CHAPTER 3 ASSESSMENT OF CURRENT STATUS OF THE WONOGIRI RESERVOIR SEDIMENTATION

3.1 Wonogiri Multipurpose Dam

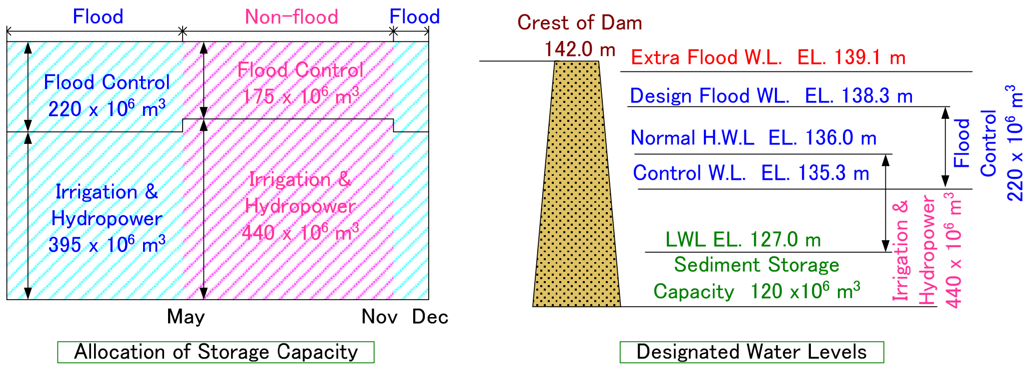
3.1.1 Principal Feature of Wonogiri Multipurpose Dam

The principal features of the Wonogiri Dam and Reservoir are summarized in Table 3.1.1 below, and the allocated storage capacities and water levels thereof are also shown in Figure 3.1.1 below:

Table 3.1.1 Principal Features of Wonogiri Multipurpose Dam and Reservoir

Dam type	Rockfilll	Normal High Water Level	EL. 136.0 m
Dam height	40 m	Design Flood Water Level	EL. 138.3 m
Crest length	830m	Extra Flood Water Level	EL. 139.1 m
Embankment volume	1,223,300 m^3	Crest Height of Dam	EL. 142.0 m
Catchment area	1,350 km^2	Spillway (Radial gate)	7.5m x 7.8m x 4nos.
Reservoir area	90 km^2	Standard Highest Flood Discharge (60-year flood)	4,000 m^3/s
Gross storage capacity	735 x 10^6 m^3	Flood outflow discharge	400 m^3/s
Active storage capacity	615 x 10^6 m^3	Design flood discharge (100-year flood x 1.2)	5,100 m^3/s
Flood control storage capacity	220 x 10^6 m^3	PMF	9,600 m^3/s
Irrigation & hydro power storage capacity	440 x 10^6 m^3	Installed capacity	12.4 MW
Sediment storage capacity	120 x 10^6 m^3	Design head	20.4 m
Sediment deposit level	EL. 127.0 m	Max. discharge	75 m^3/s
Control water level during flood season	EL. 135.3 m	Annual energy output	50,000 MWh

Source: PBS



Source:PBS

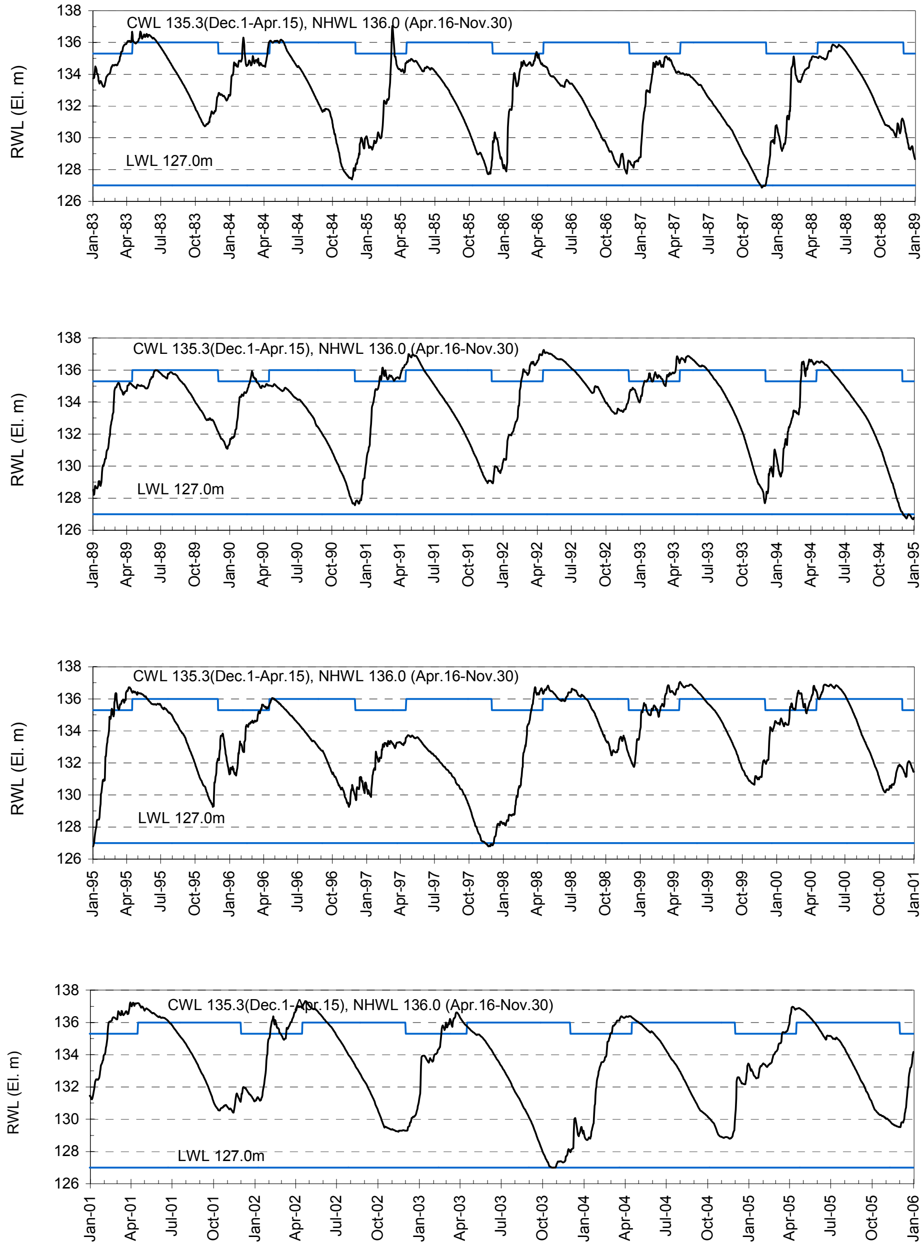
Figure 3.1.1 Allocation of Storage Capacity and Water Levels of Wonogiri Dam

3.1.2 Performance of Wonogiri Reservoir Operation

(1) Reservoir Operation

Based on the operation records of the Wonogiri Reservoir, the mean annual inflow volume into the Wonogiri Reservoir is derived to be approximately 1.23 billion m^3

between 1983 and 2005 (see Figure 3.1.3 in the next page), which exceeds the gross reservoir storage volume of 735 million m^3 at the design flood water level of EL. 138.3 m. The reservoir water level hydrograph for 1983-2005 is presented in Figure 3.1.2 below:



Source: JICA Study Team

Figure 3.1.2 Wonogiri Reservoir Water Level Hydrograph in 1983-2005

As can be seen from the above figure prepared from daily reservoir water level records, water inflow from the upper tributaries has been stored in the Wonogiri reservoir during the wet season, while the stored water has been released downstream to be utilized for irrigation during the dry season as well as hydropower generation.

Since 1998, because of the rapid progress of sedimentation in front of the intake structure in the Wonogiri Reservoir, the reservoir has been operated so that the water level is not lowered below EL. 130.0m, except when the dredging of sediments at the intake structure site was conducted under the JICA Grant Aid Program in 2003.

Figure 3.1.3 on the right side shows the estimated mean monthly inflow into the Wonogiri reservoir for the period from 1983 to 2005. As shown in the figure, the largest mean monthly inflow of 110.8 m^3/s or 268 million m^3 takes place in February, while that in August is the smallest at 2.3 m^3/s or 6 million m^3. The estimated runoff coefficient for the average annual inflow is 0.46 and the annual runoff depth is 912 mm.

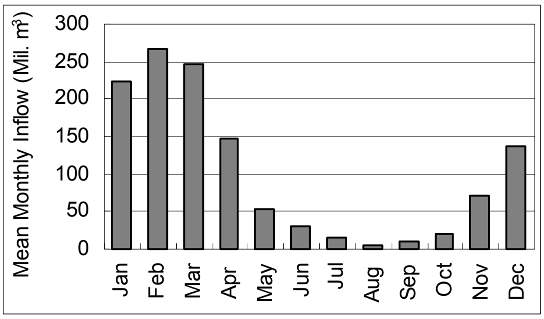
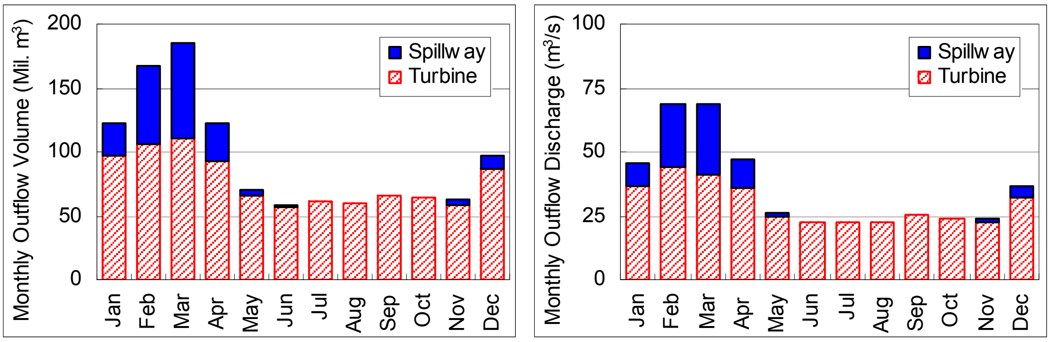


Figure 3.1.3 Estimated Mean Monthly Inflow into Wonogiri Reservoir

Figure 3.1.4 below depicts the mean monthly outflow from the Wonogiri Reservoir between 1983 and 2005. The outflow comprises water spilled out from spillway and water released downstream through the power turbines for hydropower generation. As shown in the figure, the mean annual water volume spilled out from spillway (spill-out) which is defined as the ineffective outflow in view of water use accounts for around 18% of the total annual outflow volume or 210 million m^3. The remaining volume of 932 million m^3 or 82% was used for hydropower generation for the period.



Source: JICA Study Team

Figure 3.1.4 Mean Monthly Outflow from Wonogiri Reservoir between 1983 and 2005

It is noted that spill-out of the excessive water from the spillway has so far occurred only twice in the beginning of the wet season, namely in November 1998 and December 1995.

The annual inflow volume into the Wonogiri Reservoir between 1983 and 2004 is shown in Figure 3.1.5, in which the hydrological year spanning between November and October is adopted in calculating the total inflow volume in each year. Severe droughts occurred in 1989/90, 1996/97, 2003/2004 and 2004/2005. The most severe draught occurred in 1996/97 when the water level never reached the normal high water level (NHWL) of the Wonogiri Reservoir (El. 136.0m). The Wonogiri Dam experienced three consecutive droughts for the period from 2002/03 to 2004/05. In the latter two (2) years, no spill-out of the reservoir water from spillway was required

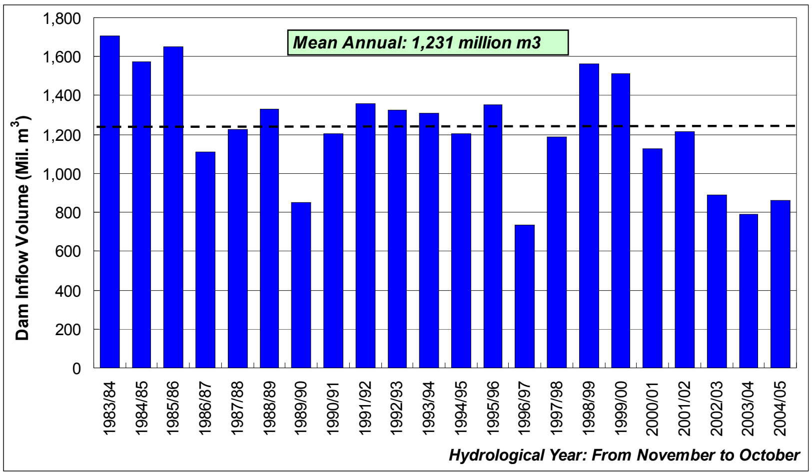
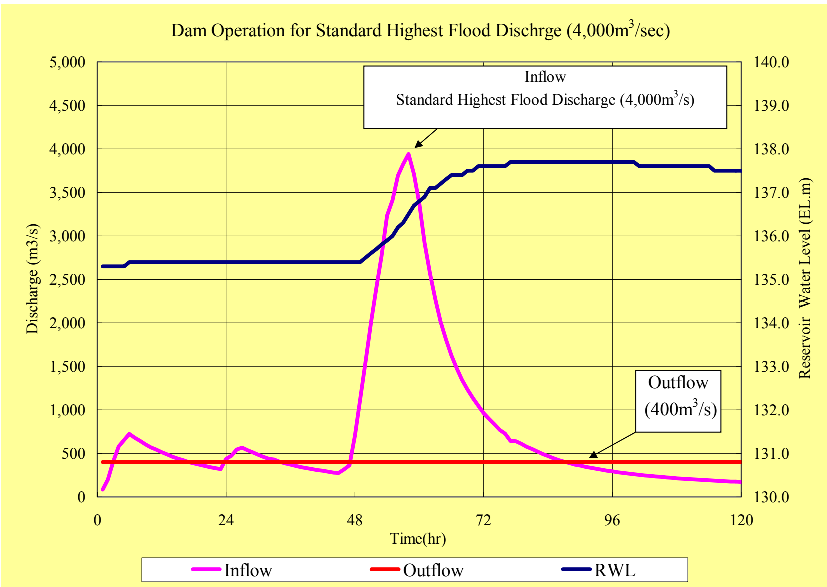


Figure 3.1.5 Estimated Monthly Wonogiri Reservoir Inflow between 1983 and 2004
Source: JICA Study Team

(2) Flood Control

To avoid the occurrence of overtopping of the Wonogiri Dam crest with a probable maximum flood (PMF), the reservoir water level has been controlled not to exceed the Control Water Level (El.135.3 m) during the flood season between December 1 to April 15. The reservoir has a flood control space of 220 million m^3 to regulate the standard highest flood discharge (SHFD) with a peak discharge of 4,000 m^3/s in the Wonogiri Reservoir. When the SHFD takes place the spill-out discharge from the spillway is controlled through the spillway gate operation to keep it at a constant outflow of 400 m^3/s during the flood, as illustrated in Figure 3.1.6 below. In view of the flood control, irrigation development and electricity supply, the Wonogiri Dam has greatly benefited the people in the basin, especially those in the downstream area.



Source: Detailed Design Report on Wonogiri Multipurpose Dam Project, 1978

Figure 3.1.6 Typical Flood Control Operation of Wonogiri Dam

The Upper Solo River Improvement Project was completed in 1994. Around 53 km in length of the river was improved under the project, which covered the river course from Nguter bridge to Jurug bridge. The Nguter bridge is located downstream of the Colo

Intake Weir and the Jurug bridge is located about 5 km downstream of Surakarta City. The catchment area of the Bengawan Solo at the Jurug bridge is around 3,220 km^2. In the project, the river improvement works were designed for a 10-year probable flood through incorporating the significant flood control effect of the Wonogiri Dam. Seven (7) short-cut channels of 13 km in total length were constructed. The design flood discharge distribution along the stretch is illustrated in Figure 3.1.7 below:

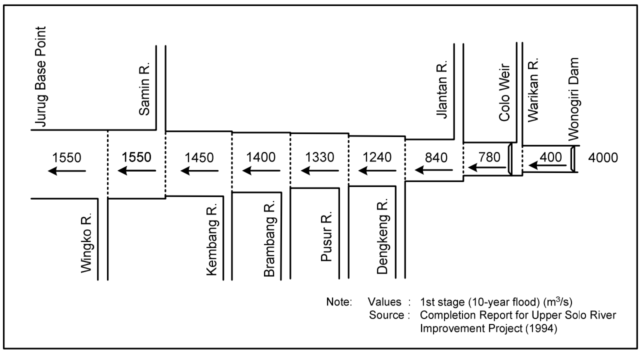


Figure 3.1.7 Design Flood Discharge Distribution in Upper Solo River Improvement Project

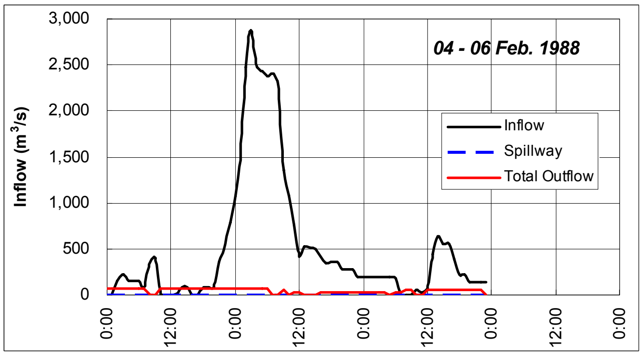


Figure 3.1.8 Wonogiri Reservoir Operation for Flood in February 4-6, 1988

The large-scale floods inflowing into the reservoir were estimated based on the hourly reservoir operation records between 1983 and 2004. It is clear from the estimates that the Wonogiri Reservoir experienced the largest flood with a peak discharge of 2,88 m^3/sec on February 5, 1988, followed by the 1985 flood of 2,720 m^3/sec. Large-scale floods with peak discharges over 2,000 m^3/s at the Wonogiri Damsite occurred frequently in 1980s.

(3) Wonogiri Irrigation System

Immediately after the completion of the Wonogiri Irrigation Project in 1986, the water supply to the Wonogiri irrigation system was commenced. Irrigation water is taken from the Colo Intake Weir located about 13 km downstream of the Wonogiri Dam. The Wonogiri irrigation system comprises 94 km of main canal and 105 km of 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. The mean monthly discharge at the Colo Intake Weir between 1986 and 2005 is shown in Table 3.1.2 below:

Colo Intake Weir

Table 3.1.2 Mean Monthly Discharge at Colo Intake Weir between 1986 and 2005

(Unit : m^3/sec)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Release for maintenance flow	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

(4) Power Generation at Wonogiri Hydropower Station


Wonogiri Power Station

The powerhouse is located just downstream of the Wonogiri Dam. It accommodates generating equipment with an installed capacity of 12.4 MW to generate annual energy of 55,000 MWh. The maximum discharge for power generation is 75 m^3/s. In the dry season of May to November, around 50-60 million m^3 of water stored in the Wonogiri Reservoir is used for power generation. The water volume is equivalent to around 20-25 m^3/sec in the mean monthly discharge. Hydropower generation is a non-consumptive water use. The majority of water released downstream through turbines of the power station is diverted at the Colo Intake Weir to be used for irrigation. The lowest reservoir water level for power generation is currently set at EL. 130 m due to the sediment deposits in front of intake structure.

(5) Operation and Maintenance

The PJT I Bengawan Solo was established on March, 2003 based on the Presidential Decree No. 129/2000. With this, the operation and maintenance of the Wonogiri Dam was transferred to the PJT I Bengawan Solo branch office from PBS. The main revenue of the PJT I Bengawan Solo is derived from tariff of water used for hydropower generation (PLN) as well as tariff of water used by PDAM and industrial water utility for the purpose of the municipal/industrial water supply. These are the main revenue sources for O&M of the Wonogiri Dam.

3.1.3 Garbage Problems at Intake

The reservoir water used for hydropower generation and the subsequent irrigation water supply needs to be fed into the power waterway through the intake structure. It would be impossible to maintain the originally planned the hydropower generation and irrigation water supply if the intake structure is not able to function properly.

Especially in recent years, at the beginning of the wet season there has been a large quantity of vegetative debris and garbage washed into the intake forebay area where it accumulates. Partial blockage of the power intake by garbage has often occurred. As a result, the intake trashracks have been blocked by vegetative debris in every rainy season, causing the hydraulic head across the turbines to drop and the turbines to shut down. The trash-racks are then cleaned by divers.

The sediments deposited in the forebay consist of very fine grained materials (wash load). There is no sands contained in the deposits. Neither wear (abrasion) nor related problem has occurred with respect to the power turbines, and consequently no part of the turbines has been replaced since the power generation began in the mid 1980s. This indicates that only very fine sediment materials such as clay and silt have passed through the turbines. According to the Wonogiri power station office (PLTA Wonogiri), there is a sufficient clearance in the power turbines that may be effective for the smooth passage of the sediment materials without any harmful abrasion.

3.2 Current Status of the Wonogiri Reservoir Sedimentation

3.2.1 Previous Monitoring Studies on the Wonogiri Reservoir Sedimentation

To evaluate numerically the sedimentation condition of the Wonogiri Reservoir, a number of studies have been carried out after the completion of Wonogiri Dam in 1981. The most recent study is the study undertaken by PT Citra Mandala Agritrans (PT CMA) in 1993. This Section 3.2 discusses the results of the previous studies on the sedimentation of the Wonogiri Reservoir. The major previous studies were performed by the following:

i) Gadjah Mada University, Yogyakarta in 1985 and 1990,
ii) Bengawan Solo River Basin Development Project (PBS) in 1986, 1987 and 1989, and
iii) PT Citra Mandala Agritrans (PT CMA) in 1993.

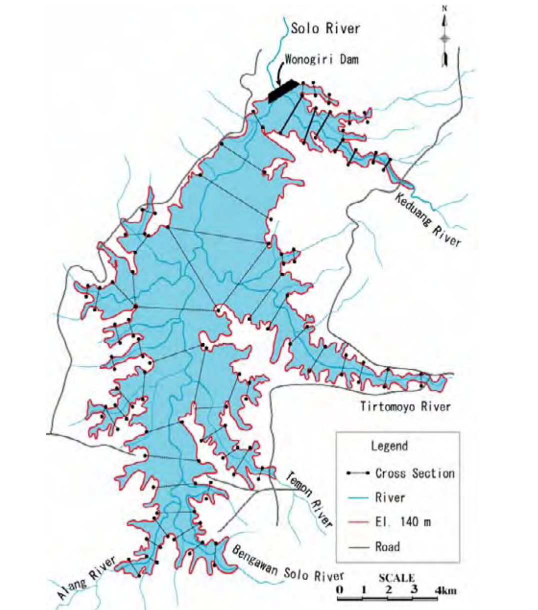


Figure 3.2.1 Location Map of Cross Sections for Sedimentation Survey
(Source: PBS)

The main results of the above three (3) previous studies are summarized below:

(1) Previous Study Performed by PBS in 1989

PBS estimated the sediment inflow into the Wonogiri Reservoir based on the sediment measurements in the major six (6) tributaries as follows:

Table 3.2.1 Estimated Annual Sediment Inflow into Wonogiri Reservoir by Tributary

(Unit: 1,000 ton/year)

River	1981	1982	1983	1984	1985	1986	1987	1988
Tirtomoyo	951	1,048	757	1,103	751	958	740	617
Keduang	299	-	398	395	357	461	94	30
Solo	-	283	343	564	282	478	248	257
Alang	54	22	224	150	66	35	123	38
Temon	44	33	61	81	102	51	27	35
Wuryantoro	3	2	4	24	15	5	6	3
Total	4,046	1,389	1,787	2,317	1,574	1,988	1,239	949
Accumulated	4,046	5,435	7,222	9,539	11,113	13,101	14,340	15,289
Total Volume (10^3 m^3)	2,549	3,424	4,550	6,010	7,001	8,254	9,034	9,632

Source: Monitoring Reports by PBS

As shown in the above table, the total sediment inflow volume into the Wonogiri Reservoir between 1981 and 1988 was estimated at 9.63 million m^3, which is equivalent to an annual average sediment deposit volume of around 1.2 million m^3/year in the Wonogiri Reservoir.

(2) Previous Study Performed by Gadjah Mada University in 1985 and 1990

The residual storage capacities of the Wonogiri Reservoir were estimated by Gadjah Mada University in 1985 and 1990. These estimates were made based on the results of the reservoir cross section survey along pre-determined lines through the reservoir as shown in Figure3.2.1. Both in 1985 and 1990, the reservoir cross section survey was performed by means of echo sounding. As a result, the sediment deposit volume corresponding to an annual average loss of storage volume below El. 138 m due to the sedimentation was estimated at around 86.2 million m^3 between 1981 and 1985 and 156.4 million m^3 between 1981 and 1990 as shown in Table 3.2.2 below. From the both estimates, the annual average sediment deposit volume was derived to be around 15.6 million m^3/year for the period from 1981 to 1990.

Table 3.2.2 Estimated Sediment Deposit in the Wonogiri Reservoir (Unit: m^3)

Elevation Range	below El. 127 m	below El. 138 m
Storage	123,590,000	718,044,000
1981-1985	41,476,804	86,165,280
1985-1990	31,654,637	74,245,750
1981-1990	68,184,603	156,389,980

Source: Gadja Mada University Faculty of Geology (GMU), 1985 and 1990, Monitoring Soil Erosion in Upper Solo by Monitoring Sedimentation in Wonogiri Reservoir

(3) Previous Study Performed by PT CMA in 1993

In 1993, PT CMA produced a reservoir map with contour lines from the reservoir cross section survey and computed the remaining reservoir storage capacity based on the reservoir map. In the Study, the Study Team only had an unclear copy of the reservoir map prepared by PT CMA. It is understood that the map be originally prepared at an approximate scale of 1:30,000 with 5 m contour intervals.

From the change in H-V curves, PT CMA found out that a significant reduction of the reservoir storage capacity due to sedimentation occurred between 1981 and 1993. The loss of storage capacity due to sedimentation below El. 138 m was estimated at 240 million m^3 corresponding to an annual loss of storage capacity of 18.5 million m^3/year below EL. 138 m. The losses in the respective storage zones of the reservoir due sedimentation between 1980 and 1993 are summarized below:

Table 3.2.3 Loss of Capacity of Wonogiri Reservoir by Storage Zone between 1980 and 1993

Reservoir Zone	Reservoir Capacity (million m^3)		Capacity Lost due to Sedimentation	
	in 1980	in 1993	Value (million m^3)	of Original (%)
Flood Control Storage (El. 135.3 – 138.3 m)	220	160	60	27
Water Use Storage (El. 127.0 – 136.0 m)	440	306	134	30
Dead Storage (below El. 127.0 m)	120	56	64	53
Total Volume	**780**	**522**	**258**	**-**

Source: JICA Study Team

(4) Comparison of the Wonogiri Reservoir Capacities Estimated in the Three (3) Previous Studies

Figure 3.2.2 on the right side compares the storage capacities of the Wonogiri Reservoir estimated in the aforesaid three (3) previous studies assuming the linear yearly reduction up to the year 2005. As shown in the figure, the storage capacity of Wonogiri Reservoir is expected to decrease to around 330 million m^3 or 270 million m^3 in 2005 applying the annual loss rate estimated by Gadja Mada University (15.6

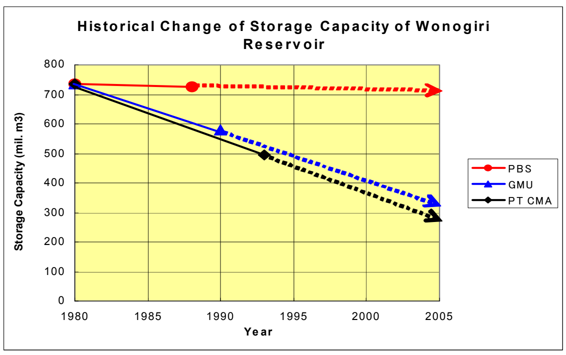


Figure 3.2.2 Projection of Wonogiri Reservoir Sedimentation by 3 Past Studies

million m^3/year in 1980-1988) and PT. CMA (18.5 million m^3/year in 1981-1993), respectively. Thus, these two (2) studies estimated that the Wonogiri Reservoir would lose about 55 and 63% of its original capacity by the year 2005.

Table 3.2.4 below shows the average soil erosion rate over the entire Wonogiri Dam catchment that is equivalent to the annual sediment deposit volume estimated in each of the three (3) previous studies:

Table 3.2.4 Comparison of Average Erosion Rates by Past Studies

Past Study	Average Sediment Deposit Volume (million m^3/year)	Average Annual Erosion Rate (mm/year)	Erosion Depth in 100 years (cm)
PBS in 1989	1.2	0.9	9
UGM in 1985 & 1990	15.6	11.6	116
PT CMA in 1993	18.5	13.7	137

Source: Estimation data by JICA Study Team based on the Past studies.

A sedimentation study on the Wonogiri Reservoir has been carried out under the Study by using the reservoir map with contour lines which was produced in the course of the Study, as well as hydro-meteorological data and other useful data. In conclusion, comparison with the results of the sedimentation study carried out in the Study, shows that all the three (3) previous study results were somewhat inaccurate and particularly the PT CMA study overestimated the sediment deposit rate in the Wonogiri Reservoir to a considerable extent.

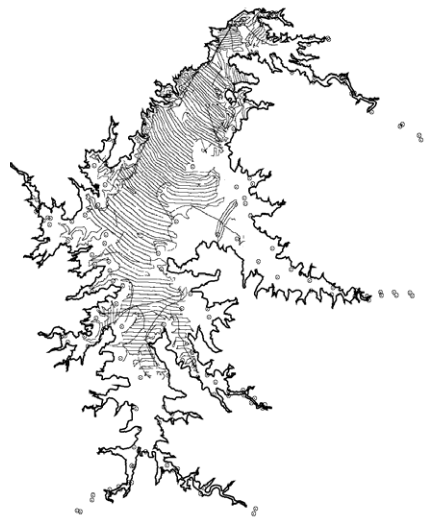


Figure 3.2.3 Location Map of Data Points by PBS Survey in 2004

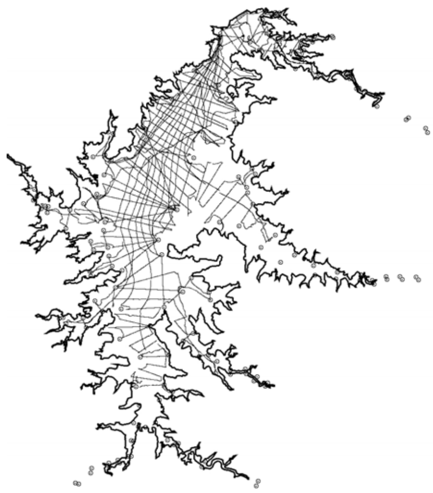


Figure 3.2.4 Location Map of Data Points by JICA Survey in 2005

3.2.2 Current Status of the Wonogiri Reservoir Sedimentation

Under the current Study, an echo sounding survey with GPS was conducted for the Wonogiri Reservoir over two periods of October to November 2004 (before the wet season) and June to July 2005 (after the wet season). The aim was to clarify the current status of the Wonogiri Reservoir sedimentation as well as incremental sediment deposited in the wet season in 2004/2005.

(1) Reservoir Sedimentation Survey in 2004 by PBS

PBS carried out the reservoir sedimentation survey independently by subletting it to a sub-contractor. The survey was done in July to September 2004. However, the final report was completed in May 2005. The echo sounding was done at as many locations as possible to increase the density of the data points so that an accurate reservoir topographic map could be produced. Totally, around 100,000 points at an interval of around 10 m were surveyed. A location map of data points is shown in Figure 3.2.3. Very unfortunately, the survey was done only for the area within the reservoir water surface (below the reservoir water level of El. 132 m).

The perimeter (ground surface) survey from the water's edge to the maximum reservoir area was not included.

In order to raise the accuracy of reservoir topographic mapping carried out under the Study in 2005, the new data points were added, mainly for several reservoir section lines as shown in Figure 3.2.4.

(2) Current Wonogiri Reservoir Conditions in 2004 and 2005

The current reservoir capacity was estimated based on the contour mapping of reservoir bed and DEM (Digital Elevation Method) as given below. The past sedimentation survey results in 1993 were reassessed by means of the same procedure.

Echo Sounding Survey → **Contour Map of Sedimentation** → **Preparation of DEM (10 m x 10 m)** → **H-A and H-V Curves**

The result of reservoir sedimentation survey by PBS in 2004 was very useful for cross-checking of the results of the survey undertaken in 2004 by the Study. Finally, the contour map from the 2004 survey result was modified through incorporating the PBS survey results in 2004. Figures 3.2.5 and 3.26 below show the reservoir contour maps in 1993 and 2004.

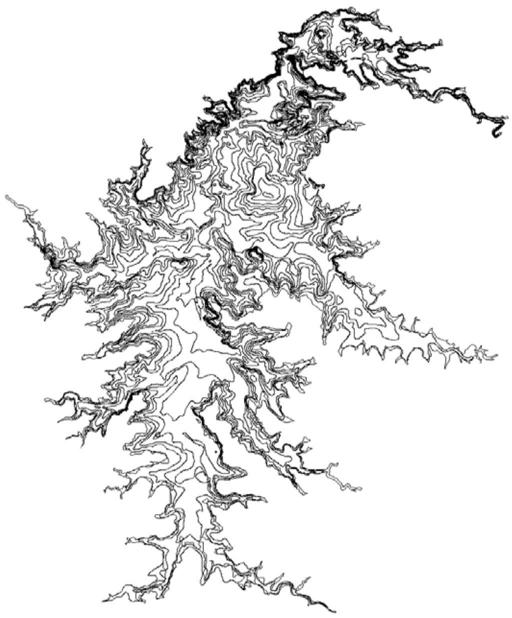


Figure 3.2.5 Reservoir Contour Map in 1993

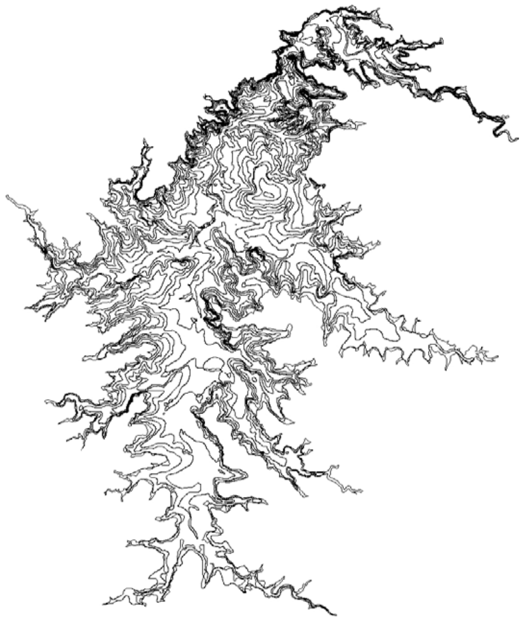


Figure 3.2.6 Reservoir Contour Map in 2004

Elevation-area-capacity relationships of Wonogiri reservoir in 1980, 1993, 2004 and 2005 were worked out by using DEM (around 900,000 meshes in total). Table 3.2.5 below presents the estimated Wonogiri reservoir storage capacity:

Table 3.2.5 Estimated Wonogiri Reservoir Storage based on DEM

Reservoir Zone	Reservoir Capacity (million m^3)				Sediment Deposit (million m^3)	
	1980	1993	2004	2005	1993	2005
below El. 127.0 m (LWL)	114	69	58	58	45 (39%)	56 (49%)
below EL.136.0 m (NHWL)	547	468	435	433	79 (14%)	114 (21%)
below EL.138.3 m (DFWL)	730	650	618	616	80 (11%)	114 (16%)

Source: JICA Study Team

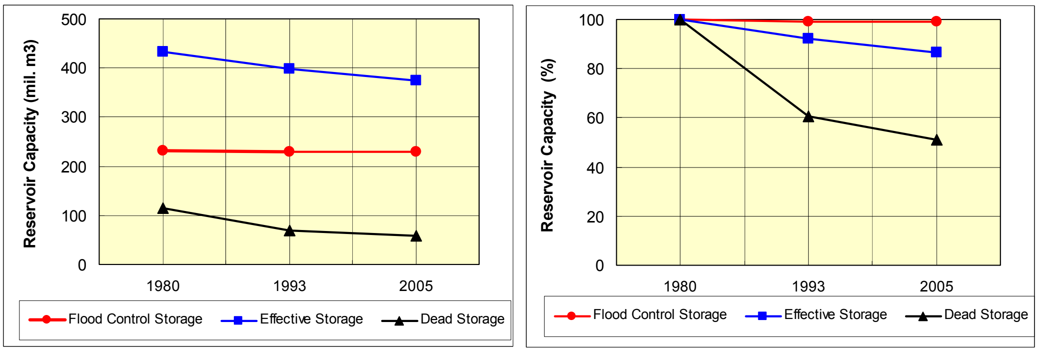
As seen in the above table, approximately 114 million m^3 or 16% of the total storage capacity of 730 million m^3 was lost due to the reservoir sedimentation in the period of 1980 to 2005. The estimated current loss of capacity in each of the three (3) reservoir storage zones due to the reservoir sedimentation between 1980 and 2005 is summarized below:

Table 3.2.6 Loss of Capacity of Wonogiri Reservoir by Storage Zone between 1980 and 2005

Reservoir Zone	Reservoir Capacity (10^6 m^3)		Capacity Lost due to Sedimentation	
	1980	2005	Value (10^6 m^3)	of Original (%)
Flood Control Storage (El. 135.3 – 138.3 m)	232	230	2	0.9
Water Use Storage (El. 127.0 – 136.0 m)	433	375	58	13.4
Dead Storage (below El. 127.0 m)	114	58	56	49.1

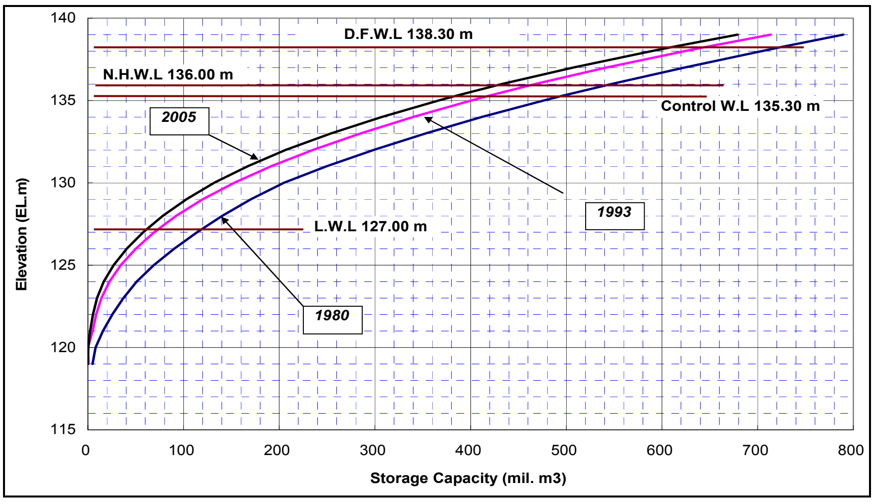
Note: Reservoir capacity in 1980 was re-estimated based on the DEM. As shown in Figure 3.1.1, the flood control storage capacity overlaps the water use storage capacity in the range of EL. 135.3 m – EL. 136.0 m.
Source: JICA Study Team

As shown in the above table, around 13% of the original effective storage volume (between El. 127.0 m and El. 136.0 m) had been filled with sediments by 2005. In other words, around 87% of the original effective storage zone is still usable. The historical change of reservoir capacity in each storage zone is illustrated below:



Source: JICA Study Team

Figure 3.2.7 Change of Wonogiri Reservoir Capacity by Storage Zone between 1980 and 2005



Source: JICA Study Team

Figure 3.2.8 Wonogiri Dam Reservoir Elevation-Capacity Curves in 1980, 1993 and 2005

3.3 Geotechnical Conditions of the Wonogiri Reservoir

3.3.1 Geological Condition

To clarify the geological conditions in the reservoir area, core drilling has been performed at 12 points in the Wonogiri Reservoir in the 1st Phase of the Study. The results of the core drilling are summarized in Table 3.3.1 below:

Table 3.3.1 Results of Core Drilling

Drilling No	Name of River	Length (m)	Geological condition (m)			
			Sediments after the dam was completed	Original river deposit, Terrace deposit	Base rock (rock type)	Remarks
BH-1	Solo	15	0.0-2.5		2.5-15.0 (tuffaceaous sand)	2.5-4.0 Organic soil
BH-2	Solo	16	0.0-2.0	2.0-8.0	8.0-16.0 (tuffaceaous sand)	2.0-5.0 Organic soil
BH-3	Temon	9	0.0-7.6	7.6−9.0		
BH-4	Solo	12	0.0-3.6	3.6-9.2	9.2-12.0 (tuff)	
BH-5	Tirtomoyo	12	0.0-1.5		1.5-12.0 (tuffaceous sand)	1.5-3.0 Organic soil
BH-6	Tirtomoyo	13	0.0-3.5		3.5-13.0 (tuff)	
BH-7	Solo	13	0.0-0.8	0.8-1.5	1.5-12.0 (tuff)	
BH-8	Solo	14	0.0-2.0		2.0-14.0 (lappili tuff, tuffaceous sand)	
BH-9	Solo	13	0.0-1.7		1.7-13.0 (lapilli tuff)	
BH-10	Solo	23	0.0-3.2		3.2-23.0 (lappili tuff)	
BH-11	Keduwang	25	0.0-17.5	17.5-25.0		
BH-12	Keduwang	17	0.0-8.0		8.0-17.0 (tuff breccia)	

Source: JICA Study Team

The location map of the drilling is shown in Figure 3.3.1 below. Figure 3.3.2 presents the longitudinal geological sections in the reservoir. The characteristics of the sediment materials yielded in the main tributary basins forming the Wonogiri Dam catchment area are described below:

- Sediment materials in the reservoir that are transported by the Keduang River are composed mainly of silt and clay and assumed to have been transported as suspended load.
- Sediment materials in the reservoir that are transported by the Alang River, Solo River, Temon River and Tirtomoyo River gradually become finer in the downstream direction and form a sandy to clayey bed in the reservoir in the vicinity of the upstream end of the reservoir.

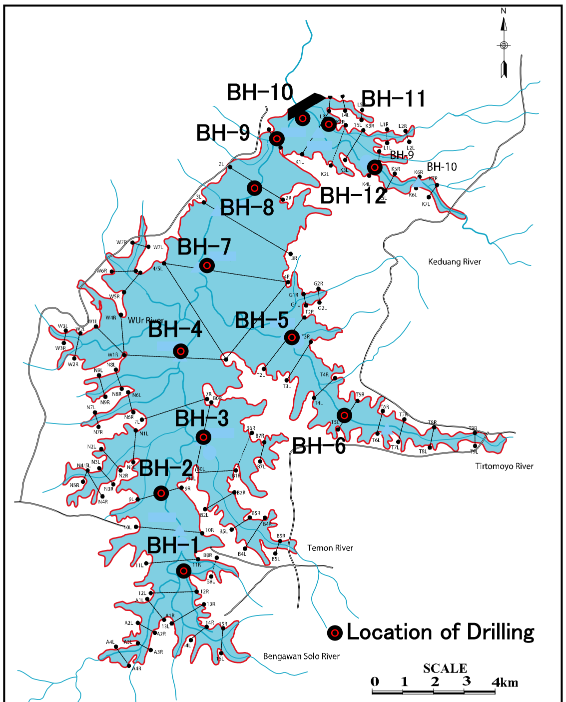


Figure 3.3.1 Location Map of Drilling Works

3.3.2 Physical Property of Sediment Material Deposited in the Wonogiri Reservoir

In this Study, sediment materials deposited in the Wonogiri Reservoir were sampled and laboratory-tested to clarify their physical properties. The locations of the sediment sampling sites in the reservoir are shown in Figure 3.3.3 together with the survey lines on the five (5) major tributaries of the Solo River. The physical properties of the sediment materials which were clarified through the laboratory test are outlined hereunder.

a) Specific gravity of soil

No significant difference was found between the specific gravity values of the samples taken from the Wonogiri Reservoir. Their maximum and minimum values are 2.728 and 2.538, respectively, with an average value of 2.670.

b) Bulk density

The density tests were executed for undisturbed samples selected in each of three (3) layers of 0.2-0.4 m, 0.6-0.8 m and 1.5-1.7 m in depth of the boring core. About 50% of boring cores drilled were almost same in length.

Table 3.3.2 Result of Bulk Density Test

Items	Maximum (g/cm^3)	Minimum (g/cm^3)	Average (g/cm^3)	Standard Deviation
Wet density	1.889	1.485	1.639	0.09
Dry density	1.438	0.792	1.063	0.15
Saturated	1.910	1.488	1.664	0.10

Source: JICA Study Team

c) Consistency

Most of the samples were classified into CH.

3.4 Monitoring of Sedimentation in front of Intake

3.4.1 Method of Monitoring

The intake structure of the dam has been seriously affected by deposits of sediment inflowing from the Keduang River. After completion of the "Project for Urgent Countermeasures for Sedimentation in the Wonogiri Dam Reservoir in March 2004", PBS has been periodically monitoring sediment levels in the approach channel in front of the intake structure. The method of the monitoring is outlined below:

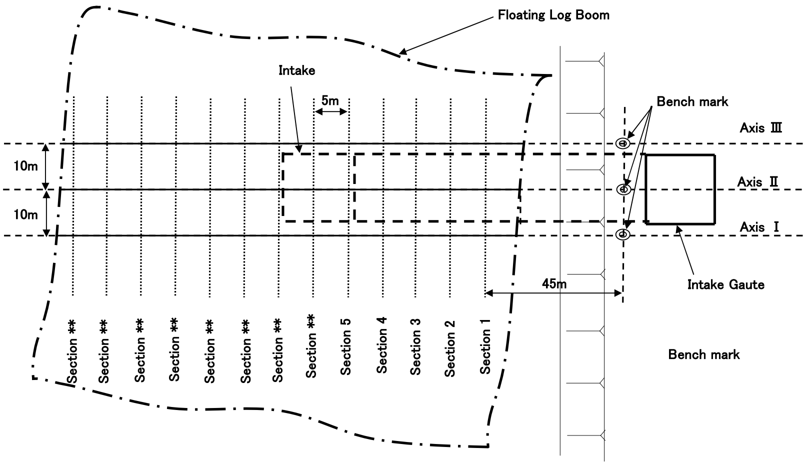
Intake after Completion in 1980

Area : Approach channel and the forebay of the intake shown in Figure 3.4.1 in next page. (20 m (W) x 120 m (L) by 3 sections with an interval of 5 m)

Method : Echo Sounder (RAYTHEON COMPANY)

Schedule : Monthly basis

Monitoring Survey in May 2005



Source: JICA Study Team

Figure 3.4.1 Location of Monitoring in the Forebay of Intake

3.4.2 Results of Monitoring

The results of sedimentation monitoring performed to date are summarized in Figures 3.4.2 and Figure 3.4.3 below which show the comparison of sediment levels at the two (2) locations on the approach channel. These are just in front of and 10 m upstream of the intake. The monitoring records reveal that:

Echo Sounder

i) Sediment levels were stable for the dry season from May 2004 to October 2004.
ii) Sediment level rose by 2.1 m for the wet season from October 2004 to July 2005.
iii) The sediment levels increased by around 3 m in the succeeding wet season from November 2004 to February 2005. On the other hand, sediment levels were almost stable for the period from March to May 2005.
iv) Sediment level was EL. 123.7 m in front of trash-rack in July 2005. The opening space between the sediment level and top of the intake is about 3.3 m in July 2005.
v) It was judged from the longitudinal sediment profiles that the stable slopes of sediment deposits were approximately 1/20-1/30.

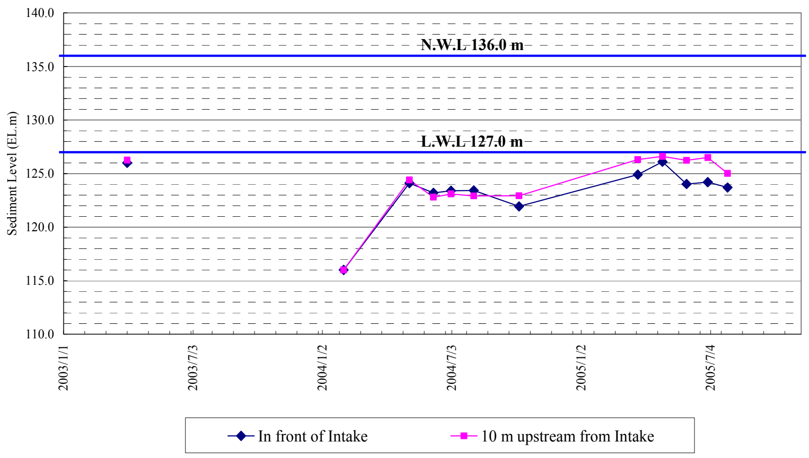


Figure 3.4.3 Comparison of Sediment Levels in front of Intake

3.5 Review of Previous Design of Reservoir Sedimentation

The dead storage capacity of 120 million m^3 was allocated for the sedimentation in the Wonogiri reservoir below the LWL 127.0 m which accommodates the total design sediment deposition for 100 years. The design sediment deposition rate of 1.2 million m^3/year was determined in the "Feasibility Study of the Wonogiri Multipurpose Dam" in 1975, based on i) the sedimentation rates in the existing 11 small irrigation reservoirs near the Wonogiri dam and ii) sediment discharge at the dam site estimated from the observed sediment concentration data. These approaches are also currently applied for prediction of reservoir sedimentation.

The horizontal inlet of bellmouth type was adopted as the intake structure of the Wonogiri dam. The bottom elevation of the inlet was set at El.116.0 m which was 11 m lower than the LWL 127.0 m. In the Detail Design in 1978, the intake structure was modified from the vertical tower type to the horizontal bellmouth type taking into consideration the construction cost and technical capability of local construction.

For a planning of multipurpose dam project, the sediment storage level is generally corresponds to the low water level. Thus, the bottom elevation of the inlet should be set at lower than the sediment storage level. This is due to the fact that the actual sedimentation is inclined and wash load materials are likely to be smoothly drawn down to the waterway through the inlet without deposition. The intake structure of the Wonogiri dam was designed based on these considerations.

Especially in recent years, at the beginning of the wet season there has been a large quantity of vegetative debris and garbage washed into the intake forebay area where it accumulates. Partial blockage of the power intake by garbage has often occurred. The garbage as well as the massive sediments from the Keduang River are the primary cause of the current sediment-related problems in the intake of the Wonogiri reservoir.