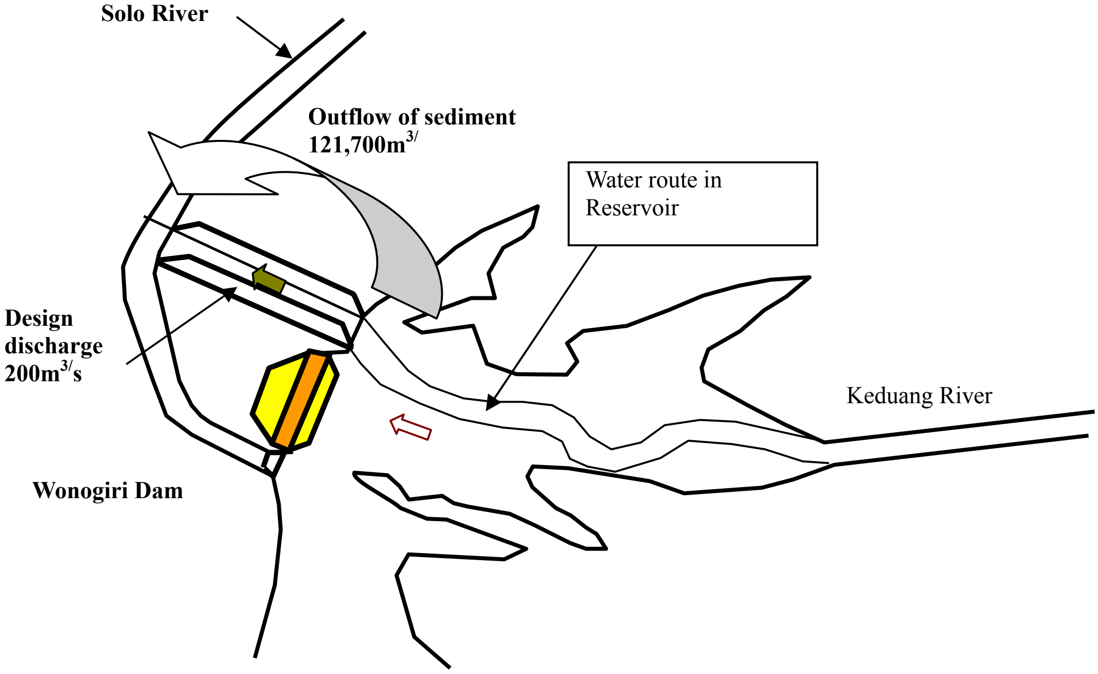
Table 2.2.12 Sediment Discharge from New Gates

Flushing Period	Design discharge Qd	Discharge Qf	Sediment discharge Qs		Average SS	Qs/Qsk
	m^3/s	m^3	t	m^3	kg/m^3	%
27,Nov,2004-4,dec,2004	50.0	22,793,388	71,303	67,267	3.128	9.3
	100.0	28,903,669	95,809	90,386	3.315	12.5
	150.0	33,365,146	114,594	108,108	3.435	15.0
	200.0	36,529,460	129,030	121,726	3.532	16.9
	300.0	40,977,312	151,103	142,550	3.687	19.7
	400.0	42,554,515	158,936	149,940	3.735	20.8
	all	43,288,588	161,426	152,289	3.729	21.1

- Total sediment inflow from Keduang River Qsk=765,248m^3
- Total inflow water from Keduang River Qf=277,366,358m^3

Source: JICA Study Team



Source: JICA Study Team

Figure 2.2.33 Sediment Discharge from New Gate

2.2.3 Sediment Storage Reservoir with New Gates

(1) Features of this Method

A reservoir in which the total storage volume is divided into two independently operating storage units is termed a compartmented reservoir. The compartments may be continuous, may consist of a smaller compartment inside a larger one, or may consist of two separate storage areas operated as a single system. Storage compartmentation allows the two portions of the total storage pool to be operated separately to enhance overall sediment management.

(2) Possibility of Application for Wonogiri Dam

1) Applicability

In case of Wonogiri dam, as turn-over rate of reservoir per year estimated only 2-5 times, it is deemed difficult to lower water level until free flow is recurred for sediment flushing in the view of securing enough water for irrigation and power generation.

However, the Keduang River side storage capacity is small and reservoir turn-over rate is estimated more than 25times on average, and that sedimentation problem at dam site is induced by the Keduang River. If Keduang River side can be comparted from Solo River side, sediment flushing can be carried out without lower the Solo River side water level. Thus, objectives of compartmented and multiple reservoir is to carry out sediment flushing to restore reservoir effective storage capacity of the Keduang River side, and to make sustainable reservoir at the Keduang.

2) Layout of the Facilities

The layout plan of Compartmented and multiple reservoirs are shown in Figure 2.2.34. A closure dike is laid out in the reservoir combining the right side abutment of the dam and peninsula existed in front of the dam. By the closure dike, the reservoir is separated into the small sediment storage reservoir and the main reservoir. New sediment flushing gate will be installed at the sediment storage reservoir. Maximum depth of Wonogiri reservoir is only about 10 m from HWL.136.0 m, especially water depth of the location where closure dike will be laid out is only 6.0 m due to the sediment deposition, and that depth of HWL 136.0 m to original ground is 21.0 m. Therefore, Double-wall sheet pile method is able to adopt as a closure dike.

The capacity-elevation curve of the sediment storage reservoir is shown in Figure 2.2.35 and Table 2.2.14. The storage capacity of the sediment storage reservoir is 14 MCM at EL.136.0 m. Average annual inflow for 1992 to 2005 is about 353 MCM. Hence, turn-over rate of sediment storage reservoir is 25 times a year on average. The facility plan is shown in Table 2.2.14 and drawings are shown in Figures 2.2.35 and 2.2.36.

Table 2.2.13 Facility Plan

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

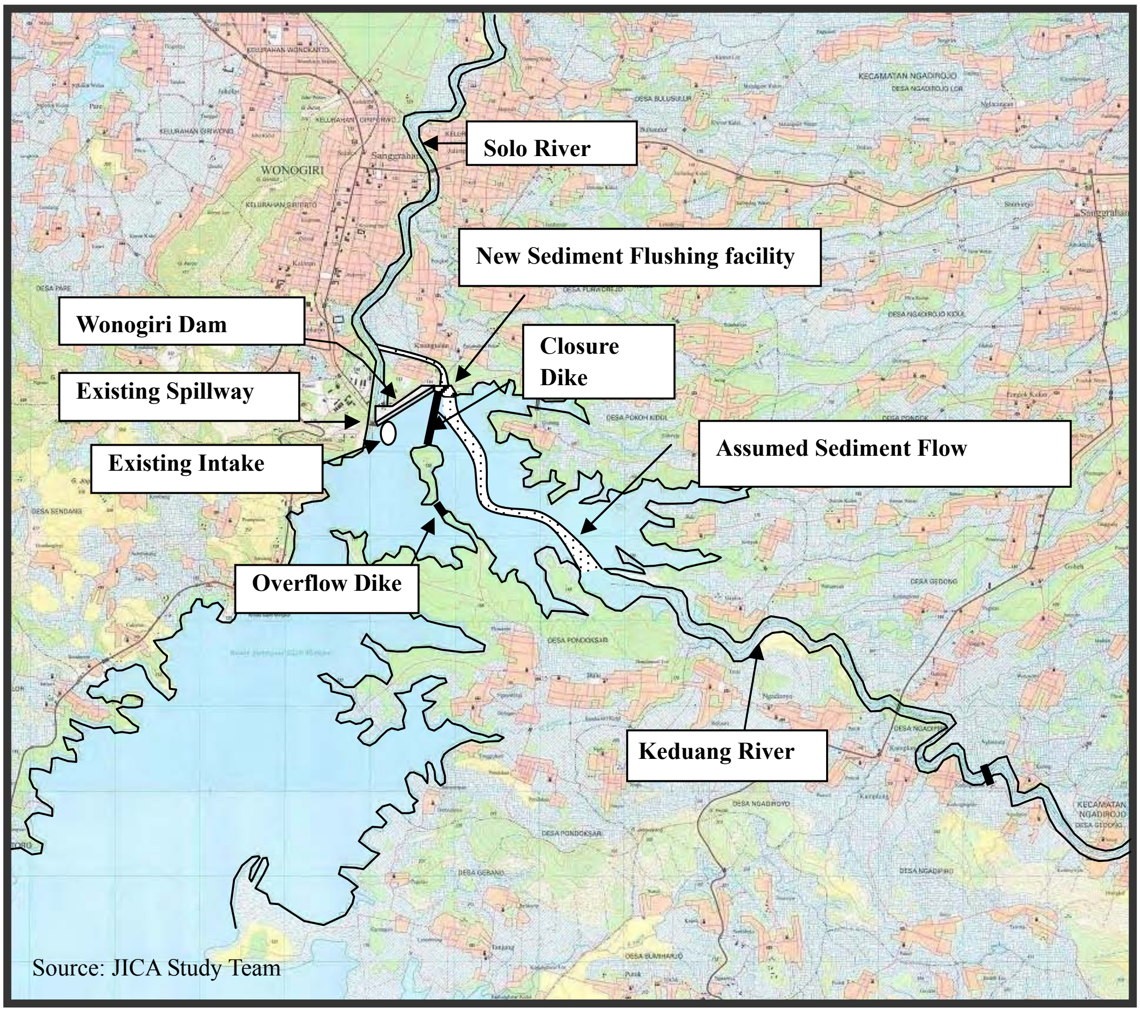


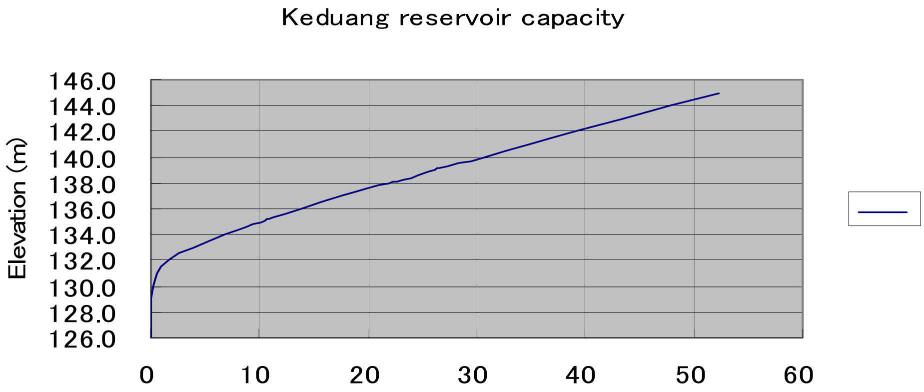
Figure 2.2.34 Location of Sediment Storage Reservoir with New Gates

Table 2.2.14 Estimated Mean Monthly Inflow from Keduang River

Unit: mil. m^3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual		
1993											9	50	59		
1994	67	54	172	39	7	2	4	6	8	0	0	4	364	**1993/94**	419
1995	37	120	117	43	10	11	7	5	0	5	44	114	512	**1994/95**	358
1996	76	76	62	31	7	2	0	3	4	10	19	33	321	**1995/96**	427
1997	55	52	26	14	10	4	0	0	2	0	5	11	179	**1996/97**	215
1998	10	64	78	79	12	28	26	5	4	17	72	54	450	**1997/98**	339
1999	110	86	96	36	16	4	5	1	3	5	42	65	471	**1998/99**	491
2000	29	133	89	99	24	12	0	0	0	3	48	18	455	**1999/00**	496
2001	59	77	72	53	12	14	6	3	5	8	16	11	336	**2000/01**	376
2002	64	145	91	81	13	3	3	0	0	0	0	16	415	**2001/02**	426
2003	41	74	91	4	6	1	1	0	0	0	7	26	251	**2002/03**	235
2004	34	55	37	10	11	4	3	1	9	16	13	61	254	**2003/04**	212
2005	18	36	60	47	2	4								**2004/05**	241
Mean	50	81	83	45	11	7	5	2	3	6	23	39	339	Average	353

Source: JICA Study Team



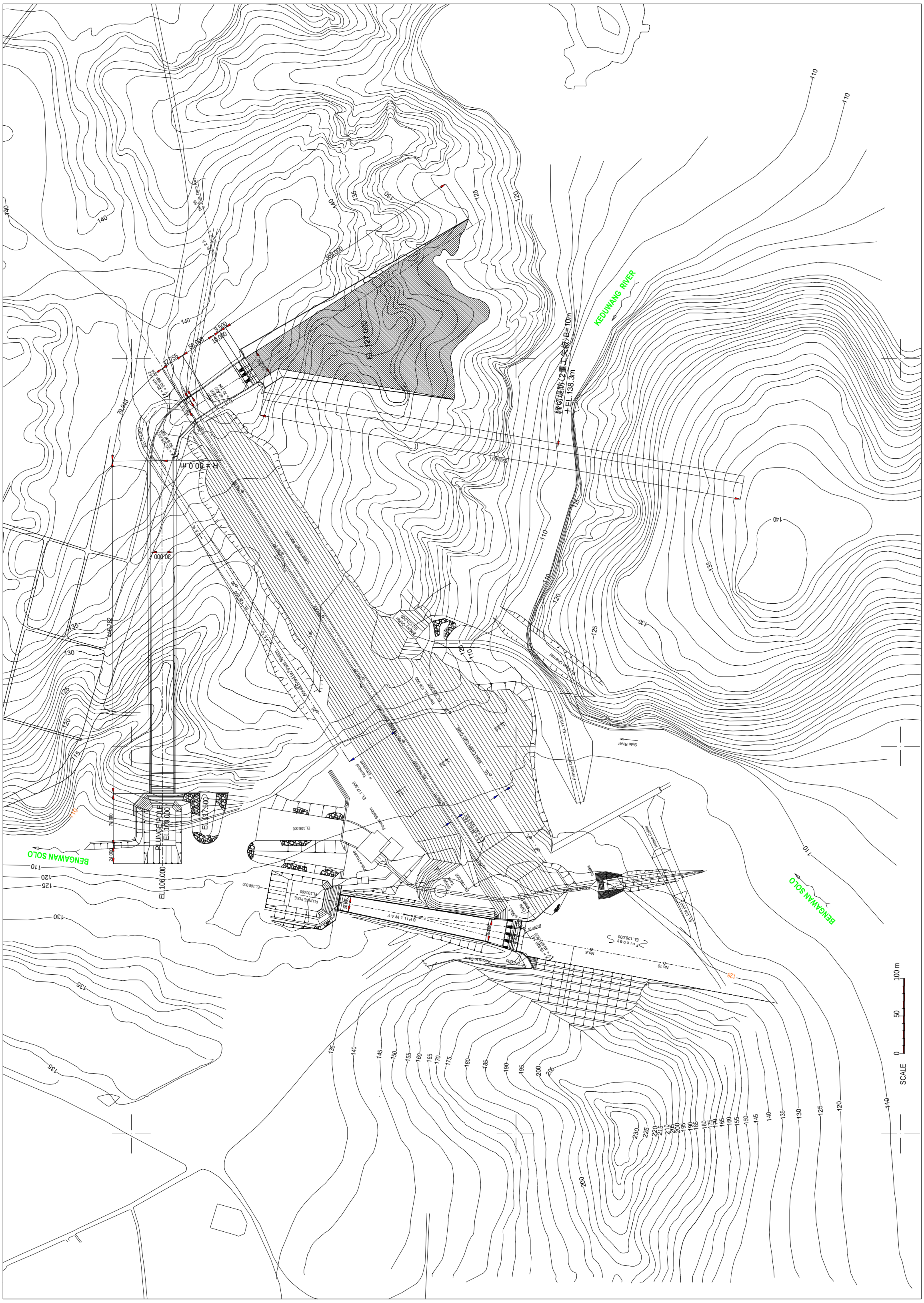
Source: JICA Study Team

Figure 2.2.35 Reservoir Capacity- Elevation Curve

Table 2.2.15 Reservoir Capacity- Elevation Curve

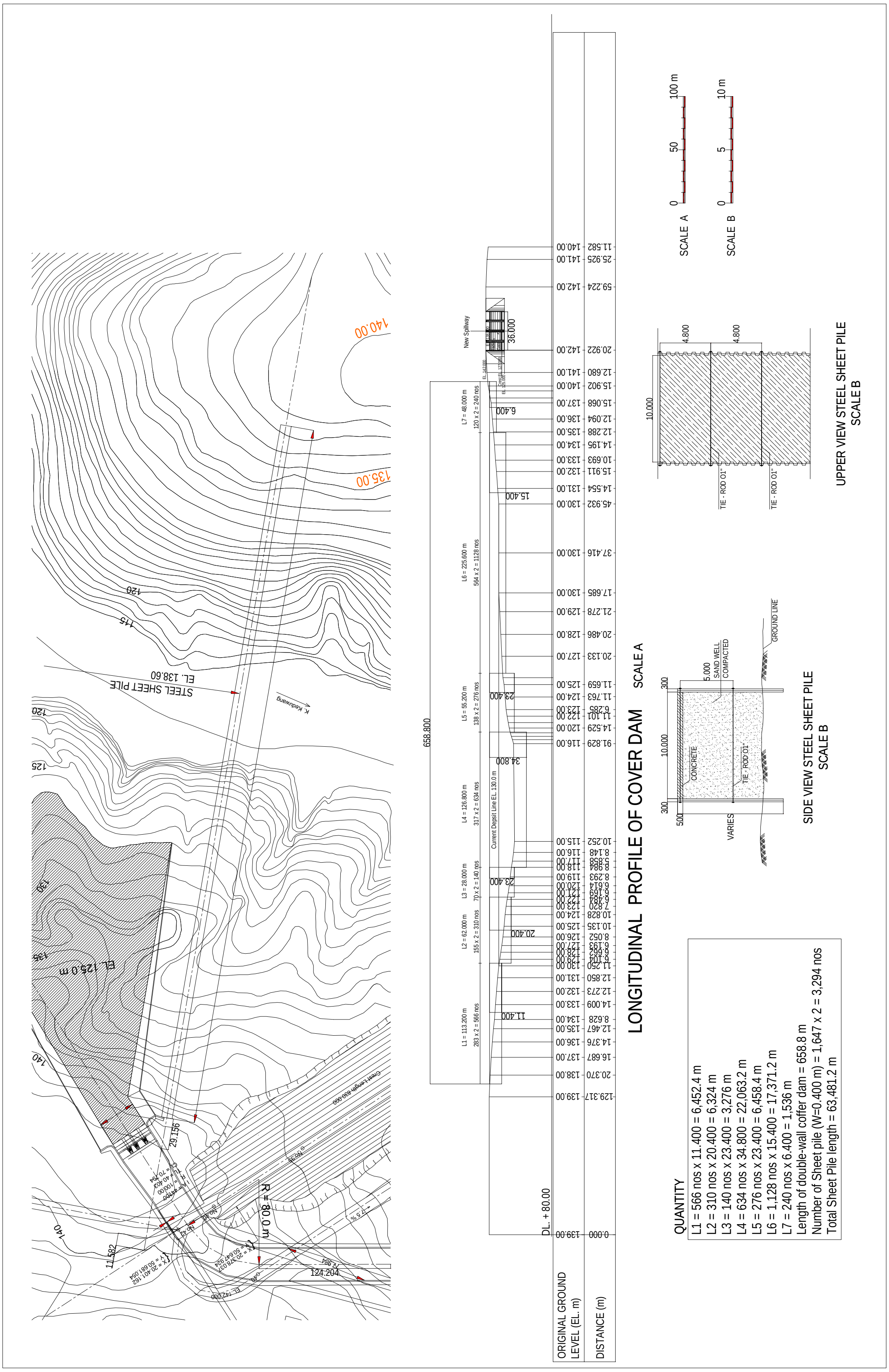
Elevation (m)	A (km2)	V (million m3)
118.0	0.000	0
119.0	0	0
120.0	0	0
121.0	0	0
122.0	0	0
123.0	0	0
124.0	0	0
125.0	0	0
126.0	0	0
127.0	0	0
128.0	0	0
129.0	0.0072	0
130.0	0.3229	0
131.0	0.6264	1
132.0	1.6023	2
133.0	2.7876	4
134.0	3.1875	7
135.0	3.4985	10
135.3	3.5804	11
136.0	3.8012	14
137.0	4.0789	18
138.0	4.2217	22
138.3	4.2476	23
139.0	4.2961	26
139.1	4.3021	27
140.0	4.332	30
141.0	4.3453	35
142.0	4.3499	39
143.0	4.3517	44
144.0	4.3531	48
145.0	4.3533	52

Source: JICA Study Team



Source: JICA Study Team

Figure 2.2.36 Layout Plan of Sediment Flushing Facility and Closure Dike



Source: JICA Study Team

Figure 2.2.37 Alignment and Structure of Closure Dike

3) Operation

a) Normal operation

Sediment flushing gates is opened at the beginning of rainy season until total outflow water volume to be 200 MCM. Allowable maximum discharge, while the reservoir water level is lower than EL. 138.2 m, is constrained to be 400 m^3/s. This discharge is corresponded to the allowable flow capacity of the stretches downstream of the dam.

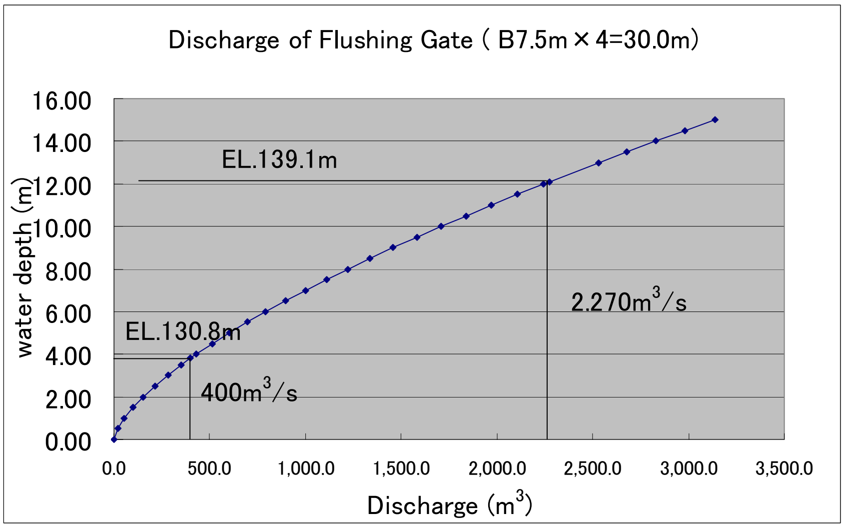
b) Sediment flushing operation

- Sediment flushing can be done at the water level under EL.135.3 m which is the crest height of the overflow dike
- When sediment flushing is carried out, new gates, which dimension is H12.1m x B7.5m x 4nos, are fully opened.
- Water volume using at sediment flushing is estimated about 11 MCM in the sediment storage reservoir exclude inflow from the river.
- Outflow discharge is 400 m^3/s at EL.130.8 m, 200 m^3/s on average, and duration of flushing will be 15.3 hours.
- Effectiveness of sediment flushing is shown as follows,

Table 2.2.16 Effectiveness of Sediment Flushing

Item	Figure
Maximum flushing discharge	400 m^3/s
Average	200 m^3/s
Total water volume	11,000,000 m^3
Duration of flushing	15.3 hr
Sediment concentration	10,000 ppm
Expected sediment flushing volume	110,000 t

Source: JICA Study Team



Source: JICA Study Team

Figure 2.2.38 Discharge of Flushing Gate

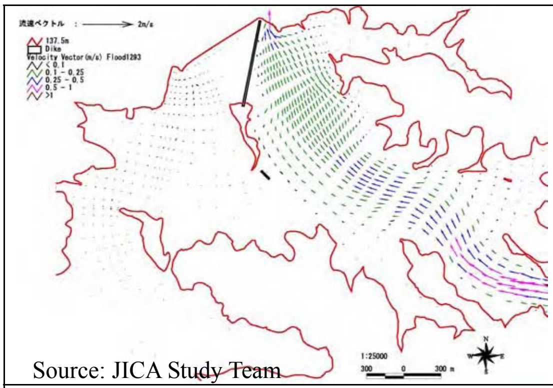
c) Reservoir sedimentation simulation at rainy season.
Applying the operation procedure in the above, a reservoir sedimentation analysis was carried out as summarized below:

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.

Table 2.2.17 Sediment Balance of Sediment Storage Reservoir with New Gates

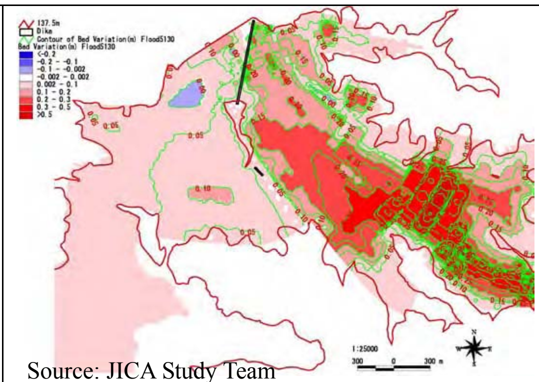
Facility	Unit	Sediment outflow				Sediment Deposit in the Reservoir	Total Sediment Inflow from Keduang
		Intake	Existing spillway	New Gate	Total		
Existing condition	1,000 m^3	394	244	-	638	1,071	1,710
Sediment Storage reservoir	1,000 m^3	100	-	1,280	1,380	330	1,710
(Difference)	1,000 m^3	-294	-244	-1,280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

Source: JICA Study Team



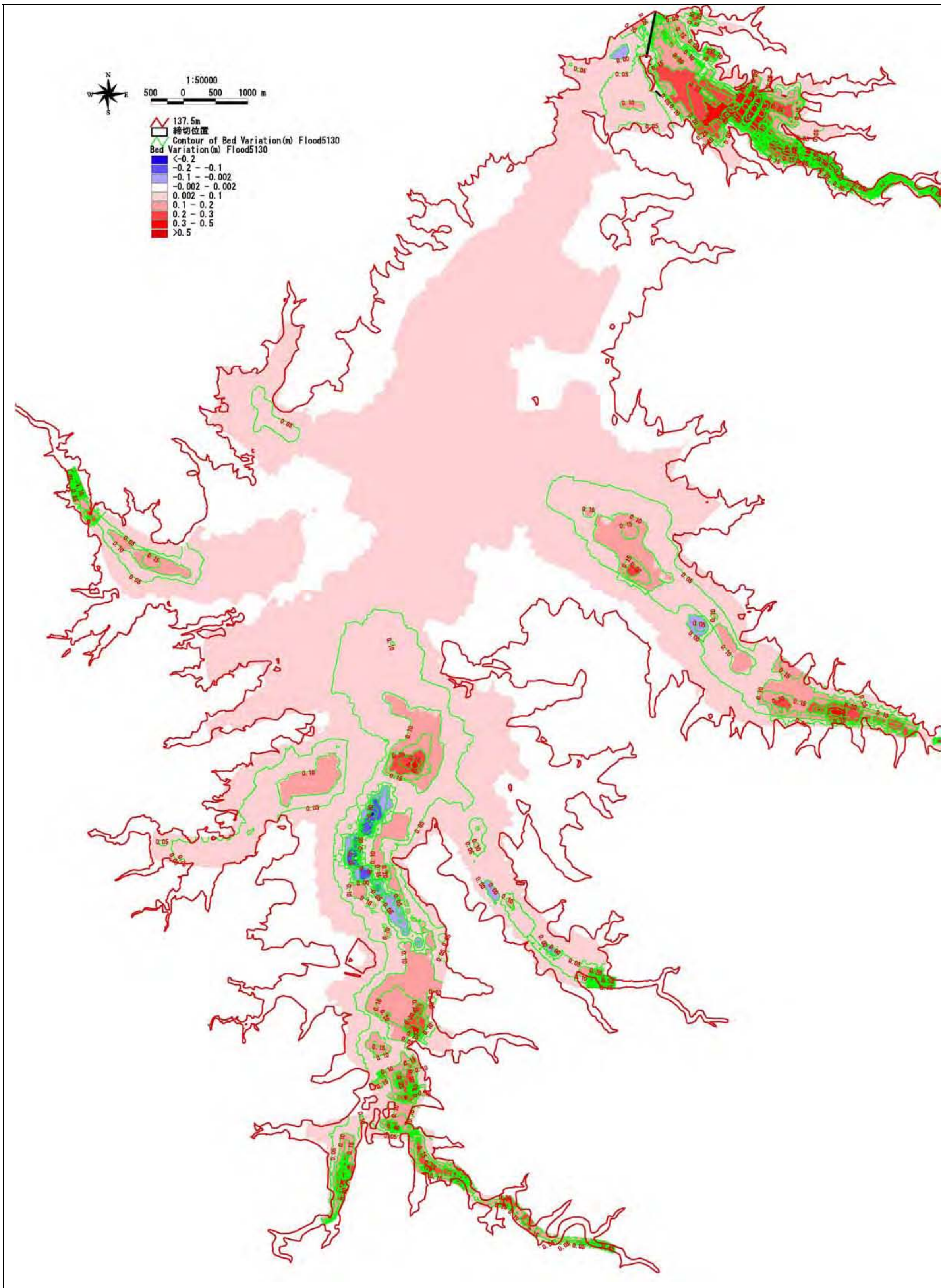
Source: JICA Study Team

Figure 2.2.39 Velocity



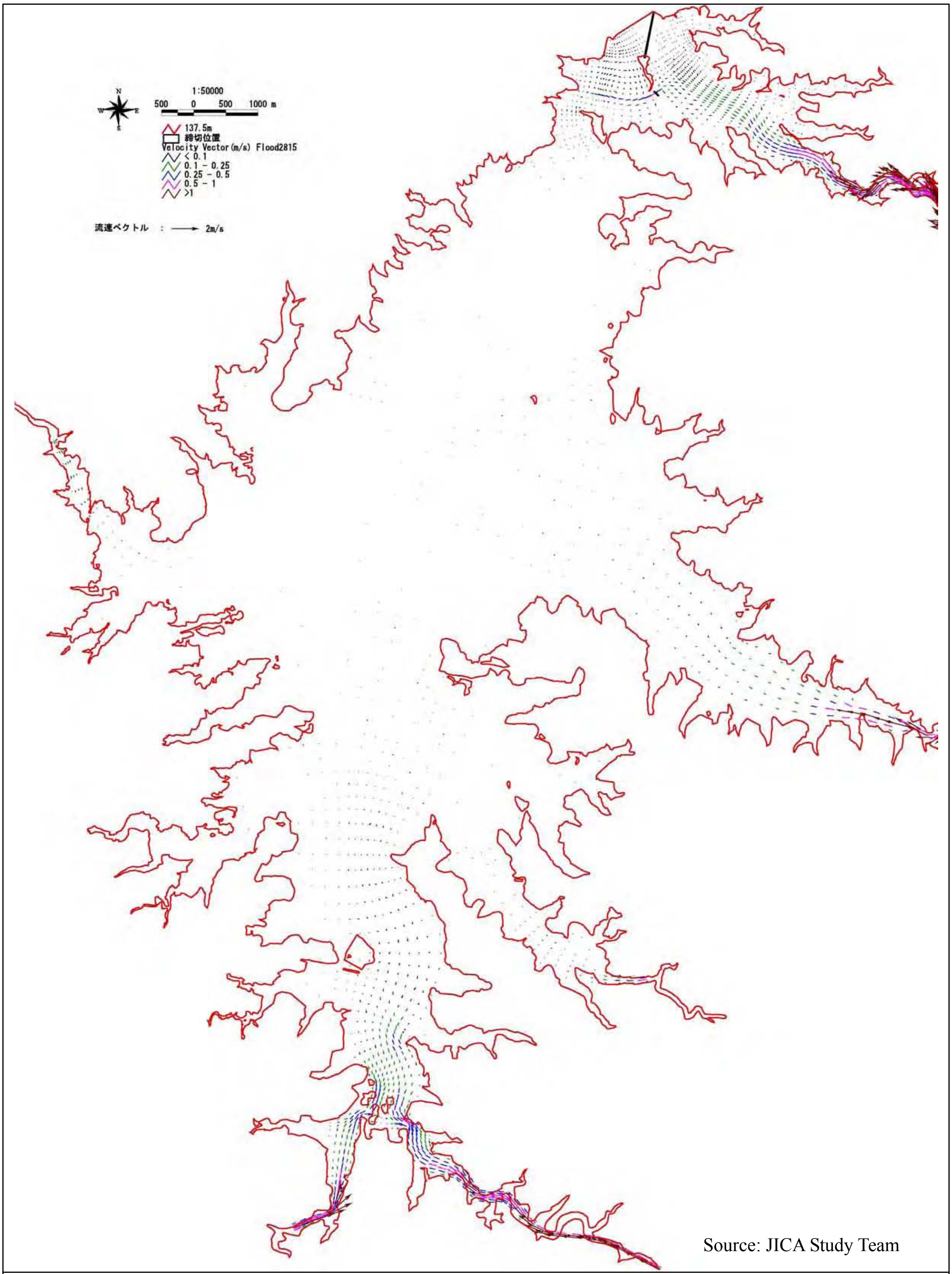
Source: JICA Study Team

Figure 2.2.40 Sedimentation



Source: JICA Study Team

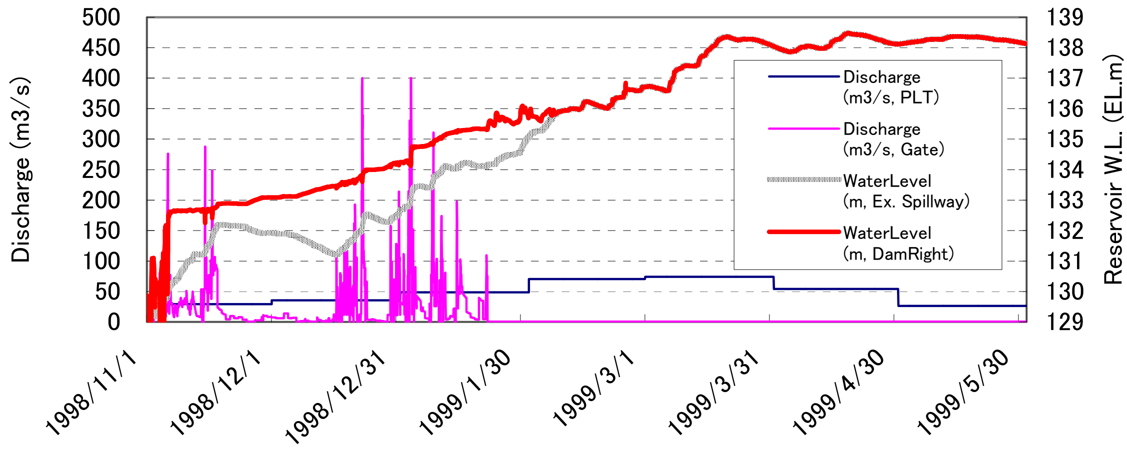
Figure 2.2.41 Sedimentation of Whole Reservoir at Sediment Storage Reservoir with New Gates

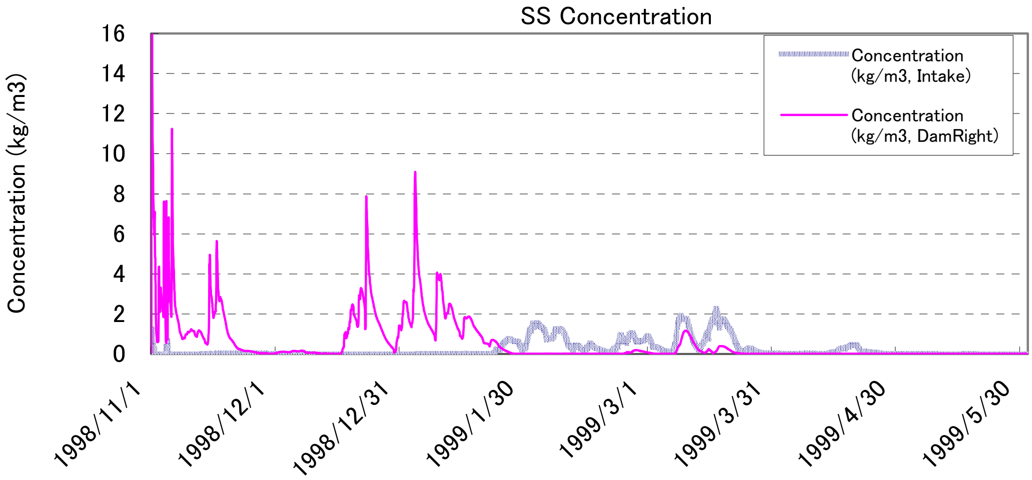


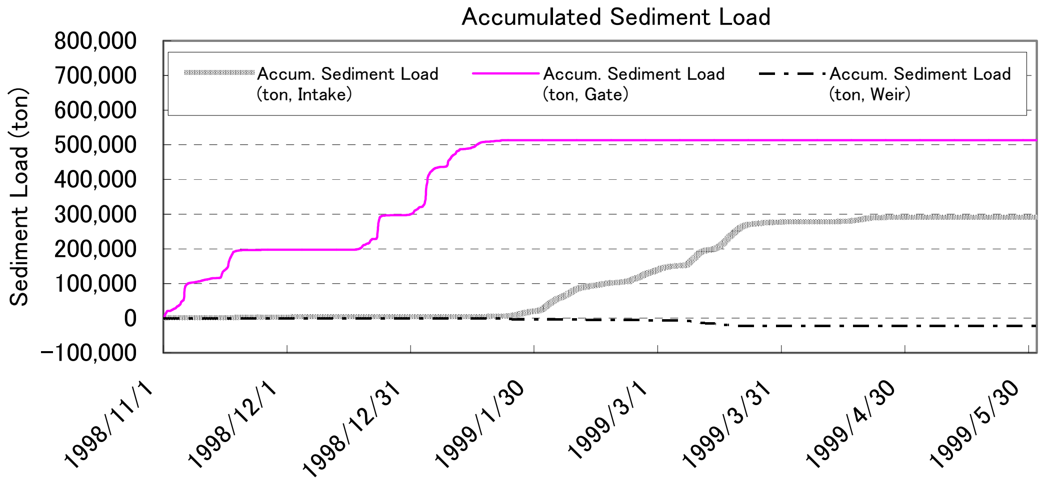
Source: JICA Study Team

Figure 2.2.42 Velocity Vector of Whole Reservoir at Sediment Storage Reservoir

MEASURE Compartmented Reservoir with New Sediment Flushing Gate
HYDRO WET YEAR
DATE 1998/11/01-1999/5/31







Source: JICA Study Team

Figure 2.2.43 Result of Reservoir Sedimentation Analysis
(Case : Sediment Storage Reservoir with New Gates)

(3) Evaluation

1) Environmental Aspect

Most of the facilities can be planned in dam site area and in the reservoir. Therefore few environmental social problems will be occurred. However in operation such as sediment flushing, high concentration sediment flow might be discharged to the downstream river. Check and monitoring will be needed.

2) Effectiveness

a) Construction cost is higher than sediment sluicing method due to installation of closing levee, however this is cheaper about ½ low-price than the bypass method.
b) As sediment flushing is being carried out periodically, reservoir of Keduang is relatively sustainable.
c) Sediment and garbage at and around intake is expected to be diminished due to most of them being trapped in the sediment storage reservoir.
d) Sediment flushing volume is the lowest among countermeasures at normal operation and sedimentation in the Keduang River side is proceed rapidly.
e) However sediment flushing can be done for this method, and sediment flushing volume is expected to be about 100,000m^3 at one time flushing operation using 11 MCM water.
f) From the viewpoint of the river environment, detailed consideration is needed at flushing.

3) Constraints of Construction

Most of the facilities can be planning in dam site area and in the reservoir.

4) Reliability

Sediment flushing function is bolstered by separation. By installation of the closure dike, it make sediment flushing capable without using the stored water in the main reservoir. Sediment flushing can be done by spillway as common manner.

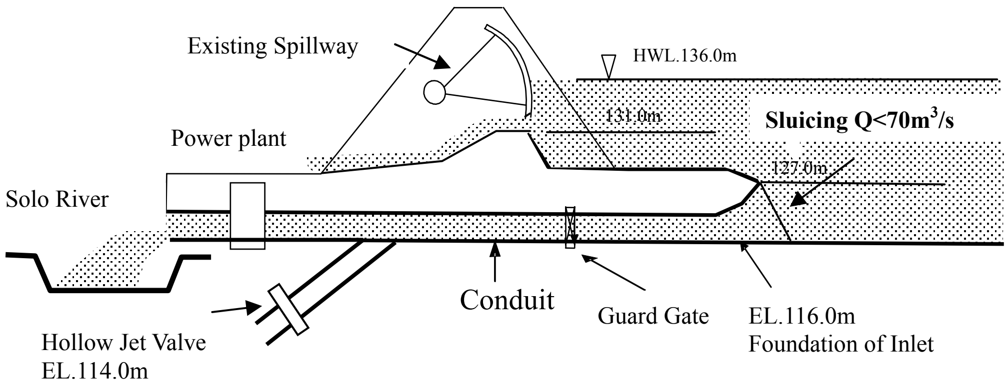
5) Cost

Cost is a little high compared with sediment sluicing. Advantage merits of this method is to conduct sediment flushing without lowering the reservoir water level exclude the Keduang River, where main sediment problem at and around dam is occurred.

2.2.4 Sluicing from Existing Outlet

(1) Features of This Method

There are two existing outlet, one is the intake for irrigation and power generation which maximum discharge is 70 m^3/s, another is a spillway which overflow foundation is set EL.131.0 m and maximum discharge ability is 1,360 m^3/s. This sluicing method is to use mainly Intake at the beginning of rainy season by drawing flood at the maximum ability.



Source: JICA Study Team

Figure 2.2.44 Image of Sediment Flushing by Hollow Jet Valve

(2) Possibility of Application for Wonogiri Dam

1) Applicability

As most of sluicing sediment is wash-load, erosion of the intake tunnel and power generation turbine would not be so serious. As sluicing water flow from the intake is used for power generation and irrigation, most of the discharge is useful. In the Wonogiri dam, the intake is seemed one of prospective sediment sluicing facilities.

However, problem is to be clogged the intake by garbage and subsequent sediment deposit. This situation had been caused occasional suspension of power generation and sediment deposit around Intake. Therefore, necessary condition is to prevent clogging from garbage and sediment.

2) Layout of the Facilities

Any new outlet facility is not need to construct for this method exclude garbage removal system.

Facilities required for this method are as follows,

a) Existing intake (Maximum intake discharge 70 m^3/s)
b) Existing waterway (Tunnel : B5.5m x H5.5m)
b) Existing spillway
c) Garbage prevention facility at the intake
d) Garbage trapping facility at the Keduang River

3) Operation

a) Existing intake for power generation is drawing 70m^3/s and flush out water to the river at flooding from the beginning of rainy season.
b) Existing intake shall be narrow down to be normal operation at the time of total volume of discharge being 200 MCM.

4) Reservoir Sedimentation Simulation at Rainy Season

The result of the sediment balance analysis using this system during '98-'99 rainy season is shown in Table 2.2.18 and Figures 2.2.45 and 2.2.46. Brief description is as follows,

a) Total Sediment out flow volume of this system is 810,500 m^3, which is occupied the 44.6% of total inflow sediment (1,819,000 m^3) from the

Keduang River.

b) Increment outflow sediment volume of this system is 131,400 m^3 compared with those of existing system. Because

c) Sediment deposit volume at and around Intake is reduced from the beginning of operation. This means if garbage covered on the trash rack of Intake which is induced the clogging of intake shall be removed appropriately, most of sedimentation problem will be resolved. And the suspension of power generation causing by clogging would be drastically reduced.

Table 2.2.18 Sediment Balance of Sediment Sluicing from Existing Intake

Facility	Unit	Outflow				Sediment Deposit in the Reservoir	Total Sediment Inflow from Keduang River
		Intake	Existing spillway	New Gate	Total		
Existing system	t	419,700	259,400	-	679,100	1,139,900	1,819.0
Sediment	t	529,600	280,900		810,500	1,008,500	1,819.0
(Difference)		109,900	21,500		131,400	131,400	-
Outflow	MCM	859.0	186.2		1,045	-	-
Average Concentration	Kg/m^3	0.617	1.509		0.775	-	-

Source: JICA Study Team

(3) Evaluation

1) Environmental Aspect

This method is to use maximum intake volume to slue sediment from existing Intake. and this method is to use existing discharge facilities such as Intake and spillway, only need to have garbage removal system. Therefore few environmental problems would be occurred.

2) Effectiveness

a) Sediment concentration indicates about 1.3 to 2.5 times figure compared with other system as the result of reservoir sedimentation simulation. However as it is only 617 ppm on average, no harmful affection is deemed given to the power generation.

b) However this method is totally depended on garbage removal reliability. At the time of flooding, garbage monitoring and removal system is indispensable.

c) As a whole, this method is seemed to be useful countermeasure. However reliability of this system is inferior to other system,

3) Constraints of Construction

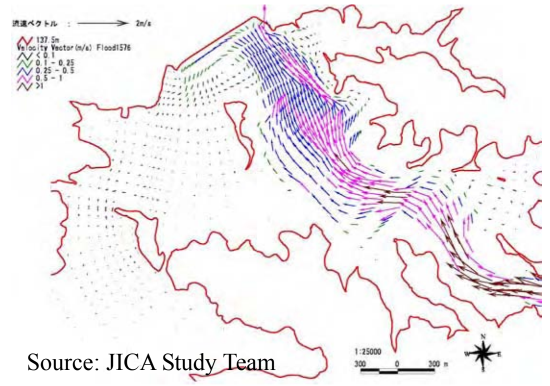
No facilities are needed for this method except garbage removal system.

4) Reliability

Most of the function of this method is depend on conditions that is never occurred the intake clogging. However in Wonogiri dam clogging of intake is often occurred due to garbage. Therefore reliability of this method is low. Garbage removal system at and around the intake and monitoring at flood are indispensable.

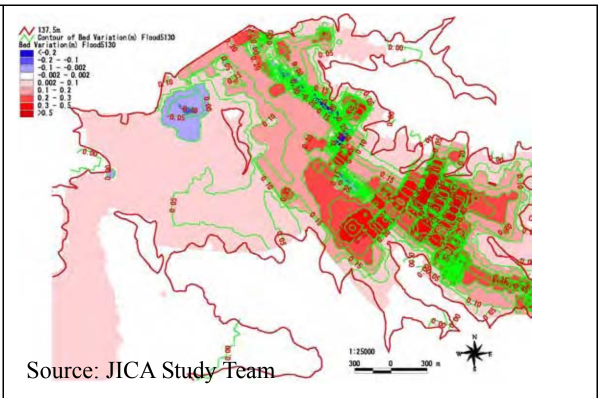
5) Cost

O/M cost for garbage removal at and around intake is required.



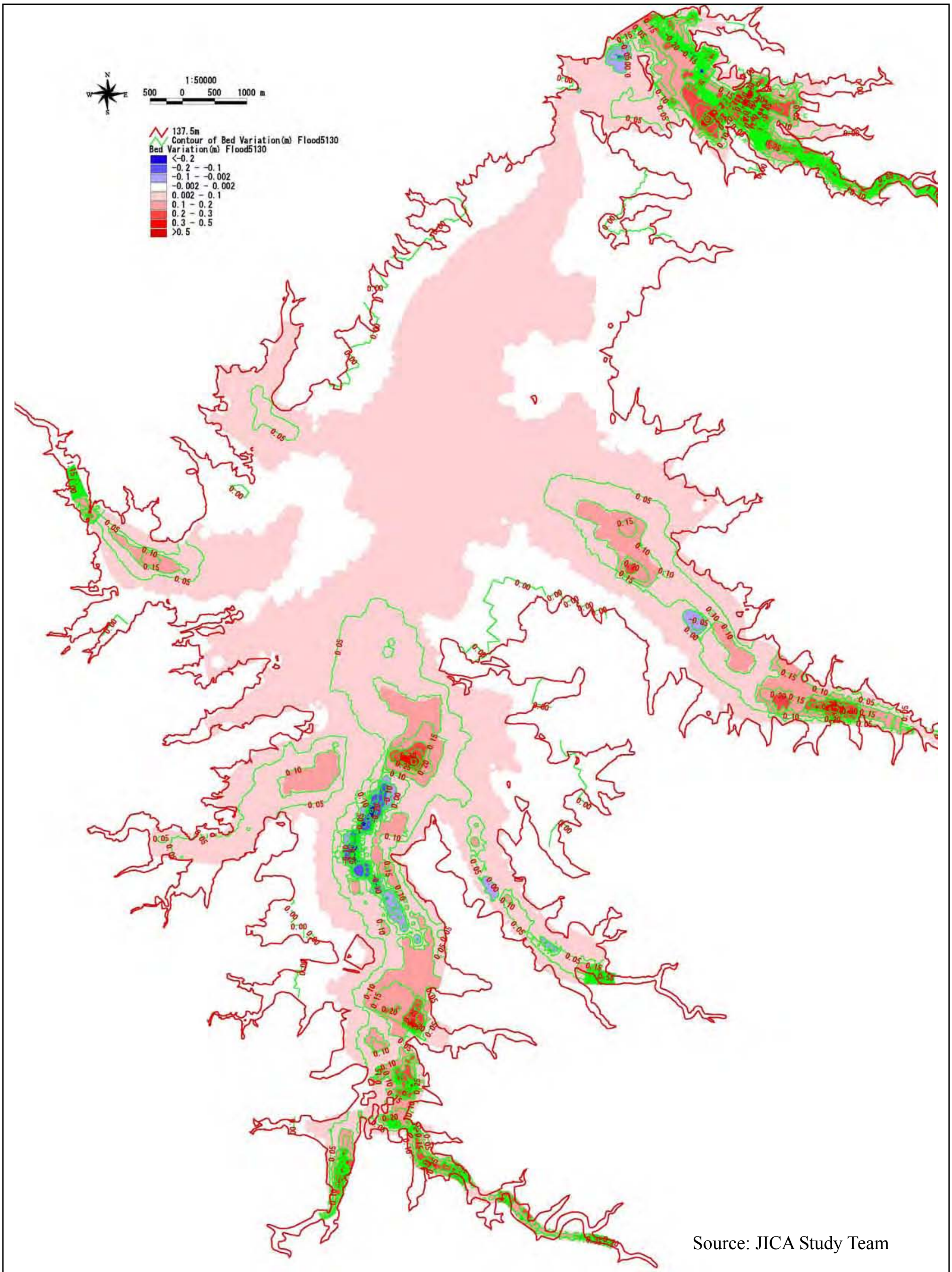
Source: JICA Study Team

Figure 2.2.45 Velocity



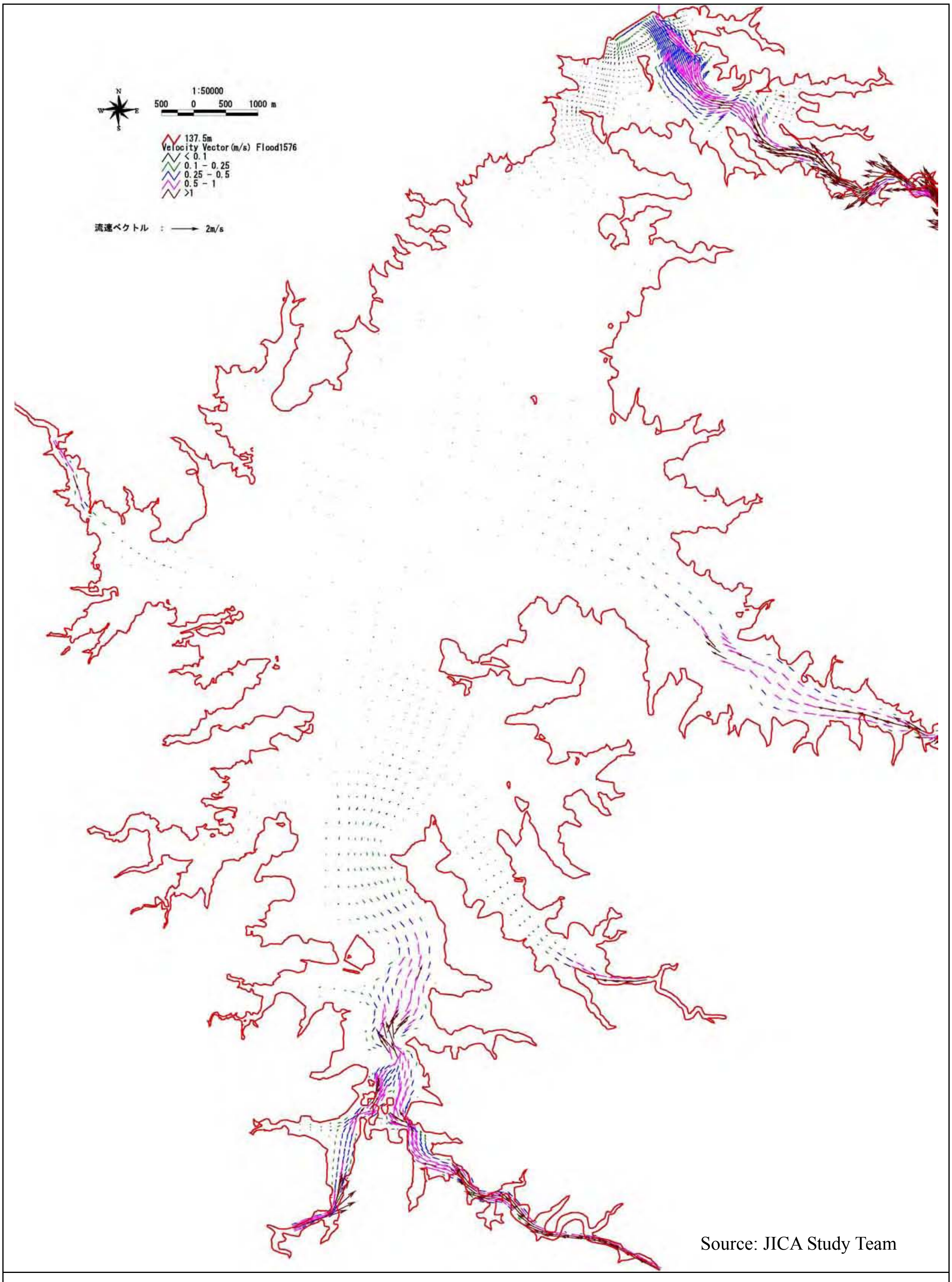
Source: JICA Study Team

Figure 2.2.46 Sedimentation



Source: JICA Study Team

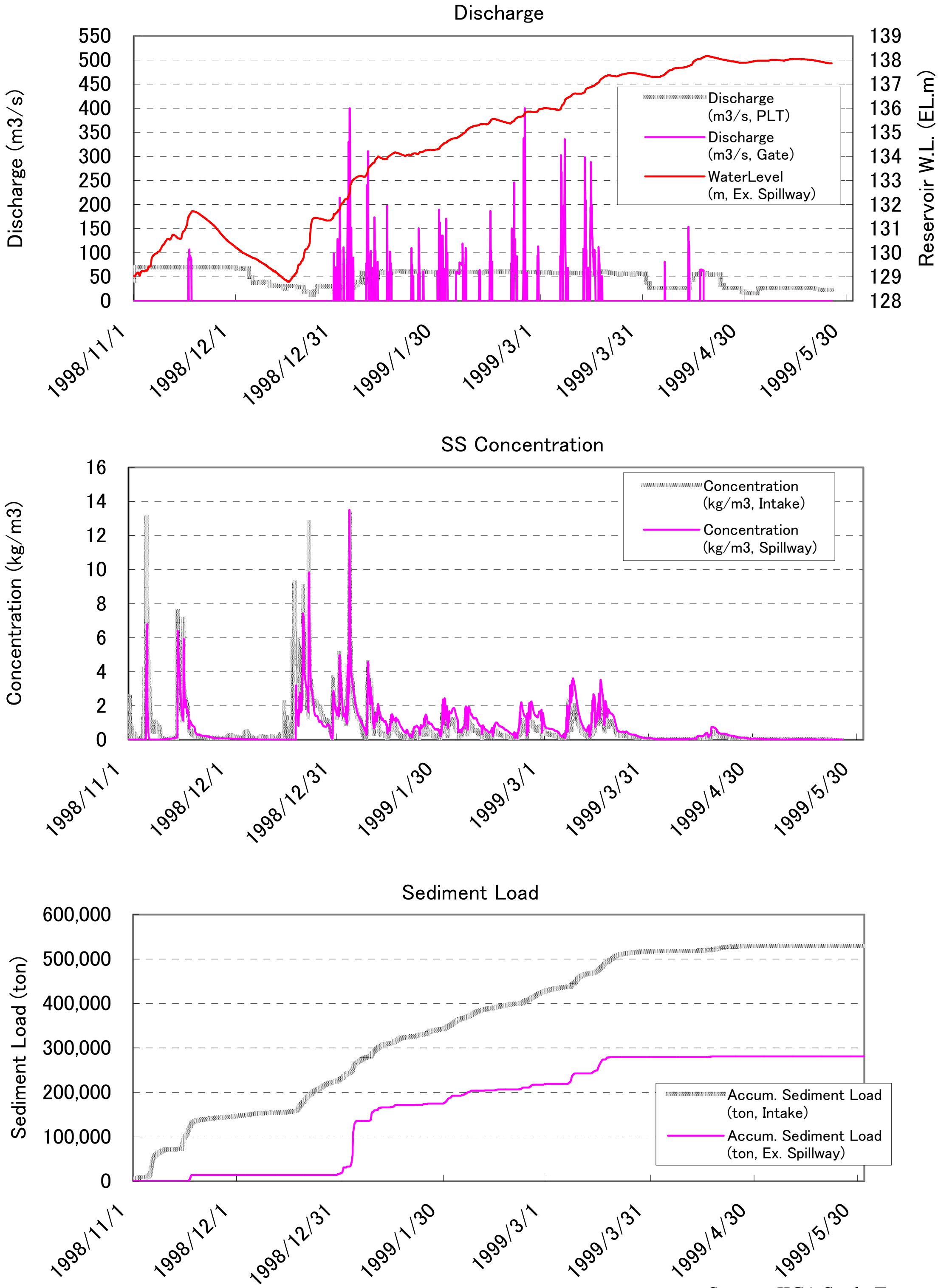
Figure 2.2.47 Sedimentation of Whole Reservoir at Sediment Sluicing from Existing Intake



Source: JICA Study Team

Figure 2.2.48 Velocity Vector of Whole Reservoir at Sediment Sluicing from Existing Intake

MEASURE Sluicing from Existing Intake
HYDRO WET YEAR
DATE 1998/11/01-1999/5/31



Source: JICA Study Team

Figure 2.2.49 Result of Reservoir Sedimentation Analysis

(Case : Sediment Sluicing from Existing Intake)

2.2.5 Sediment Storage Dam

(1) Features of Sediment Storage Dam

Sediment storage dam is common countermeasure against sedimentation in dam reservoir. Sediment storage dam is planned at the upstream of reservoir to deposit the inflow sediment and to remove it by excavation. By planning sediment storage dam on the Keduang River, conveyance works of sediment deposited in the sediment storage dam reservoir shall be able to carry out in dry circumstance excluding a period of flood. Sediment conveyed from there would be effectively utilized for aggregate of concrete. At flood, inflow sediment would be classified by grain size, relatively coarse sediment is deposited in the sediment storage dam and fine sediment flow into dam reservoir. This method will be promising countermeasure by excavation of deposited sediment for reiterate use.

(2) Possibility of Application

1) Applicability

In case of target sediment is wash-load, sediment storage dam is not so useful. Accordingly, this method shall not be adopted for the sedimentation countermeasures in Wonogiri dam.

2) Layout of the Facilities

Lay out of the sediment storage dam in the Keduang River is shown in Figure 2.2.50.

Facility of the Keduang sediment storage dam is shown in Table 2.2.19

Table 2.2.19 Dimension of Sediment Storage Dam in Keduang River

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

Source: JICA Study Team

3) Operation

Periodical sediment removal work is needed.

If target sediment volume of 100 MCM is expected, about 42 times sediment removal work is required.

(3) Evaluation

1) Environmental Aspect

Sediment storage dam is planned in uppermost reservoir, therefore few social environmental consideration would be occurred. And As elevation of sabo dam crest is set same with dam control water level EL.135.3 m, environmental segmentation at upstream and downstream of the Keduang River. However many of sediment disposal land is needed which will be induce environmental problems.

2) Effectiveness

a) Storage capacity is 24,000 m^3 at EL.135.3 m which is under 1/40 of sediment inflow from the Keduang River. This means that excavation and conveyance of deposited sediment is needed to carry out 40 times per years.

b) As most of the sediment is expected to be wash-load, sediment trapping ratio would be small.

3) Constraints of Construction

Foundation work should be dry season.

4) Reliability

Function of wash-load trapping is small.

5) Cost

O/M cost would be expensive due to excavation work to restore dam capacity.

From these points of view, sediment storage dam in the Keduang River is not a promising option as the sedimentation countermeasure due to small capacity and wash-load. If sediment storage dam is utilized for garbage trapping, it will be useful option to reduce garbage at and around Intake. Periodical garbage removal work is needed.

(4) Sediment Storage Dam Alternative

1) Outline of Countermeasure

In reservoir of the Keduang River side, two sediment storage dam would be planned and connect these two reservoirs. At downstream reservoir, flushing channel connect to the Solo River. By these sediment storage dam, sediment inflow from the Keduang River is expected to be extremely reduced. Consequently, sedimentation at and around intake facility is expected to be reduced.

Figure 2.2.50 shows the arrangement of sediment storage dams and facilities concerned. In upstream storage dam, sediment inflows from the Keduang River is trapped at once, and then flows into downstream reservoir. When storage dam reservoir is filled with sediment, sediment flushing is carried out to restore capacity of reservoir without lowering dam water level. Figure 2.2.51 shows the sediment flushing system of sediment storage dam.

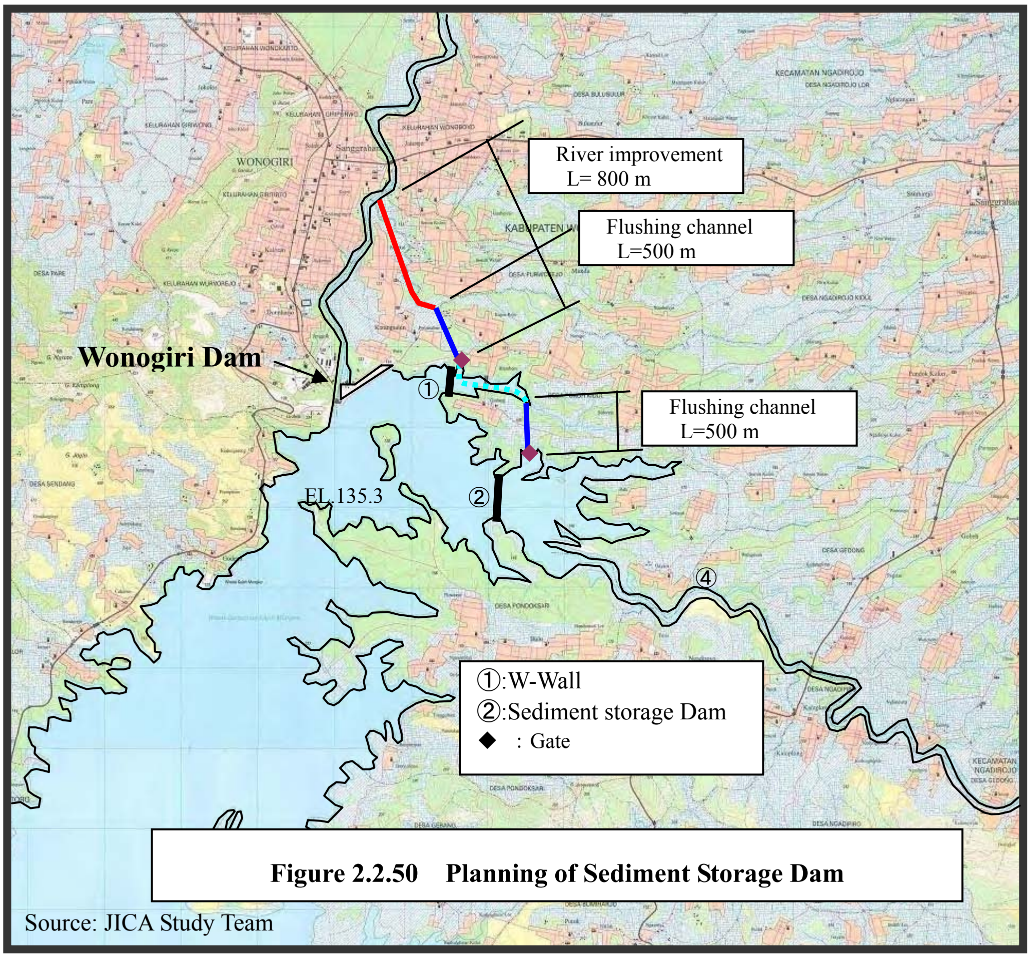
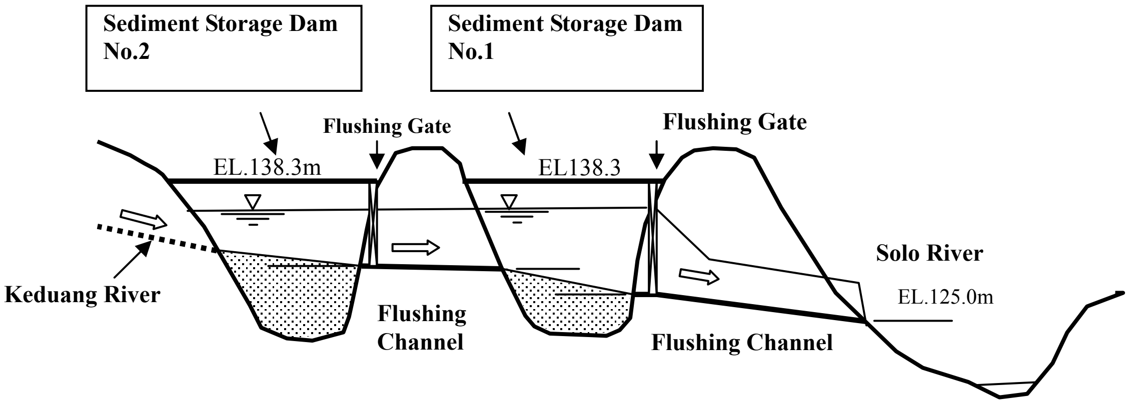


Figure 2.2.50 Planning of Sediment Storage Dam

Source: JICA Study Team



Source: JICA Study Team

Figure 2.2.51 Longitudinal Profile of Sediment Storage Dam

Merit

1. As most of facilities of this method would be arranged in reservoir or near reservoir, land acquisition and transfer of local people might be small .
2. Being connected the two sediment storage reservoirs and the Solo River with channel and those reservoir separated with dam, sediment flushing could be carried out without lowering the dam water level. Therefore with periodically sediment flushing, capacity of sediment storage dam reservoir can be restored semi-permanently.
3. As Sediment storage dams are constructed in the dam reservoir and flushing

channel would be shorten compared with other bypassing method, and environmental consideration problems such as transfer and land acquisition are expected to be reduced.

4. As water level of sediment storage dam reservoir could be kept at same water level with those of dam reservoir, back water to the Keduang River should not be generated. Therefore almost no consideration for flooding should be paid on the Keduang River

Demerits

1. Sediment flushing can be carried out only during rainy season. And as massive sediment flow down to the Solo River, impact against river environmental should be considered to be reduced.

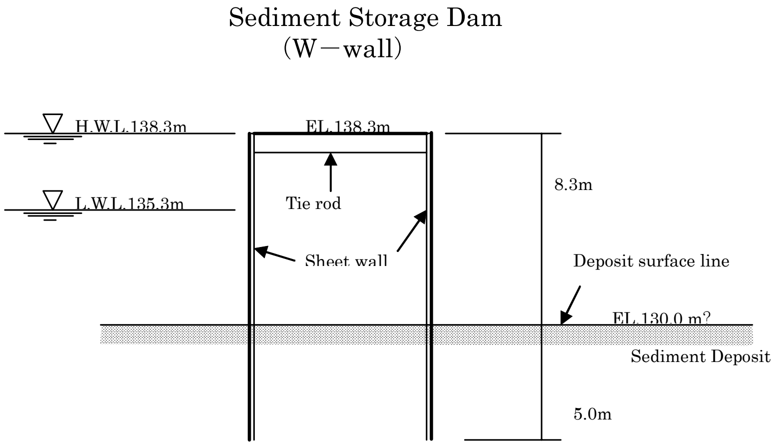
2) facility planning

Facility planning of sediment storage dam method is shown in Table 2.2.20

Table 2.2.20 Facility Plan

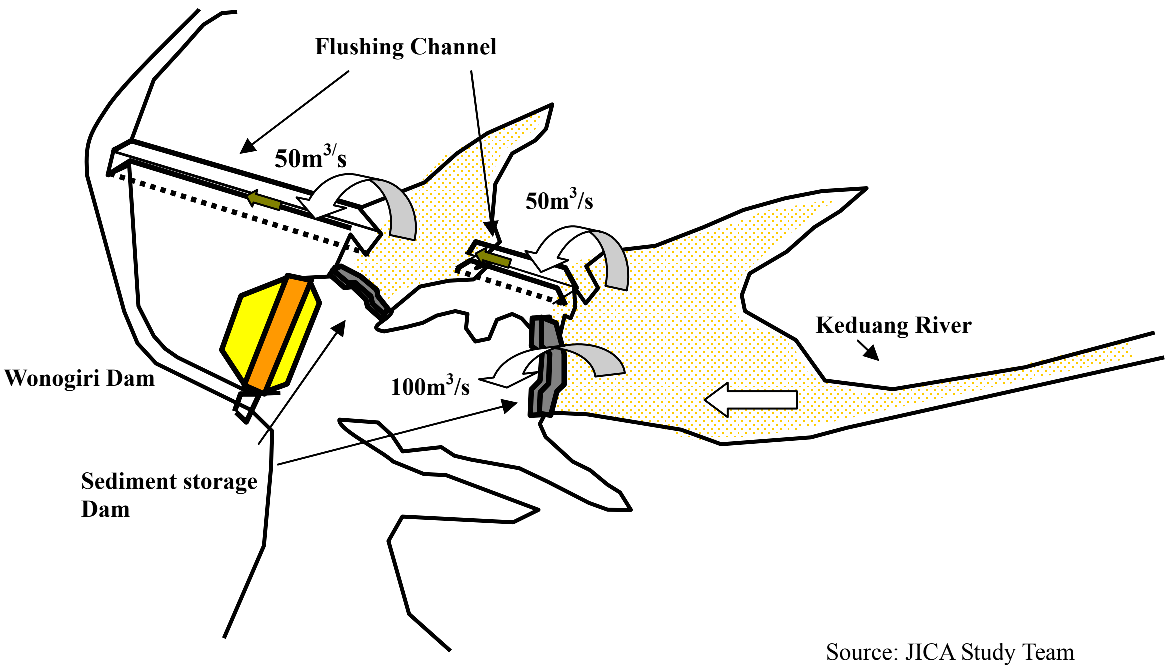
Structure	Dimension
Sediment storage dam	
No.1 sediment storage dam	Length L= 250 m, Crest height=EL.138.3 m Type of structure : Sheet pile W-wall
No.2 sediment storage dam	Length L= 500 m, Crest height=EL.138.3 m Type of structure : Sheet pile W-wall
Flushing channel	Connect two sediment storage. Design flood Q=200 m^3/s Length L=500 m Gradient of channel I=1/500 Gate : radial gate Foundation height :EL.131.0 m B 5.0 × h 7.3 m×2 Nos
Flushing channel	Connect No.1 sediment storage reservoir and Solo River Design flood Q = 200 m^3/s Length L = 600 m Gradient of channel I = 1/300 Gate : radial gate Foundation height :EL.127.0 m B 5.0 × h 11.3 m×2
River improvement	Design flood Q = 200 m^3/s Length L = 1,500 m Gradient I = 1/100
Others	Spillway of NO.1 and NO.2 sediment storage dam,

Source: JICA Study Team



Source: JICA Study Team

Figure 2.5.52 Typical Cross Section of Sediment Storage Dam



Source: JICA Study Team

Figure 2.2.53 Sediment Storage Dam System

2.2.6 Dry Excavation

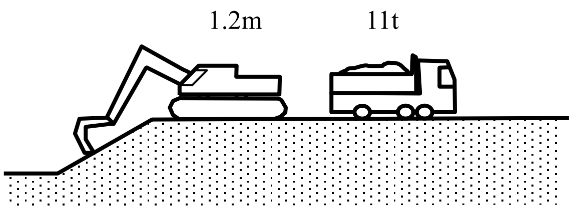
(1) Features

In dry season, as water level were keeping on low elevation and sediment deposited at river mouth appear on water level in the reservoir, dry excavation is carried out with back hoe or crawler-mounted bulldozer for swamp and convey those by truck to spoil bank. This method is the most common countermeasure and the cheapest way to remove sediment in the reservoir.

(2) Provability of Application for Wonogiri Dam

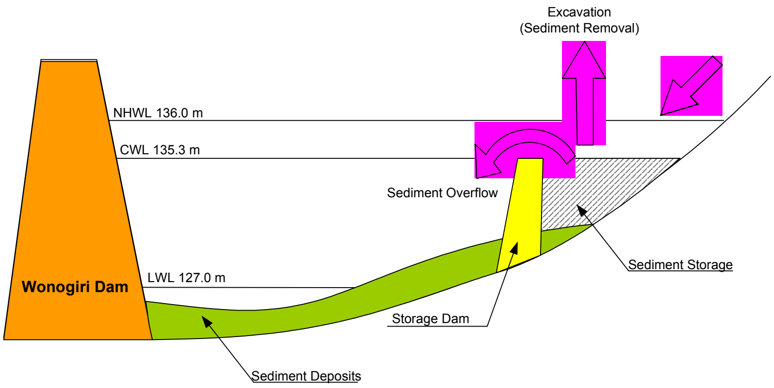
1) Applicability

However it is almost unrealistic to cope with of sediment volume 20,000 m^3/da by sole dry excavation. This method is recommended to be used supplementary in collaboration with other countermeasures, especially at the river mouth on each tributaries. Sediment trapping dam are constructed at each river mouth to prevent sediment flow into the deep potion of dam.



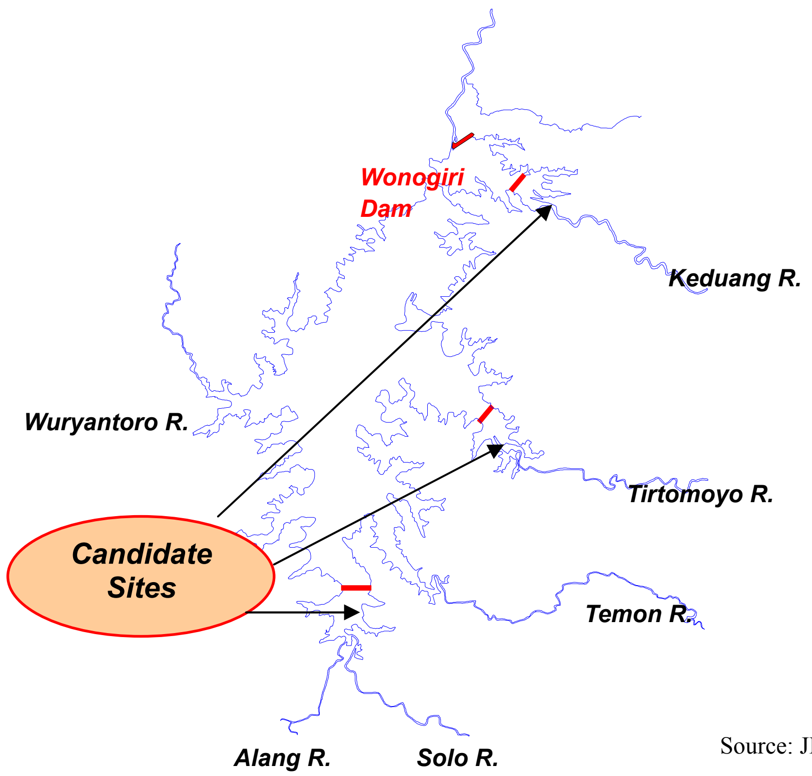
2) Layout of the Facility

Layout of the dry excavation areas are shown in Figure 2.2.55.



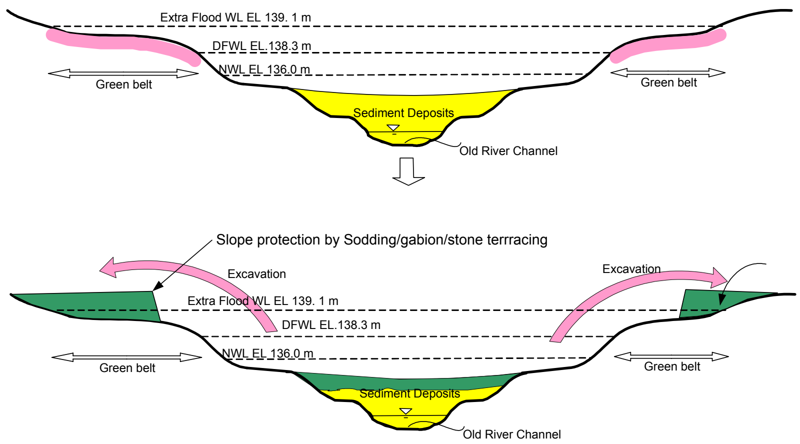
Source: JICA Study Team

Figure 2.2.54 Profile of Sediment Trapping Dam



Source: JICA Study Team

Figure 2.2.55 Layout of the Dry Excavation Areas



Source: JICA Study Team

Figure 2.2.56 Illustration of Periodic Excavation of Sediment Trapping Dam

2.2.7 Hydraulic Dredging

(1) Features of the Hydraulic Dredging

This method is to remove the sediment deposited in the dam reservoir by hydraulic dredging. This is the most common countermeasure to remove sediment in the existing reservoir. Hydraulic dredging had been experienced at Wonogiri dam to remove the sediment at and around the intake. This method is very reliable, however it is very difficult to secure huge spoil bank to dispose sediment.

Table 2.2.21 shows the estimated required work to dispose the sediment at whole reservoir and the Keduang River by dredging. As the result of the consideration, 5 dredger at the Keduang River area and 15 dredger at whole reservoir area are needed to dispose the entire inflow sediment. To realize this method, large spoil bank and huge running costs are required. Both are almost difficult to accommodate the requirement for dredging work. As conclusion, dredging work is considered to be difficult to adopt as solo countermeasure. However this method is useful and in collaboration with other countermeasures as supplemental work.

Table 2.2.21 Dredging Work and Cost

Location	Unit	Whole Reservoir	Keduang River
Sediment inflow	m^3	3.0 million	1.0 million
Dredging volume/	m^3/month m^3/day	500,000 20,000	167,000 6,680
Dredger productivity	m^3/month m^3/day	39,990 1,333	39,990 1,333
Needed dredger	Unit	15	5
Running cost per year	Rp	71.7 billion	23.9 billion

* unit cost for dredging is Rp 23,900 from existing data.

Source: JICA Study Team

1) Sediment Inflow

Estimated inflow sediment volume are as follows roughly,

Table 2.2.22 Estimated Sediment Volume

Location	Sediment inflow per year
Whole dam reservoir	3.0 million m^3
Keduang River	1.0 million m^3

Source: JICA Study Team

2) Dredging Volume

Average working month is 6 months on rainy season.

Dredging volume per month

Whole reservoir 3,000,000÷6 month = 500,000 m^3/month
Keduang reservoir 1,000,000÷ 6 month = 167,000 m^3/month

Dredging volume per day

Average working day per month is 25 days, thus, dredging volume is
Whole reservoir 500,000 m^3/month ÷25 = 20,000 m^3/day
Keduang River 167,000 m^3/month ÷25 = 6,680 m^3/day

3) Needed Dredger

Dredging ability of a dredger is about 1,333 m^3/day (24 hours working) from the previous records.

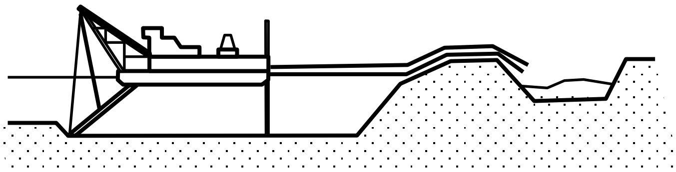
The number of dredger

Whole reservoir 20,000 m^3/day÷1,333 m^3/day = 15.0 units
Keduang River 6,680 m^3/day÷1,333 m^3/day = 5.0 units

4) Cost of dredging

Unit cost of dredging is about 23,900 Rp/m^3 from existing example.

Total cost of Dredging at Keduang River = 23,900 Rp/m^3 x 3.00million m^3
= 71.7 billion Rp/m^3
Total cost of Dredging at Keduang River = 23,900Rp/m^3 x 1.00million m^3
= 23.9 billion Rp/m^3



(2) Possibility of Application

This method is required huge sediment disposal land. In current situation it seemed difficult to acquire the land. However it is possible to dispose sediment to the downstream of the dam, this method can be used.

(3) Evaluation

1) Environmental aspect

Disposal land acquired for this method might be induce the environmental problems.

2) Effectiveness

Target sediment volume is so huge that it is difficult to adopt this method. However at and around intake, it is promising method to remove sediment and garage. Feasible sediment volume will be 200,000m^3/years per 1 units.

3) Constraints of Construction

none

4) Reliability

Hydraulic dredging is the most common method to remove sediment from reservoir. Therefore reliability of this method is very high.

5) Cost

O/M cost is required.

2.2.8 Dam Heightening

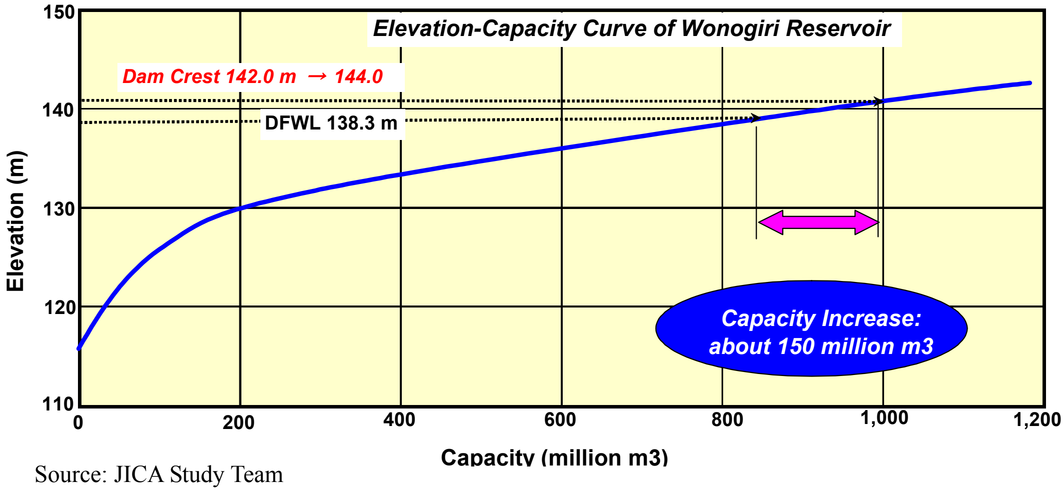
This counter measure is to raise the dam crest to secure the effective storage capacity. As rate of incremental storage capacity is huge at high portion of reservoir, efficiency for securing capacity become large.

However dam heightening can not be applied for every dam. It depends on factors such as geographical and geological conditions, safety of dam structure, affected area by back water, affection for environment. Most auxiliary structure should be renewed. Therefore same level of consideration with new dam shall be required to plan. The extent of dam heightening to secure needed capacity is estimated to be only 2 m. If 1 m heightening is made, about 75 million m^3 of capacity is increased, 2 m will be more than 150million m^3.

Figure 2.2.57 shows the elevation-capacity curve of the Wonogiri reservoir.

However there are many properties such as houses and fields around the reservoir. Dam heightening has possibility to affect huge area and local people. If impact to the social and natural environment is estimated to be low, this method should be recommended. If this method is taken, transfer and compensation for removal of local people should be inevitable. This situation might bring out the social problem. Table 2.2.23shows the land area and living area around the reservoir.

If dam is heightened up to 142.0 m, 121.2 km^2 land area and 765 ha living area would be affected. Therefore this method should be adopted as final option.



Source: JICA Study Team

Figure 2.5.57 Elevation-Capacity Curve of Wonogiri Reservoir

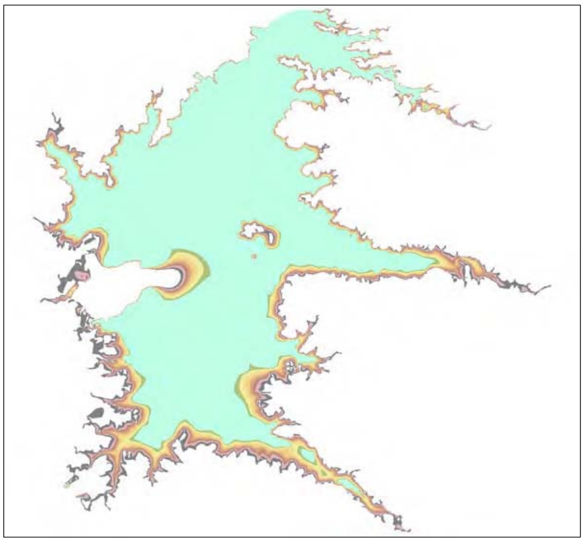
Table 2.2.23 Affected Living Area by Dam Heightening

Elevation	Area (km^2)		Increase capacity Volume
	A km^2	ΔA	(million m^3)
- 142m	121.2		930
- 143m	125.9	4.6	1,056
- 144m	130.2	4.3	1,186
- 145m	134.6	4.4	1,321
- 146m	139.3	4.7	1,460
- 147m	144.5	5.2	1,604
- 148m	150.3	5.8	1,755
- 149m	157.4	7.1	1,912
- 150m	170.4	13.0	2,083
151m -	1,332.9	1,162.5	

Source: JICA Study Team

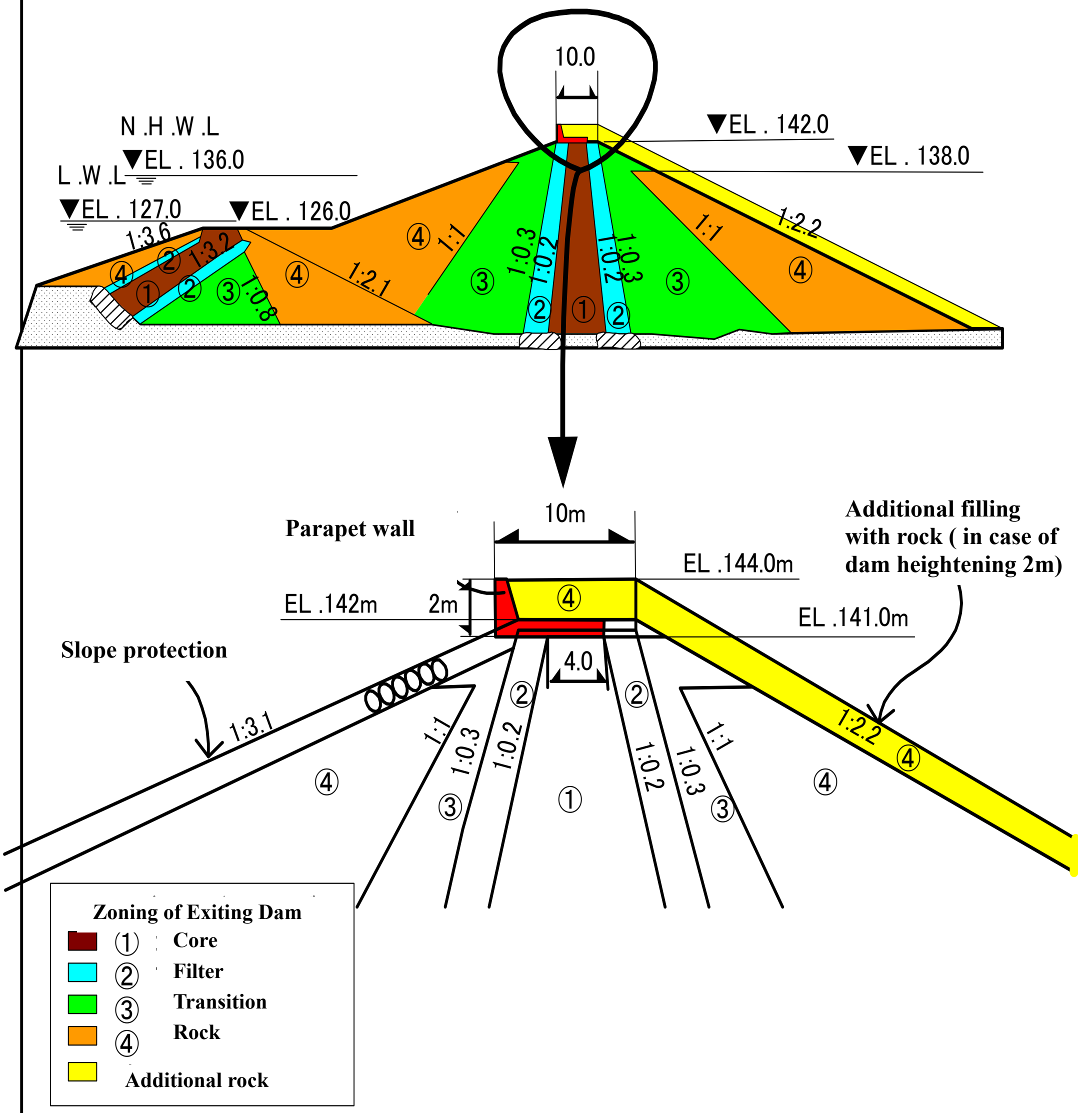
ELVATION(m)	LIVING AREA (ha)
- 142 m	765
142 - 143 m	103
143 - 144 m	108
144 - 145 m	119
145 - 146 m	133
146 - 147 m	162
147 - 148 m	176
148 - 149 m	210
149 - 150 m	376
150 m -	25,040

Source: JICA Study Team



*0.25ha of residential compound area per farm househould
*0.53ha of dry field area per farm househould

Figure 2.2.58 Inundation Area Due to the Dam Heightening

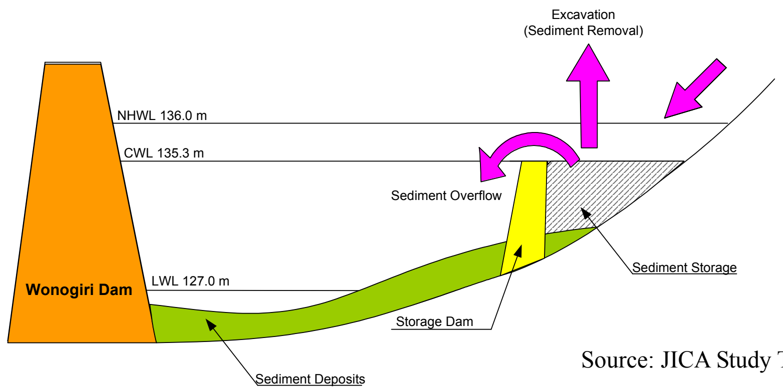


Source: JICA Study Team

Figure 2.2.59 Typical Cross Section of Dam Heightening

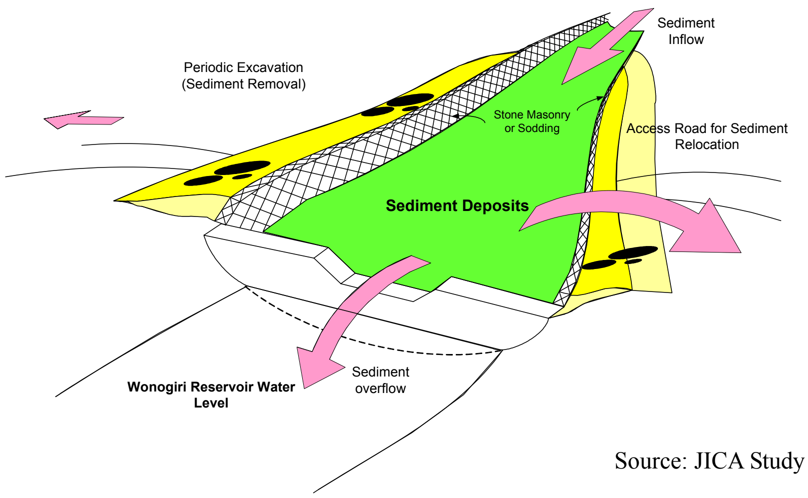
2.2.9 Sediment Trapping Dam (Periodic Excavation Dam)

Sediment trapping dam are constructed at each river mouth to prevent sediment flow into the deep potion of dam. Sediment in the dam will excavate by backhoe or crawler-mounted bulldozer for swamp and truck and covey to the spoil bank by truck.



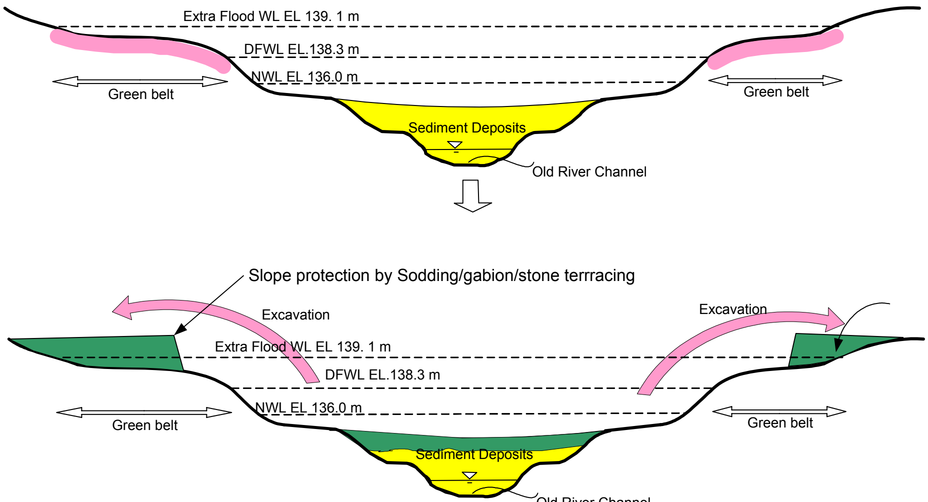
Source: JICA Study Team

Figure 2.2.60 Profile of Sand Trapping Dam



Source: JICA Study Team

Figure 2.2.61 Illustration of Periodic Excavation of Sediment Trapping Dam (1/2)



Source: JICA Study Team

Figure 2.2.62 llustration of Periodic Excavation of Sediment Trapping Dam (2/2)

2.2.10 Modification of Reservoir Operation Rule

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.

(1) Review of Freeboard of the Dam

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 Table2.2.63 below:

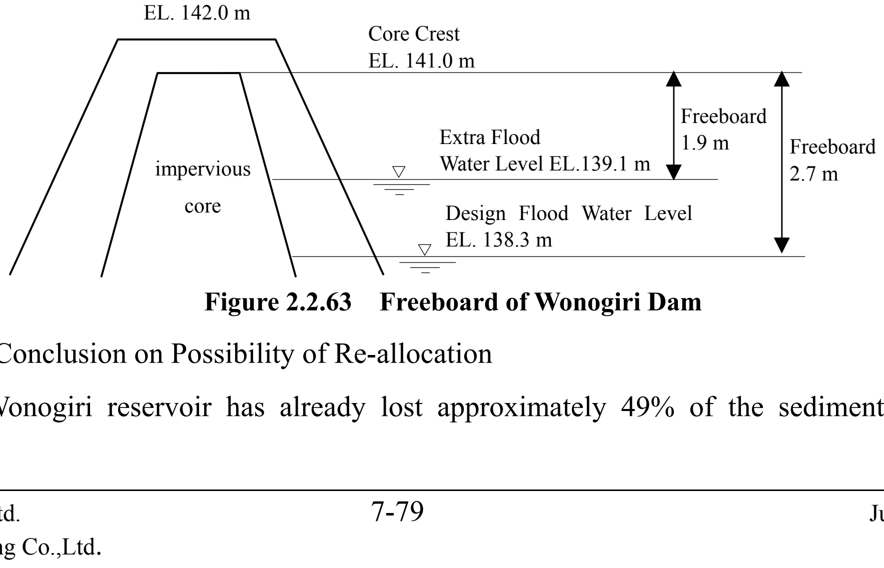


Figure 2.2.63 Freeboard of Wonogiri Dam

(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.

2.3 Alternatives to Keep Proper Function of Intake

2.3.1 Modification of Existing Intake

(1) Features of this Method

Objective of this method is to avoid the intake from being buried by sedimentation, and to raise the inlet foundation height and prevent garbage from entering the inlet. To solve these problems, modification of existing Intake is considered, which is connecting existing intake. Foundation height of existing inlet is set at EL.116.0 m, which is 11.0 m lower than design sediment deposit level. This situation might have been induced sedimentation in front of intake. Therefore Intake Tower having selective intake is considered to be laid out on existing intake.

(2) Provability of Application for Wonogiri Dam

1) Applicability

This method is to connect intake tower and existing intake. Supply of water for irrigation and power plant should be suspended during construction. As foundation works need dry condition, water level shall be lowered during construction. Strong load bearing capacity of foundation is need to support superstructure. Judging from these situation, it is deemed difficult to adopt this method.

2) Layout of the Facilities

Layout of the facility is the front of the existing intake. The layout of the intake tower is shown in Figure 2.3.1. Components of this method are intake tower with gate and screen. Facility plan are shown in Table 2.3.1.

Table 2.3.1 Facility Plan

Intake Tower	Dimension
Height	H=26.0m
Gates	H5.0m×B12.6m×2
Foundation height of inlet	El.127.0m
Screen	H14.0m×B12.6m

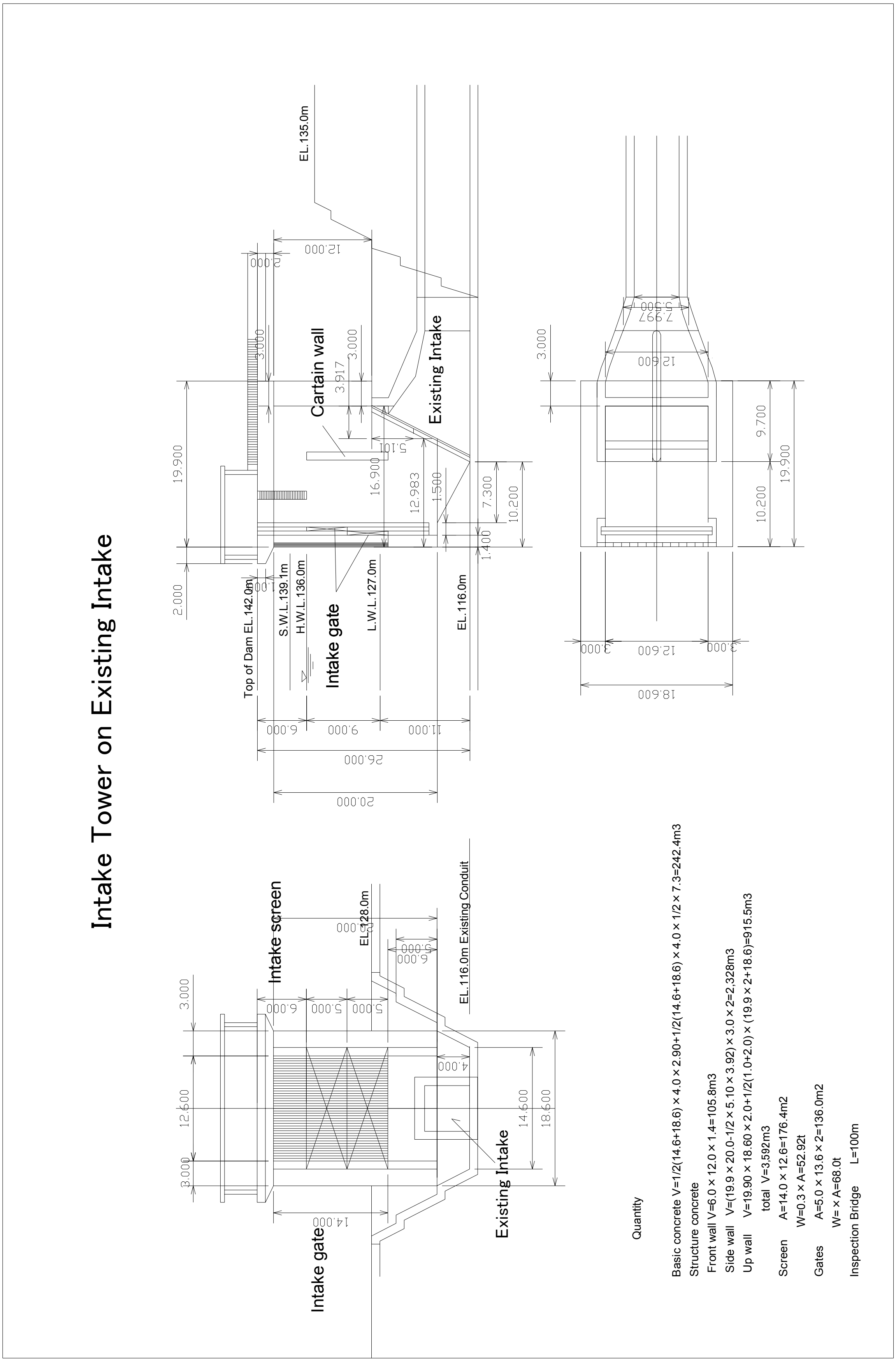
Source: JICA Study Team

3) Operation

- Usually gate is fully opened.
- At the time sediment deposit level to be more than EL.127.0m, the gate shall be adjusted on deposit level to prevent sediment from inflowing into the intake tower.

(3) Evaluation

- Water supply should be suspended during construction.
- No contribution to the dam life lengthening due to reducing sediment sluicing function of existing intake.
- A number of clogging intake by garbage is expected to be reduced considerably.
- Sedimentation would be accelerated due to the 11.0 m heightening of the inlet foundation.



Source: JICA Study Team

Figure 2.3.1 Modification of Existing Intake

2.3.2 Relocation of Intake

(1) Feature of this Method

To prevent the intake inlet from burying by sediment, relocation of the intake to the location where sedimentation is expected to be less than existing intake location, is considered. Type of the intake shall be intake tower having selective intake gates. At the front of the inlet, trash rack should be provided. Transmission pipe is laid down to connect existing conduit.

(2) Provability of Application for Wonogiri Dam

1) Applicability

According to the site reconnaissance and simulation of sediment deposit, there are no promising places near the dam where sedimentation can be avoided. Most expecting location among them is the about 300 m front of left bank from dam

2) Layout of the Facility

Layout of the facility is shown in Figures 2.3.2 and 2.3.3. Facility plan is shown in Table 2.3.2.

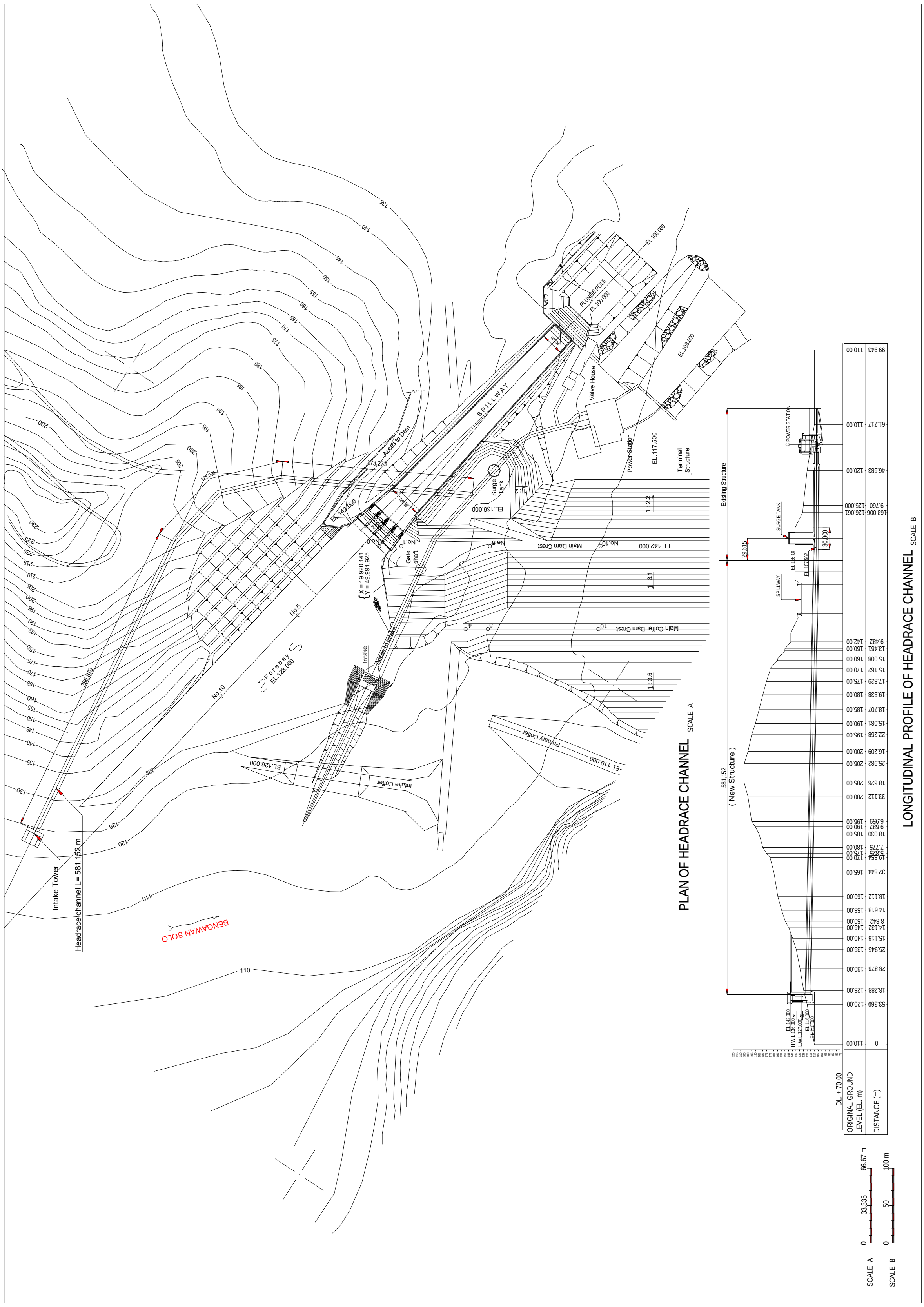
Table 2.3.2 Facility Plan

Intake Tower	Dimension
Height	H=32.0m
Gates	H5.0m x B10.0m×2
Foundation height of Inlet	EL.127.0m
Transmission Tunnel	
Diameter	D=5.5m
Length	L=570m

Source: JICA Study Team

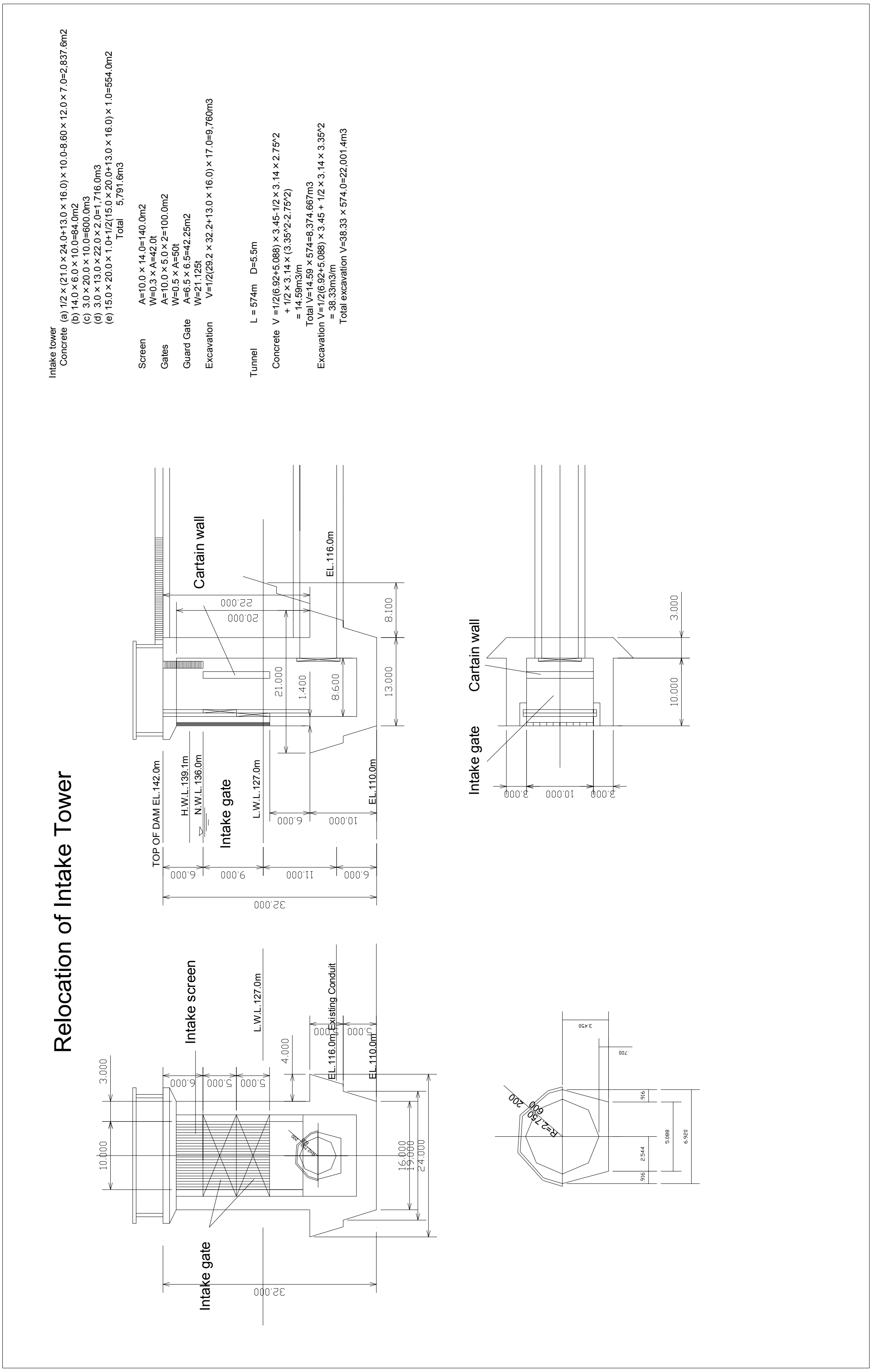
3) Operation

- Usually gates are fully opened.
- At the time sediment deposit on more than EL.127.0 m, gate shall be adjusted on sediment deposit level to prevent sediment from inflowing into the intake.



Source: JICA Study Team

Figure 2.3.2 Alignment and Profile of Relocation of Intake



Source: JICA Study Team

Figure 2.3.3 Structure of Relocation Intake

(3) Evaluation

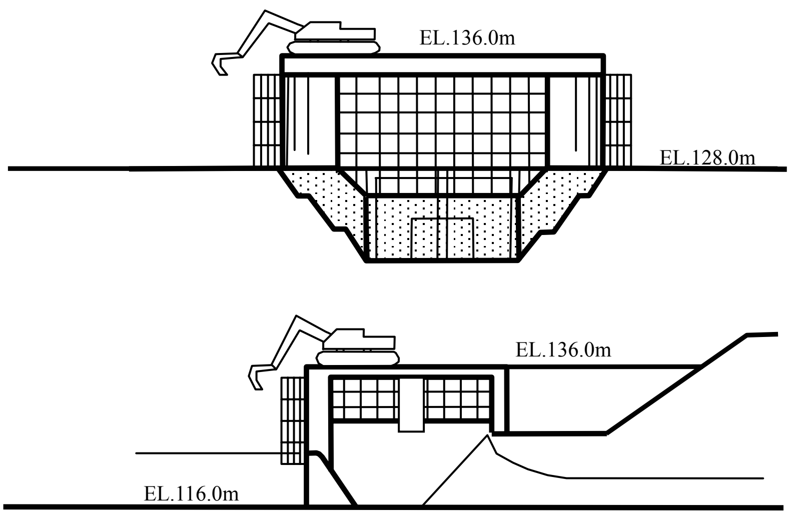
- From results of site reconnaissance and sedimentation calculation in the reservoir, sedimentation would be proceed around the candidate site for the intake relocation. So it is difficult to avoid sedimentation around there.
- As transmission tunnel is long about 570 m and is set under the existing spillway, it is expected to be difficult of the construction work. Hence construction cost would be high.
- Water intake should be suspended during connection work with existing tunnel.
- No contribution to dam life lengthening due to reducing sediment removal function of intake.
- A number of clogging intake by garbage is expected to be considerably reduced.

2.3.3 Debris Trapping Structure at Intake

(1) Features of Debris Trapping Structure at Intake

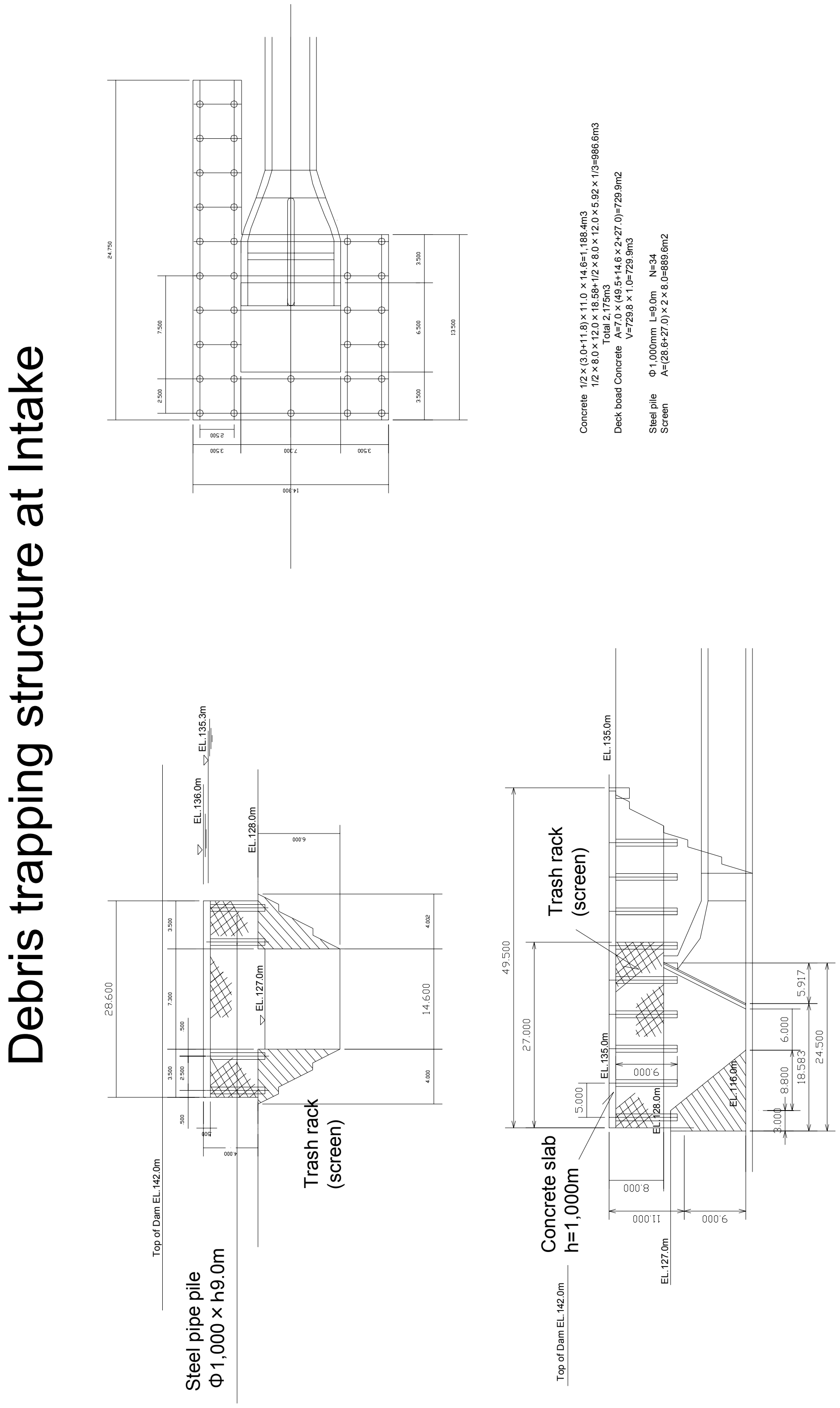
Main reason of clogging intake is thought of debris such as crop stem, root of plant. And the shape of ground at the front of the intake is formed deep ditch, sediment with debris on the terrace behind of slop should be drawn into ditch easily. Figure below is the tentative design of the debris trapping structure at the intake.

Overflowing weir is constructed in the ditch and both side of Intake with its crest elevation EL.127.0 m at the front and EL.128.0 m at the side. Weir at EL.128.0 m should block sediment to enter the intake from the Keduang River. A trash rack is installed around the weir at front and both side to prevent the debris from entering into the intake. Access road connecting the dam crest and this structure is planned to ease maintenance work. Debris on the trash rack shall be removed by heavy equipment such as back hoe and crane easily. This access road and top of the debris trapping structure is designed to be submergible and those construction height is EL.131.0 m to save construction cost at present. Maintenance work should carry out during water level being low.



Source: JICA Study Team

Figure 2.3.4 Debris Trapping Structure Around Intake



Source: JICA Study Team

Figure 2.3.5   Debris Trapping Structure at Intake

(2) Provability of Application for Wonogiri Dam

1) Applicability

Screen is laid out to be enclosed the existing intake to prevent garbage and debris from entering on trash rack. To widen the screen is to disperse garbage and debris, which is expected to be weakened clogging force.

- Access deck is laid out from the dam to new screen to ease heavy equipment such as back hoe entering on new screen to pick up debris and garbage gathered at around screen.

According to the maintenance works reported before, sometimes backhoe had been used for picked up and remove the garbage at the front of intake. This method is only proposed the approach deck from the dam crest and the intake, which bed height is set at EL.136.0 m to be able to carry out garbage removal even at the time water level is high. This method can be carried out without suspending water supply.

2) Layout of the Facility

Layout of the facility is shown in Figure 2.3.5. Dimension of this method is shown in Table 2.3.3.

Table 2.3.3 Dimension of Facilities

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

Source: JICA Study Team

3) Operation

Operation of this method is only garbage removal work by introducing heavy machine. This work can be done at anytime or periodically. No special operation is needed.

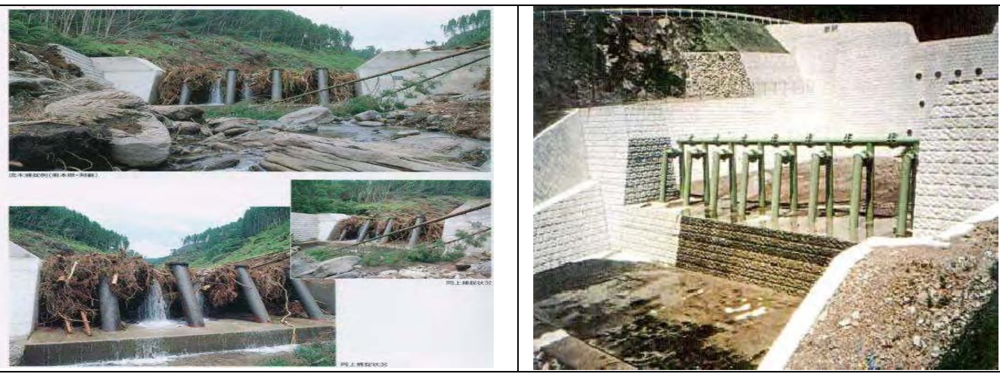
(3) Evaluation

- Intake clogging would be drastically disappeared by double screen and periodical garbage removal works by heavy machine.
- Suspension of water supply can be avoided.

2.3.4 Debris Trapping Structure on Keduang River Mouth

(1) Features of this Method

Problem of the intake clogging is caused by debris and garbage flowing down from the Keduang River. Thus, it is considered to trap and remove debris on the Keduang River before flowing down the reservoir. In this type of method, steel-pipe girded sabo dam is adopted commonly in Japan. Below picture is one of steel -pipe girded structure for debris trapping structure. Debris removal work shall be carried out periodically.



Example of Steel pipe girded structure

Source: JICA Study Team

(2) Provability of Application of Wonogiri Dam

1) Applicability

This facility can be laid out not only Keduang main stream but each tributary.

2) Layout of the Facility

Layout of the Facility on Keduang main stream is shown in Figure 2.3.6. Dimension of this facility is indicated in Table 2.3.4.

Table 2.3.4 Dimension of Debris Trapping Structure

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

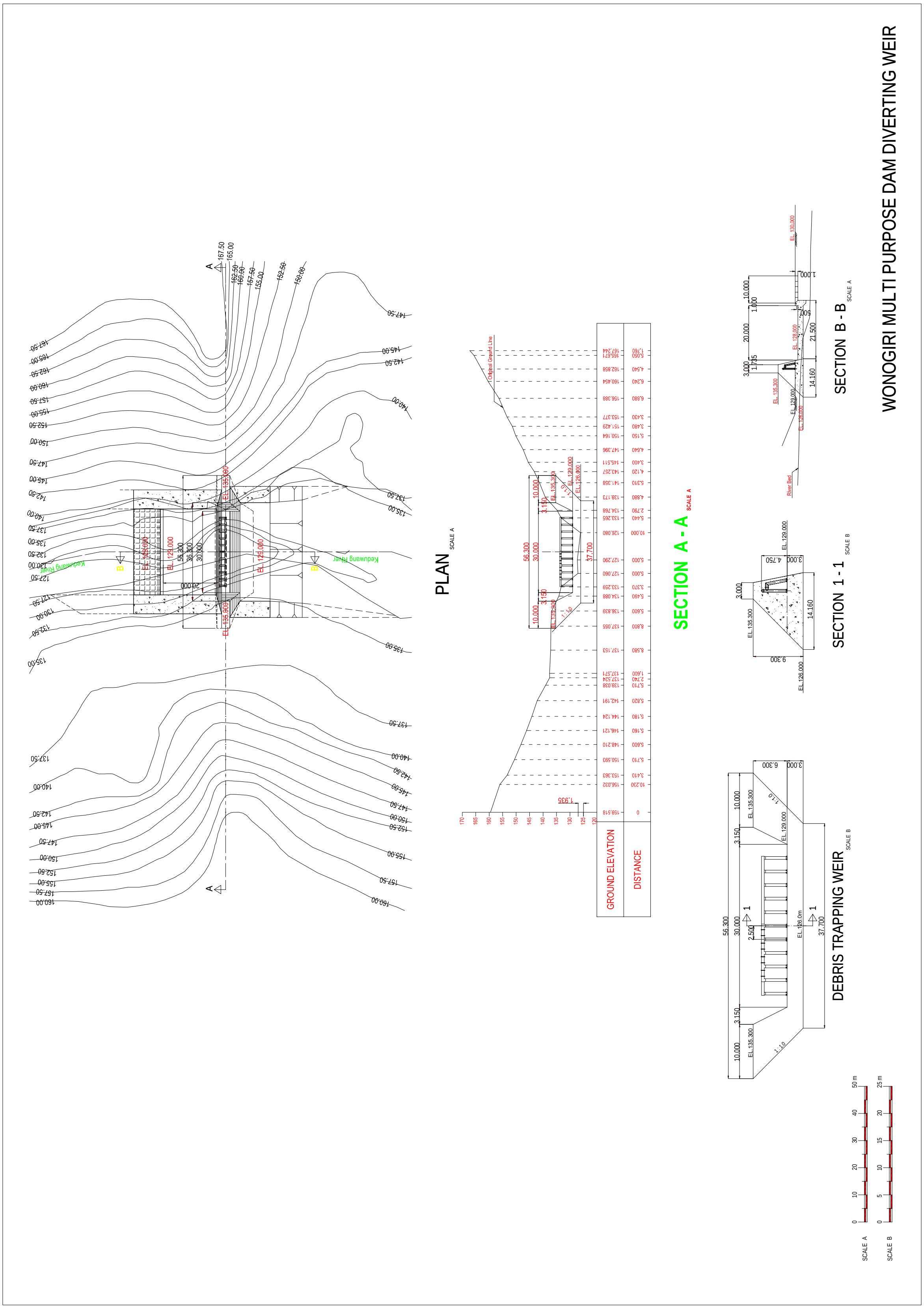
Source: JICA Study Team

3) Operation

- Periodical garbage removal is needed.

(3) Evaluation

- Periodical dispose of garbage and debris which is trapped on weir should be carried out and also disposal land is needed.
- This method is likely to be useful as a supplemental work of sediment removal at and around intake.
  - However, as analysis of garbage volume from the Keduang River has not been grasped, to evaluate effectiveness of this method is difficult.



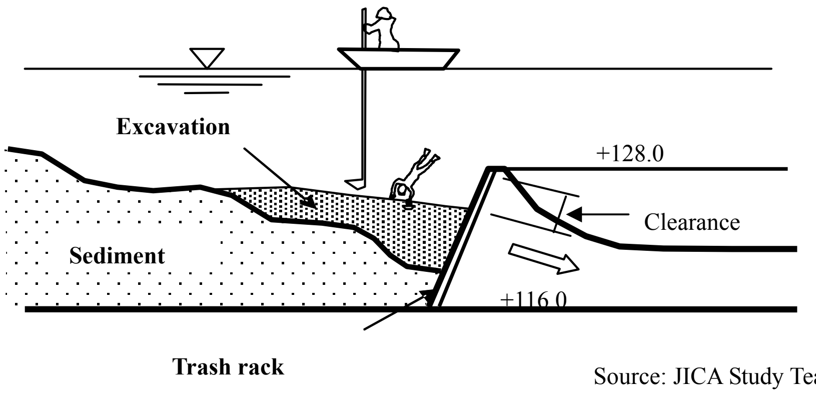
Source: JICA Study Team

Figure 2.3.6   Debris Trapping Structure at Keduang River

2.3.5 Regular Maintenance Dredging at Intake

As for regular maintenance dredging at the intake, sediment removal was practiced by divers and work from small the boat. Table 2.3.7 shows the annual sediment removal practices. According to this data, from 1996 to 2003, two (2) to four (4) times practices per year were carried out and totally 663 m^3 sediment was removed. It was 94.8 m^3 volume of sediment per year on average. In all of it, about 525 m^3 sediments was removed by diver and 138 m^3 was dredged from small boat. As the result of the practices, clearance from the top of bell mouth (EL.128.0 m) to bottom of the intake conduit (116.0 m) had been restored 7.0 m to 11.0 m. About 20 days on annual average were taken for this regular maintenance dredging work. During dredging work being carried out, power generation should be constrained to stop operation, resulting in economic loss.

However this method is considered to be most cheapest way to keep the intake function.



Source: JICA Study Team

Figure 2.3.7 Regular Maintenance Dredging

Table 2.3.5 Sediment Removal at the Front of Intake on Regular Maintenance

Date		Sediment removal (m3) from boat	by diver	Total	Clearance (m)	Working days
1996	January	17.6	36.4			12
	February	17.2				4
	March	4.4				1
	November	12.0	42.0			12
	December	8.4	36.0			10
	sum	59.6	114.4	174.0		39
1997	January	14.8	43.2			12
	February		32.8			7
	sum	14.8	76.0	90.8		19
1998	April		29.2			6
	October	9.2				2
	November	12.8	36.8			9
	December		21.6			4
	sum	22.0	58.4	80.4		21
1999	October		6.4			1
	November	3.6				2
	December	12.4				4
	sum	16.0	6.4	22.4		7
2000	January		48.0		11.0	7
	March		11.6		11.0	4
	November	15.8	24.4		9.0	15
	December	5.2	33.6		7.0	8
		21.0	117.6	21.0		34
2001	January	5.0	42.4		9.0	10
	April		31.6		8.0	6
	sum	5.0	74.0	79.0		16
2002	January		17.2		4.0	2
	February		25.2		7.5	3
	October		16.8		10.0	5
	sum	0.0	59.2	59.2		10
2003	January		19.2		10.0	6
	sum	0.0	19.2	19.2		
Total Volume		138.4	525.2	663.6		146
annual average		19.8	75.0	94.8		

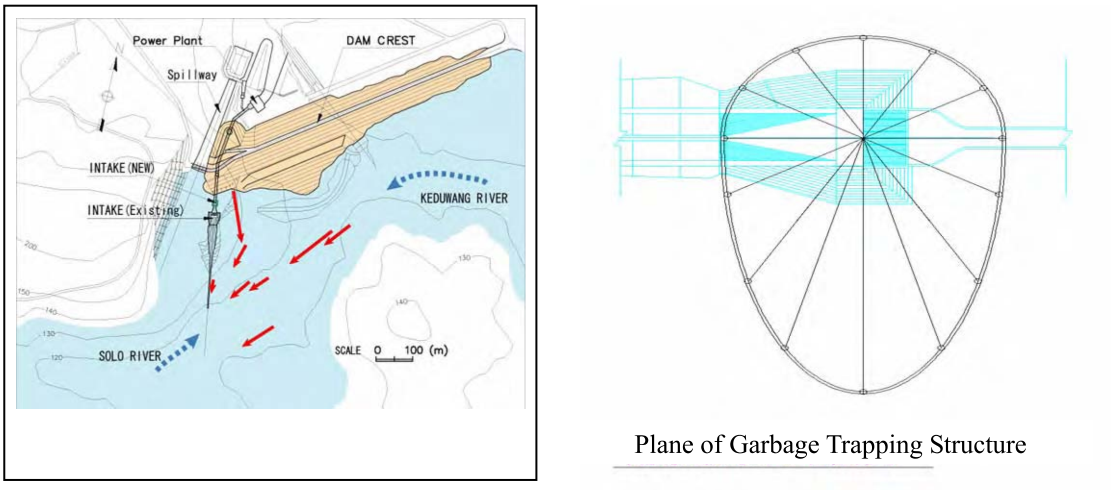
Source: JICA Study Team

2.3.6 Garbage Trapping Structure at Intake

It is reported that the garbage stacked on the trash-rack of the intake have had caused clogging of the intake in the Wonogiri reservoir. To keep function of the intake, regular maintenance work by diver have been carried out by PLTA more than twice a year.

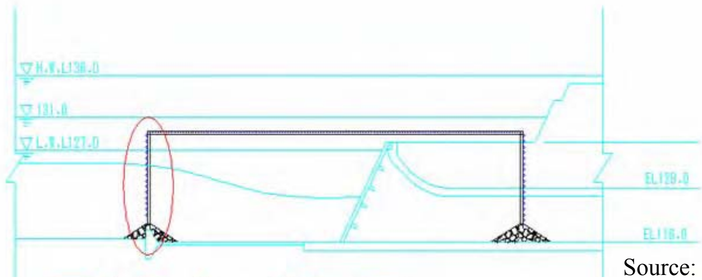
To mitigate these situations, counter-measure for garbage should be taken to keep clearance for through-water to the intake. Figure 2.3.8 shows the garbage trapping structure installed around the intake to prevent garbage inflowing in front of it directly. By this structure, the maintenance frequency is expected to decrease owing to the garbage trapping area of this structure is much larger than that of the intake. Considering the flow line from the Keduang River, arrangement and form of this structure should be determined.

The detail of the garbage trapping structure are shown in Figures 2.3.8 to 2.3.10.



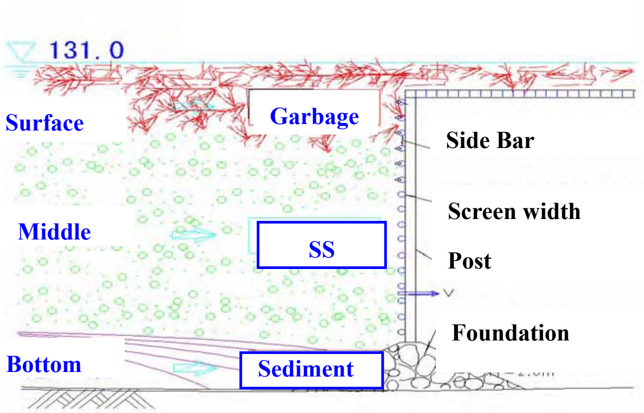
Source: JICA Study Team

Figure 2.3.8 Garbage Trapping Structure Surrounding Intake



Source: JICA Study Team

Figure 2.3.9 Cross Section of Garbage Trapping Structure



Source: JICA Study Team

Figure 2.3.10 Detailed Cross Section of Garbage Trapping Structure

2.3.7 Hydro-suction Sediment Removal System (New Sediment Removal System)

In Verification Test for the hydro-suction sediment removal system, the applicability of this system has been confirmed.

Hereinafter, the hydro-suction sediment removal system for practical use in front of the intake in Wonogiri reservoir is described.

In consideration of the river environment, it is not desirable to operate this system singly. It is necessary to mitigate high concentration as not to reach downstream. Therefore, the usage of this system is divided into 2 ways, one is in flooding time and the other in the power plant operation time.

(1) In Flooding Time

1) Operation Time

Averting of danger, the operation time is limited the flooding time over 100 m^3/s and below 800 m^3/s of the inflow.

The averaged flooding time over 100 m^3/s and below 800 m^3/s of the inflow from December to April in the period of 1993 to 2004 is 732 hours. The operation time is estimated 183 hours excluding night-time and preparation time for operating, which is assumed to be 75% of the total hours.

2) Reservoir Water Level

The reservoir water level of the above period is roughly estimated El.133.64 m.

3) Suction area

The suction area is determined in front of the intake as shown in Figure 2.3.11.

4) Calculation of the sediment removal amount

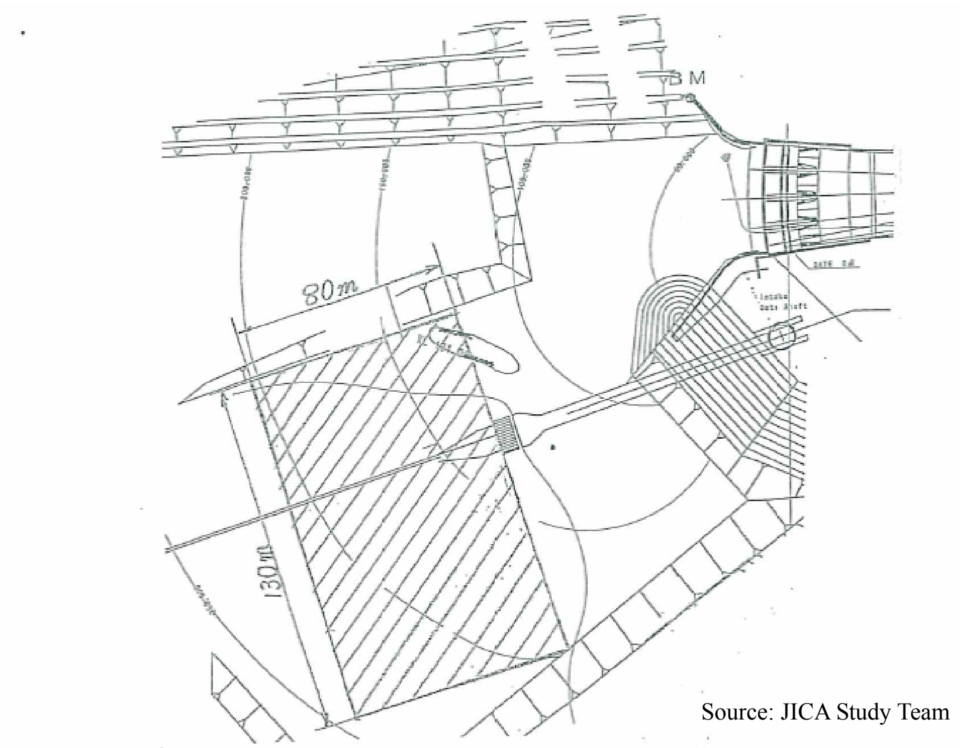
The Darcy-Weisbach equation for the pipe flow resistance is used to obtain pipeline loss resistance.

$$H = \alpha \cdot \lambda \cdot \gamma \frac{v^2}{2g} \times \frac{L}{D}$$

where;

H: Pipeline head loss (m)
The pipeline head loss H is necessary to be less than the vertical drop between the reservoir water level and the outlet elevation.
H<18.64 m (=133.64 m – 115.00 m)

α: Percentage increase in the pipeline frictional loss factor when conveying mud-flow
$\alpha=1+\beta(\gamma-1)$, β: Soil coefficient; 4.0 is adopted considering soil test



Source: JICA Study Team

Figure 2.3.11 Suction Area

γ: Density of mud flow
λ: The pipeline friction coefficient at clear water (= 0.0258)
L: Pipeline length 500 m (= 240 m (Spillway side) + 250m (Reservoir side))
D: Diameter of the pipe (Φ600 mm)
v: Flow velocity (m/s)

The density is estimated 1.19 in Figure 6.3.9 on the premise that the flow velocity v = 2.2 m/sec and particle size 0.11 mm. (Based on Soil analysis at B-3 point.)

The percentage increase of the pipeline frictional loss factor during suction, α is 1.76 (= 1 + 4 x (1.19-1)). The pipeline flow velocity for practical use is 2.7 m/s, 1.2 times of the flow velocity so as to need the value over the critical flow velocity.

Pipeline head loss H is estimated 16.7 m as follows, consequently, the suction with some margins is possible.

$H = 1.76 \times 1.19 \times 0.0258 \times 2.72 / 19.6 \times 500 / 0.6$
$= 16.7\ m$

The suction rate per unit of hour is obtained using the following equation.

$Q' = (\pi/4) \times D \times D \times V \times (C'/100)$

where;

C': Volumetric concentration (%)

The volumetric concentration in the case of density = 1.19, as obtained in Figure 6.3.10, is 25%.

$Q' = (\pi/4) \times 0.6 \times 0.6 \times 2.7 \times (25/100) = 0.19\ m^3/s$

When the volumetric concentration is 25% and the diameter of the pipe isΦ600 mm, the critical flow velocity is 2.5 m/s in Figure 2.3.12. There will be no problem of sediment accumulation in the pipe with the practical flow velocity exceeding the critical flow velocity.

Suction amount is estimated approximate 125,200 m3 as follows. The summary of Suction in flooding time is shown in Table 2.3.6.

$Q = Q' \times T$
$= 0.19\ m^3/s \times 183 \times 3600$
$= 125{,}200\ m^3$

where;

Q: Suction amount(m^3)

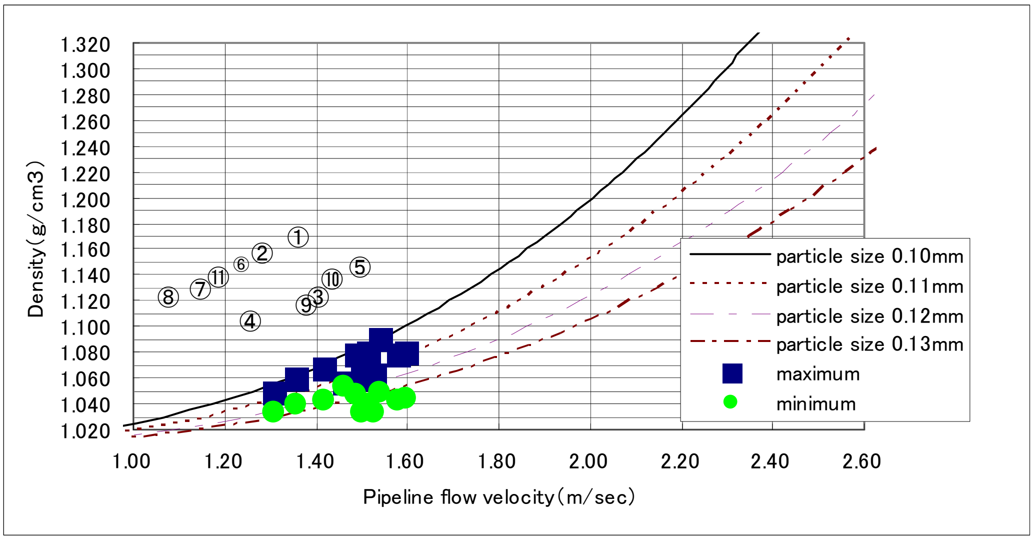
Q': Suction rate per unit of time (m^3/s)

T: Operation time (sec)

Table 2.3.6 Summary of Suction in Flooding Time

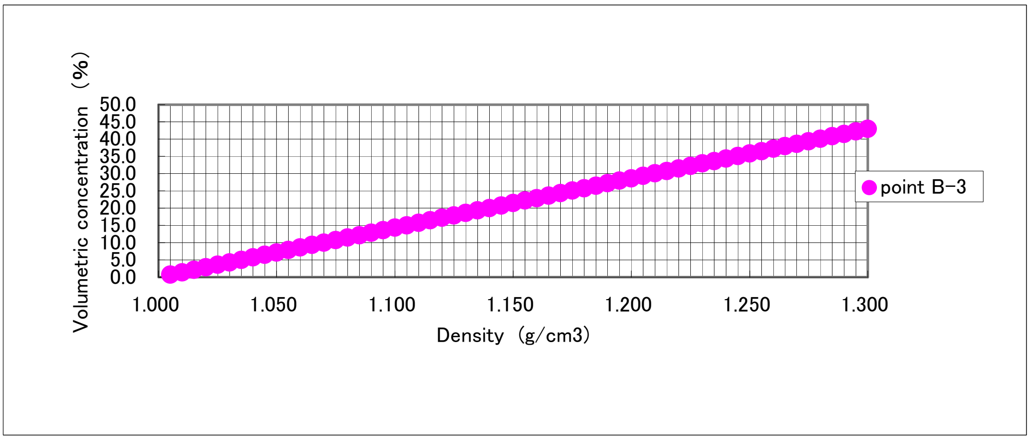
Operation time (hrs.)	Pipe flow velocity (m/s)	Volumetric concentration (%)	Suction rate (m^3/s)	Suction amount (m^3)	Water consumption (m^3)
183	2.7	25	0.19	125,200	502,700

Source: JICA Study Team



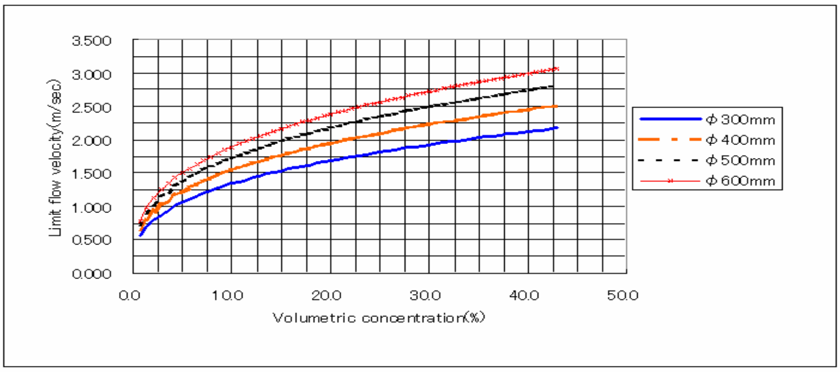
Source: JICA Study Team

Figure 2.3.12 Critical Flow and Density



Source: JICA Study Team

Figure 2.3.13 Density and Volumetric Consistency



Source: JICA Study Team

Figure 2.3.14 Volumetric Concentration and Critical Flow Velocity

(2) In Power Plant Operation Time

As the hereinbefore, this system can remove the sediment amount of 125,200 m^3 in flooding time. On the other hand, extremely high concentration of discharge flow as 25% of volumetric concentration, run down to the downstream of the dam. It might be a large impact on the environment of the river.

The following index has been proposed for the evaluation of the impact on fish in Canada. This index has been introduced and used on trial in Japan, and SI of 10 is a standard for water quality management.

*SI = loge (SS * T)*

where;

SI: Stress Index

SS: Suspended Solids (mg/l)

T: Duration (hr)

Table 2.3.7 shows SI value of the flow in scale mixed with the suction discharge flow, 25% and 7% of volumetric concentration respectively. And the scale more than 100 m^3/s of the flow is estimated for reference. Hydro-suction system is limited to less than 3-hour operation under *SI* of 10, aiming at 30 m^3/s, the average of the power plant discharge flow, while it is free from restraint in case of 7% of volumetric concentration.

4-hour operation time with 7% of volumetric concentration is preferable to the environment, showing less *SI* of 9, having a margin.

Table 2.3.7 Stress Index

		Hydro-suction discharge (25%)						Hydro-suction discharge (7%)					
		T (hrs.)						T (hrs.)					
		1	2	3	4	5	6	1	2	3	4	5	6
Power plant discharge	10m^3/s (SS=100)	9.8	*10.5*	*10.9*	*11.2*	*11.4*	*11.6*	8.3	9.0	9.4	9.7	9.9	*10.1*
	30m^3/s (SS=500)	8.9	9.5	9.9	*10.2*	*10.5*	*10.6*	7.6	8.2	8.7	8.9	9.2	9.3
	50m^3/s (SS=700)	8.4	9.1	9.5	9.8	*10.0*	*10.2*	7.3	8.0	8.4	8.7	9.0	9.1
	75m^3/s (SS=900)	8.2	8.9	9.3	9.6	9.8	*10.0*	7.3	8.0	8.4	8.7	8.9	9.1
Spill-out flow	100m^3/s (SS=1,000)	8.0	8.7	9.1	9.4	9.6	9.8	7.3	8.0	8.4	8.6	8.9	9.1
	200m^3/s (SS=1,500)	7.8	8.5	8.9	9.2	9.4	9.6	7.4	8.1	8.5	8.8	9.1	9.2
	300m^3/s (SS=2,000)	7.9	8.6	9.0	9.3	9.5	9.7	7.7	8.4	8.8	9.1	9.3	9.5
	600m^3/s (SS=3,000)	8.1	8.8	9.2	9.5	9.7	9.9	8.0	8.7	9.1	9.4	9.6	9.8

Source: JICA Study Team

1) Operation Time

Operation time can be obtained 480 hours, 4 hours times 120 days from December to April.

2) Reservoir Water Level

The reservoir water level during December to April is El.133.64 m as mentioned in (1).

3) Calculation of the Sediment Removal Amount

$$H = \alpha \cdot \lambda \cdot \gamma \frac{v^2}{2g} \times \frac{L}{D}$$

where;

H: Pipeline head loss *(m) H<18.64 m (=133.64 m – 115.00 m)*
α: Percentage increase in the pipeline frictional loss factor when conveying mud-flow, $\alpha = 1+\beta(\gamma-1)$
β: Soil coefficient
γ: Density of mud flow
λ: The pipeline friction coefficient at clear water
L: Pipeline length (m)
D: *Diamet*er of the pipe
v: Flow velocity (m/s)
V: Flow velocity for practical use (m/s)

Table 2.3.8 shows the constant and others.

Table 2.3.8 Summary of Constant

‘α’	β	γ	λ	D	L	v	H
1.4	4	1.1	0.0258	Φ600 mm	500 m	1.8 m/s	8.2 m

Source: JICA Study Team

The suction rate per unit of hour is 0.04 m3/s using the following equation.

Q’= (π/4) x D x D x V x (C’/100)

Suction amount is approximate 69,100 m^3 as follows. The summary of Suction in normal time is shown in Table 2.3.9.

$Q = Q' x T$
$= 0.04 m^3/s x 480 x 3600$
$= 69,100 m^3$

Table 2.3.9 Summary of Suction in Power Plant Operation Time

Operation time (hrs.)	Pipe flow velocity (m/s)	Volumetric concentration (%)	Suction rate (m^3/s)	Suction amount (m^3)	Water consumption (m^3)
480	2.2	7	0.04	69,100	1,074,300

Source: JICA Study Team

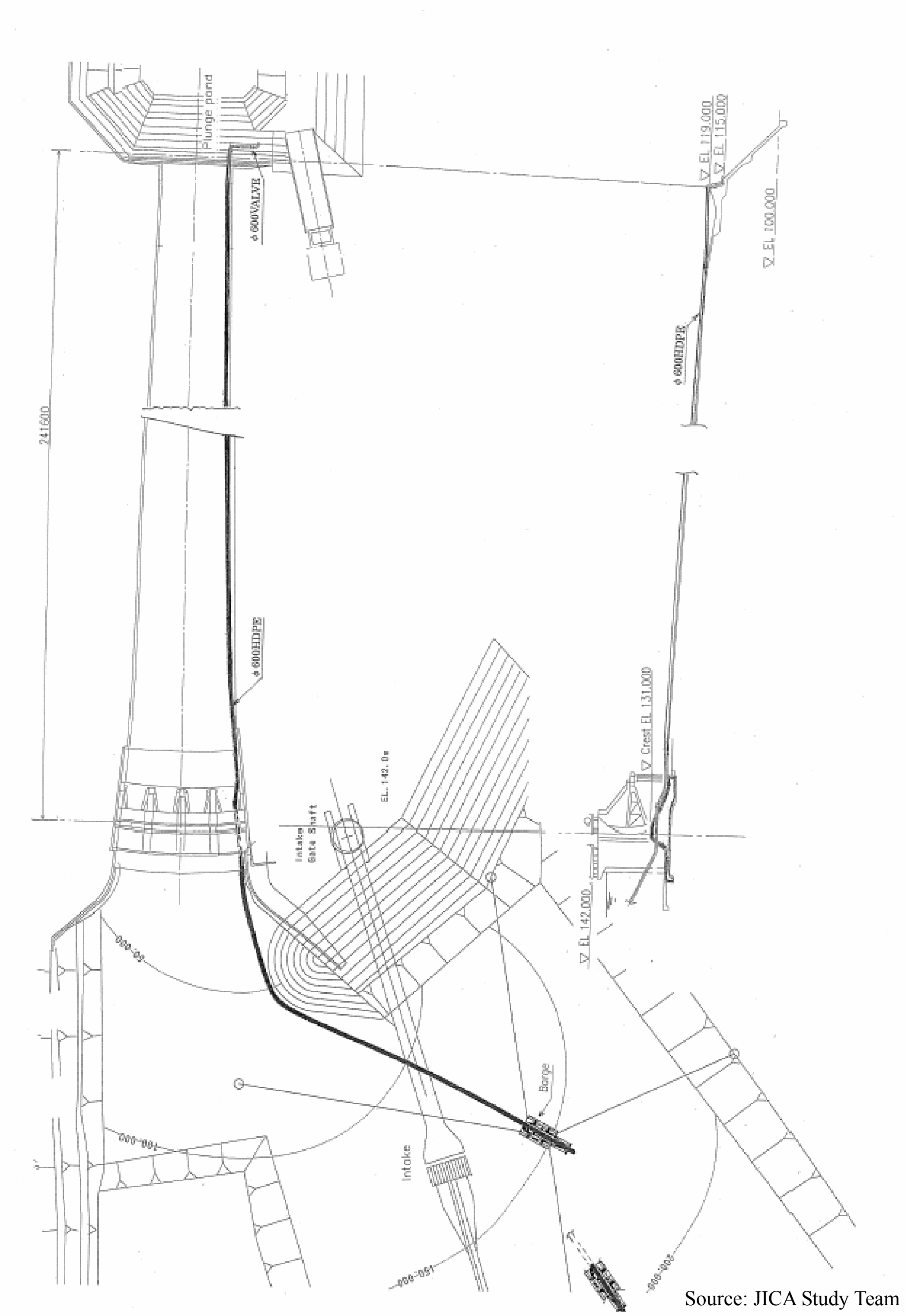
Conclusively, Hydro-suction sediment removal system operation in Wonogiri reservoir is designed to be compounded of Power plant operation time and Flooding time, as shown in Table 2.3.10, aiming at suction amount of 100,000 m^3.

Table 2.3.10 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

Figure 2.3.15 shows the plan of Hydro-suction Sediment Removal System in Wonogiri reservoir. The initial cost of the system is roughly estimated 433 million Japanese yen.



Source: JICA Study Team

Figure 2.3.15 Plan of Hydro-suction Sediment Removal System

2.4 Summary of Countermeasures

Summary of countermeasures for Alternatives for reducing sediment deposition within reservoir is shown in Tables 2.4.1 and 2.4.2. Summary of countermeasures to keep proper function of existing intake is shown in Table 2.4.3.

Problems in the Wonogiri dam and required consideration for selection of sedimentation countermeasures are as follows,

(1) Problems in Wonogiri Reservoir

1) Sedimentation at and around existing Intake
2) Decrease effective storage capacity
3) Lowering dam safety

(2) Consideration Contents on Sedimentation Countermeasures

1) Countermeasures which should be taken in near future (within 5 years)
2) Countermeasures which should keep reservoir function for 100years.
3) Water supply should be maintain during construction of countermeasures
4) Minimize operation and maintenance cost.

Table 2.4.1 Alternatives for Sediment Removal in Dam Reservoir

<table>
<tr><th>Alternatives</th><th>Design sediment removal</th><th>Facility Plan</th><th>Cost and Sediment consentration</th><th>Evaluation</th></tr>
<tr>
<td>(1)Sediment Bypassing</td>
<td>・When Flooding discharge of Keduang river is over 30m3/s, Q=50m³/s flow is taken into Bypass channel.
Design sand removal on annual average are shown in Table below.
・sediment sluicing gates shall be closed at the time total volume of discharge become 200 MCM.

・Design sediment removal
m³/year
<table>
<tr><td>Case</td><td>Intake</td><td>Exit spillway</td><td>Bypass</td><td>Total</td></tr>
<tr><td>Dry</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Normal</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Wet</td><td>349,000</td><td>0</td><td>692,000</td><td>1,041,000</td></tr>
</table>
＊Dry year 04-05, Normal year 95-96, Wet year 98-99</td>
<td>①Bypass Tunnel
L=6,435m
I=1/1,000、
Typical horseshoe section 2 r =5.0m
Design discharge Qmax=50m³/s
②River improvement
Design discharge Qmax=65m³/s
L=2,395m,
I=1/160
Cross section B=10m,H=3.0m
Slope gradient 1:0.5
③Diverting weir
Design discharge Q=1,370m³/s
Width of flow area B=70m
Depth of flow 4.9m
Height of Dam H=9.3m
Width W=137.9m
Gates H6.7m×B5.0m×2</td>
<td>・Construction Cost
82,940,000 USD
・O&M cost 67,302,000USD/year
・Unit Cost of sediment removal
16.03 USD/m³

・Sediment concentration of discharge
<table>
<tr><td>Dry</td><td>-</td></tr>
<tr><td>Normal</td><td>-</td></tr>
<tr><td>Wet</td><td>3.460ppm</td></tr>
</table></td>
<td>・As Food flow is diverted into Bypass channel before the dam reservoir, efficiency of removal of sediment from Keduang is high.
・Construction cost shall be large due to length of tunnel being long.
・Bypass channel shall be laid out under residential area, so environmental and social considerations are needed.</td>
</tr>
<tr>
<td>(2)Sediment Sluicing by New Gate</td>
<td>・Sediment Sluicing gates are installed on right side of the Dam and certain part of Flooding from Keduang river shall be sluiced out to the downstream of the Dam.
・sediment sluicing gates shall be closed at the time total volume of discharge become 200 MCM.
・Maximum discharge from Sluicing gates is set at Q=400m³/s in corresponding to river flow capacity at downstream.
・Design sediment removal
m³/year
<table>
<tr><td>Case</td><td>Intake</td><td>Exit spillway</td><td>New Gate</td><td>Total</td></tr>
<tr><td>Dry</td><td>292,240</td><td></td><td>246,339</td><td>538,580</td></tr>
<tr><td>Normal</td><td>269,083</td><td></td><td>410,393</td><td>679,476</td></tr>
<tr><td>Wet</td><td>349,173</td><td></td><td>557,670</td><td>906,843</td></tr>
</table></td>
<td>① Sediment flushing gates
H12.6m×B5.0m×4nos
② Spillway channel
L=723m、B=20m
③ Fore bay excavation
Level of excavation EL.127.0m
Volume 183,000m³</td>
<td>・Construction Cost
35,630,000 USD
・O&M cost 32,495 USD/year
・Unit Cost of sediment removal
7.02 USD/m³

・Sediment concentration of discharge
<table>
<tr><td>Dry</td><td>3.211 ppm</td></tr>
<tr><td>Normal</td><td>2.052 ppm</td></tr>
<tr><td>Wet</td><td>2.793 ppm</td></tr>
</table></td>
<td>・As most of the facilities concerning sediment sluicing can be laid out in the PBS land Area, social considerations such as land acquisition and resident transfer is less than Bypass channel.
・As flooding containing high sediment concentration should be entered in the reservoir at once, sediment precipitation would be occurred. Subsequently efficiency of sediment removal would be inferior to Bypass method due to reducing sediment concentration in sluicing water.
・Construction costs of sluicing facilities is about 1/2 -1/3 of low-cost with Bypass method.
・Whole reservoir turn over rate is only 2 times on annual average, so it is difficult to lower the water level in dam for sediment sluicing. Therefore sediment sluicing can not be conducted effectively.
・Volume of sediment and garbage stacked in front of intake will be reduced. However certain garbage will be stacked, garbage removal system should be needed.</td>
</tr>
<tr>
<td>(3)Compartmented reservoir with New Gate</td>
<td>・Closing levee is laid out in the reservoir combining the right side abutment of dam and peninsula existed in front of dam, which separate Keduang river portion from Solo river portion. New sediment flushing gate will be installed at Keduang river portion.
・Herewith periodical sediment flushing can be carried out in Keduang river reservoir without lowering water level of Solo river portion due to turn-over rate being estimated more than 20 times.
・Sediment sluicing gates shall be closed at the time total volume of discharge become 200 MCM.
・Maximum discharge from Sluicing gates is set at Q=400m³/s correspond to river flow capacity at downstream.
・ Design sediment removal m³/year
<table>
<tr><td>Case</td><td>Intake</td><td>Exit spillway</td><td>New Gate</td><td>Total</td></tr>
<tr><td>Dry</td><td>279,736</td><td></td><td>259,,301</td><td>539,037</td></tr>
<tr><td>Normal</td><td>223,850</td><td></td><td>397,188</td><td>621,038</td></tr>
<tr><td>Wet</td><td>285,248</td><td></td><td>458,289</td><td>743,537</td></tr>
</table></td>
<td>①Closing levee : double-steel sheet
L=650m、H=15.0m、B=10.0m
②Overflowing levee L=100m、B=10m
③Sediment flushing gates
H12.6m×B7.5m×4nos
④Spillway
L=723m、B=20m
⑤Fore bay excavation
Level of excavation EL.127.0m
Volume 183,000m³</td>
<td>・Construction Cost
47,090,000 USD
・O&M cost 43,060,000 USD/year
・Unit Cost of sediment removal
10.12 USD/m³

・Sediment concentration of discharge
<table>
<tr><td>Dry</td><td>3.020 ppm</td></tr>
<tr><td>Normal</td><td>1.989 ppm</td></tr>
<tr><td>Wet</td><td>2.294 ppm</td></tr>
</table></td>
<td>A reservoir in which the total storage volume is divided into two independently operating storage units is termed a compartmented reservoir. The compartments may be continuous, may consist of a smaller compartment inside a larger one, or may consist of two separate storage areas operated as a single system. Storage compartmentation allows the two portions of the total storage pool to be operated separately to enhance overall sediment management.

・Construction cost is high than sediment sluicing method due to installation of closing levee compared with Sediment sluicing method, however ½ low-price than Bypass method.
・Sediment flushing is capable at anytime during rainy season, due to reservoir turnover rate of Keduang portion is more than 20 times.
・Sediment and garbage at intake is expected to be almost diminished due to trapping most of them in the Keduang reservoir. However sedimentation ratio is increased in the Keduang river.</td>
</tr>
</table>

Source: JICA Study Team

Table 2.4.2 Alternatives for Sediment Removal in Dam Reservoir

<table>
<tr><th>Alternatives</th><th>Design sediment removal</th><th>Facility plan</th><th>Cost and Sediment consentration</th><th>Evaluation</th></tr>
<tr><td>(4)Sluicing from Existing Intake</td><td>·Existing Intake for power is draw 70m^3/s and flush out water into the river at flooding from the beginning of rainy season.
·Existing Intake shall be narrow down to be normal operation at the time of total volume of discharge being 200MCM.
・ Design sediment removal m^3/year<table><tr><td>Case</td><td>Intake</td><td>Exit spillway</td><td>New Gate</td><td>Total</td></tr><tr><td>Dry</td><td>-</td><td>-</td><td>-</td><td>-</td></tr><tr><td>Normal</td><td>-</td><td>-</td><td>-</td><td>-</td></tr><tr><td>Wet</td><td>530,000</td><td>281,000</td><td></td><td>811,000</td></tr></table></td><td>① Existing Intake Tunnel
maximum intake discharge 75m3/s
Tunnel B5.5m×H5.5m</td><td>・Construction Cost
3,160,000 USD
・O&M cost 53,000 USD/year
・Unit Cost of sediment removal
-USD/m^3
・Sediment concentration of discharge<table><tr><td>Intake</td><td>617 ppm</td></tr><tr><td>Spillway</td><td>1509 ppm</td></tr><tr><td></td><td></td></tr></table></td><td>・This method is to use existing discharge facilities such as Intake and spillway, only need to have garbage removal system and to modify intake operation rule. Therefore this method will be the lowest-cost countermeasure.
・Sediment concentration indicates about 2times figure compared with other system from reservoir sedimentation simulation. However as it is only 617ppm on average, no harmful affection is deemed given to power.
·Reliability of this method is very low. Because to realize this efficiency of sediment removal, no clogging of the intake is indispensable. However it is almost difficult to keep intake function without any clogging and suspension of Intake for maintenance.
・Monitoring and garbage removal work is indispensable during sediment flushing.</td></tr>
<tr><td>(5)Sediment storage dam</td><td>・Sediment storage dam is laid out at the uppermost of Keduang reservoir to trap sediment.
・Storage capacity is about 24,000m^3 at EL.135.3m in Keduang river.
・Design sediment removal model is 1,0MCM/year .</td><td>①Sabo Dam
width of Dam W=115.9m
height of Dam H=9.3m
Design discharge Q=1,370m^3/s
width of overflow B=70m
Depth of overflow h=4.9m</td><td>・Construction Cost
2,720,000 USD
・O&M cost 23,389,000 USD/year
・Unit Cost of sediment removal
28.19 USD/m^3</td><td>・Storage capacity is 24,000m^3 at EL.135.3m which is under 1/40 of sediment yield from Keduang river. This means almost no effectiveness for sediment removal from reservoir.
・and that, most of the sediment is expected to be wash-load, sediment trapping ratio in storage dam is small.
・Sediment removal work should be carried out in dry condition.</td></tr>
<tr><td>(6)Dry Excavation</td><td>・Dry excavation is carried out when water level is low during dry season by backhoe or crawler-mounted bulldozer for swamp and conveyed by truck to spoil bank. This method is the most common and cheapest way to remove sediment in the reservoir.
・Design sediment removal volume is 2,0MCM / year I n whole reservoir.</td><td>Bulldozer 4t, swamp x 2,960nr
Crawler loader, 2.3m3 x 11nr
Dump truck 20t x 65nr</td><td>・Construction Cost
287,990,000 USD
・O&M cost 314,602,000 USD/year
・Unit Cost of sediment removal
18.95 USD/m^3</td><td>・It is almost unrealistic to cope with sediment volume 20,000m^3/day by sole dry excavation.
·This method is recommended to be used as supplementary of other main countermeasures.</td></tr>
<tr><td>(7)Hydraulic dredging</td><td>・This method is to remove sediment deposited in the dam reservoir by hydraulic dredging.
・This method had been experienced at Wonogiri dam to remove sediment at and around Intake.
・Design sediment removal volume is 1,0 MCM /year.</td><td>Dredger
Cutter-suction dredger, 600PS x 6nr</td><td>・Construction Cost
26,740,000 USD
・O&M cost 35,739,000 USD/year
・Unit Cost of sediment removal
4.31 USD/m^3</td><td>・This is the most common countermeasure to remove sediment in the existing reservoir.
・In Wonogiri dam, sediment volume is too huge to cope with hydro dredging. And it is almost difficult to acquire sediment disposal land.
・This method is very useful to use as supplementary of other main countermeasures at and around Intake.
・O/M cost is high.</td></tr>
<tr><td>(8)Modification of Dam reservoir operation rules</td><td>・This method is to raise HWL to secure effective storage capacity.
・PMF water level cannot be raised from the view point of dam safety, so new spillway is needed to flow out the flood.</td><td></td><td></td><td>・In actual operation, reservoir operation rule had been breached. HWL 136.0m is set in 137.0m illegally due to the increment of required water supply.
・To secure dam safety at PMF, new spillway is useful to operate water level.
・This new spillway can be used both spillway and sediment flushing facility.
・Reliability is bery high for carrying out it function.
・Most of facilities can be planned within Dam site area.
・Initial cost is relatively high, however O/M cost is small.</td></tr>
</table>

Source: JICA Study Team

Table 2.4.3 Alternatives for Sediment of Intake

Alternatives	Features	Facility Plan	Cost	Remarks
(1)Modification of Existing Intake	・To prevent Intake inlet from burying by sediment, Modification of existing intake is considered. Foundation height of Inlet is set at EL.116.0m, which is 11.0m lower than design sediment deposit level. This situation should be induced sedimentation in front of intake. Therefore Intake Tower having selective intake is considered to construct on existing intake.	① Intake Tower Height H=26.0m Gates H5.0m×B12.6m×2 Foundation height of Inlet : EL.127.0m	・Construction Cost 3,214,000 USD ・O&M cost 49,000 USD ・Unit Cost of sediment removal 65.58 USD/year	・Water intake should be suspended during construction. ・No contribution to dam life lengthening due to reducing sediment removal function of Intake. ・A number of clogging Intake by garbage is expected to be reduced considerably. ・Sedimentation would be accelerated due to the 11.0m heightening of inlet foundation.
(2)Relocation of existing Intake	・To prevent Intake inlet from burying by sediment, relocation of Intake is considered at about 300m front of left bank from dam, where is seemed to be less affection of sedimentation.	① Intake Tower Height H=32.0m Gates H5.0m×B10.0m×2 Foundation height of Inlet : EL.127.0m ② Transmission Tunnel Diameter D= 5.5 m Length L= 570 m	・Construction Cost 8,892,000 USD ・O&M cost 49,000 USD ・Unit Cost of sediment removal 181.47 USD/year	・From results of site reconnaissance and sedimentation calculation in the reservoir, sedimentation would be proceed around the candidate site for Intake relocation. So it is difficult to avoid sedimentation around there. ・Transmission Tunnel is long about 570m and is set under the existing Spillway, it is expected to be difficult construction work. Hence construction cost would be high. ・Water intake should be suspended during connection work with existing tunnel. ・No contribution to dam life lengthening due to reducing sediment removal function of intake. ・A number of clogging Intake
(3)Debris trapping structure at Intake	・Screen is laid out to be enclosed the existing Intake to prevent garbage and debris from entering on trash rack. To widen the screen is to disperse garbage and debris, which is expected to be weakened clogging force. ・Access deck is laid out from Dam to new screen to ease heavy equipment such as back hoe entering on new screen to pick up debris and garbage gathered at around screen.	① Double Screen H8.0m×L111.2m Area A=889.6m^2 ② Access road (Deck) L=105.7m B=7.0m A=739.9m^2 ③ Steel pile Φ1,000mm H=9.00m,N=３４	・Construction Cost 3,761,000 USD ・O&M cost 49,000 USD ・Unit Cost of sediment removal 76.75 USD/year	・Intake clogging would be disappeared by garbage and debris and sedimentation. ・By laying out access deck, removal of garbage and debris would be make easy drastically. ・Construction cost is low compared with Tower Intake.
(4)Debris Trappin Weir at Keduang RIver	・At uppermost of Keduang reservoir, Debris Trapping Weir is considered to be laid out to trap debris and garbage to reduce them into reservoir.	① Concrete weir W=56.3m Height H=9.3m ② Steel material B=25.0m H=4.0m	・Construction Cost 1,380,000 USD ・O&M cost 49,000 USD ・Unit Cost of sediment removal 28.160 USD/m^3	・Periodical dispose of garbage and debris which is trapped on weir should be carried out.
(6)Hydro suction	・By hydro suction system, sediment and debris stacked at around intake is removal continuously. Design sediment removal volume 100,000m3/s	① Hydro suction system	・Construction Cost -USD ・O&M cost - USD ・Unit Cost of sediment removal - USD/m^3 ・Sediment concentration of discharge 240,000 ppm Flooding: 250,000 ppm Normal time: 70,000 ppm	・Installation of facility is capable without suspending construction. ・Sole facility equipped with the function of sediment removal among alternatives of securing the function of intake. ・This facility can dispose garbage and debris, however this is not equipped trough a year, other facilities for garbage prevention such as fence is needed. ・O/M cost is cheaper than pump dredging type due to utilization of siphon principles which use the difference of water level from dam reservoir water level and downstream water level. ・Measure for safety at flooding should be considered. ・Training and capacity building is needed to operate and maintain the facility.

Source: JICA Study Team

Table 2.4.4 Evaluation of Alternatives for Reducing Deposition Within the Reservoir

Alternatives \ Evaluation	Recover Effective storage capacity	Dam safety	Constructivety	Water Supply at construction	Reliability	Target year: Urgent	Target year: Near future	Target year: 100 years	Life cycle Costs	Evaluation
Bypass method	◎	×	○	◎	◎	×	×	○	○	3
Sediment Sluicing	◎	◎	◎	◎	◎	×	×	○	○	1
Compartmented reservoir	◎	◎	◎	◎	◎	×	×	○	○	2
Sluicing from exisiting intake	◎	×	◎	◎	△	○	○	○	◎	4
Sediment Storage Dam	×	×	◎	◎	△	×	△	×	△	6
Dry Excavation	×	△	×	◎	◎	×	△	△	×	7
Dredging	◎	△	△	◎	◎	◎	◎	△	×	5

Source: JICA Study Team

Table 2.4.5 Evaluation of Alternatives to Keep Proper Function of Intake

Alternatives \ Evaluation	Sedimentation at Intake	Garbage at Intake	Effectiveness	Reliability	Target year: Urgent	Target year: Near future	Target year: 100 years	Supply water at construction	Life Cycle Costs	Evaluation
Modification of Existing Intake	△	○	○	○	×	○	×	×	○	3
Relocation of Intake	△	○	○	○	×	○	×	×	△	4
Debris trapping structure at Intake	○	◎	○	○	×	○	○	○	○	2
Garbage trapping Weir at Keduang River	×	△	×	○	×	○	○	◎	○	5
Hydro suction	◎	◎	○	○	◎	◎	○	◎	○	1

Source: JICA Study Team