CHAPTER 8 PRELIMINARY DESIGN AND TECHNICAL EVALUATION ON STRUCTURAL SEDIMENT MANAGEMENT ALTERNATIVES

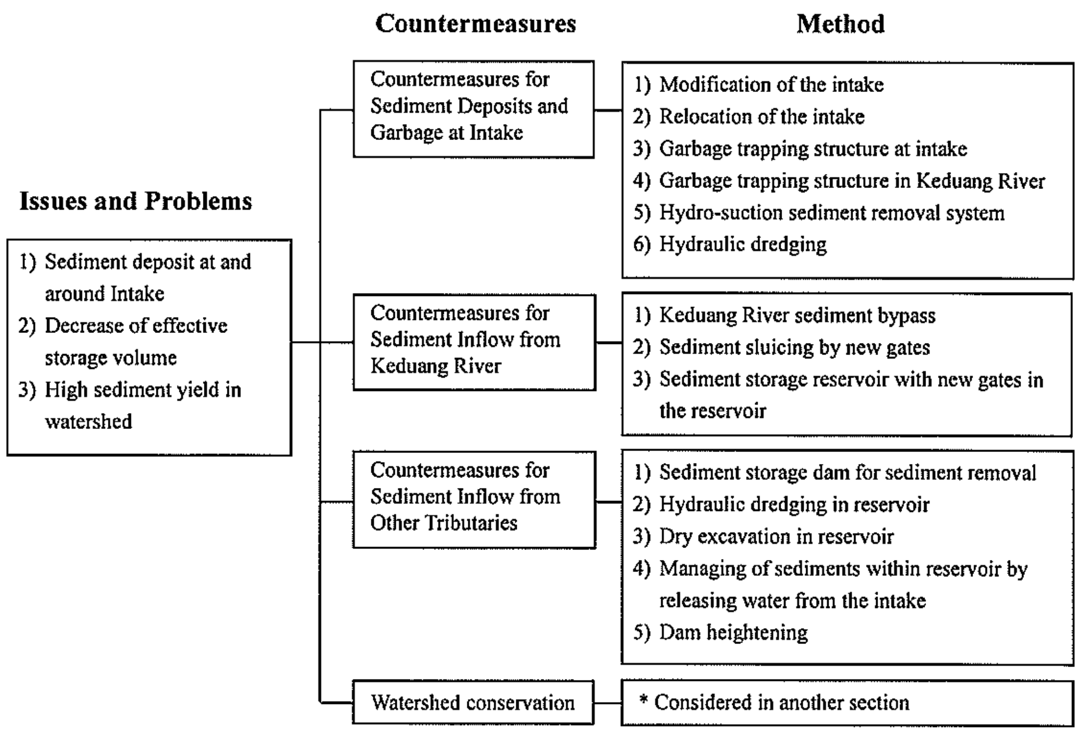
8.1 Conceivable Structural Sediment Management Alternatives

As mentioned previously in Chapter 7, the following measures are prioritized considering the sediment inflow characteristics of the tributaries:

i) Most urgent are measures to cope with the sediment and garbage inflow from the Keduang River as well as the sediment deposits at/around the intake structure
ii) Mid- and long-term measures are those designed to cope with the sediment inflow from other tributaries

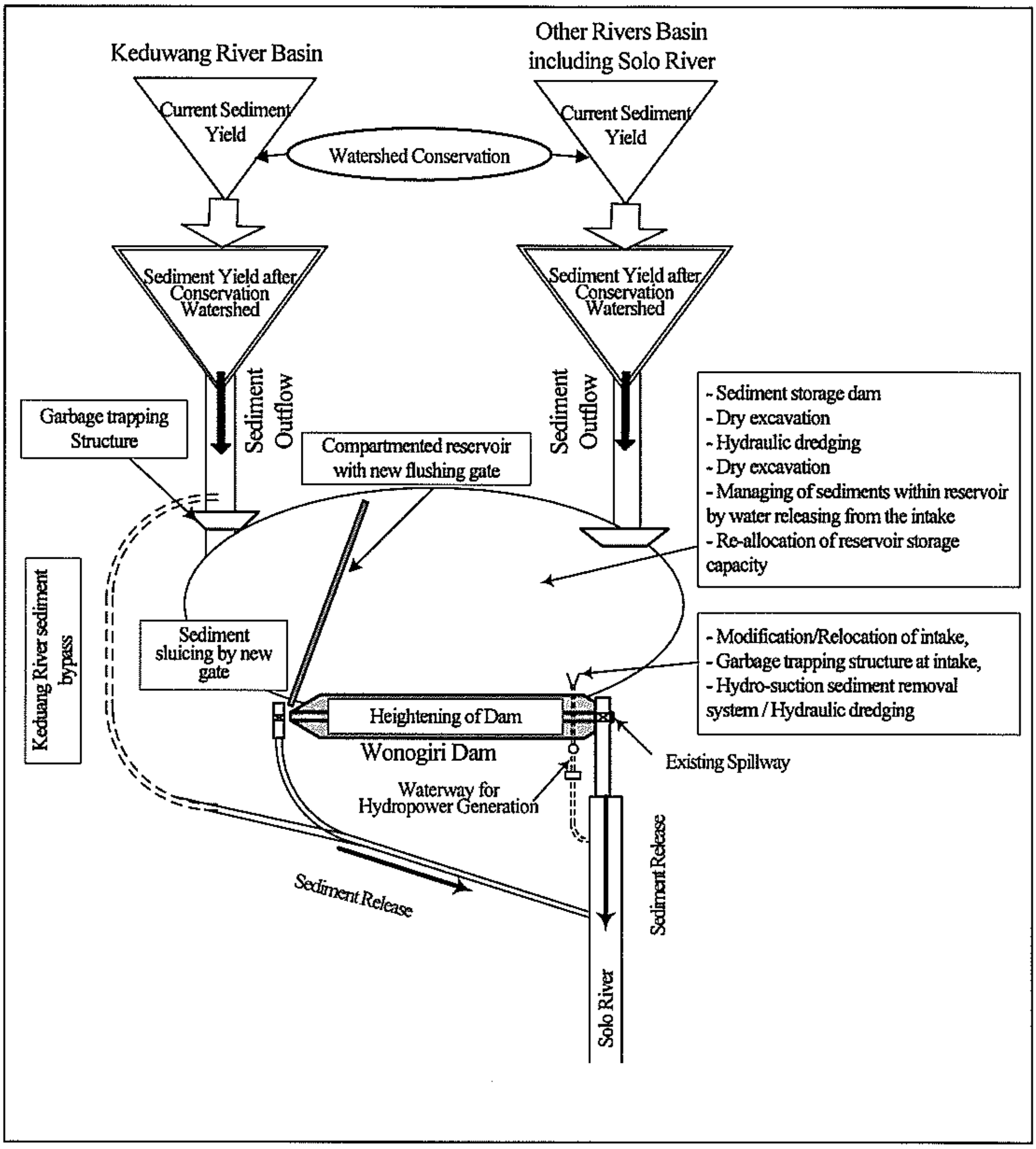
As for the measures to cope with the sediment inflow from other tributaries excluding the Keduang River, conceivable structural measures are evaluated herein, although it would be more practical to apply the non-structural measures to reduce the sediment yield rate in the Wonogiri watershed.

Figure 8.1.1 presents conceivable structural alternatives to be technically evaluated for the respective measures. Figure 8.1.2 illustrates the concept of these alternatives. A more detailed description of the evaluation procedure is given in Supporting Report I Annex No. 7.



Source: JICA Study Team

Figure 8.1.1 Conceivable Structural Alternatives for Wonogiri Reservoir Sedimentation Issues



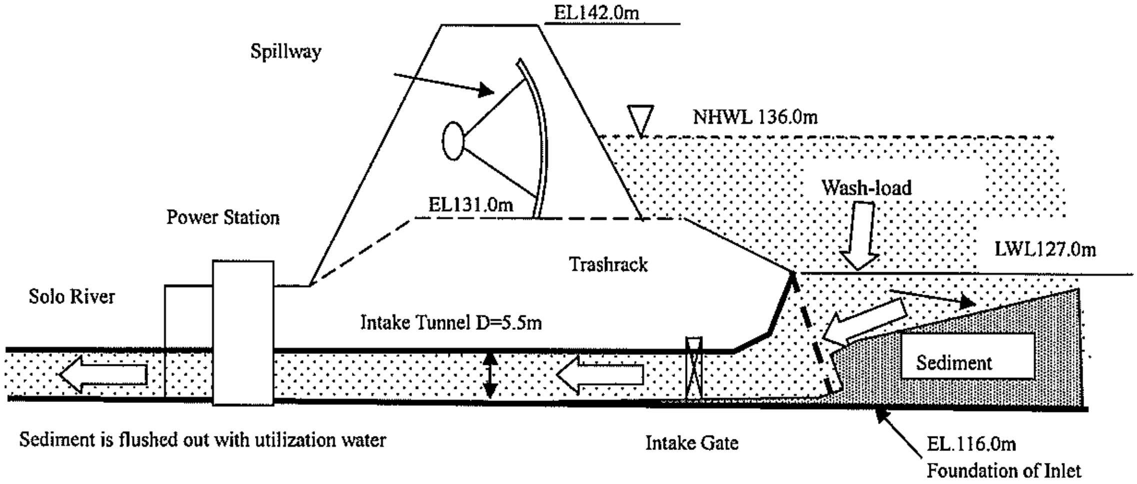
Source: JICA Study Team

Figure 8.1.2 Concept of Conceivable Structural Countermeasures on Tributary

8.2 Countermeasures for Sediment Deposits and Garbage at Intake

The intake structure for irrigation and hydropower water supply is set on a foundation at height El. 116.0 m, which is 11 m below the design sediment deposit elevation (El. 127.0 m). The inlet is the only facility that can release sediment to the Bengawan Solo River. The intake was constructed by cutting off the natural ground (see Figure 7.3.1). This topographical condition looks like a vase where the rim is at El.126.0 m and the bottom at approximately El. 110.0 m, which was the original Keduang riverbed.

This structural condition contributed to the sedimentation, and consequently the intake has been surrounded by sediment. Figure 8.2.1 illustrates an image of the sediment transportation from the intake structure. The spillway overflow is set at El. 131.0 m, so sediment cannot be flushed until the sediment deposit level exceeds El. 131.0 m.



Source: JICA Study Team

Figure 8.2.1 Illustration of Sediment Transportation at Intake

8.2.1 Modification of Intake

(1) Features of Method

Modification of the existing intake aims at preventing the intake from being buried by sediment deposits and also preventing garbage from entering the intake. The intake will be modified by providing a new intake tower on the inlet portion. The intake tower will be equipped with selective gates and screens because sedimentation will continue in front of the intake. When the sediment deposition level exceeds LWL. 127.0 m, the intake gate will be adjusted over the deposit level to prevent sediments from flowing into the inlet.

(2) Layout Plan

The general layout plan is shown in Figure 8.2.2 and facility plan is shown below:

Table 8.2.1 Facility Plan of Intake Modification

Structure	Dimension	
Intake Tower	H=26.0 m (Inlet elevation: El.127.0 m)	
	Gate	H 5.0 m x B 12.6 m x 2 nos.
	Screen	H 14.0 m x B 12.6 m

Source: JICA Study Team

(3) Applicability

The major work of the modification is to construct the intake tower with a higher intake level than the existing intake. As foundation work needs dry conditions, the reservoir water level would need to be lowered during the work and thus water supply for irrigation and power generation would be suspended. The superstructure would need a foundation with a strong load bearing capacity. Because of these conditions, it is deemed difficult to adopt this method.

This method would not be sustainable solution for the sedimentation problems of the Wonogiri reservoir, because sedimentation over the inlet elevation would still continue year by year.

8.2.2 Relocation of Intake

(1) Features of Method

This method is to relocate the intake to a new location where less sedimentation is expected. An intake tower with selective intake with gates is recommended. A trash-rack would be provided at the front of the inlet. A transmission tunnel would be provided to connect the existing conduit to the power station.

(2) Layout Plan

The selected location is on the upper left bank approximately 300 m from the dam. The general layout plan is shown in Figure 8.2.3 and facility plan is shown below:

Table 8.2.2 Facility Plan of Intake Relocation

Structure	Dimension
Intake Tower	H=32.0 m
	Inlet elevation: El.127.0 m
	Gate H5.0 m x B10.0 m×2 nos.
	Screen H14.0 m×B12.6 m
Transmission Tunnel	D=5.5 m
	L=570 m

Source: JICA Study Team

(3) Applicability

From the results of reservoir sedimentation analysis, sedimentation would occur around the proposed site, although the sedimentation rate would be less than at the existing intake. It might be difficult to avoid sedimentation around the proposed site. Water supply would need to be suspended during connection work to the existing waterway of intake structure. However, the frequency of garbage blocking the intake would be reduced considerably because the proposed intake is located away from the channel of Keduang River.

Relocation of the intake would enable the intake structure to function properly when the existing intake is completely filled with sediment deposits. However, in view of sustainable management of the Wonogiri reservoir function, relocation of the intake might be applicable in conjunction with other measures such as periodic maintenance dredging in front of the new intake.

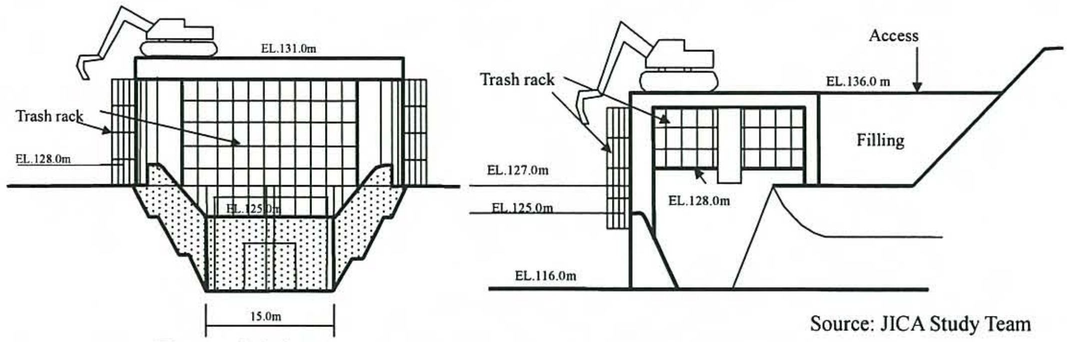
8.2.3 Garbage Trapping Structure at Intake

(1) Features of Method

Garbage inflow from the Keduang River is the primary cause of blockage of the intake. If the garbage problems are solved, almost no intake blockage is likely to occur. Since the shape of ground in front of the intake is formed by the excavated deep approach channel, sediment with garbage on the side slopes easily washes into the cutoff channel.

(2) Layout Plan

Figure 8.2.4 below is the preliminary design of the garbage trapping structure at the existing intake. An overflow weir would be constructed in the cutoff channel of the intake. The crest elevation is set at El.127.0 m at the front and El.128.0 m at the side. The overflow weir would block sediments from entering the inlet. A trash-rack would be installed at the front and both sides to prevent garbage from entering the inlet. An approach deck is planned for connecting between the dam crest and this structure to minimize maintenance works. Garbage on the trash-rack would be easily removed by heavy equipment such as a backhoe and crane. This approach deck and top of the garbage trapping structure is designed to be submergible to minimize construction cost. Garbage would be removed periodically when the reservoir water level is below El.136.0 m.



Source: JICA Study Team

Figure 8.2.4 Illustration of Garbage Trapping Structure at Intake

The general layout plan is shown in Figure 8.2.5 and facility plan is shown below:

Table 8.2.3 Facility Plan of Garbage Trapping Structure at Intake

Structure	Dimension
Overflow weir	Crest elevation El.127.0 m Width of crest B=14.6 m
Approach deck	B=7.0 m L=105.7 m A=739.9 m^2
Steel pile	Φ1,000 L=9.0 m, Nos.=34
Trash rack (Screen)	H=7.0 m L=111.2 m A=889.6 m^2

Source: JICA Study Team

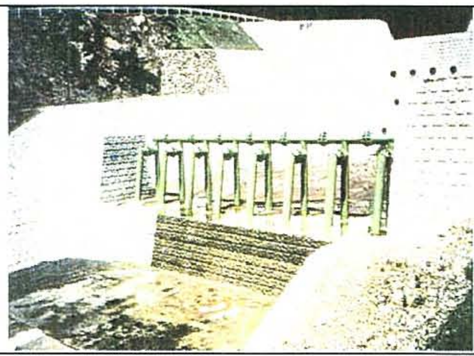
(3) Applicability

As foundation work needs dry conditions, the reservoir water level would be lowered during the work and thus water supply for irrigation and power generation would have to be suspended. Provided that the garbage is removed periodically, intake blockage due to garbage would be solved. However, other measures would be required to reduce sediment deposits at the intake. In view of sustainable management of the Wonogiri reservoir function, a garbage trapping structure at the intake might be applicable provided there are other measures such as periodic maintenance dredging in front of the new intake.

8.2.4 Garbage Trapping Structure in Keduang River

(1) Features of Method

In this method is to trap and remove garbage on the Keduang River before entering the reservoir. A check dam with steel-pipes is recommendable, that is commonly applied in Japan. Pictures below are the example of garbage trapping check dam in Japan. Garbage removal works shall be carried out periodically.



Example of Steel Pipe Garbage Trapping Structure in Japan

(2) Layout Plan

The general layout plan of the garbage trapping structure in the Keduang River is shown in Figure 8.2.6, and facility plan is given below:

Table 8.2.4 Facility Plan of Garbage Trapping Structure in Keduang River

Structure	Dimension
Concrete weir	Width W=56.3 m Height H=9.3 m
Steel pipe	B=25.0 m h=4.0 m

Source: JICA Study Team

(3) Applicability

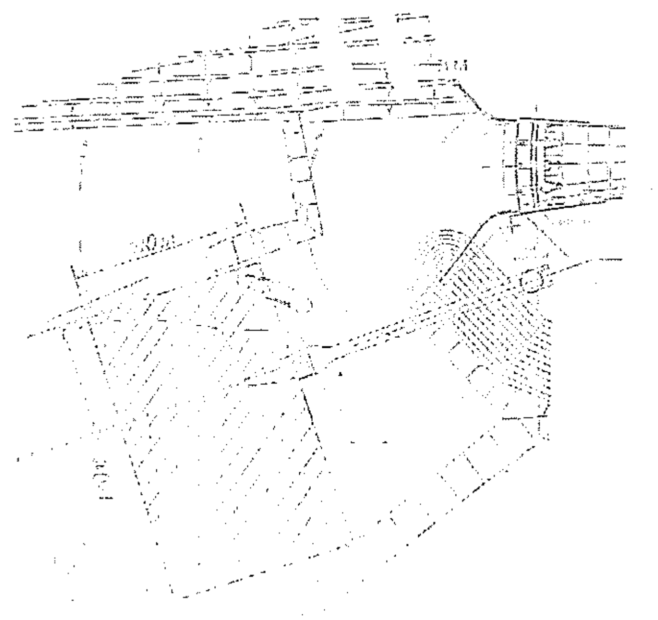
Periodic removal of the trapped garbage and land for disposal are needed. Sediment inflow from the Keduang River continues to enter into the Wonogiri reservoir without being trapped at the check dam. This method would be useful as a supplement to sediment removal work at the intake

8.2.5 Hydro-suction Sediment Removal System

As explained in Chapter 6, the verification test of a hydro-suction sediment removal system confirmed applicability of this system. Based on the test results, the dredging volume is roughly estimated for the following condition:

Period	:	December to April
Suction Area	:	The suction area is determined in front of the intake as shown in Figure 6.2.7.
Diameter of Pipe	:	600 mm
Pipe Length	:	500 m (=240 m (spillway side) + 250 m (reservoir side))
Outlet Elevation	:	EL.115.0m (receiver tank on the end of spillway)

The operation of this system is divided two ways; one is in time of floods (flood period) and the other in the power plant operation time (non-flood period). The area subject to dredging is shown below:



Source: JICA Study Team

Figure 8.2.7 Dredging Area by Hydro-suction System

To avoid dangerous operation of the system during the flood period when floodwater flows into the Wonogiri reservoir, the system operation would be limited to only the flood period when the total reservoir inflow is from 100 to 800 m^3/s. The annual average flood period from December to April in the period of 1993 to 2004 was estimated to be 732 hours. The operation time is estimated to be 183 hours excluding nighttime and preparation time for the system operation, which is assumed to be 75% of the total hours. The average reservoir water level during the above period is roughly estimated at El.133.64 m. The suction amount is estimated to be approximately 125,200 m^3 as follows:

Table 8.2.5 Summary of Suction during Flood Period

Operation time (hrs.)	Pipe flow velocity (m/s)	Volumetric concentration (%)	Suction rate (m^3/s)	Suction amount (m^3)	Water consumption (m^3)
183	2.7	25	0.19	125,200	502,700

Source: JICA Study Team

Though the system can remove 125,200 m^3 of sediment during the flood period, the discharge would have an extremely high concentration of sediment, at 25% volumetric concentration, which would be released to the downstream reach of the dam. It might cause serious impacts on the environment of the Bengawan Solo River. To mitigate the impacts, daily operation of hydro-suction system would need to be limited to less than four (4) hours. This limitation would reduce the suction volume to around 31,500 m^3.

During the non-flood period, the suction discharge would be mixed with the mean power plant discharge of 30 m^3/s and its volumetric concentration is assumed to be 7%. Operation time at 4 hours times 120 days from December to April would be 480 hours.

In conclusion, it is recommended that the hydro-suction sediment removal system in the Wonogiri reservoir is operated in both the flood and non-flood periods. The estimated volume that would be released is as follows:

Table 8.2.6 Summary of Suction Operation

Division	Operation time (hrs.)	Pipe flow velocity (m/s)	Volumetric concentration (%)	Suction rate (m^3/s)	Suction amount (m^3)	Water consumption (m^3)
Power plant operation time	480	2.2	7	0.04	69,100	1,074,300
Flooding time	46	2.7	25	0.19	31,500	126,400
Total	**526**	-	-	-	**100,600**	**1,200,700**

Source: JICA Study Team

8.3 Countermeasures for Sediment Inflow from Keduang River

8.3.1 Keduang River Sediment Bypass

(1) Features of Method

Sediment bypassing for the Keduang River is the method where part of the incoming sediment-laden flood inflow from the Keduang River is diverted into a bypass tunnel to the downstream river of the dam. This method is usually effective for reservoirs where it would be difficult to lower the reservoir water level and the reservoir size is relatively small. However, the construction cost is usually huge.

(2) Layout Plan

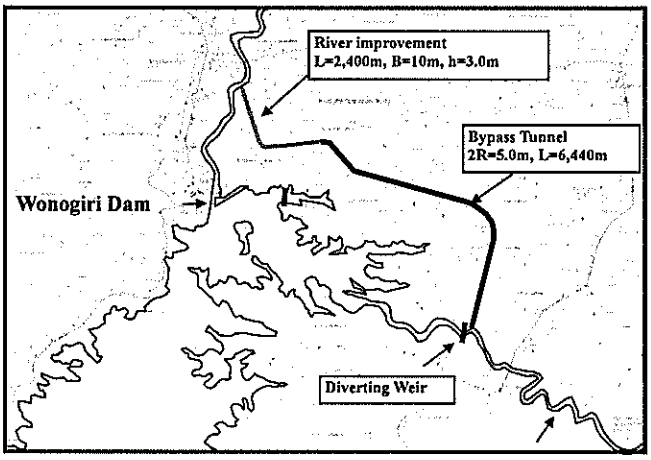
Usually the adopted gradient of the bypass tunnels is around I=1/100 to secure enough tractive force against bed load or suspended load including wash load. In case of the

Wonogiri dam, the gradient of the bypass tunnel would need to be as small as I=1/1,000 due to the flat topography. Therefore it might be difficult to bypass the bed load materials. The proposed bypass diverts only the suspended load materials including wash load. The discharge capacity of bypass tunnel was determined to be 50 m^3/s considering efficiency between the sediment concentration and flood discharge. Bypass tunnel route alternatives and optimization of tunnel capacity are detailed in Supporting Report II Annex No.7.

Figure 8.3.1 below illustrates the general layout of the proposed sediment bypass system for the Keduang River. The proposed sediment bypass system is composed of four (4) facilities, a diverting weir, control gates, a bypass tunnel and improvement of the small local river that connects the bypass tunnel and the Bengawan Solo River.

(3) Operation

Control gates to divert the flood flow into the bypass tunnel would be installed on the right side abutment of the diverting weir. When the flood discharge exceeds 30 m^3/s, the gates are fully opened to divert floods of up to 50 m^3/s directly into the bypass tunnel. When flood flow declines to 30 m^3/s, the gates are closed. Consequently, parts of the flood flow of less than 30 m^3/s and more than 50 m^3/s directly enter into the Wonogiri reservoir. Operation of sediment bypassing is illustrated in Figure 8.3.3 below.



Source: JICA Study Team

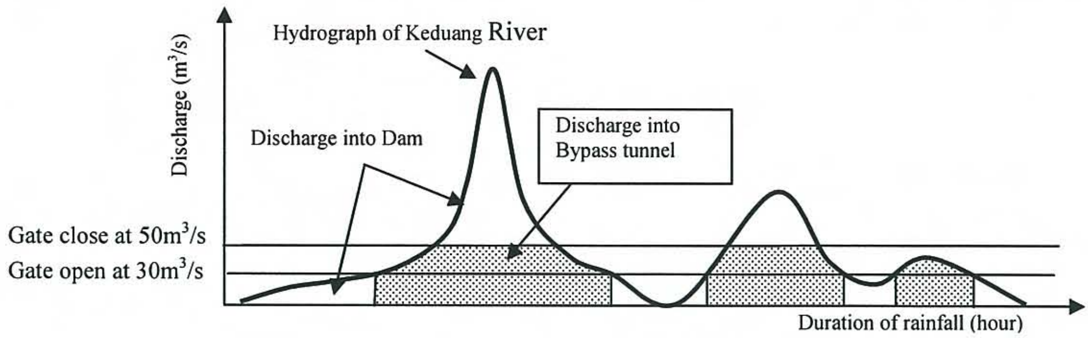
Figure 8.3.1 General Layout of Keduang River Sediment Bypass

Figure 8.3.2 presents the general layout plan of sediment bypass system and its facility plan is given below:

Table 8.3.1 Facility Plan of Keduang River Sediment Bypass

Facility	Dimension	
Diverting weir	Design discharge	Q=1,370m^3/s
	Width of flow area	70 m
	Overflow depth	4.9 m
	Height of dam	9.3 m
	width of dam	137.9 m
Control gates	Roller gate x 2 nos	H6.7 m x B5.0 m x 2 nos.
	Foundation height	EL.134.0 m
Bypass tunnel	Gradient of channel	I = 1/1,000
	Horseshoe channel	2R = 5.0 m
	Length of channel	L = 6,435 m
River improvement	Gradient of channel	I = 1/200
	Length of channel	L = 2,395 m
	Width of bottom	B=10.0 m
	High of channel	H=3.0 m

Source: JICA Study Team



Source: JICA Study Team

Figure 8.3.3 Illustration of Design Discharge of Bypass Tunnel

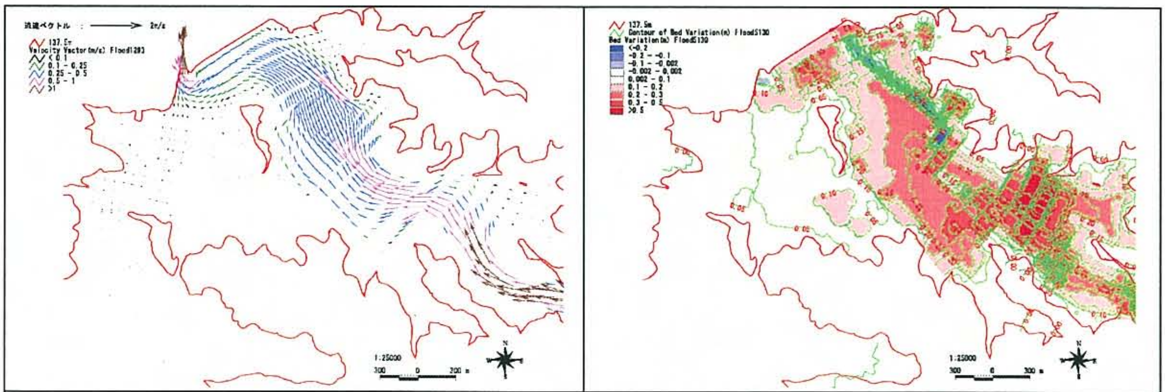
(4) Reservoir Sedimentation Analysis

By use of the developed Wonogiri reservoir sedimentation analysis model (detailed in Chapter 5), simulation of reservoir sedimentation was carried out applying the condition that the sediment bypass system is provided. Due to the limited calculation time for simulation, the reservoir inflow of the hydrological wet year 1998/99 (reservoir inflow volume in the wet season is around 1.4 billion m^3) was applied. Results of analysis are summarized in Table 8.3.2 and Figure 8.3.4 below. It was assumed that the bypassing water volume would be up to around 200 million m^3 at maximum, which is almost equivalent to the mean annual excess water volume released from the existing spillway in 1983-2005.

Table 8.3.2 Sediment Balance of Keduang River Sediment Bypass

Facility	Unit	Sediment outflow				Sediment Deposit in the Reservoir	Total Sediment Inflow from Keduang
		Intake	Existing spillway	Bypass tunnel	Total		
Existing condition	1,000 m^3	394	244	-	638	1,071	1,710
Bypass system	1,000 m^3	189	91	476	757	953	1,710
(Difference)	1,000 m^3	-205	-152	476	118	-118	
Released water	MCM	806	90	182	1,078	-	
Concentration	ppm	250	1,077	2,789	747	-	

Source: JICA Study Team



Velocity distribution	Sedimentation at Keduang River Area

Source: JICA Study Team

Figure 8.3.4 Simulation Results of Keduang River Sediment Bypass

From the reservoir sedimentation analysis it appears that:

i) The diverted sediment volume into the bypass tunnel would be around 476,000 m^3, which corresponds to around 28% of the total sediment inflow volume of Keduang River in 1998/99 (1,710,000 m^3).

ii) Sediment outflow volume from the existing intake would be reduced to be 289,000 m^3 from 638,000 m^3. The excess volume would be 349,000 m^3, which is about 55.0%.

iii) Consequently, the net increase in volume of sediment released by provision of the sediment bypass system would be only 118,000 m^3, which is only 6.9% of the sediment inflow from the Keduang River.

iv) The diverted water volume is 182 million m^3 and average sediment concentration is 2,789 ppm.

(5) Applicability

The sediment deposits in the Wonogiri reservoir are mainly composed of wash load materials. Thus the proposed Keduang River sediment bypass system is applicable. It is noted that due to flat topographic condition, the discharge capacity of the bypass tunnel becomes relatively small (50 m^3/sec in maximum) and thus the flood inflow from the Keduang River with high sediment concentration cannot be fully diverted. Considerable volume of sediment flow from the Keduang River would still enter the Wonogiri reservoir. Modification of intake or maintenance dredging at the intake would also be necessary for sustainable operation of the reservoir.

8.3.2 Sediment Sluicing by New Gates

(1) Feature of Method

This method is to pass the incoming sediment-laden flood inflows from the Keduang River through the new gates to the downstream reaches of Wonogiri dam preventing deposition in the reservoir. The new gates would be on the right abutment of the dam. This method requires modification of the current reservoir operation rule due to the requirement for massive release of water and the water level would have to be lowered to near the sediment deposit elevation in front of the dam.

The Wonogiri dam is very large and its storage capacity is so huge that it takes a long time to lower the water level in the reservoir. In addition, the reservoir turnover rate is very small at 2-3 times per year on average. Thus it might be difficult to carry out sediment sluicing with the existing operation rule. However, this method could be applied at the beginning of wet season when the water level is the lowest.

(2) Layout Plan

In December at the beginning of wet season, the inflow from the Keduang River runs in front of dam and turns its direction to the left, directly attacking the existing intake. In order to pass through (sluicing) the sediment-laden flood inflows from the Keduang River to the downstream reach without sediment deposition at the intake, a new gated spillway would be constructed on the right abutment. The elevation of spillway crest would be set at EL.127.0 m to release sediments efficiently.

The facility plan is shown in Table 8.3.3 and the layout plan is shown in Figure 8.3.5.

Table 8.3.3 Facility Plan of Sediment Sluicing by New Gates

Facility	Dimension	
Sediment sluicing gates	Radial gate	H 12.6 m x B 7.5 m x 4 nos.
Spillway	Chute type spillway and channel	B=30 m, L=723 m, I=1/108
Forebay excavation	Sediment deposit level	EL.127.0 m

Source : JICA Study Team

(3) Operation

Basically the gates would be fully opened from the beginning of wet season until the total released water volume becomes 200 million m^3. However, the released flow through the new gates would be controlled not to exceed 400 m^3/s according to the current reservoir operation rule.

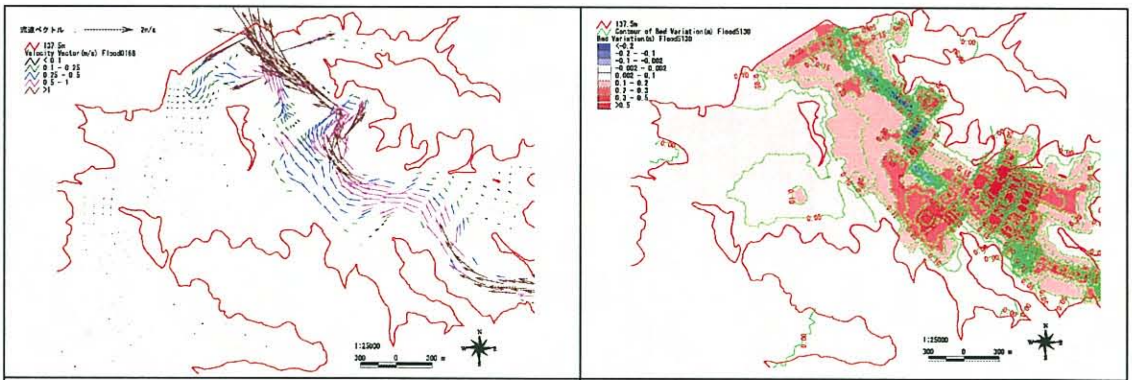
(4) Reservoir Sedimentation Analysis

A reservoir sedimentation analysis was made applying the operation for the new sluicing gates mentioned in the above. The applied hydrological information is from the reservoir inflow in 1998/99. Results of the analysis are summarized in Table 8.3.4 and Figure 8.3.6 below.

Table 8.3.4 Sediment Balance of Sediment Sluicing by New Gates

Facility	Unit	Sediment outflow				Sediment Deposit in the Reservoir	Total Sediment Inflow from Keduang
		Intake	Existing spillway	New gate	Total		
Existing condition	1,000 m^3	394	244	-	638	1,071	1,710
Sluicing	1,000 m^3	334	-	509	843	866	1,710
(Difference)	1,000 m^3	-60	-244	509	205	-205	
Released water	MCM	878	-	200	1,078	-	
Concentration	ppm	405	-	2,712	832	-	

Source : JICA Study Team



Velocity distribution | Sedimentation at Keduang River Area

Source: JICA Study Team

Figure 8.3.6 Simulation Results of Sediment Sluicing by New Gates

Major findings from the reservoir sedimentation analysis are:

i) The released sediment volume through the new sluicing gates is around 509,000 m^3, which is about 33,000 m^3 larger than that of Keduang River sediment bypassing. Net increase of sediment released by sluicing is estimated 205,000 m^3.

ii) It is expected that most of the garbage from the Keduang River would be released through the new gates to the downstream reach from the dam.

iii) Released water volume would be 200 million m^3 and average sediment concentration 2,712 ppm.

(5) Applicability

Considering the construction cost and efficiency of sediment releasing, sediment sluicing by new gates would be more effective and attractive than the Keduang River sediment bypass system. Garbage inflow usually concentrates at the beginning of wet season. If the gates were fully opened from the beginning of wet season, considerable amount of garbage would be released to the downstream reach. As the new gates and spillway would be constructed within the Wonogiri dam area, it is expected that almost no land acquisition would be required for relocation of local people.

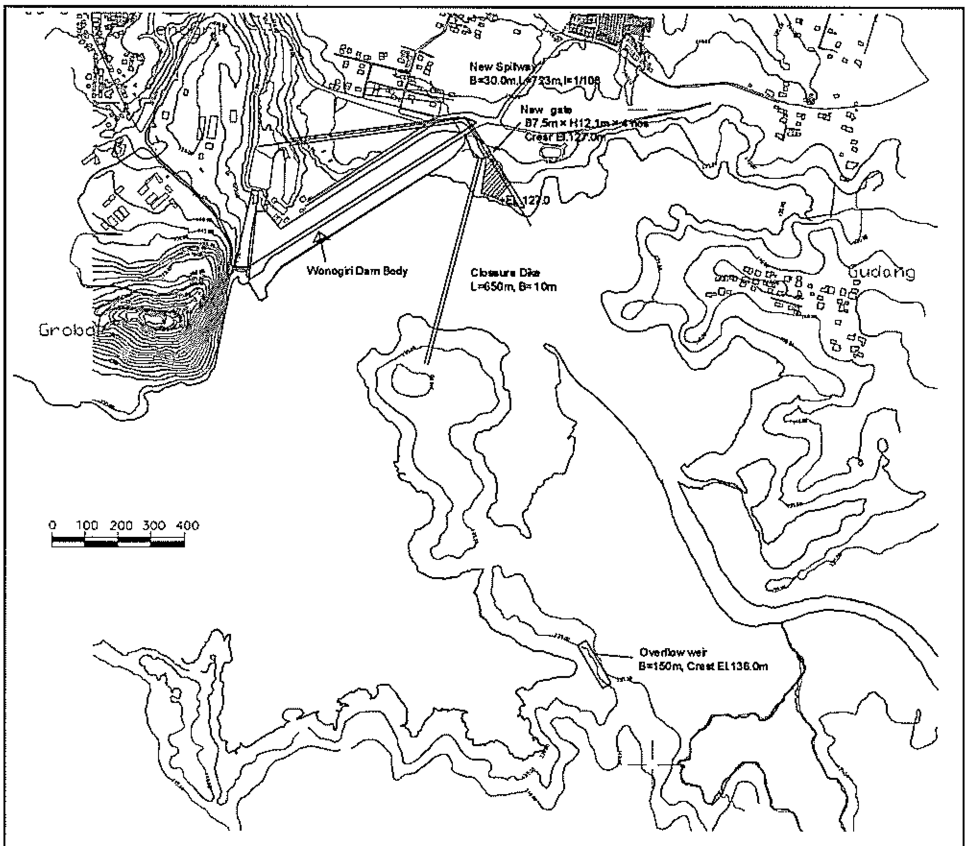
8.3.3 Sediment Storage Reservoir with New Gates in the Wonogiri Reservoir

(1) Features of Method

This method is to create a small sediment storage reservoir for the sediment inflow from the Keduang River inside the Wonogiri reservoir by installation of a closure dike. The Wonogiri reservoir is thus separated into two reservoirs. These two reservoirs can be operated separately and independently. The separated portions are named the sediment reservoir portion and main Wonogiri reservoir portion. New gates would be installed at the same location as required for the method of sediment sluicing with new gates. Thus, sediment-laden flood inflow from the Keduang River would be passed through the new gates before deposition in the reservoir.

(2) Layout Plan

Figure 8.3.7 below shows general layout of the proposed sediment storage reservoir system. As shown, the Wonogiri reservoir is separated by the closure dike into two reservoir portions; the sediment storage reservoir and main Wonogiri reservoir.



Source: JICA Study Team

Figure 8.3.7 General Layout of Sediment Storage Reservoir with New Gates

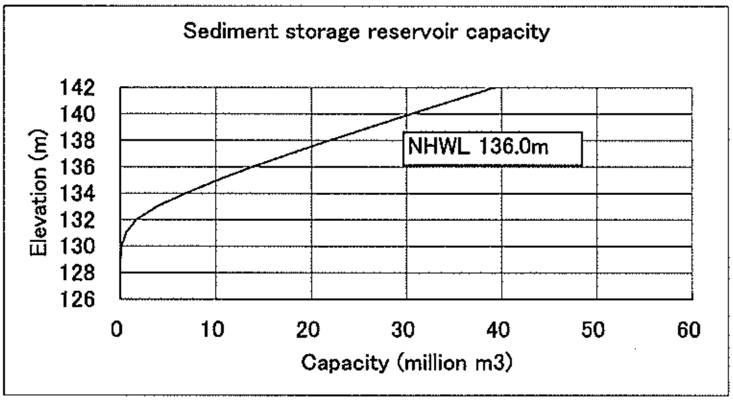
A closure dike would be constructed in the reservoir connecting the right side dam abutment and small peninsula in front of the dam as shown above. New gates would be installed in the sediment storage reservoir portion. Water depth from NHWL 136.0 m on the closure dike location is only 6.0 m due to the sediment deposition and is 21.0 m from the original ground. Therefore, the double-wall sheet pile method is proposed for the closure dike. The facility plan is shown in Table 8.3.5 and general layout plan of the closure dike is shown Figure 8.3.8.

Table 8.3.5 Facility Plan of Sediment Storage Reservoir with New Gates

Facility	Dimension	
Closure Dike	Double-wall sheet pile method	L=650 m, H=15.0 m, B=10.0 m
Overflow Dike	Filling and revetment	L=100 m, B=10 m
Sediment sluicing/flushing Gates	Radial gate	H12.6 m x B7.5 m x 4 nos.
Spillway	Chute type spillway and channel	B=30 m, L=723 m, I=1/108
Forebay excavation	Sediment deposit level	EL.127.0 m

Source: JICA Study Team

The storage capacity-elevation curve of the sediment storage reservoir is shown in Figure 8.3.9 below. The storage capacity of the sediment storage reservoir is around 14 million m^3 (only 2.3% of the total Wonogiri capacity) at NHWL.136.0 m and average annual Keduang River inflow in 1992-2005 was about 353 million m^3. Hence, turnover rate of the sediment storage reservoir would be 25 times a year on average. This means that the storage capacity of the sediment storage reservoir would be easily recovered by the inflow from Keduang River after emptying the reservoir for sediment release.



Source: JICA Study Team

Figure 8.3.9 Storage Capacity- Elevation Curve of Sediment Storage Reservoir

(3) Operation

Sustainable use of the sediment storage reservoir would be possible provided the sediment deposits are effectively flushed and sediment-laden flood inflows from the Keduang River are effectively passed through before deposition in this portion. The sediment storage reservoir would be filled with sediment deposits within 20 years without sediment release. The sediment storage reservoir would become like a sabo dam once it completely filled with sediment deposits. Sediment sluicing (sediment routing) and flushing aims to effectively utilize the water power (sediment transport capacity) of a natural river to reduce running cost.

The sediment storage reservoir would be operated with the current reservoir operation rule as follows:

a. In the beginning of wet season (November to December):

Inflow from all the tributaries would be fully stored in both the Wonogiri main reservoir and sediment storage reservoir. The reservoir outflow would be for hydropower generation. New gates would be closed as illustrated below.

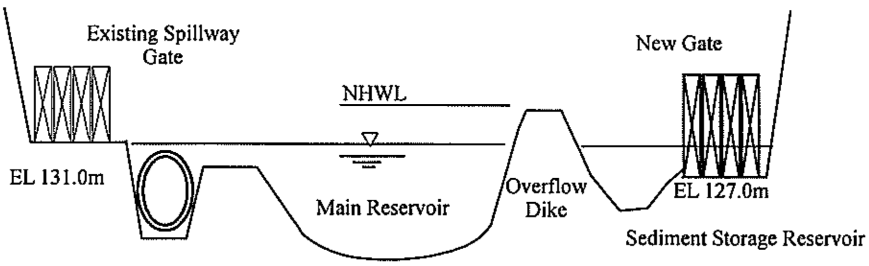


Figure 8.3.10 Illustration of Operation of Sediment Storage Reservoir (1/3)

b. In the middle of wet season (December to January):

Because of very small storage capacity in the sediment storage reservoir, the water level therein would rise rapidly. When water level of the sediment storage reservoir exceeds the crest of overflow dike, the stored water in the sediment storage reservoir would overflow into the Wonogiri main reservoir as illustrated below.

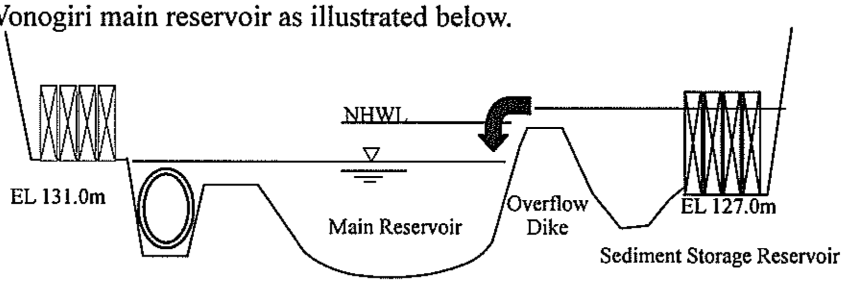
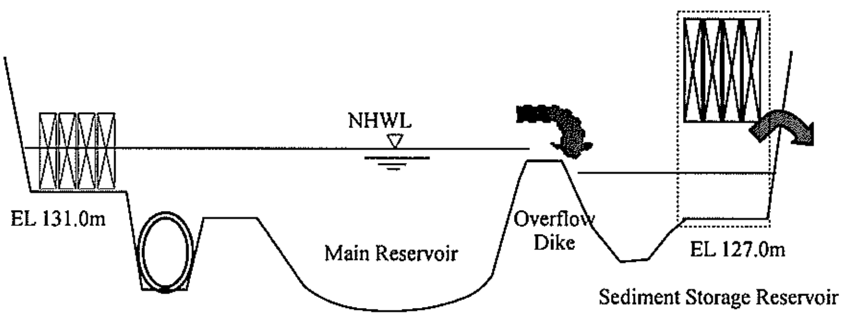


Figure 8.3.10 Illustration of Operation of Sediment Storage Reservoir (2/3)

c. At the end of wet season (February to April):

If the water level in the Wonogiri main reservoir portion reaches CWL 135.3 m, water storage is be completed. When a flood occurs in the Keduang River, the new gates would be opened to pass through the sediment inflow without deposition inside the reservoir. On the other hand, when the water level in the Wonogiri main reservoir exceeds CWL due to flood inflows from other tributaries, the stored water would overflow adversely into the sediment storage reservoir over the overflow dike as shown below. When excess water is available, all the excess water would be released through the new gates instead of the existing spillway until the end of wet season (on April 15).



Source: JICA Study Team

Figure 8.3.10 Illustration of Operation of Sediment Storage Reservoir (3/3)

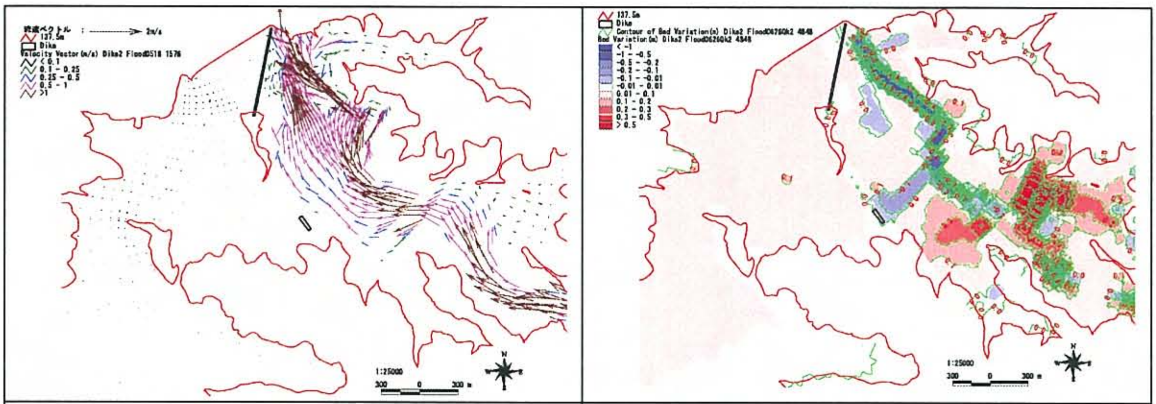
(4) Reservoir Sedimentation analysis

Applying the operation procedure in the above, a servoir sedimentation analysis was carried out as summarized below:

Table 8.3.6 Sediment Balance of Sediment Storage Reservoir with New Gates

Facility	Unit	Sediment outflow				Sediment Deposit in the Reservoir	Total Sediment Inflow from Keduang
		Intake	Existing spillway	New Gate	Total		
Existing condition	1,000 m^3	394	244	-	638	1,071	1,710
Sediment Storage reservoir	1,000 m^3	100	-	1,280	1,380	330	1,710
(Difference)	1,000 m^3	-294	-244	-1,280	742	-741	
Released water	MCM	607	-	670	1,277	-	
Concentration	ppm	176	-	2,037	1,152	-	

Source: JICA Study Team



Velocity distribution	Sedimentation at Keduang River Portion

Source: JICA Study Team

Figure 8.3.11 Simulation Results of Sediment Storage Reservoir with New Gates

From the reservoir sedimentation analysis it appears that:

i) The released sediment volume through the new gates would be around 1,280,000 $m^{3,}$ which corresponds to around 75% of the total sediment inflow volume of Keduang River.

ii) All of the garbage from the Keduang River would be completely retained in the sediment storage reservoir and be released to the downstream reach of the dam.

iii) The major portion of sediment inflow from the Keduang River would be trapped in the sediment storage reservoir. Due to this, the released sediment volume through the existing intake for power generation becomes drastically small. Almost no sedimentation occurs in the forebay of the intake.

iv) The incremental sediment volume to be released from the Wonogiri reservoir would be 741,000 m^3 more than the current condition.

(5) Applicability

Among alternatives to cope with the sediment inflow from the Keduang River, the sediment storage reservoir system shows the highest efficiency in terms of released sediment volume. The current garbage issue at the intake would be completely solved because the garbage retained in the sediment storage reservoir would be flushed or retained in this reservoir portion. All of the system components would be constructed within the Wonogiri dam area without relocation of local people. The technical merit of the sediment storage reservoir system results from the closure dyke, which allows the water level of the Wonogiri main reservoir to be maintained even when sediment is being released by opening the new gates.

It is noted that the simulation analysis above was made to assess the effectiveness of the ability to release sediment from sediment storage reservoir according to the current reservoir operation rule. The resulting released water volume through the new gates is 670 million m^3. The sediment releasing operation depends on having excess water available. Sediment releasing from the sediment storage reservoir would not be practiced every year. In the past excess water has been released through the existing spillway. When releasing excess water from the Wonogiri reservoir, the new gates would be opened instead of the existing spillway gates.

8.4 Countermeasures for Sediment Inflow from Other Tributaries

8.4.1 Sediment Storage Dam for Sediment Removal

(1) Feature of Method

Using a sediment storage dam is a common countermeasure to cope with a reservoir sedimentation problem. A sediment storage dam is planned on the river mouth of the major tributaries to trap and store the inflow sediment, which would be removed by excavation. Periodic removal of sediment deposits would have to be carried out in the dry season to maintain the storage function for trapping sediment inflow from the tributary. Sediment excavated could be effectively utilized as aggregate for concrete.

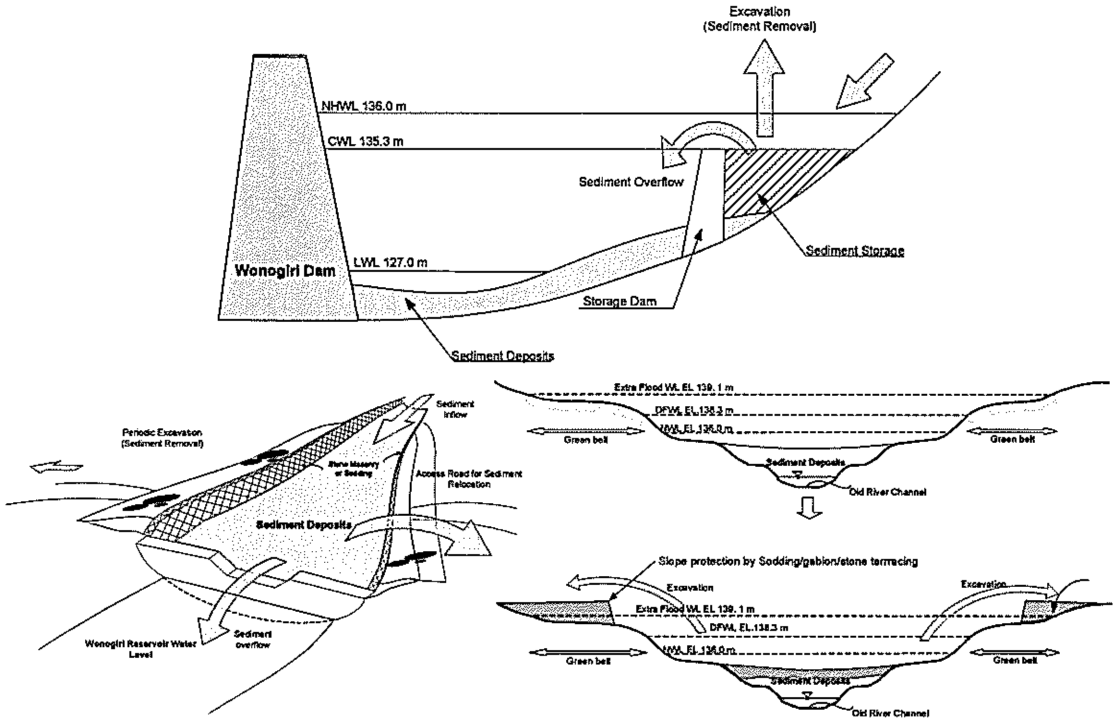
(2) Layout Plan

The facility plan of the sediment storage dam on the Keduang River is shown in Table 8.4.1 below. Figure 8.4.1 illustrates the sediment storage dam for sediment removal. The elevation of the dam crest is at CWL.135.3 m. The planned storage capacity of the storage dam is around 24,000 m^3, which accommodates only 1.4% of the annual sediment inflow from the Keduang River. Around 83 units of storage dam would be necessary for storing the annual sediment inflow volume of 2.0 million m^3.

Table 8.4.1 Facility Plan of Typical Sediment Storage Dam

Item	Dimension
Width of Dam	W=115.9 m
Height of Dam	H=9.3 m
Design discharge	Q=1,370 m^3/s
Width of overflow	B=70 m
Depth of overflow	h=4.9 m
Capacity of the Dam	V=24,000 m^3

Source: JICA Study Team



Source: JICA Study Team

Figure 8.4.1 Illustration of Sediment Storage Dam for Sediment Removal

(3) Applicability

Provided all of the sediment inflow from the Keduang River was trapped in the sediment storage dam, sediment removal would be required 83 times every year. Furthermore, huge disposal areas would be necessary. Annual O/M cost would be extremely high because of almost continuous excavation works to restore the dam capacity. The majority of sediment deposits in the Wonogiri reservoir are composed of very fine-grained materials such as silt and clay that are transported from major tributaries as suspended load and wash load. These fine materials are likely to overflow the sediment storage dam without deposition. Trapped materials would be coarse sediments (bed load materials). It is considered that such a sediment storage reservoir would not be practical and applicable as a sustainable and economic countermeasure for the Wonogiri sedimentation issues.

8.4.2 Hydraulic Dredging in Reservoir

(1) Features of Method

In this method sediment deposited in the reservoir is removed by hydraulic dredging. This is a most common countermeasure for removal of sediment from many existing reservoirs.

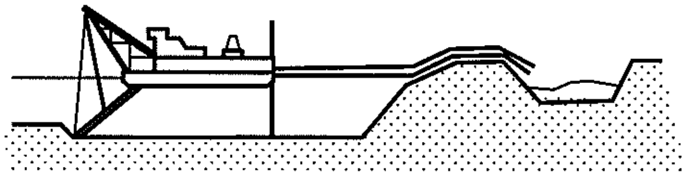


Image of Hydraulic Dredging

(2) Layout Plan

Table 8.4.2 below shows the estimated required works for hydraulic dredging in the whole reservoir and in the Keduang River reservoir areas for comparison. Five (5) dredgers in the Keduang River reservoir area and 15 dredgers in the whole reservoir area would be necessary to dispose of the entire mean annual sediment inflows. To realize this method, large spoil banks and huge running costs would be required.

Table 8.4.2 Dredging Work and Cost

Location	Unit	Whole reservoir	Keduang reservoir area
Sediment inflow	m^3	3,000,000	1,000,000
Dredging volume/	m^3/month m^3/day	500,000 20,000	167,000 6,680
Productivity by dredger	m^3/month m^3/day	39,990 1,333	39,990 1,333
Dredger required	Unit	15	5
Running cost per year	Rp	71.7 billion	23.9 billion

* unit cost for dredging is Rp.23,900 from the existing data.
Source: JICA Study Team

(3) Applicability

Hydraulic dredging was carried out at the intake structure in the Wonogiri reservoir in 2003 (around 250,000 m^3). However, considering that the annual sediment deposition from other tributaries of around 1.96 million m^3 (see Figure 7.4.2), hydraulic dredging would require huge spoil bank areas for the disposal of dredged sediments. Basically, this method is only recommendable as a supplemental work in conjunction with other countermeasures or urgent/maintenance works to cope with blockages of the intake structure. Furthermore, as seen above, huge running cost would be required. Hydraulic dredging is not considered practical and applicable as a sustainable and economic countermeasure for the Wonogiri sedimentation issues.

8.4.3 Dry Excavation in Reservoir

(1) Features of Method

In the dry season deposited sediments appear on the ground near the river mouths in the reservoir (see photo). The proposed location for dry excavation is near the mouths of tributaries. Dry excavation would be carried out in the dry season by use of backhoe or crawler-mounted bulldozer for swamp areas and then the excavated sediments would be conveyed to spoil banks by trucks. This method is a common and cheaper countermeasure for removal of sediment deposits in reservoirs.

Photo: Sediment Deposits near the River Mouth of Solo and Alang Rivers

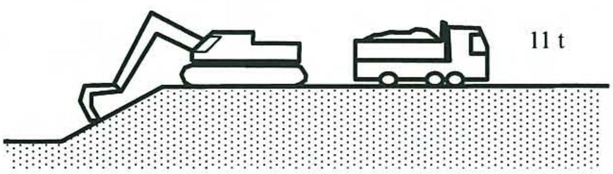


Image of Dry Excavation

(2) Applicability

It is unrealistic and impractical to cope with all sediments deposited in the reservoir solely by dry excavation. Available spoil bank areas around the reservoir are also very limited. It is recommended that this method should only be used as a supplementary measure in conjunction with other countermeasures. Dry excavation in the reservoir is not considered applicable as a sustainable and economic countermeasure for the Wonogiri sedimentation issues.

8.4.4 Managing of Sediments within Reservoir by Water Releasing from Intake

(1) Features of Method

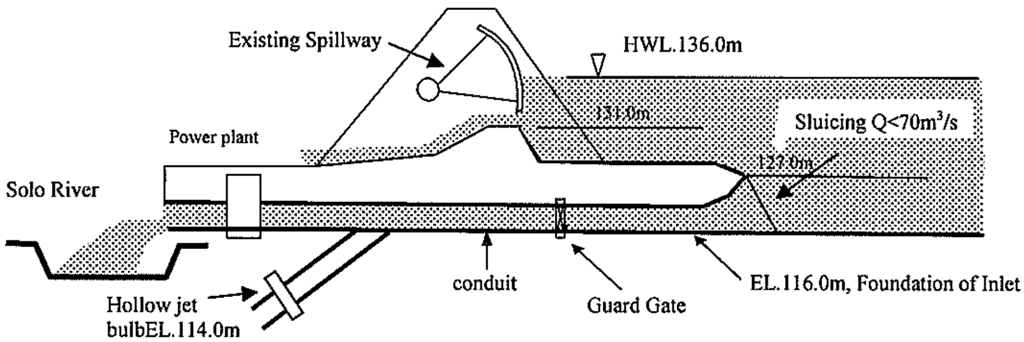
This method aims at moving the previously deposited sediments towards the dead zone of the reservoir, thereby maintaining or increasing the effective capacity of the reservoir. At the beginning of wet season, intake water would be used for drawing turbidity currents, using the maximum intake discharge for as long as possible.

(2) Layout Plan

No new outlet facility would be needed for this method, excluding provision of a garbage removal facility. Facilities to be used for this method would be as follows,

i) Existing intake: Maximum intake discharge 70 m^3/s
ii) Garbage trapping facility at the intake
iii) Garbage trapping facility at the Keduang River

The image for sediment management in the reservoir is illustrated in Figure 8.4.2 below:



Source: JICA Study Team

Figure 8.4.2 Image of Sediment Sluicing from Existing Outlet

(3) Operation

The existing power generation intake would be used with the maximum discharge of 70 m^3/s, which contains a high concentration of sediment from the beginning of the wet season. When the total outflow volume becomes 200 million m^3, the intake discharge would be controlled according to the current reservoir rule curve.

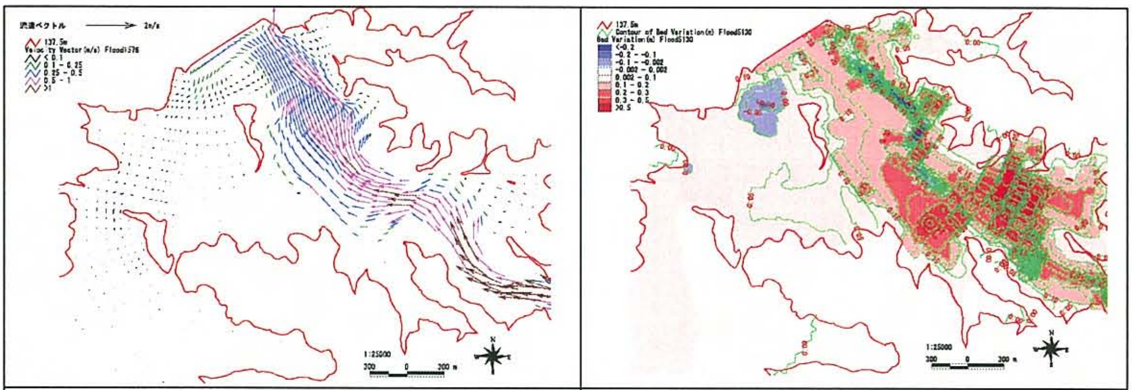
(4) Reservoir Sedimentation Analysis

A reservoir sedimentation analysis was made applying the operation procedure mentioned in the above. The applied hydrological information of reservoir inflow was as for 1998/99. Results of the analysis are summarized in Table 8.4.3 and Figure 8.4.3 below.

Table 8.4.3 Sediment Balance of Managing of Sediments within Reservoir by Releasing Water from Intake

Facility	Unit	Sediment outflow			Sediment Deposit in the Reservoir	Total Sediment Inflow from Keduang
		Intake	Existing spillway	Total		
Existing System	1,000 m^3	394	244	638	1,071	1,710
This method	1,000 m^3	498	264	762	948	1,710
(Difference)	1,000 m^3	103	20	123	-123	
Outflow water	MCM	859	186	1,045	-	
Concentration	ppm	617	-	775	-	

Source: JICA Study Team



Velocity distribution | Sedimentation at keduang

Source: JICA Study Team

Figure 8.4.3 Simulation Results of Managing of Sediments by Releasing Water from Intake

Sediment balance during the 1998-1999 wet season is summarized below:

i) The total sediment outflow volume was 762,000 m^3, which is 44.6% of the total sediment inflow (1,710,000 m^3) from the Keduang River.

ii) Incremental sediment outflow volume was 123,000 m^3.

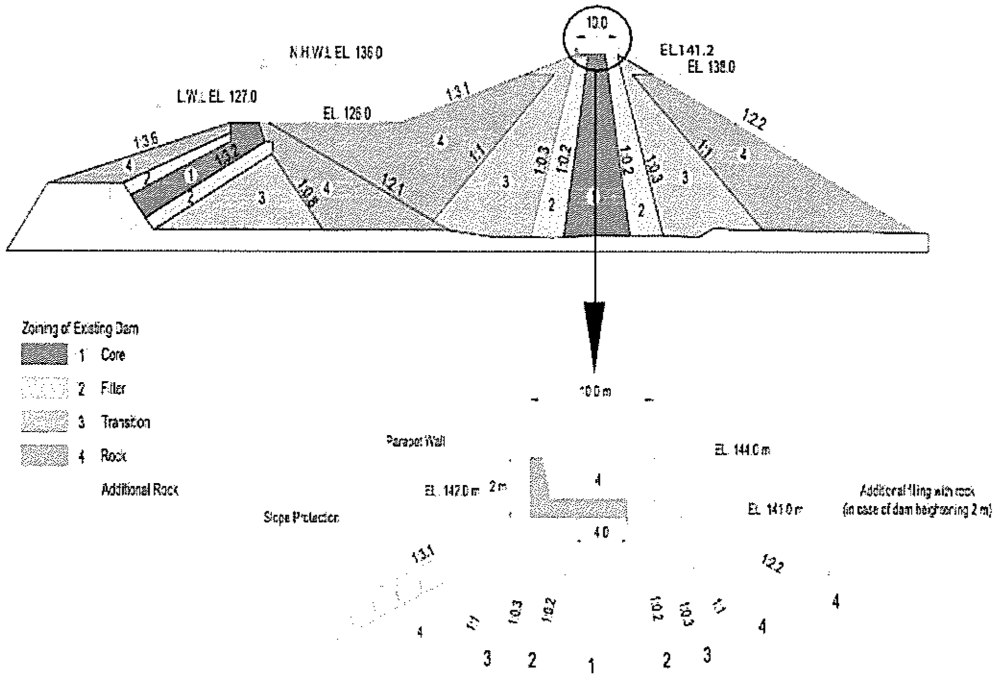
iii) The result of reservoir sedimentation simulation indicates that the sediment concentration released from the existing intake is about 1.3 to 2.5 times higher than with other systems. However as it is only 617 ppm on average, there should be no harmful effects on the intake tunnel and the hydropower turbine.

(5) Applicability

This method uses the existing intake to release the sediment. As most of sediment to be released is wash load, erosion of the intake tunnel and power generation turbine would not be so serious. For this method to be effective, there can be no blockage of the existing intake. Under present conditions in the Wonogiri dam, blockage of intake due to garbage often occurs so the reliability of this method is considered to be low. A garbage removal system at the intake would be indispensable. The disadvantage of this method is that a significant amount of water would have to be released through power generation, and there would be a risk that the reservoir water level would not reach NHWL. To apply this method, modification of the current reservoir operation rule would be necessary.

8.4.5 Dam Heightening

This method is to raise the dam crest to secure the effective storage capacity. As the incremental storage capacity is huge in the high portion of reservoir, this is an efficient option for increasing the capacity by a large amount. However dam heightening cannot be applied to every dam. It depends on factors such as geographical and geological conditions, safety of dam structure, area affected by backwater, impacts to socio-environment. And most auxiliary structures would need to be renewed. Therefore same level of due consideration to planning of a new dam would be required. The extent of dam heightening to secure the required capacity is estimated to be only 2 m for the Wonogiri dam. If the height were to be increased by 1 m, the increase in storage volume would be about 75 million m^3. In case of 2 m, the storage capacity would be increased to be more than 150 million m^3. Figure 8.4.4 below illustrates heightening of the Wonogiri dam.



Source: JICA Study Team

Figure 8.4.4 Typical Cross Section of Dam Heightening

However there are many properties such as houses and paddy fields around the reservoir. Thus dam heightening would bring about serious social problems. If impacts to the social and natural environments were estimated to be low, this method would become a promising alternative. At the Steering Committee meeting held in Jakarta on August 22, 2005, it was concluded that the idea of heightening of Wonogiri dam was not acceptable as a structural alternative because it would cause a very wide range of impacts such as dam body issues, acquisition of reservoir area, social problems, etc.

8.5 Re-allocation of Reservoir Storage Capacity

If the Wonogiri reservoir supplies water according to the current operation rule, the reduction in the water supply would be around 75 million m^3 under the current sedimentation condition in the reservoir. This would cause serious impacts to the stakeholders in the downstream because they are accustomed to the current water use practice, even though the total stored volume in the reservoir exceeds the initially allocated storage volume. Guarantee of future supply for the current water use might be of strong need for all the stakeholders. Therefore an evaluation on re-allocation of the current remaining storage capacity as of 2005 was made in order to secure the current water supply from the Wonogiri reservoir.

8.5.1 Review of Freeboard of the Dam

Reviews of the reservoir operation rules and basic concept of reservoir operation as well as the dam freeboard are detailed in the Supporting Report Annex. No.7.

Freeboard is the vertical distance between the top of the impervious core zone of embankment (without camber) and the reservoir water surface. The freeboard provides a safety factor against many contingencies, such as settlement of the dam, occurrence of an inflow flood somewhat larger than the design flood, or malfunction of spillway controls or outlet works etc.

To establish the freeboard and to determine the top elevation of the impervious core zone of the main dam, the following three (3) cases were considered. The criteria of Cases 1 and 2 are given in "Design of Small Dams" and that of Case 3 is given in "Design Criteria for Dams of Japan".

Case 1: PMF occurs and the spillway functions as planned. In this case the freeboard is provided to prevent the water surface rising over the impervious core zone of the embankment by wave action, which may coincide with the occurrence of the probable maximum flood.

Case 2: PMF occurs when the spillway malfunctions from human or mechanical failure to open gates. In such instances, allowances for wave action or other contingencies are not made, but the dam should not be overtopped.

Case 3: Design flood occurs when the spillway functions as planned. In this case the freeboard consists of allowance for wave action, malfunction of spillway gates and allowance due to the dam type whether fill type or not. If the half height of wave due to earthquake exceeds the wave height due to wind, the former is adopted instead of the latter.

The calculation results for above three cases are summarized in Figure 8.5.1 below:

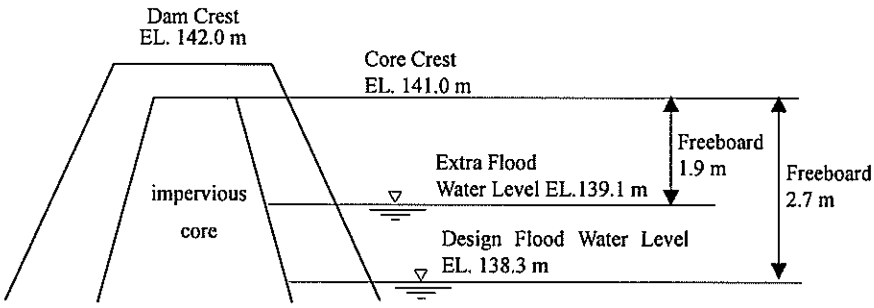


Figure 8.5.1 Freeboard of Wonogiri Dam

8.5.2 Conclusion on Possibility of Re-allocation

The Wonogiri reservoir has already lost approximately 49% of the sediment storage capacity and 13% of the effective storage capacity. A conceivable solution to recover the decreased storage capacity is to raise NHWL EL. 136.0m without decreasing the dam safety. In order to secure the dam safety against overtopping, both the extra flood water level and DFWL should not be modified without heightening of the impervious core zone of the dam embankment.

If NHWL is raised, it is necessary to raise the CWL or extend the recovery period from April 15 to April 30 so that the reservoir water level can recover to NHWL from CWL during the recovery period. In case the CWL is raised, both the flood control storage and

PMF control storage would be decreased because DFWL and the extra flood water level cannot be raised. Construction of a new spillway could be a solution against decreasing of PMF flood control storage, by the effect of increasing the release discharge. However, there is a constraint on flood control operation to keep the outflow discharge so as not to exceed 400 m^3/s during inflow discharge less than Standard Highest Flood Discharge (4,000 m^3/s) even though a new spillway could increase spillway discharge capacity. Because of this constraint due to the flood control operation rule, NHWL cannot be raised.

In conclusion, re-allocation of the current remaining storage capacity cannot be made without increasing the height of the dam body. For extension of the recovery period, there is a possibility though it would need detailed study.

8.6 Summary of Countermeasures

Sediment management alternatives for i) sediment deposits and garbage at intake, ii) sediment inflow from Keduang River and iii) sediment inflow from other tributaries, are evaluated independently for comparison from technical and economic points of view. Evaluation results and comparison of alternatives are summarized in Tables 8.6.1 to 8.6.3 respectively.