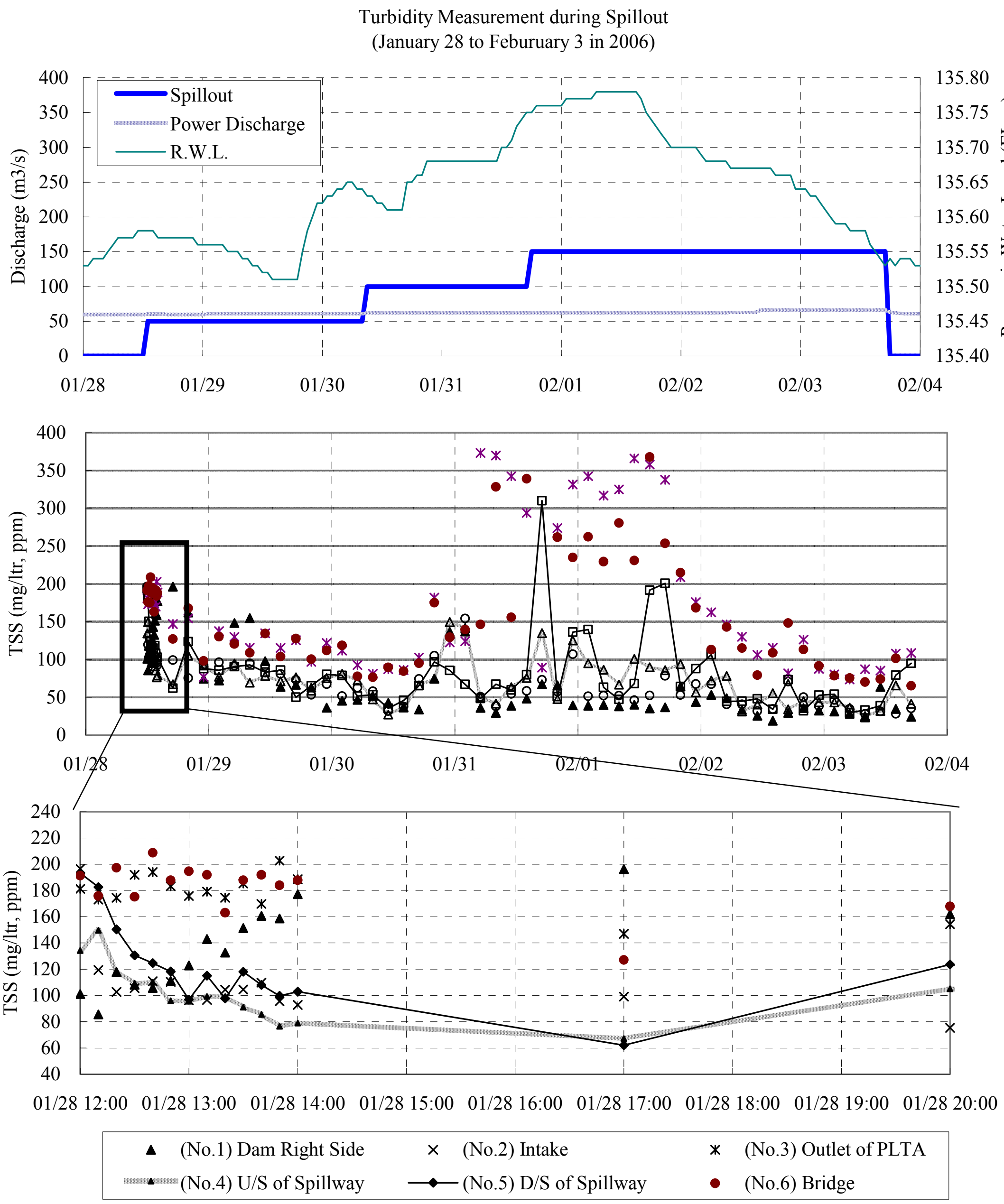


Source : JICA Study Team

Figure 2.5.3 Dam Operation Record during Spillout from January 28 to February 8 in 2006

1) Immediately after Spillout (12:00 – 20:00 on January28)

- The fluctuations of SS concentration of upstream and downstream of the spillway and at the intake were almost same.
- Within first two hours of spillout, SS concentrations of above three locations immediately dropped to 80-100 mg/ltr from 160 -200 mg/ltr. Though it is difficult to judge from only this observation results, it is considered that immediately after opening the spillway gate stagnant turbid water around the forebay was released and then relatively clear water was drawn into the forebay from the surrounding area mainly from the Solo river side.
- Compared the concentration between upstream and downstream of the spillway, that of the downstream was slightly higher by 20%. It is estimated that high concentration of downstream of the spillway was caused due to re-suspension of sediment deposits in front of the spillway gate.
- SS concentration at the bridge downstream of the dam and the outlet of the power station were around 160 -200 mg/ltr and unchanged.



Source : JICA Study Team

Figure 2.5.4 Observed SS Concentration during Spillout from January 28 to February 8 in 2006

Table 2.5.3 Concentrations during Spillout in 2006

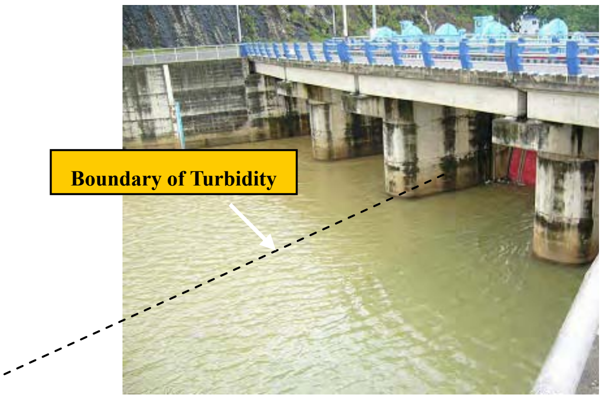
Location	SS (mg/ltr, ppm)		
	Average	Min.	Max.
Dam right size	74	19	196
Intake	73	28	197
outlet of power station	173	74	373
u/s of spillway	77	25	150
d/s of spillway	89	29	310
Bridge	161	65	406

Source : JICA Study Team

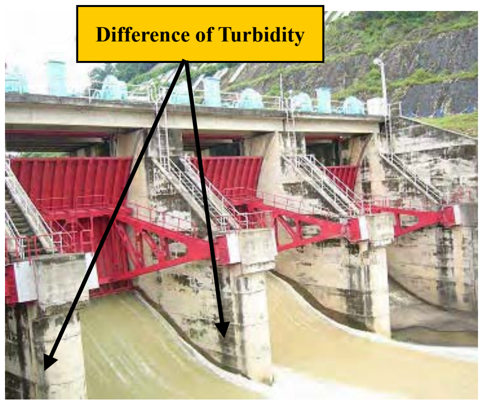
2) During Spillout

- The average concentration around the spillway was 77 mg/ltr in the upstream side and 89 mg/ltr in the downstream side. The maximum concentration is 150 mg/ltr in the upstream and 310 mg/ltr in the downstream.
- SS concentration around the spillway were lower than those at the bridge and the outlet of the power station.
- As shown in the increase of the reservoir water level from January 31st to February 2nd, some large floods flew into the reservoir in this period. Because of these floods, some peaks of SS concentration were observed at the downstream of the spillway.

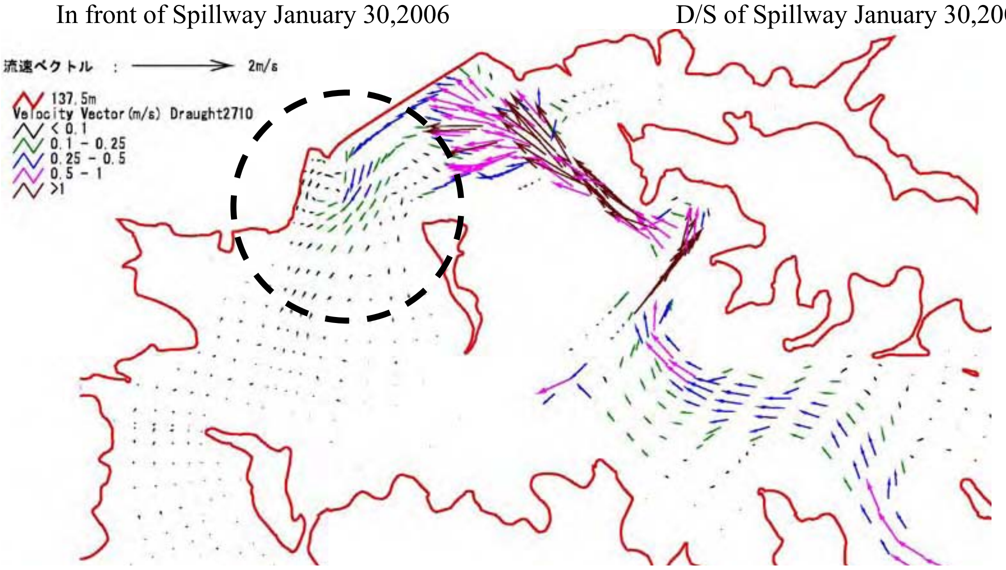
During spillout on January 30 2006, a visible difference of turbidity between left and right at the spillway was observed. At that time, the turbidity at the left side was 86 mg/ltr and 407mg/ltr at the right side As the result of reservoir sedimentation analysis presented in Figure 2.4.5, this phenomena might be caused by the small lateral vortex flow at the forebay of the spillway.



In front of Spillway January 30,2006



D/S of Spillway January 30,2006



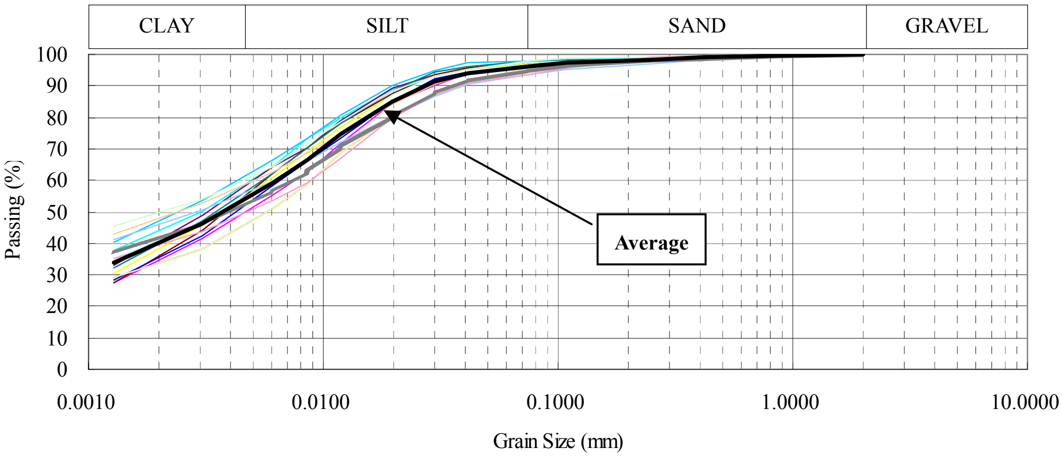
Source : JICA Study Team

Figure 2.5.5 Example of Vortex Flow in Front of Spillway (Result of Reservoir Sedimentation Simulation on March 13, 2004)

(3) Grain Size Distribution of Spillout Water

Totally 15 samples were taken from spillout water and analyzed grain size distributions.

As presented in Figure 2.5.6, the suspended sediments in the spillout water were composed of 68% clay, 28% silt and 4% fine sand. The composition of wash load (smaller than 74 μ m) was 96%.



Source : JICA Study Team

Figure 2.5.6 Grain Size Distribution of Spillout Water

2.6 Upper Solo River downstream of Wonogiri Dam

2.6.1 Outline of Measurement

In the Uppwer Solo mainstream between the Wonogiri dam and Tangen, turbidity was periodical measured since November 2004 to May 2006 by following manners. Measured turbidity was converted to SS concentration applying the correlation function between turbidity and SS concentration as shown in Figure 2.2.1. The results of observation were used to calibrate the turbidity analysis model for downstream reaches as described in Chapter 3.

Target	:	River flow in Upper Solo River d/s of Wonogiri
Location	:	(i) Wonogiri Bridge, (ii) Colo Weir, (iii) Jurug Bridge, (iv) Tangen Bridge
Period	:	2005/01 – 2006/05
Monitoring Interval	:	one time per a week in wet season, one time per two weeks in dry season
Monitoring Item	:	Turbidity (NTU) , SS(mg/ltr)
Main Objective	:	For calibration of turbidity analysis in Upper Solo River downstream of the Dam

D/S of the Wonogiri Dam

Colo Weir

Tangen Bridge

Jurug Bridge

Site Conditions of Turbidity Measurement in Upper Solo River

2.6.2 Result of Measurement

The fluctuations of SS concentration in the Upper Solo mainstream are presented in Figure 2.6.1. Longitudinal variations of SS concentration in both dry and wet season are presented in Figure 2.6.2.

There are good correlations among the concentrations observed. Main findings based on the weekly monitoring are summarized as below:

(Wet season)
- Correlation of the SS concentration among four stations is high.
- Maximum SS concentration at four stations ranges from 763-1321 mg/ltr.
- Average SS concentration ranges from 151 to 329 mg/ltr and tends to increase to the downstream.
- Minimum SS concentrations ranges 9 to 23 mg/ltr.

(Dry season)
- In dry season, SS concentrations at four stations were constantly lower excluding a large fluctuation on June.

(Comparison between wet and dry season)
- Average SS concentration of wet season was 4 to 6 times higher than those of dry season.
- Maximums SS concentration of wet season were 3 to 8 times higher than those of dry season,
- Minimum SS concentration were almost same in both seasons.

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Table 2.6.1 The Result of SS Concentration along Upper Solo River in Wet and in Dry Seasons

Location	Distance from Dam	SS (mg/ltr)					
		Wet Season (Nov. To Apr.)			Dry Season (May to Oct.)		
		Ave.	Min.	Max.	Ave.	Min.	Max.
Bridge d/s of Dam	0 km	151		889	33	6	117
Colo	14 km	189	17	763	46	9	160
Jurug	51 km	235	16	790	39	19	115
Tangen	99 km	329	23	1321	83	11	543

Source : JICA Study Team

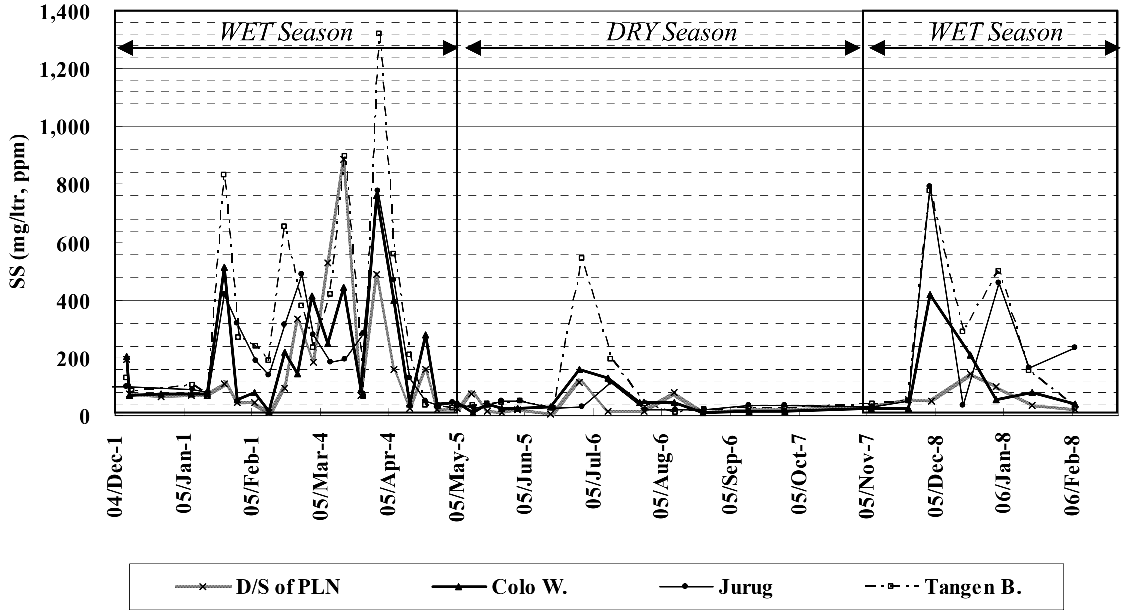
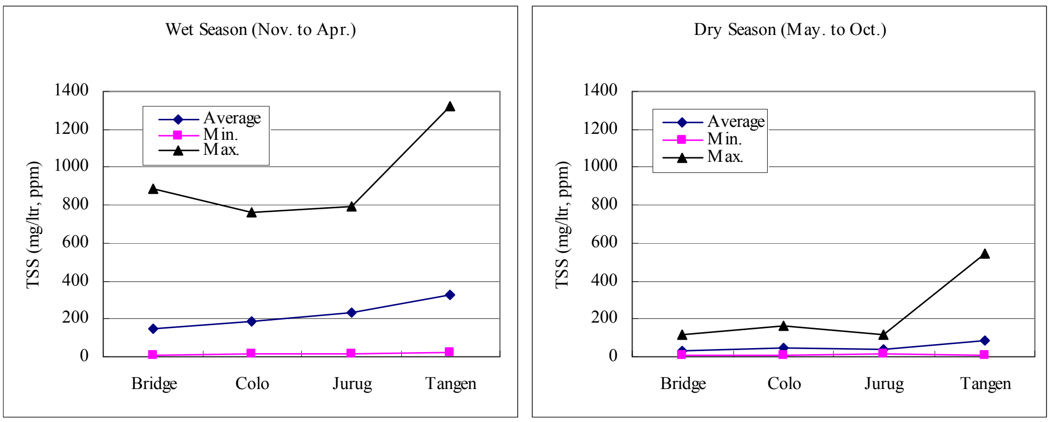


Figure 2.6.1 SS Monitoring in Upper Solo River from November 2004 to February 2006



Source : JICA Study Team

Figure 2.6.2 Longitudinal Variation of SS Concentration along Upper Solo River in Wet and in Dry Seasons