CHAPTER 4 PRELIMINARY EVALUATION ON STRUCTURAL SEDIMENT MANAGEMENT ALTERNATIVES

The sedimentation in the Wonogiri reservoir is severe and the situation is deteriorating. Countermeasures against the sedimentation are necessary. Among the countermeasures considered, the above reservoir sedimentation analysis model---NKhydro2D model is employed to preliminarily evaluate the effects of structure management alternatives.

4.1 Current Status of Wonogiri Reservoir Sedimentation

4.1.1 Sedimentation in Wonogiri Reservoir

Table 4.1.1 below summarizes the results of reservoir sedimentation measured in 1993, 2004 and 2005, respectively that are discussed in detail in Chapter 3 of Interim Report.

Table 4.1.1 Historical Change of Wonogiri Reservoir Capacity and Sediment Deposit

Reservoir Zone	Reservoir Capacity (million m^3)				Sediment Deposit (million m^3)	
	1980	1993	2004	2005	1993	2005 (%)
Below EL. 127.0m (LWL)	114	69	58	58	45	56 (49%)
Below EL. 136m (NHWL)	547	468	435	433	79	114 (21%)
Below EL. 138.3m (DFWL)	730	650	618	616	80	114 (16%)

Source: JICA Study Team

The losses of reservoir storage capacities due to sedimentation in the three (3) storage zones between 1980 and 2005 are summarized in Table 4.1.2 and Figure 4.1.1 below.

Table 4.1.2 Wonogiri Reservoir Capacity Loss by Storage Zone between 1980 and 2005

Reservoir Zone	Reservoir Capacity (million m^3)		Capacity Lost due to Sedimentation	
	1980	2005	Volume (million m^3)	Ratio to Original Volume (%)
Flood Control Storage (EL. 135.3-138.3m)	232	230	2	0.9
Effective Storage (EL. 127.0-136.0m)	433	375	58	13.4
Dead Storage (below EL. 127.0m)	114	58	56	49.1

Note: Reservoir capacity is reevaluated based on the DEM created under the Study.

Source: JICA Study Team

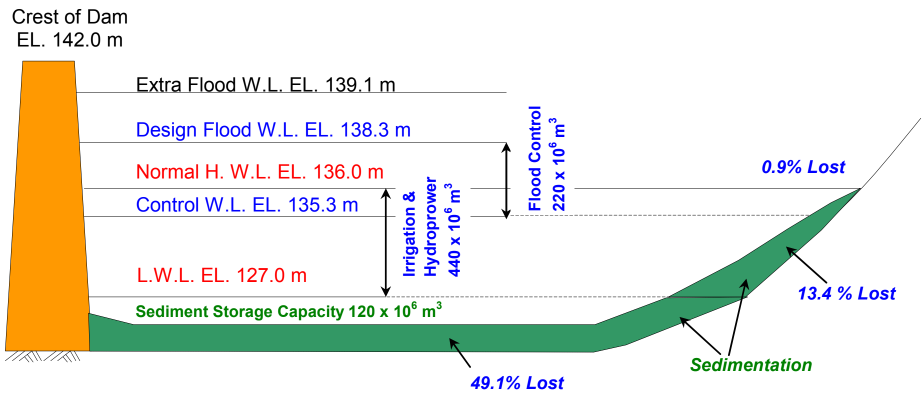

Figure 4.1.1 Wonogiri Reservoir Loss of Capacity by Storage Zone as of 2005

From the above sedimentation survey results, the current status of the Wonogiri Reservoir is assessed as follows:

i) There is almost no change in the flood control storage zone between EL. 135.3 m and EL. 138.3 m. This is because the sediment inflow occurs during the rainy season and then sediment deposition occurs dominantly in a range of the storage zone between LWL (EL. 127.0 m) and NHWL (EL. 136.0 m).

ii) Therefore, sediment deposit in the flood control storage zone above NHWL hardly occurs, while the visible bank failures/erosions readily occur around the fringe of reservoir area due to wave actions in the reservoir. These reveal that the safety of the Wonogiri Dam against a PMF is secured even under the current severe sedimentation condition.

iii) In the sediment storage zone below EL. 127.0 m, a volume of 56 million m^3 in total or 49.1% of the original storage capacity has been lost due to sedimentation in 1980-2005 (See Table 4.1.2 above).

iv) The volume of the effective storage zone between El. 127.0 m and 136.0 m has been reduced from 433 to 375 million m^3. The volume lost is 58 million m^3 or equivalent to 13.4% of the original storage capacity due to sedimentation between 1980 and 2005 (See Table 4.1.2 above).

v) Approximately 16% of the original gross storage capacity (= 730 million m^3) below DFWL (EL 138.3 m) was lost due to sedimentation between 1980 and 2005. The average annual rate of reservoir capacity loss is therefore around 0.64% (=16%/25 years) (See Table 4.1.1 above).

4.1.2 Sedimentation Issues and Problems in Wonogiri Reservoir

The sedimentation issues and problems of the Wonogiri Reservoir are summarized below.

i) Sediment deposits and garbage at the intake structure,

ii) Decrease of effective storage volume due to high sediment yields in Wonogiri Dam watershed, and

iii) Risky Reservoir Operation against PMF due to decrease of effective storage volume.

The current situations of sedimentation issues and problems are briefed below.

(1) Sediment Deposits and Garbage at Intake

The intake structure is a head structure to feed the reservoir water into a power waterway through which the water is conveyed to turbines for power generation and the downstream irrigation systems. It has been seriously affected by sediment deposition transported from the Keduang River. Sedimentation levels have risen almost to LWL 127 m in the forebay located immediately upstream of Wonogiri Dam (Figure 4.1.2).

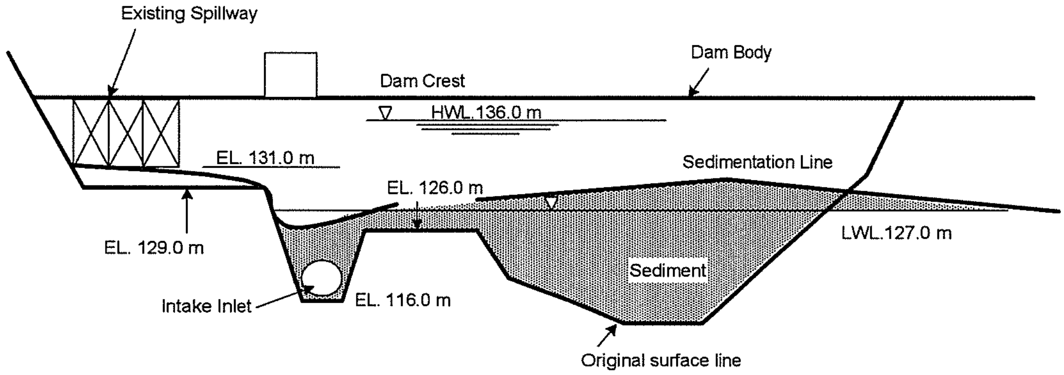

Figure 4.1.2 Typical Cross Section in Forebay of Intake

The sediment inflow into the reservoir from the Keduang River basin is the primary cause of the current sediment-related problems on the intake structure. The Keduang River enters the reservoir portion just the upstream of the dam and has deposited massive quantities of sediments in the area adjacent to the dam.

Furthermore, a considerable quantity of vegetative debris and garbage washes into the forebay area around the intake in the beginning of the rainy season. Partial blockage of the intake structure by garbage frequently occurs. As a result, the intake structure is shut down on a regular basis to remove the vegetative debris and garbage. Approximately for 20 days per rainy season, the intake trash-rack is blocked by such garbage causing the hydraulic head across the turbines to drop and the turbines to be shut down. The trash-rack is then cleaned by divers.

The sediment deposited in the forebay area consists of very fine materials (wash load). No sands are contained in the sediment deposits. Neither wear (abrasion) nor related problems have occurred with respect to the power turbines and no parts of the turbines have been replaced since operation began in the mid 1980s. This indicates that only very fine sediment materials such as clay and silt have passed through the turbines.

From a preliminary analysis on the suction effect of the intake inlet, it appeared that friction velocity at the inlet is around 0.24 m/s, which is far larger than the estimated critical tractive velocity of 0.01 m/s for the sediment deposits at the intake ($D_{60\%}$=0.01 mm). This implies that, if no garvage deposits exist, the intake blockage would not occur.

(2) Decrease of Effective Storage due to High Sediment Yield in Wonogiri Watershed

The average annual sediment inflow into the Wonogiri Reservoir in 1993-2004 is around 3.18 million m^3. The Wonogiri Reservoir has been filled with sediments more rapidly than that initially conceived since its completion in 1980. As discussed above, it is forecasted that the main function of water supply will be seriously affected within the coming 50 to 60 years.

The source of the sediment deposits is the Wonogiri watershed. As discussed in detail in Chapter 4 of the Interim Report, almost 95% of the source is surface soil erosion from cultivated lands.

The Upper Solo (Wonogiri) Watershed Protection Project funded by IBRD was carried out by the Ministry of Forestry for the period from 1988/89 to 1994/95. The purpose of the project was to reduce the surface soil erosion from the Wonogiri watershed and thereby to extend the reservoir life. The soil conservation practices were adopted, including improving farming techniques to reduce sheet and rill erosion, and structures to reduce gully and river bank erosions.

Historical change of the Wonogiri storage capacity (sum of the effective and dead storage zones) since its completion in 1980 is shown in Figure 4.1.3, in which the reservoir sedimentation survey was conducted in 1990, 1993, 2004 and 2005, resepectively.

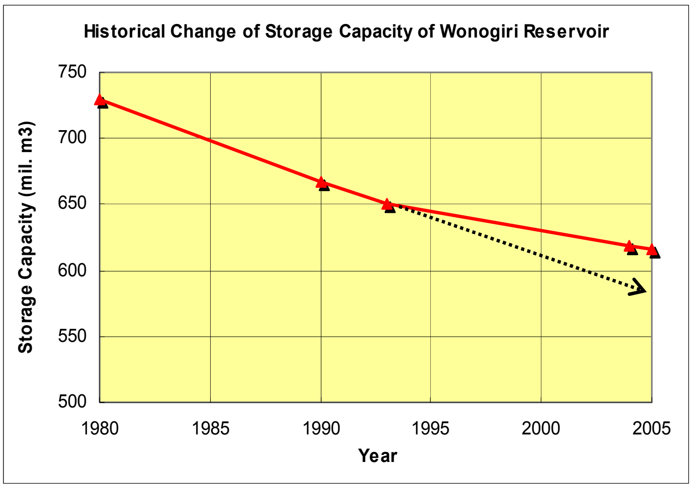

Figure 4.1.3 Historical Change of Wonogiri Reservoir Capacity

The averaged reservoir sedimentation rates were around 6.2 million m^3/year in 1980-1990, 5.7 million m^3/year in 1980-1993, 4.6 million m^3/year in 1980-2004 and 4.7 million m^3/year in 1980-2005, respectively. On the other hand, the sedimentation rate apparently decreased from 5.7 million m^3/year in 1980-1993 to 2.8 million m^3/year in 1993-2005.

The annual sediment inflow volume highly depends on hydrological condition in each year, which is usually represented by the hydrological dry year and wet year. Therefore, the sedimentation rate varies year by year. It appears that one of the causes for such significant difference in sedimentation rates before and after 1993 is that many historic large floods with a peak discharge of more than 2,500 m^3/s have occurred only in 1980s, resulting in massive sediment inflows into the Wonogiri Reservoir. The other conceivable cause is the reduction of surface erosion rate from the Wonogiri watershed after completion of the said project by the Ministry of Forestry in 1988/89-1994/95. The historical change of the Wonogiri Reservoir capacity reveals that a significant reduction in the soil erosion entering the reservoir has occurred as a result of the project.

(3) Risky Operation of Reservoir against PMF due to Decrease of Effective Storage

According to the operation rule, during the flood period from 1st December to 15 April, the reservoir water level has been controlled so as not to exceed the Control Water level

(CWL: EL. 135.3 m) for securing the dam safety against PMF. However, the operation records of the Wonogiri Reservoir in 1991-2005 show that no observance of maintaining CWL has been so far made except the hydrological dry years of 1996 and 1997. In the hydrological ordinary year, the reservoir water level has been raised up to around EL. 137 m exceeding CWL (EL. 135.3 m) and NHWL (EL. 136.0 m).

For detailed description of the operation records, please refer to the ***Interim Report*** of the study.

Figure 4.1.4 below presents the annual maximum excess of water volume stored in the reservoir water levels higher than CWL (EL. 135.3 m) during the flood period. The excess water of 140 million m^3 was stored when the maximum reservoir water level was El. 137.23 m on April 5, 2001 exceeding CWL (EL. 135.3 m) by 1.93 m.

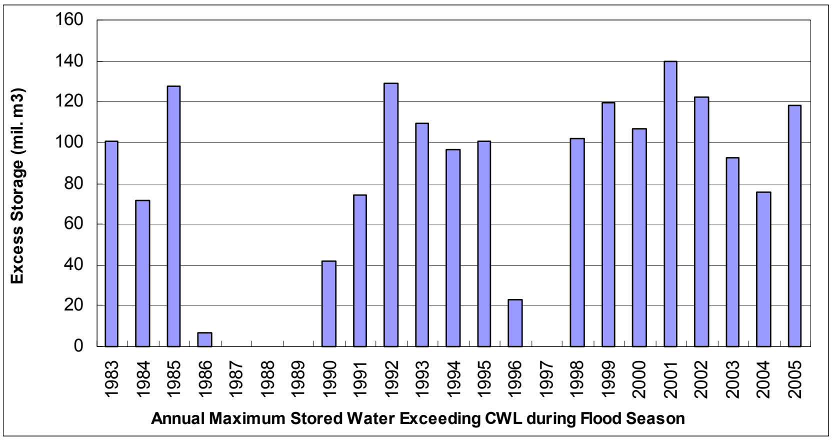

Figure 4.1.4 Annual Maximum Stored Water Volume Exceeding CWL during Flood Season

The current capacity of effective storage zone between LWL (EL. 127.0 m) and NHWL (EL. 136.0 m) has decreased from 440 million m^3 in 1980 to 375 million m^3 in 2005. Therefore, under the current practice of the Wonogiri Reservoir operation that the Wonogiri Reservoir stores water up to around El. 137.0 m, totally 450 million m^3 (= 375 + 75) of water has been stored and used for hydropower generation and irrigation water supply. The storage volume exceeds the initially allocated storage of 440 million m^3.

Due to the excess storage of water during flood season, the water level in the Wonogiri reservoir is usually higher and the flow becomes slower. As a result, sediment release from the reservoir becomes less and the sedimentation in the reservoir deteriorated.

(4) Prediction of Long-term Sedimentation in Keduang Area of the Wonogiri Reservoir

For predicting future sedimentation in the Wonogiri reservoir, long-term simulation of bed deformation, usually during 100 years, is necessary. However, simulation for 100 years by using two-dimensional model proposed above is almost unacceptable because of large amount of the computation. Usually a one-dimensional model is employed for long-term simulation instead.

In this section, one-dimensional simulation of long-term sedimentation during 100 years is introduced.

Plan-form of the Wonogiri reservoir is complicated because of the inflow rivers (6 major rivers). Therefore, for whole of the reservoir, a one-dimensional method is inappropriate.

The above simulation has shown that the sedimentation in the front area of the dam is mainly contributed by the flood flow from Keduang river. Effect by the other inflow rivers is minor. Herein, one-dimensional simulation of sedimentation for 100 years in Keduang river area is conducted. By the simulation, sedimentation in Keduang bay area can be evaluated.

The simulation area is as follows:

- The upstream end (cross section) is located at where effect due to backwater from the Wonogiri reservoir could almost be ignored.
- The downstream end is at peninsula in the front of the dam.
- Topographic measurement of the reservoir in October 2004 is employed as the initial bed level for the simulation.

Locations of the cross sections for computation are shown in Figure 4.1.5.

Actual inflow and outflow during 1993-2004, as shown in Figure 3.5.2~3.5.23, are employed. 9 more cycles of the inflow and outflow (1993-2004) are repeated. As the downstream boundary condition, water level at the downstream end (the peninsula location) is specified. The water level is calculated according to the H-V curve (Figure 3.4.2) and the balance between the inflow and the outflow in the period of the Wonogiri reservoir. The sedimentation in the main body of the reservoir is not considered. This may result in underestimation of the sedimentation in the area near the downstream end.

Prediction result of bed level variation in longitudinal profile is shown in Figure 4.1.6. It shows that finally, the bed level in Keduang bay area will aggradate to about 133.7m. It means that comparing with the current sedimentation, more than 3m sedimentation in near future will occur in Keduang bay area. In Keduang river, the sedimentation will be little because the river width is relative narrower and the flow is fast. Near the peninsula in the front of the dam, no sedimentation will occur. However, it should be emphasized that this may be underestimated because of the specification for the downstream boundary condition on flow in main body of the reservoir. In the first stage of rainy season, water level in the reservoir is always lower, at about 127~129m. This may result in erosion of bed in the front of the dam because the water is relative shallower and the flow velocity is fast. Furthermore, the sedimentation in Keduang bay area may also be underestimated because the bed level at the downstream end is lower. This is a limit of the simulation by one dimensional model. For the simulation of sedimentation in the Wonogiri reservoir, the whole reservoir area should be taken into account.

The measurements and the simulation results by the two-dimensional model have shown that similar to the sedimentation in Keduang bay area, severe sedimentation in the peninsula area as well as the area around the intake also occurs. Therefore, it might be estimated that in near future, severe sedimentation in the area around the intake will occurs as that in Kedunag bay area. This will result in blockading the intake. Urgent measures are necessary against the problem.

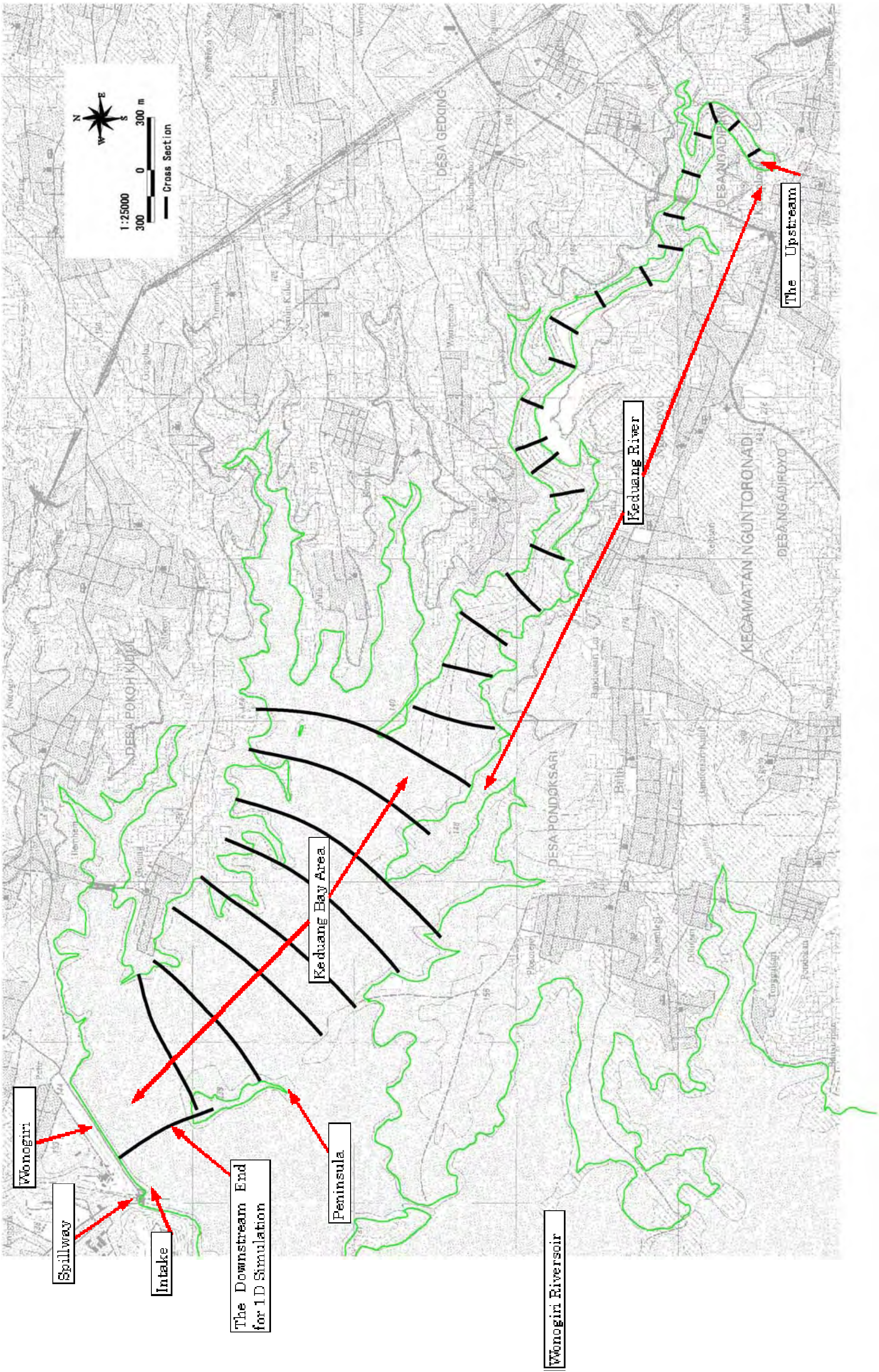

Figure 4.1.5 Cross Section in Keduang Area for One-dimensional Simulation

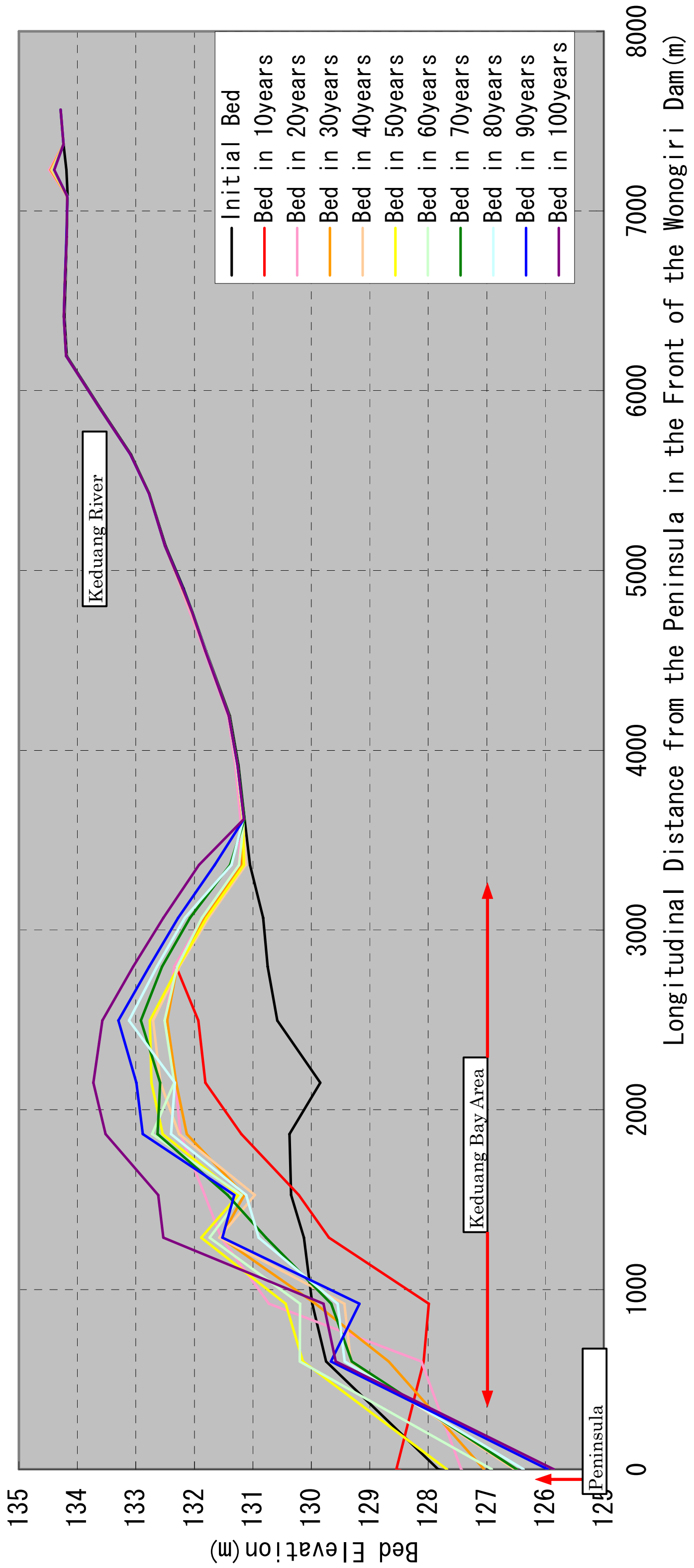

Figure 4.1.6 Computational Results of Bed Level Variation in Longitudinal Profile in Keduang Area

4.2 Projection of Future State of Wonogiri Reservoir Sedimentation in Case without Countermeasure

Severe sedimentation has occurred in the Wonogiri Reservoir. As a result, the storage volume of Wonogiri Reservoir has been reduced every year. Based on the annual average sediment balance with the reservoir capacity mentioned above, the future state of Wonogiri Reservoir on the condition without any countermeasure for the sedimentation problem is preliminarily projected as described below:

i) If any reservoir sediment management measure is taken up from now on, it is forecast that problems of sediment blocking at the intake structure take place within the projection period of 100 years.
ii) The continuing sedimentation occurs only in both of the effective and dead storage zones below NHWL (EL. 136.0 m).
iii) The current sedimentation condition in 2005 that is illustrated in Figure 4.1.1 above is adopted as the initial condition for the projection.
iv) The annual average sediment inflow volume is assumed to be 3.18 million m^3, which is equivalent to the average one in 1993-2004 as shown in Figure 3.6.1 above. On the other hand, the annual sediment outflow is assumed to be 0.41 million m^3 which is the estimated average one for the period from 1993 to 2004 by the Wonogiri Reservoir sedimentation analysis model in this Study, consisting of 0.26 million m^3 through the Intake for power generation and 0.15 million m^3 through the existing spillway (Figure 3.6.1).
v) Annual deposition rate is assumed at 50% for the effective storage zone and at 50% for the dead storage zone based on the sedimentation volume in 1980-2005 (See Table 4.1.2 above).

The projected condition in the year 2105 is illustrated in Figure 4.2.1 below:

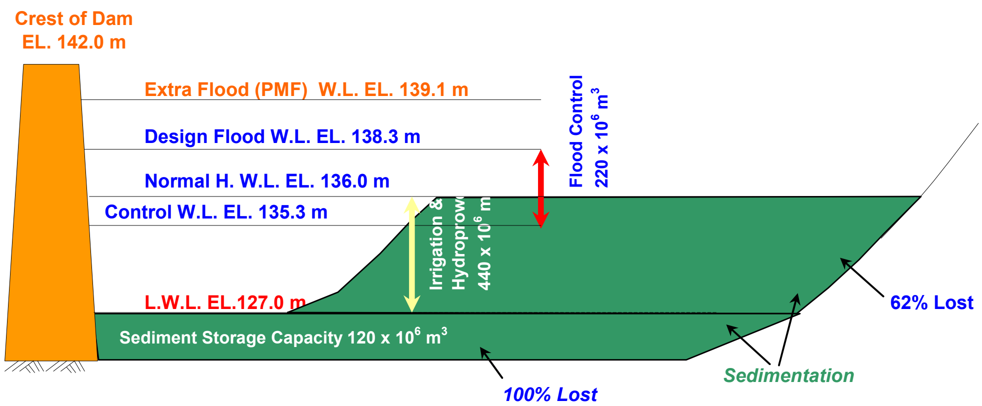

Figure 4.2.1 Projected Sedimentation Condition of Wonogiri Reservoir in Year 2105

By year 2051, the Wonogiri Reservoir will lose around 28% of its effective storage capacity and completely lose its dead storage capacity. Furthermore, the Wonogiri Reservoir will lose about 62% of the effective storage capacity around by the year 2105. As of 2005, around 21% of the original capacity below NHWL (El. 136.0 m) is lost as shown in Table 4.1.1 above.[7]

In general, impact or severity of reservoir sedimentation problems is represented by the years taken to lose half the initial reservoir volume. It is generally recognized that reservoirs often experience the serious operational constraints by the time when half its original capacity is lost.[8]. As estimated above, the Wonogiri Reservoir will lose half of the capacity by the year 2062. Concerning the current water uses such as hydropower generation, irrigation and domestic water supply, the situation is severe.

4.3 Countermeasures against Sedimentation in the Wonogiri Reservoir

The sedimentation in the Wonogiri reservoir is severe and the situation is deteriorating. Countermeasures against the sedimentation are necessary. The countermeasures consist of the river basin measures (soft) and the structure alternatives in the reservoir.

4.3.1 Restricting Conditions for Structure Alternative Countermeasures

In view of considering sediment management alternatives, restricting conditions for alternative countermeasures shall be screened from the aspects of flood control and water use.

(1) Flood Control Operation

Flood control plan of the Wonogiri Reservoir is to regulate the design flood with peak discharge 4,000 m^3/s to the outflow at maximum discharge 400 m^3/s by flood control gates. Hence in case of flood inflow contains sediments, outflow from reservoir shall be regulated not to exceed 400 m^3/s.

(2) Available Water for Sediment Release (Flushing/Sluicing)

In case of lowering the reservoir water level under NHWL by releasing the stored water, it seems difficult to utilize the storage water for sediment release. Figure 4.3.1 shows the actual reservoir operation of the Wonogiri Dam in 1983 -2005. In 1983 - 1991, water level had been kept under EL.136.0 m of NHWL. While from 1991 up to now, water level during flood season has been raised to EL.137.0 m except draught years. The Wonogiri reservoir operation rule has not been observed since 1991. However, it appeared that the mean annual water release from spillway in 1983 - 2005 is around 210 million m^3. This released water might be used for sediment releasing from the Wonogiri reservoir.

---

7 JICA Study Team, The Study on Countermeasures for Sedimentation in the Wonogiri Multipurpose Dam Reservoir, Chapter 9, Interim Report, 2006.

8 Gregory L. Morris、P.E. Ph.D., Reservoir Sedimentation management, Worldwide Status and Prospects, Session on Challenges to the Sediment Management for Reservoir Sustainability, The 3rd World Water Forum, 2003

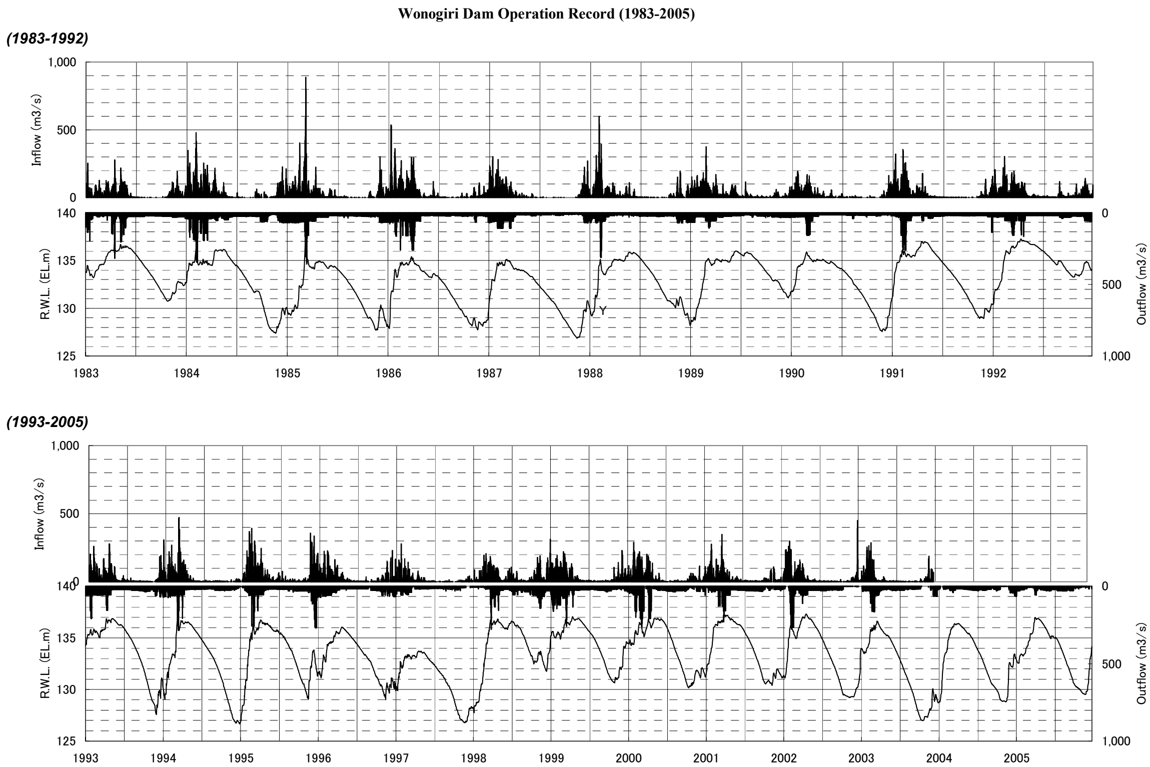

Figure 4.3.1 Wonogiri Dam Reservoir Actual Operation

(3) Restricting Conditions from Water Utilization

In the original design, 440 million m^3 of effective storage capacity is allocated to irrigation and hydropower use. To meet with such requirement, NHWL of EL.136.0 m should be kept at the end of wet season. Therefore it is unable to lower the reservoir water level in the flood season. On the other hand, Control Water Level (CWL) of EL.135.3 m has been designated during the flood season from December 1st to April 15th for eliminating the possibility of overtopping of the dam crest due to PMF. According to the Figure 4.3.1, the month being lowest water level is obviously identified in November to December, which is in the end of dry season and the beginning of wet season. Therefore, from the beginning of wet season, it seems effective to use inflow discharge for sediment releasing. However, from the actual dam reservoir operation, as the Wonogiri reservoir storage turn-over rate is as small as 2-4 times, CWL shall be raised from EL.135.3 m.

(4) Existing Facilities for Water Release

a) Location of Outlet Facilities

Outlet facilities, consisting of intake for hydropower and spillway (see Figure 3.1.1 for their locations), are located at the left side of the dam. The Keduang River inflow runs to the right side of dam and then turns its direction to the left side due to the dam body, running in front of the dam to outlet facilities. On the way to the outlet facilities, massive sediment inflow from the Keduang River has deposited in front of the dam body and outlet facilities.

b) State of Intake

The intake facility for irrigation and hydropower is set on its foundation height EL.116.0

m, which is 11 m below the planned sediment deposit elevation. The inlet is the only facility that sediment could be released to the Solo River downstream below EL.131.0 m of spillway weir crest. This inlet was constructed by ditching the natural ground whose elevation was approximately EL.126.0 m at the right side and EL.129.0 m at the left side on average. This topographical condition looked like a vase where the rim was EL.126.0 m and the bottom was approximately EL.110.0 m, which was the original Keduang Riverbed. This condition contributed to the sedimentation, and consequently at and around of the intake had been surrounded by sediment. Sediment deposited on the original ground table EL.126.0 m of right side and EL.129.0 m of left side, had dropped into the ditch of the intake and accumulated in front of the intake. When trash rack on the intake surface was blocked with garbage, sedimentation occurred on the intake. It might be closure from lower portion. Figure 4.3.2 shows the image of sediment transportation from the intake facility. According to the interview to PLTA Wonogiri, garbage removings have been conducted at least twice a year in June and December since 1993.

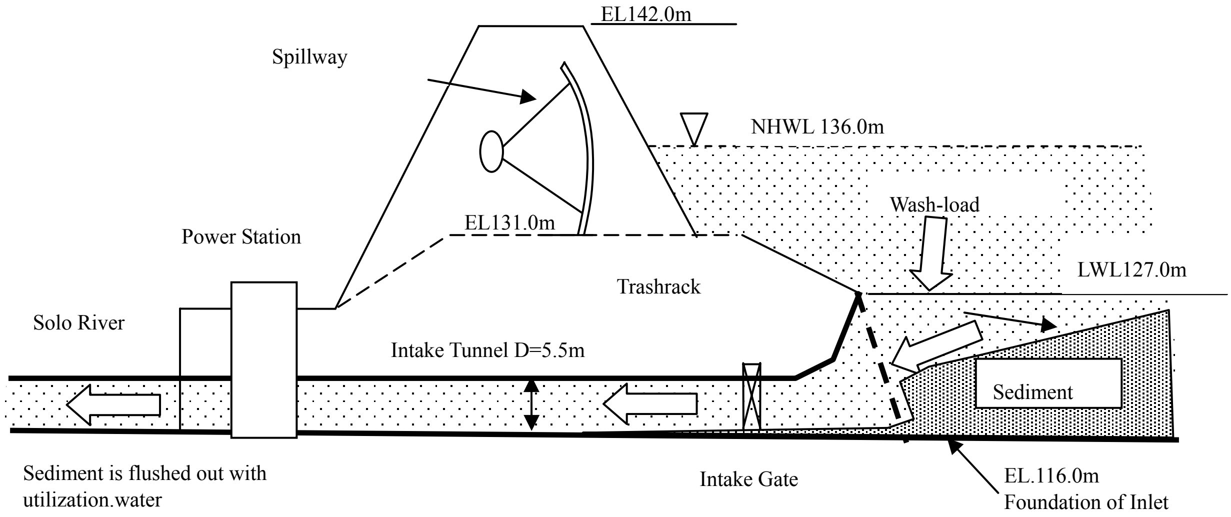

Figure 4.3.2 Image of Sediment Transportation at Intake Facility

c) State of spillway

Overflowing portion of spillway is set at EL.131.0 m. Sediment flushing can not be conducted until the sediment deposit exceeds EL. 131.0 m.

4.3.2 Distribution of Wonogiri Reservoir Sedimentation

The Wonogiri Dam reservoir is primary separated the Keduang River portion and the Solo River portion including other rivers, and the Keduang River occupies one-third (1/3) of the Wonogiri Dam catchment, whereas the capacity of the reservoir for the Keduang River portion is presumed to occupy only one-thirtieth (1/30) of the whole reservoir capacity, and that outlet of the Keduang River is very near to the dam. Partly due to the special locations of intake and spillway for water release, most of the sediments from the Keduang River deposited in forebay area near the dam. As a result, portion of the Keduang River reservoir has been filled with sediment rapidly.

On the other hand, during flood in Keduang river, portion of the sediment from Keduang river was transported inversely to the reservoir center area. The sediment supplied from the other rivers almost cannot be transported to the area near the dam.

The above feature of sedimentation in the Wonogiri reservoir is important for considering countermeasures against the sedimentation. The major countermeasures should be river basin measures (mainly soft measures) for the sediment supplied from other rivers except Keduang river. For the sediment from Keduang river, structure measures might be possible. Hereinafter, the later will be discussed.

4.3.3 Conceivable Alternative Structures

The sedimentation problems of the Wonogiri reservoir have become quite serious in view of the following points:

(a) Sediment deposits near the intake
(b) Decrease of effective storage volume
(c) Higher sediment yield in watershed of the Wonogiri Dam

Figure 4.3.3 presents conceivable structural countermeasures to be studied for technical evaluation, and illustrated in Figure 4.3.4.

(1) Countermeasures for Sediment Deposits and Garbage at Intake

The following alternative countermeasures are conceivable as those to tackle for sediment deposits at the intake:

- Construction of intake structures to keep proper function of intake structure even in case it is completely filled with sediments.
  1) Modification of the intake
  2) Relocation of the intake
- Construction of garbage trapping structures
  3) Garbage trapping structure at intake
  4) Garbage trapping structure at Keduang River
- Removal of sediments deposited at the intake
  5) Hydro-suction sediment removal system
  6) Hydraulic dredging

(2) Countermeasures for Sediment Inflow from Keduang River

1) Keduang River sediment bypass
2) Sediment sluicing by new gates
3) Compartmented reservoir with new flushing gates

(3) Countermeasures for Sediment Inflow from Other Tributaries

1) Sediment storage dam for sediment removal
2) Hydraulic dredging in reservoir
3) Dry excavation in reservoir
4) Managing of sediments within reservoir by water releasing from the intake
5) Re-allocation of reservoir storage capacity

The alternatives (2) will be evaluated by the reservoir sedimentation analysis model---NKhydro2D model.

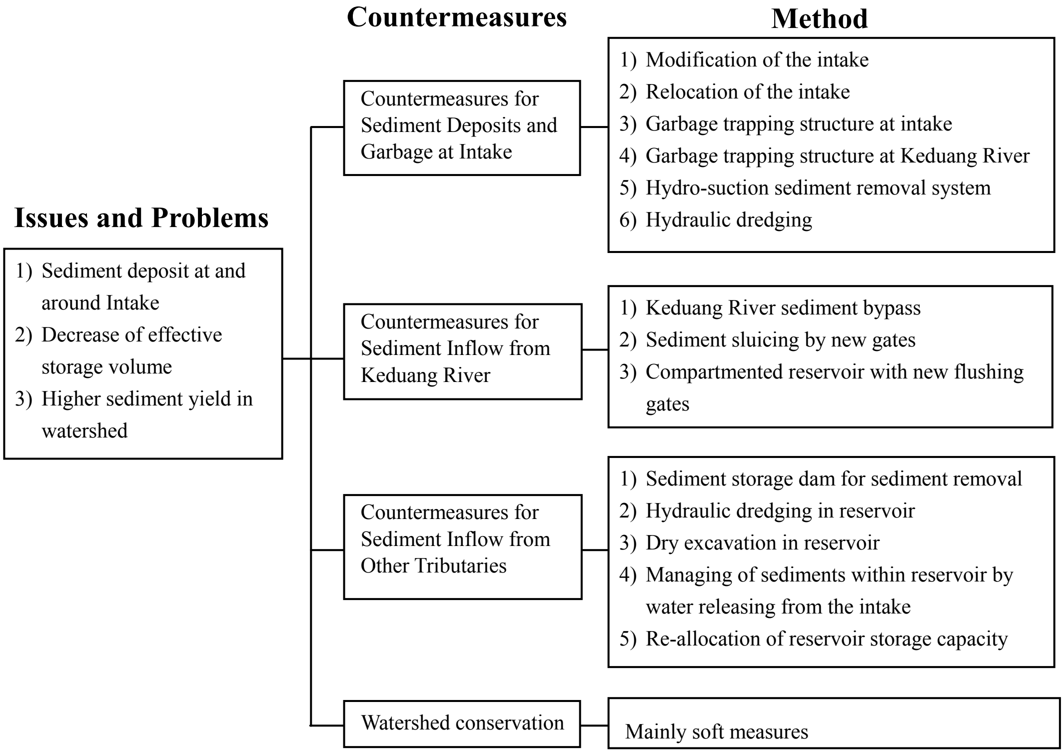

Figure 4.3.3 Conceivable Countermeasures for Wonogiri Reservoir Sedimentation Issues

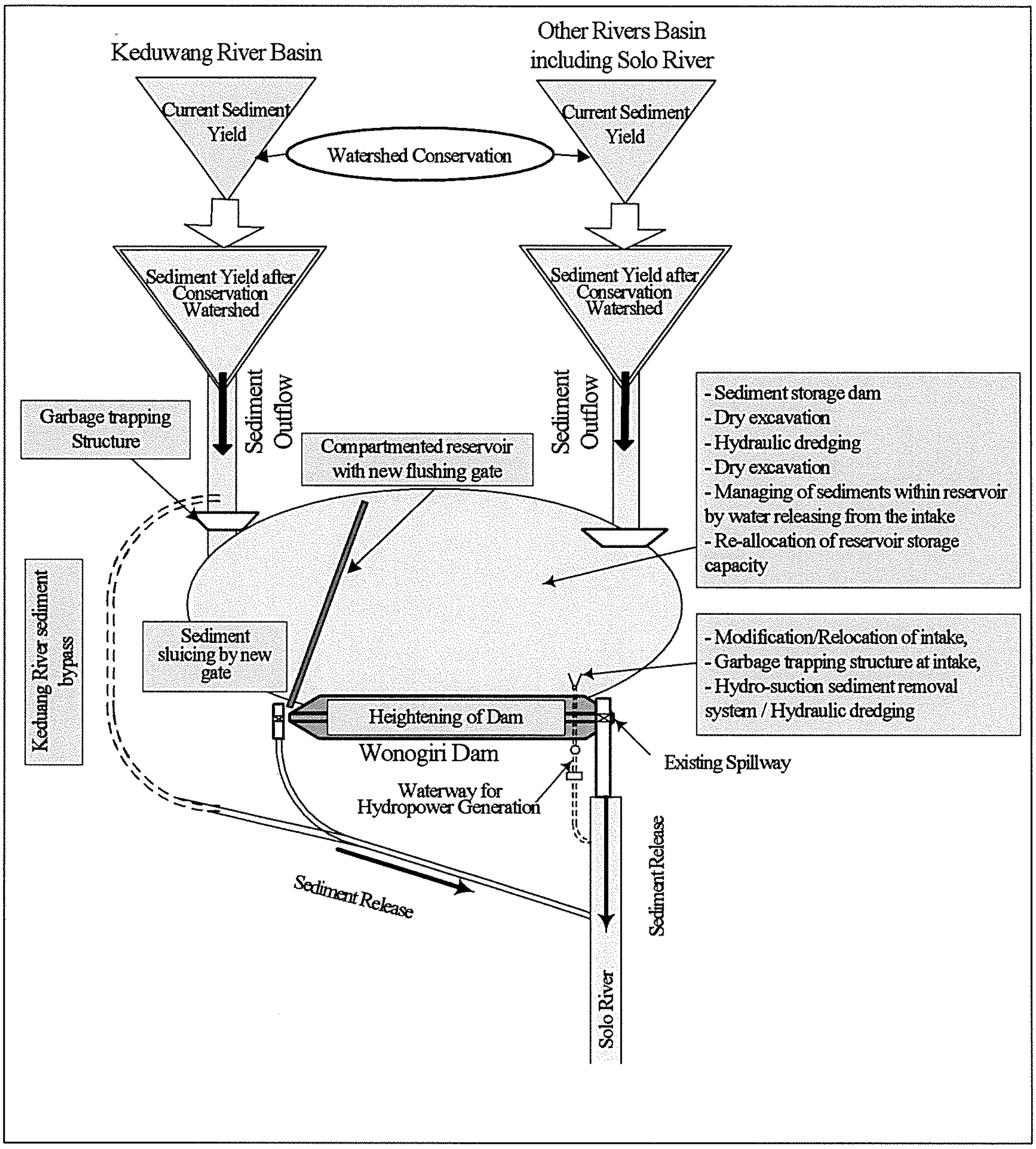

Figure 4.3.4 Illustrated Conceivable Countermeasures for Wonogiri Sedimentation Issues

4.4 Preliminary Evaluation of Structural Countermeasures for Sediment Inflow from Keduang River

Conceivable structure alternatives for the sediment from Keduang river are shown in Figure 4.4.1:

1) Keduang River sediment bypass: diverting portion of Keduang river flood from the reservoir at the inflowing location (Bypass route B)
2) Sediment sluicing by new gates: setting a new gate near the right end of the dam for sluicing the Keduang river flood
3) Compartmented reservoir with new flushing gates and dike: constructing a dike up to the level 138.3m to divide the reservoir into Keduang portion (right) and the main body (left), a new gate near the right end of the dam for sluicing the

Keduang flood and a weir for the water exchange between the Keduang portion and the main body.

Dam area of the Wonogiri reservoir and image for dike and weir are shown in Photo 4.4.1.

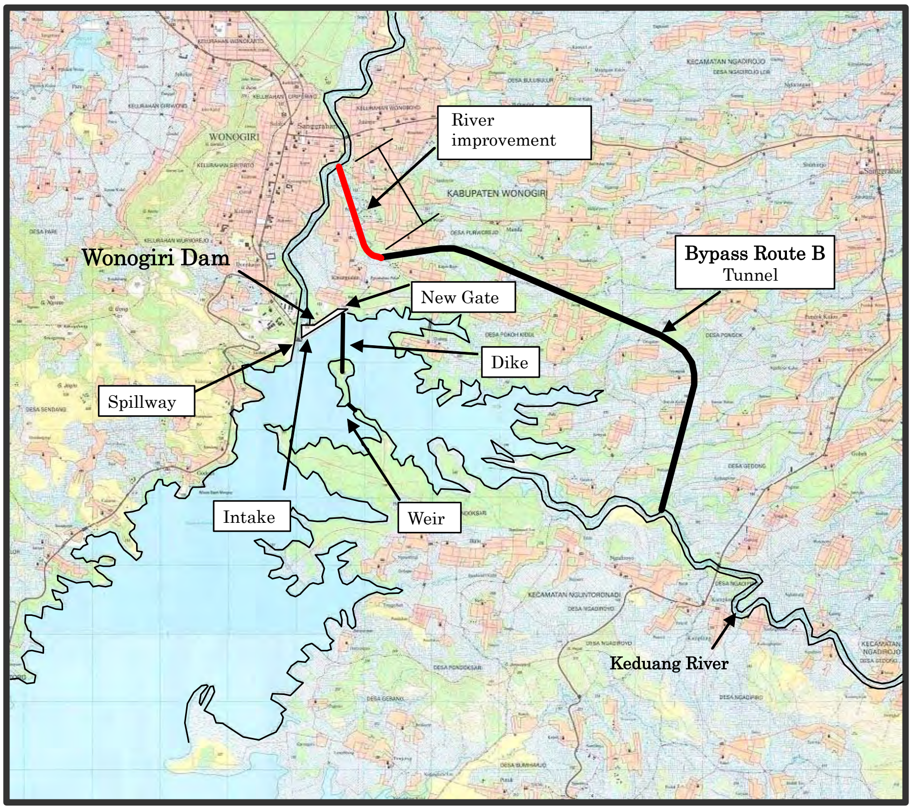

Figure 4.4.1 Locations of Conceivable Structure Alternatives for the Keduang River

Dam Area of the Reservoir and Image of Locations for Dike and Weir

By using the above reservoir sedimentation analysis model --- NKhydro2D model, simulations are conducted under the conditions of structure alternatives for the sediment from Keduang river and the computational results of sedimentation distribution and sediment release from the reservoir are evaluated for comparing the effect of the alternatives. Besides the simulations with the alternative conditions, simulation under the current facility condition (without hard countermeasure) is also conducted as a basic case. In this case, besides the water release through the intake, release at maximum 400m^3/s from the existing spillway is also considered when the water level in the reservoir is above 131.5m as well as the flood discharge from Keduang river is over 50m^3/s.

4.4.1 Computational Conditions

The computational domain and grids are the same as those for the calibration and verification, as shown in Figure 3.1.1.

(1) Flow Conditions

For the predictions, flow conditions of hydrological dry year, hydrological average year as well as hydrological flood (wet) year are considered. According to the hydrological and meteorological data in the Wonogiri reservoir since 1993, it shows that the rainy seasons of 2004~2005, 1995~1996 and 1998~1999 are the representatives for the hydrological dry year, hydrological average year and hydrological flood year, respectively. The hydrographs of total inflow and that from Keduang river are shown in Figure 4.4.2 ~ 4.4.7. The total volumes inflowing into the reservoir are 0.8 billion m^3, 1.3 billion m^3 and 1.5 billion m^3, respectively.

According to the hydrological and meteorological feature in the region, the evaluation is focused on the flow and sediment transportation in the rainy season. Therefore, the simulation starts from November 1 (the common beginning of the rainy season) and ends at the end of next May. The initial water level in the reservoir is specified to 129m.

For the hydrological dry year, the simulation is conducted in period of November 23 ~ next May 15, because of limitation in the hydrological data.

Water release through the existing spillway is specified to zero. Discharge through the intake for hydropower generation is specified according to the monthly-averaged discharge at Colo weir which is located at about 14km downstream away from the Wonogiri dam. The monthly-averaged discharge at Colo weir is listed in Table 4.4.1.

Table 4.4.1 Monthly-averaged Discharge at Colo Weir in Downstream Side of the Wonogiri Dam

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Discharge (m^3/s)	48.4	70.2	74.0	54.1	26.2	23.3	23.3	22.5	25.6	26.0	29.0	35.5

For the condition with a new gate, the gate is opened from the beginning of rainy season and closed by the end of next January or when total volume of water release reaches to 0.2 billion m^3.

(2) Other Conditions

Sedimentation volume in the reservoir during 2004~2005 was about 2 million m^3 and there was no significant variation on the bed level in the season. Therefore, for the predictions hereinafter, the initial bed level and the initial bed material distribution of the reservoir are specified as the measurements in October 2004.

The sediment inflow from the rivers is specified according to Equation (2.27) and the discharge in Figure 4.4.2 ~ 4.4.7.

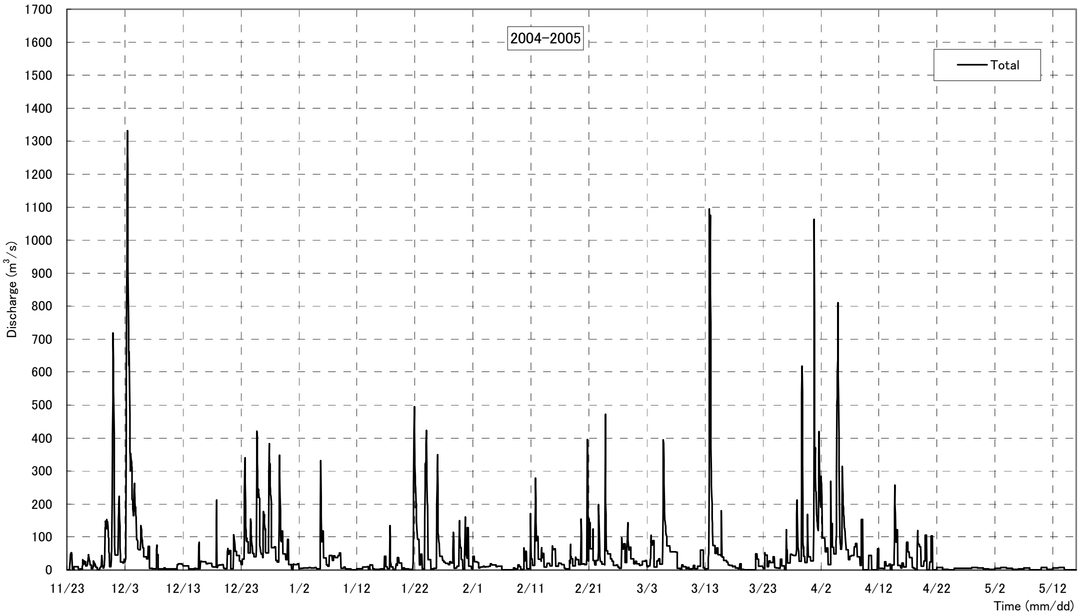

Figure 4.4.2 Representative Hydrograph of Total Inflow in Hydrological DroughtYear (November 2004 ~ May 2005)

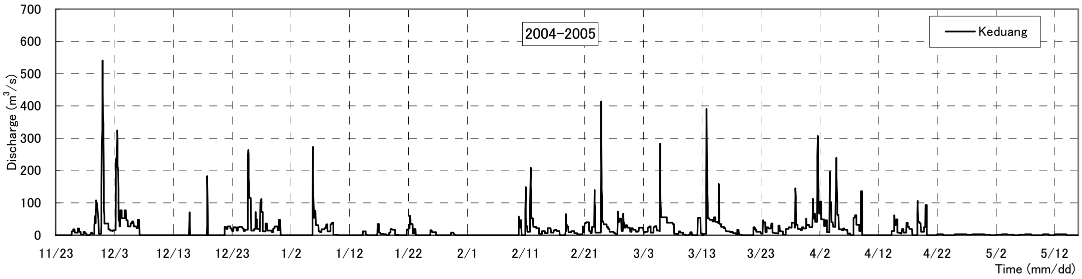

Figure 4.4.3 Representative Hydrograph of Keduang River in Hydrological Drought Year (November 2004 ~ May 2005)

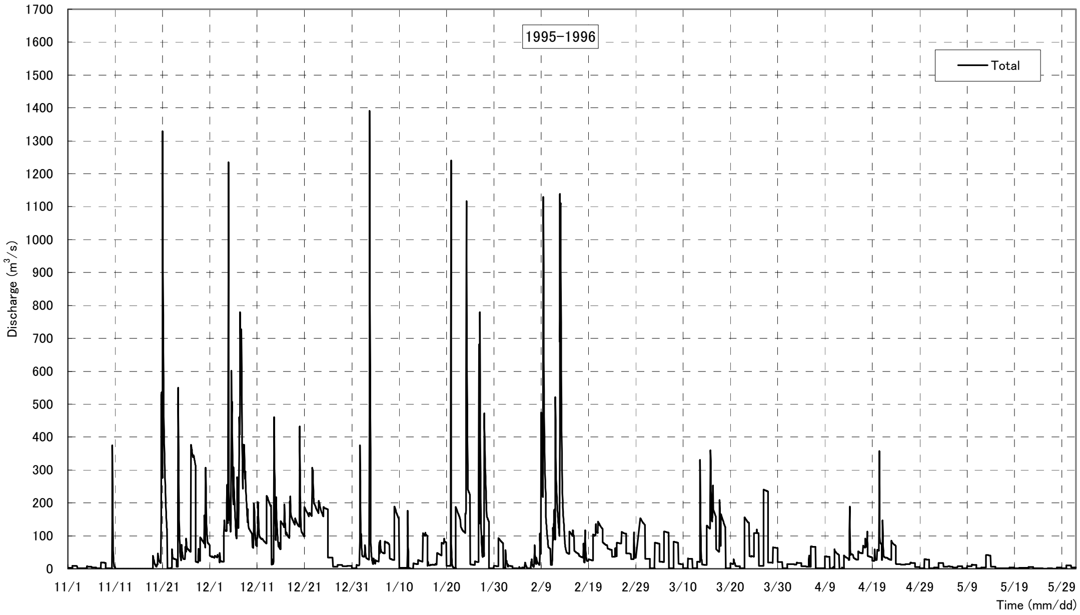

Figure 4.4.4 Representative Hydrograph of Total Inflow in Hydrological Average Year (November 1995 ~ May 1996)

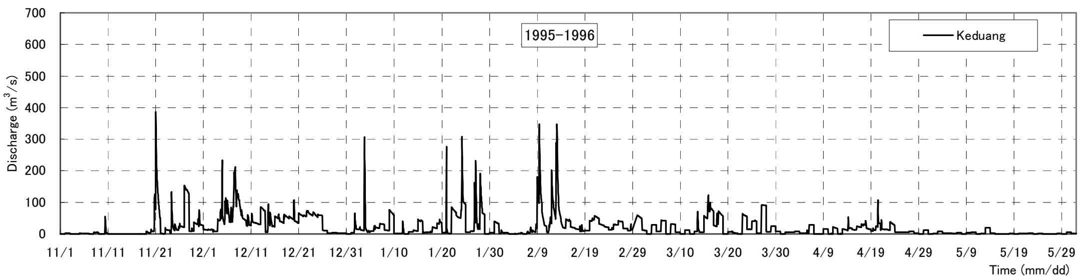

Figure 4.4.5 Representative Hydrograph of Keduang River in Hydrological Average Year (November 1995 ~ May 1996)

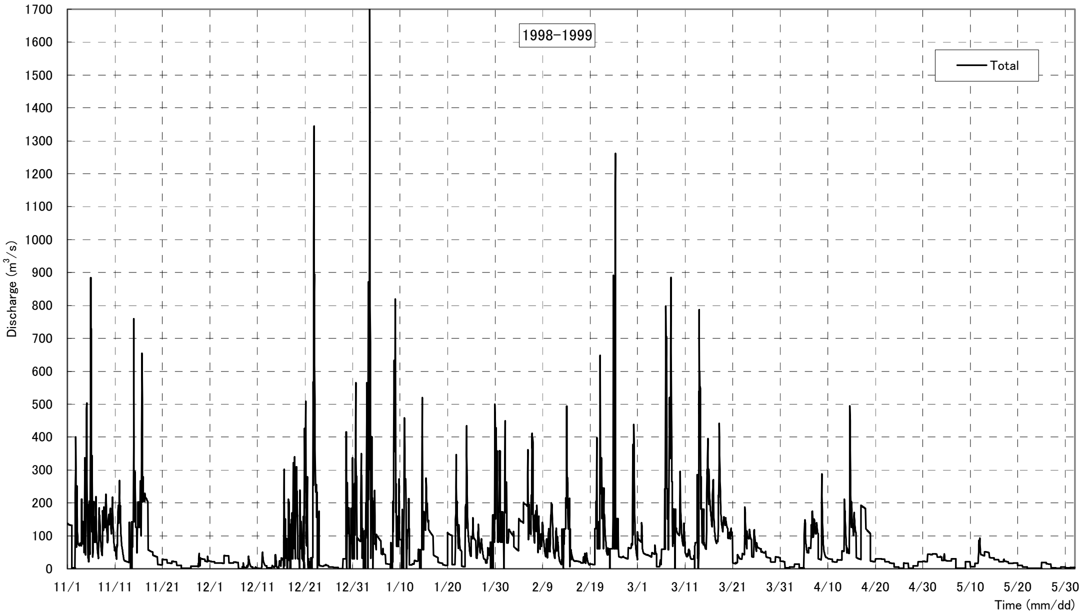

Figure 4.4.6 Representative Hydrograph of Total Inflow in Hydrological Flood Year (November 1998 ~ May 1999)

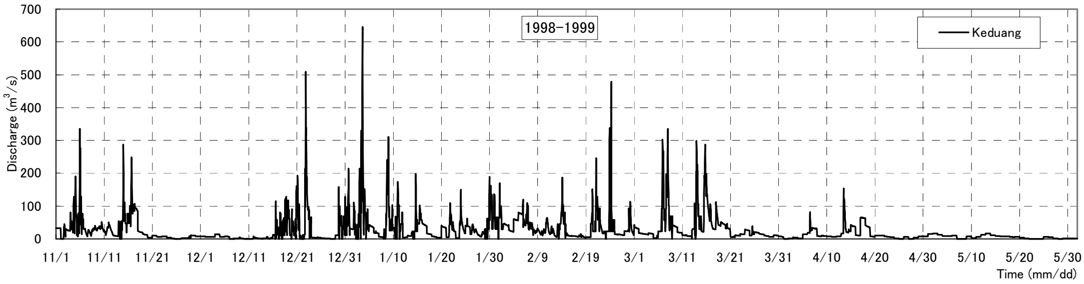

Figure 4.4.7 Representative Hydrograph of Keduang River in Hydrological Flood Year (November 1998 ~ May 1999)

4.4.2 Flood Release from the Existing Facilities Only (Basis Case)

Before the simulations with the alternative conditions, simulation under the current facility condition (without hard countermeasure) is first conducted as a basic case. In this case, besides the water release through the intake, release at maximum 400m^3/s from the existing spillway is also considered when the water level in the reservoir is above 131.5m as well as the flood discharge from Keduang river is over 50m^3/s.

(1) Computational Conditions

Computational conditions are listed in Table 4.4.2.

Table 4.4.2 Input Data for the Simulation (Flood Release from Existing Facilities Only)

Item	Data	Note
Methodology	Depth-integrated 2-dimensional sediment transport model—NKhydro2D model	Based on boundary-fitted orthogonal curvilinear grids
Topogrphical Map	Topographical map with the scale 1:25,000	Published in 1999
Bathymetric data	Cross-section data measured in October 2004	
Inflow Discharge	Temporal discharge (hourly) is employed. Hydrological drought year: Figure 4.4.2 and 4.4.3 Hydrological average year: Figure 4.4.4 and 4.4.5 Hydrological flood year: Figure 4.4.6 and 4.4.7	Data in rainy season are used.
Water Release through intake	Monthly-averaged discharge at Colo weir: Table 4.4.1	
Water Release through spillway	Release at maximum 400m^3/s from the existing spillway when the water level in the reservoir is above 131.5m as well as the flood discharge from Keduang river is over 50m^3/s.	The crest is at the level 131m
Water Level	The initial water level is specified to 129m.	
Bed Material	Data of particle size distribution at different locations sampled in October 2004. As non-uniform material (consists of 9 classes in simulation)	The size in deeper area is quite fine.
Sediment Transport Mode	As both the bed load and suspended load	Non-uniform sediment (consists of 9 classes in the simulation)
Sediment Supply	Sediment transport rate for bed load is calculated by Ashida & Michiue's formula. Concentration of suspended sediment is specified as function of river discharge.	Particle size distribution is considered.
Sediment Release	Sediment release accompanied with water release through the spillway and intake is considered.	Bottom concentration of suspended sediment is specified as the release concentration from the intake.
Other Information	Rainfall, Evaporation, etc.	

(2) Computational Results: Water Release from the Spillway and Reservoir Water Level

Water release discharge and its total volume through the existing spillway, reservoir water level under different inflow conditions are shown in Figure 4.4.8 ~ 4.4.13. In hydrological drought year, water level in the reservoir is lower in the season and the level cannot be recovered to the NWL (Normal Water Level: 136m) by the end of the rainy season, although the total volume of water release through the spillway is only 50 million m^3. The dam operation should be careful.

On the other hand, in both hydrological average year and hydrological flood year, the total volume of water release through the spillway reaches to over 0.2 billion m^3 and the water level in the reservoir can be recovered to NWL in the rainy season.

(3) Computational Results: SS Concentration at Different Locations

SS (Suspend Sediment) concentrations at four (4) locations in the reservoir (the existing spillway, the intake, the right end of dam, bypass entrance) are shown in Figure 4.4.14 ~

4.4.16.

The maximum SS concentrations through the new gate in the early stage (first month) of the season are about 20.3g/l in hydrological drought year, 11g/l in hydrological average year and 13.6g/l in hydrological flood year, respectively. However, after the first stage, the SS concentration becomes lower and the maximum is lower than 6g/l. Check and monitoring are needed from social environmental viewpoint.

There is no remarkable change on the SS concentration at different locations in the reservoir when the reservoir water level is lower in the early stage of the rainy season. However, in the later stage of the season, SS concentration at the bypass entrance is higher than those at locations near the dam. This means that sediment release efficiency might be higher in the location of bypass entrance than that in location near the dam.

SS concentration at right end of the dam is higher than that at the existing spillway, although it is lower than that at the bypass entrance.

(4) Computational Results: Sedimentation Distribution

Sediment release volume through the intake and the spillway and sediment transport volume through cross section No.1 (Figure 3.1.1) are shown in Figure 4.4.17 ~ 4.4.25. The released sediment is quite fine.

Sediment transport volumes through cross section No.1 in hydrological drought year, hydrological average year and hydrological flood year are 12000m^3、5000m^3、3000m^3 , respectively. The results show that the sediment transported to the area near the dam from the upstream rivers except from Keduang river is less.

Sedimentation volume in different area of the reservoir (Figure 3.2.1) is listed in Table 4.4.3. In the 'Area' column of Table 4.4.3, 'PowerPlant' and 'Spillway' represent the existing intake and spillway, respectively. By the results, it can be calculated that sediment trap ratios under different inflow conditions are 82.5％、85％、82.5％, respectively. There is no remarkable difference with different flow conditions. However, in hydrological drought year, water level in the reservoir is lower in the season and the level cannot be recovered to the NWL (Normal Water Level: 136m) in the rainy season. The dam operation should be careful.

Sedimentation in area 'Center' and 'CenterUP' (see Figure 3.2.1 for the location) reduces when inflow increases. In both hydrological average year and hydrological flood year, sedimentation in the reservoir center area decreases and sedimentation in effective storage area in Keduang increases a lot, although sediment release through the spillway increases.

Table 4.4.3 Sedimentation Distribution and Sediment Release Volume
(Flood Release from Existing Facilities Only)

Area	Sedimentation Volume (m3)		
	Drought Year	Average Year	Flood Year
Dam	129,200	101,400	115,400
Keduang	278,200	724,500	847,200
Tirtomoyo	266,600	498,800	638,100
Temon	100,600	81,700	154,100
Solo&Alang	-7,800	632,000	775,600
CenterUP+ Wuryantoro3	689,200	554,500	517,200
Center	432,600	267,200	224,700
Wuryantoro	74,900	199,800	189,400
Wuryantoro2	24,700	52,000	47,100
PowerPlant	350,000	306,600	408,400
Spillway	72,100	242,100	333,300
Total	2,410,000	3,660,000	4,250,000

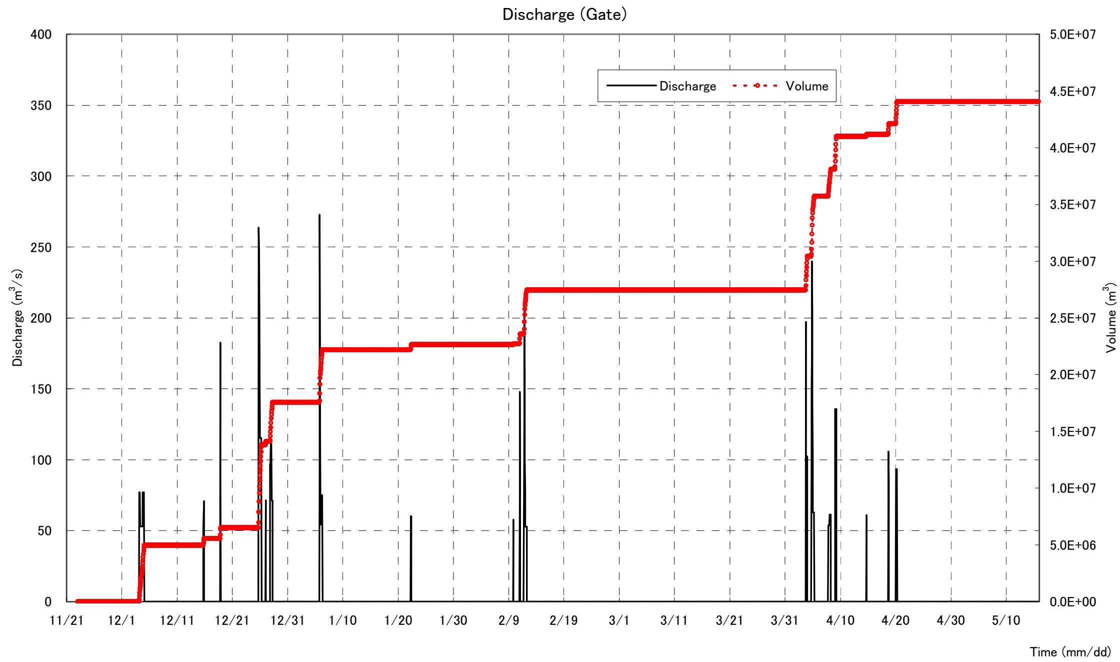

Figure 4.4.8 Release Discharge and its Total Volume through the Existing Spillway in Hydrological Drought Year

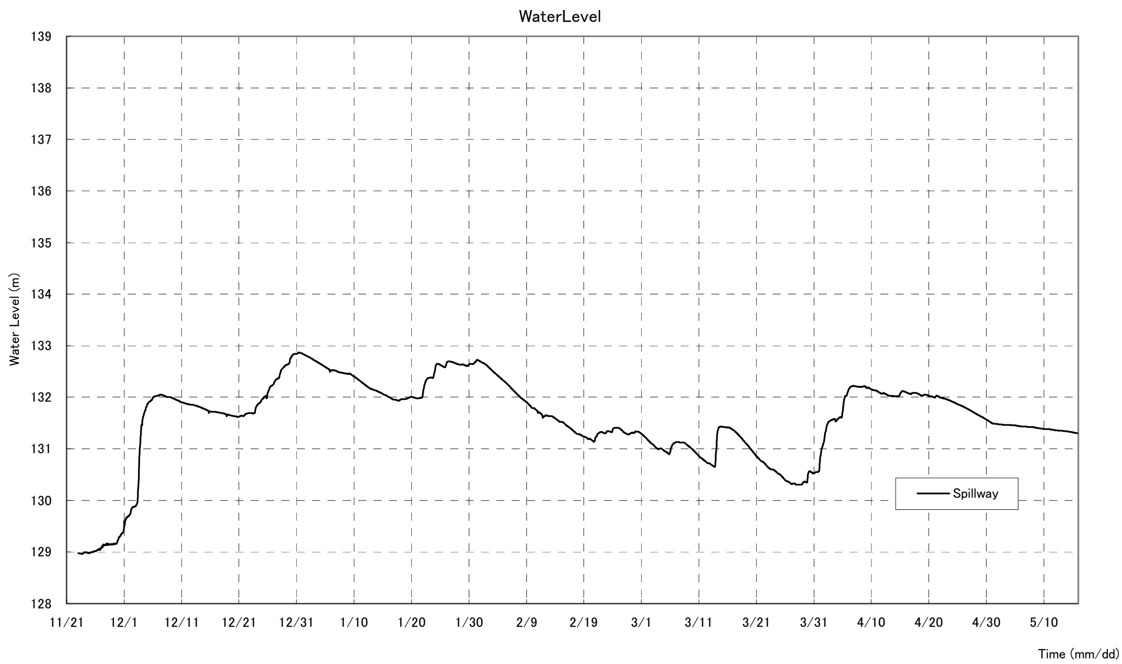

Figure 4.4.9 Water Level in the Wonogiri Reservoir in Hydrological Drought Year

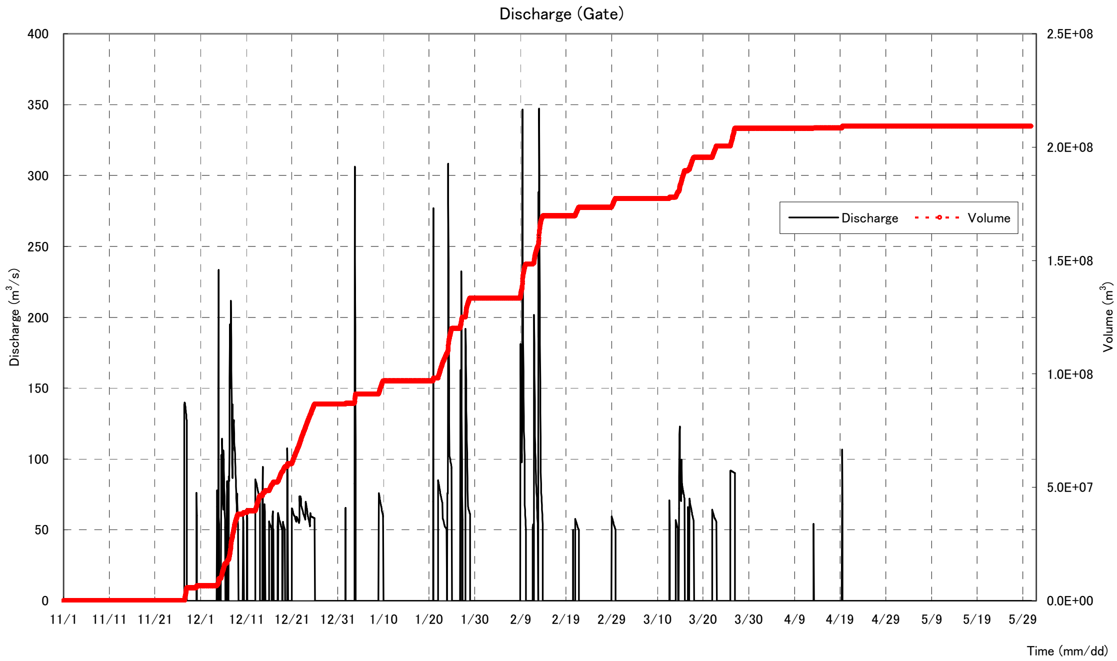

Figure 4.4.10 Release Discharge and its Total Volume through the Existing Spillway in Hydrological Average Year

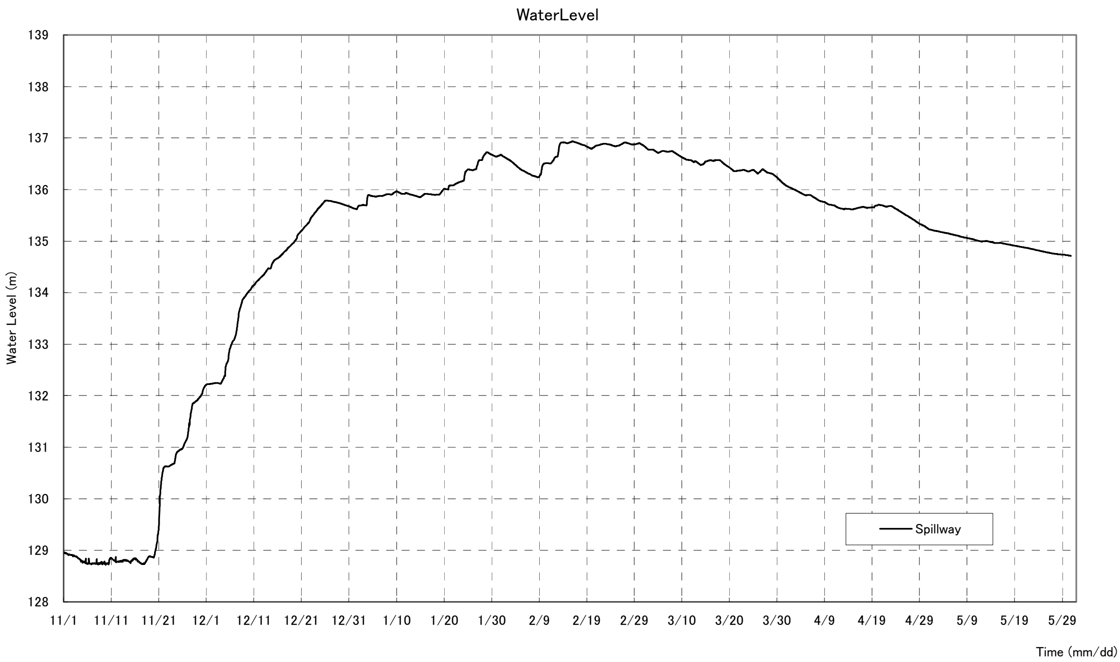

Figure 4.4.11 Water Level in the Wonogiri Reservoir in Hydrological Average Year

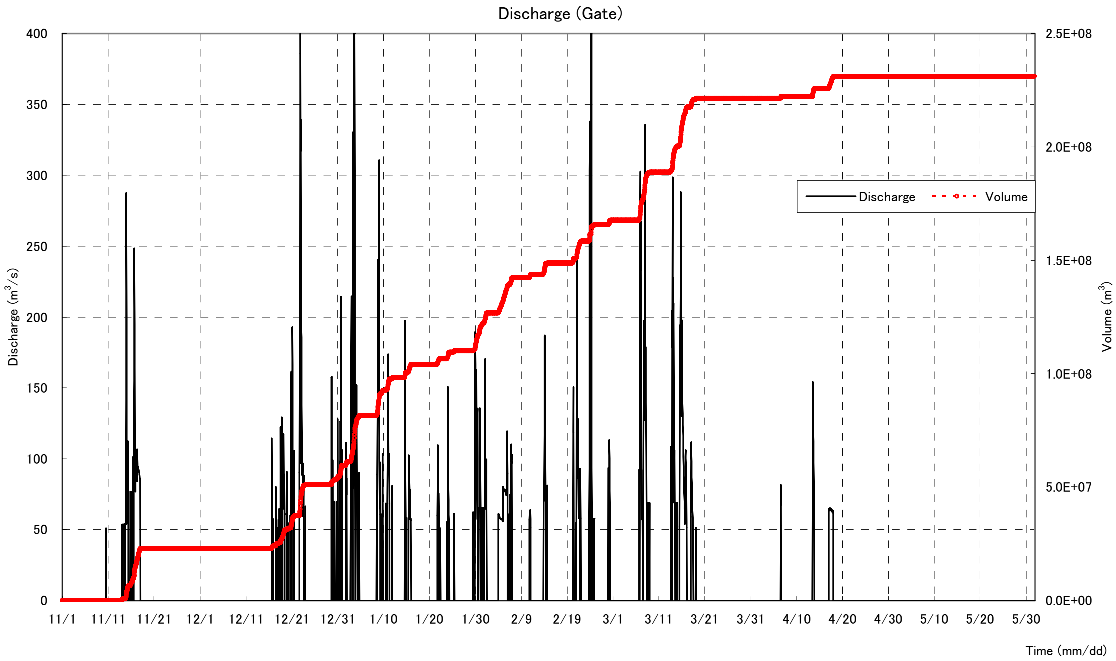

Figure 4.4.12 Release Discharge and its Total Volume through the Existing Spillway in Hydrological Flood Year

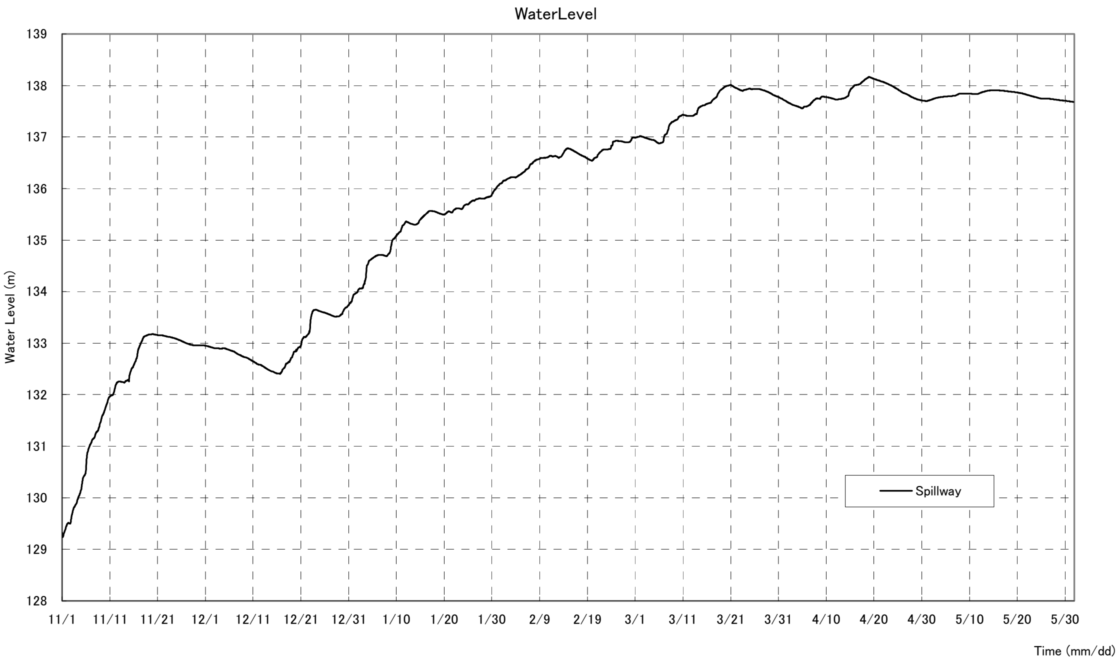

Figure 4.4.13 Water Level in the Wonogiri Reservoir in Hydrological Flood Year

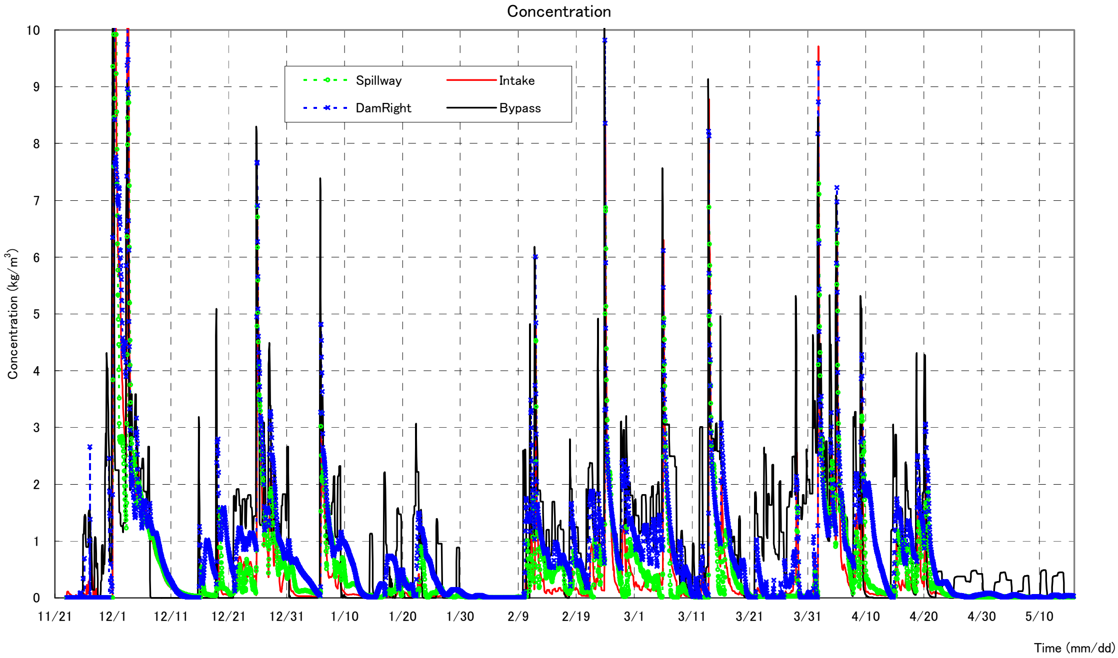

Figure 4.4.14 SS Concentration at Different Locations in the Wonogiri Reservoir in Hydrological Drought Year

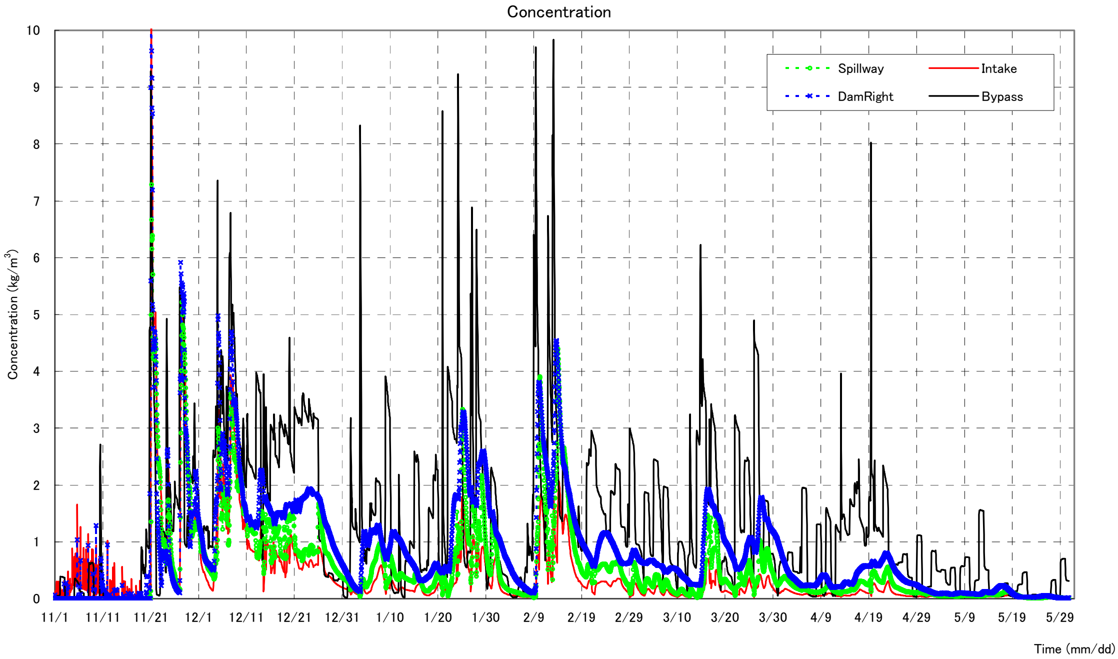

Figure 4.4.15 SS Concentration at Different Locations in the Wonogiri Reservoir in Hydrological Average Year

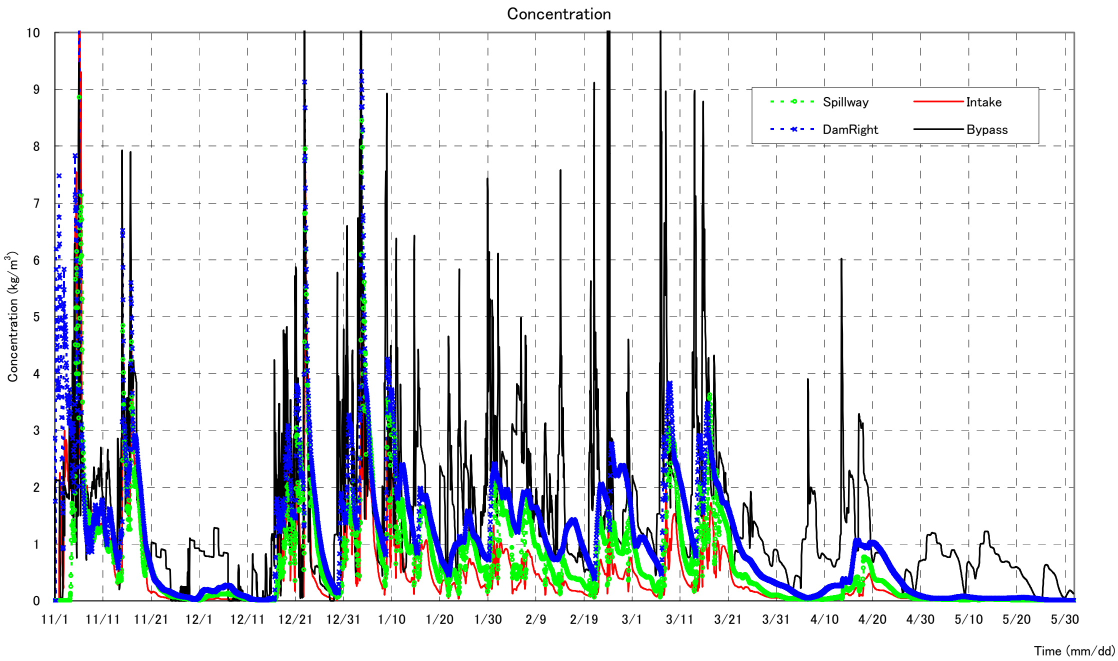

Figure 4.4.16 SS Concentration at Different Locations in the Wonogiri Reservoir in Hydrological Flood Year

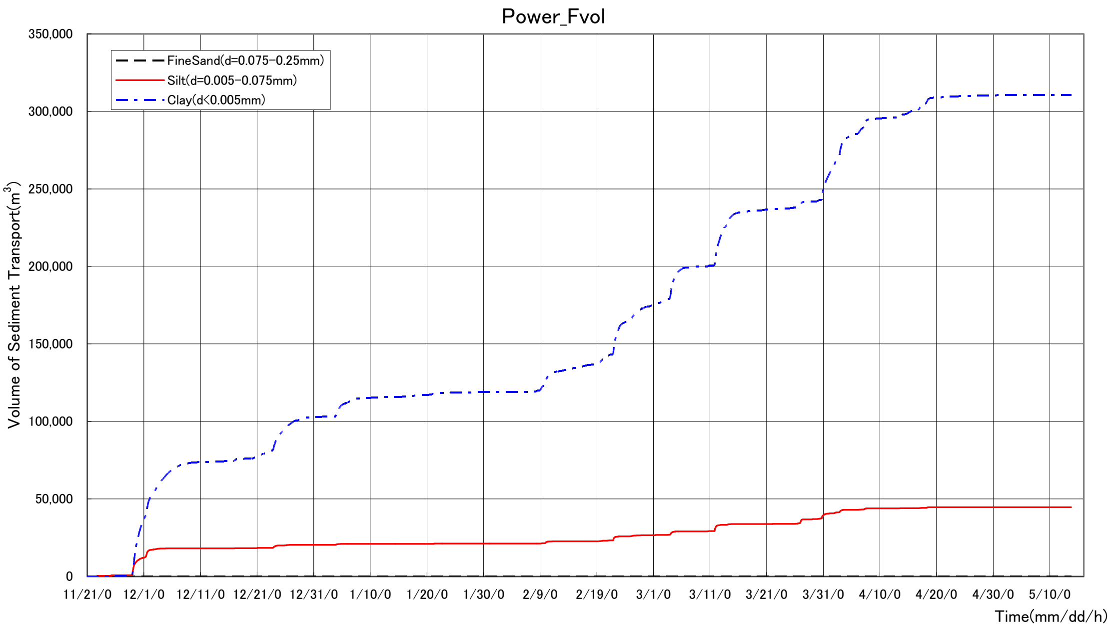

Figure 4.4.17 Sediment Release through the Intake in the Wonogiri Reservoir in Hydrological Drought Year (Deposition Volume)

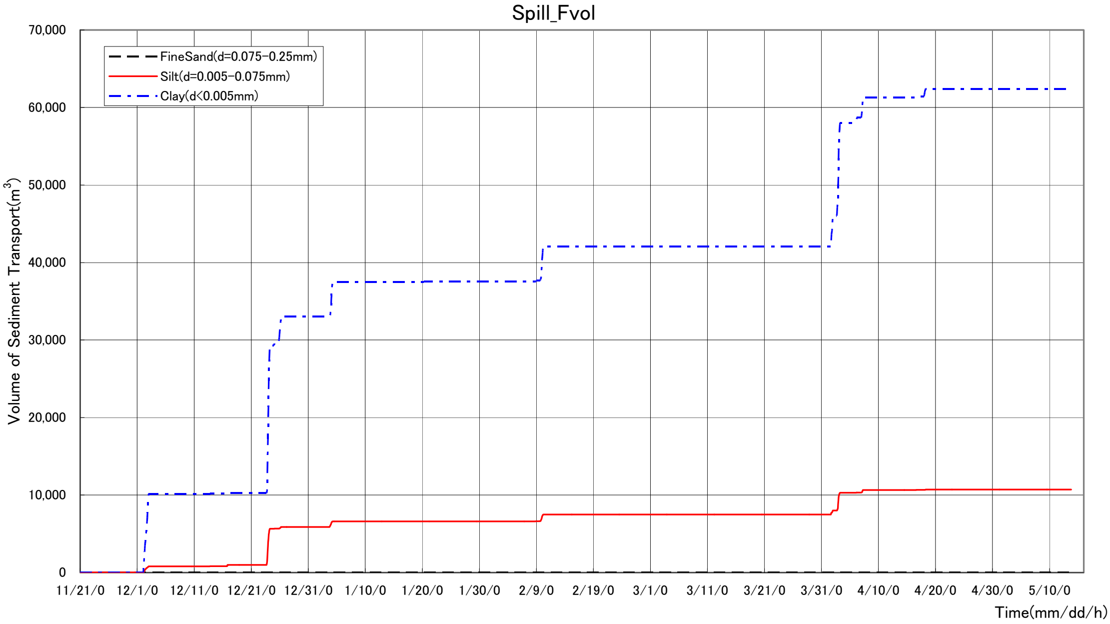

Figure 4.4.18 Sediment Release through the Existing Spillway in the Wonogiri Reservoir in Hydrological Drought Year (Deposition Volume)

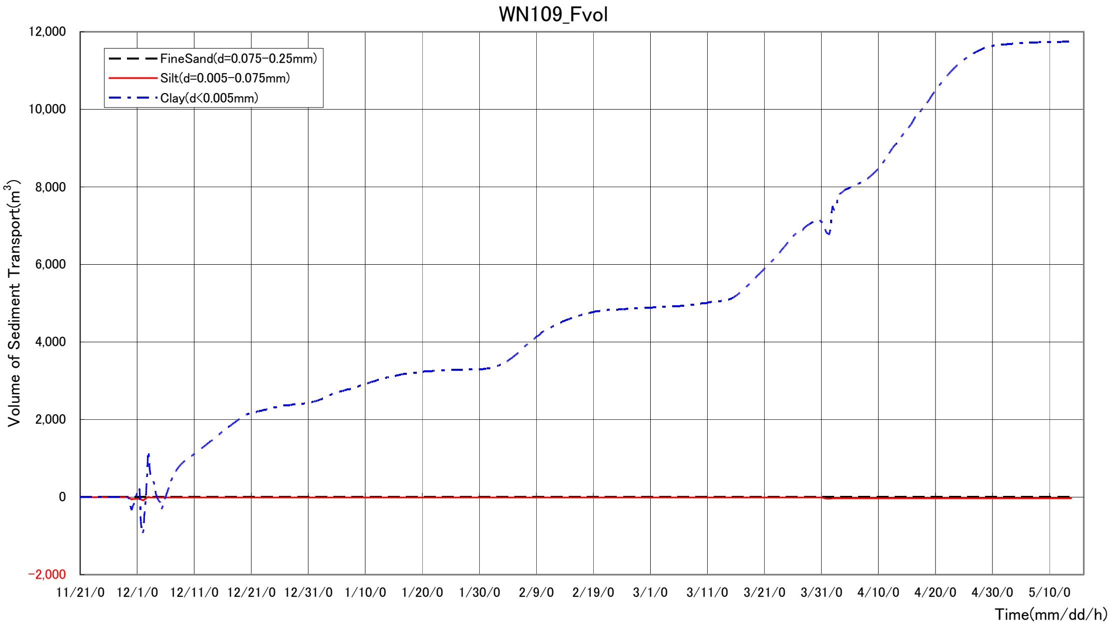

Figure 4.4.19 Sediment Transport Volume through Cross Section No.1 in the Wonogiri Reservoir in Hydrological Drought Year (DepositionVolume)

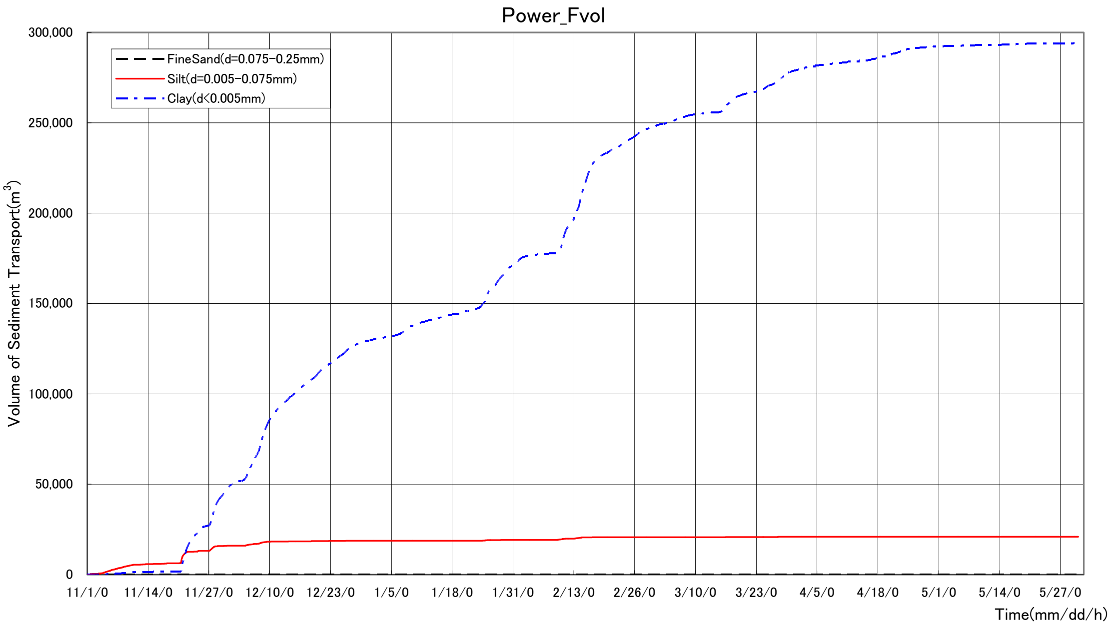

Figure 4.4.20 Sediment Release through the Intake in the Wonogiri Reservoir in Hydrological Average Year (Deposition Volume)

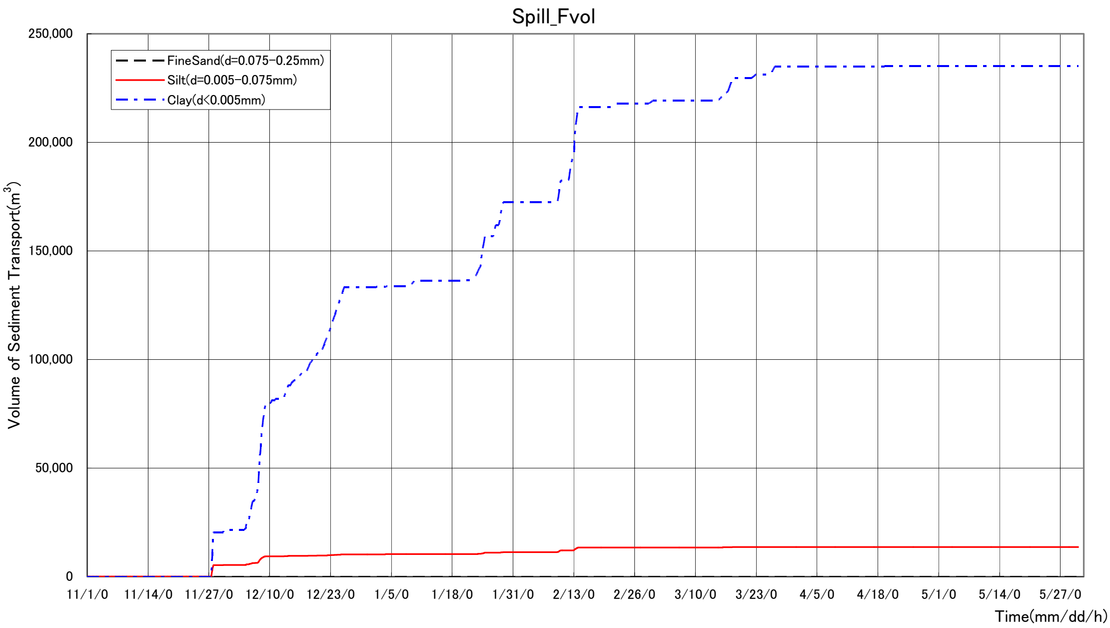

Figure 4.4.21 Sediment Release through the Existing Spillway in the Wonogiri Reservoir in Hydrological Average Year (Deposition Volume)

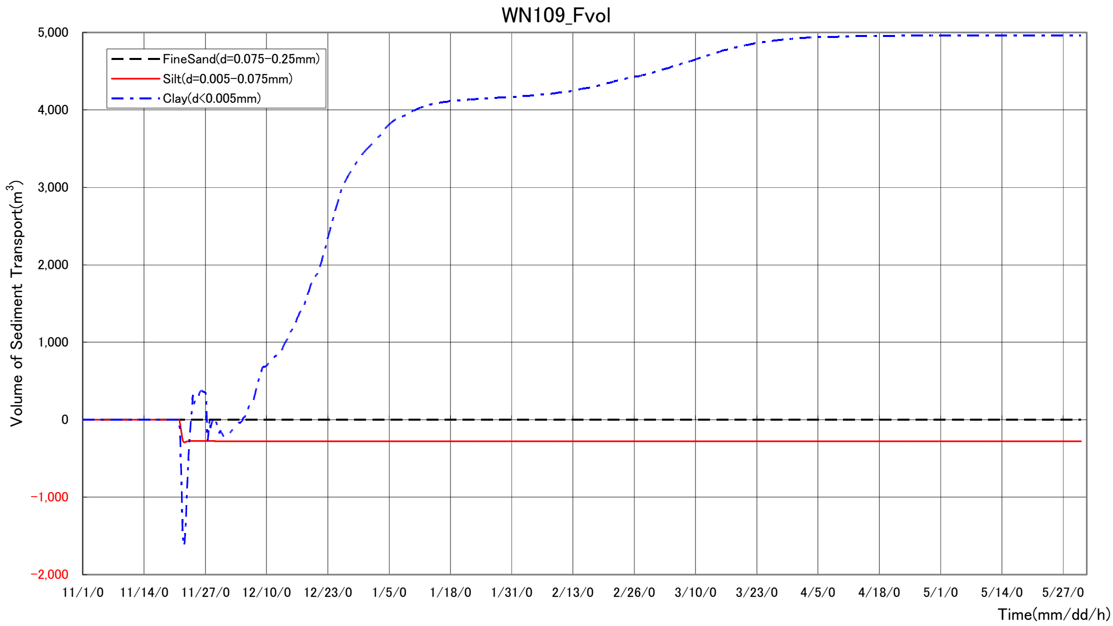

Figure 4.4.22 Sediment Transport Volume through Cross Section No.1 in the Wonogiri Reservoir in Hydrological Average Year (DepositionVolume)

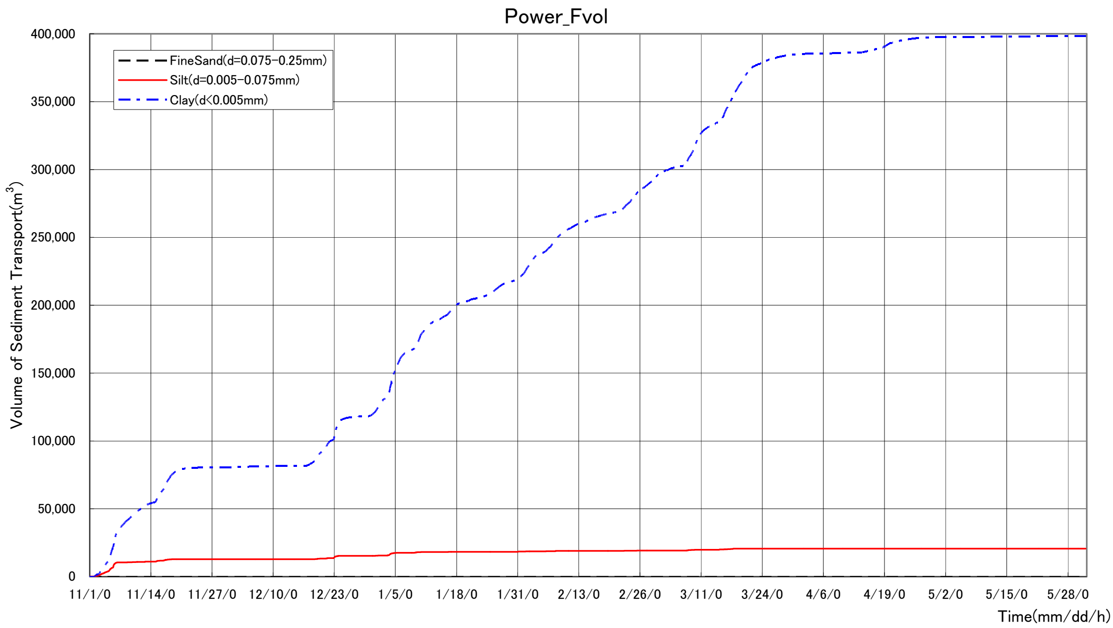

Figure 4.4.23 Sediment Release through the Intake in the Wonogiri Reservoir in Hydrological Flood Year (Deposition Volume)

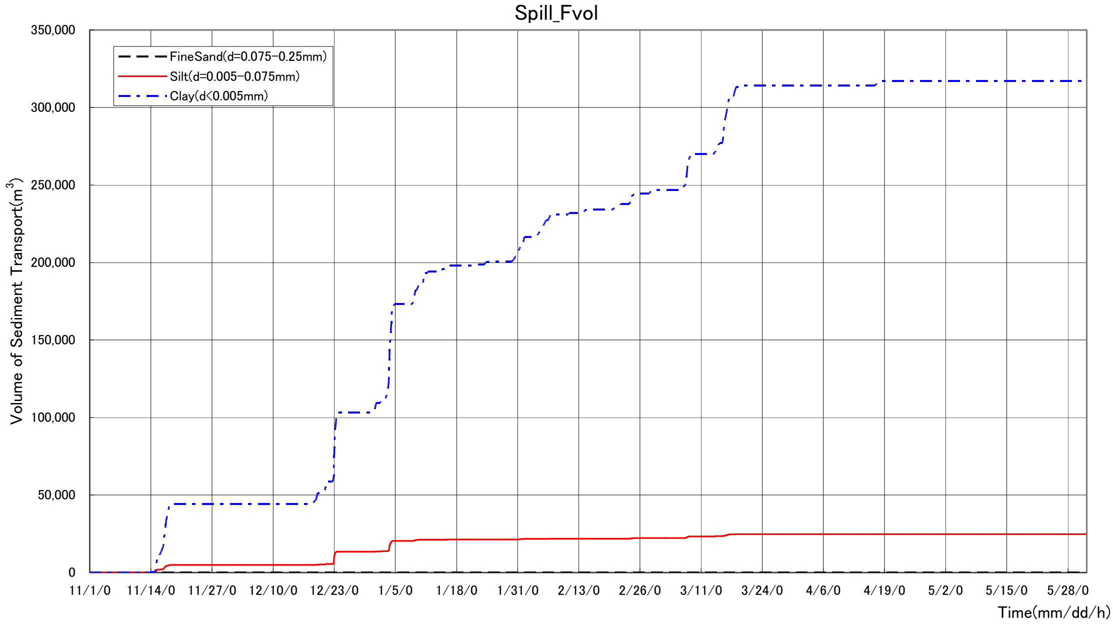

Figure 4.4.24 Sediment Release through the Existing Spillway in the Wonogiri Reservoir in Hydrological Flood Year (Deposition Volume)

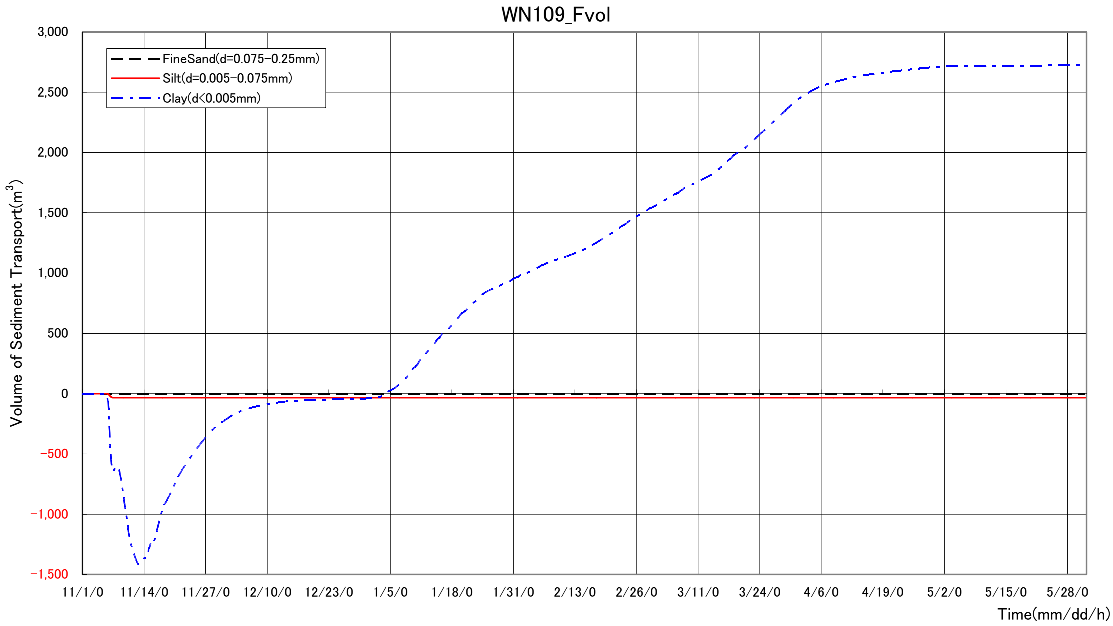

Figure 4.4.25 Sediment Transport Volume through Cross Section No.1 in the Wonogiri Reservoir in Hydrological Flood Year (Deposition Volume)