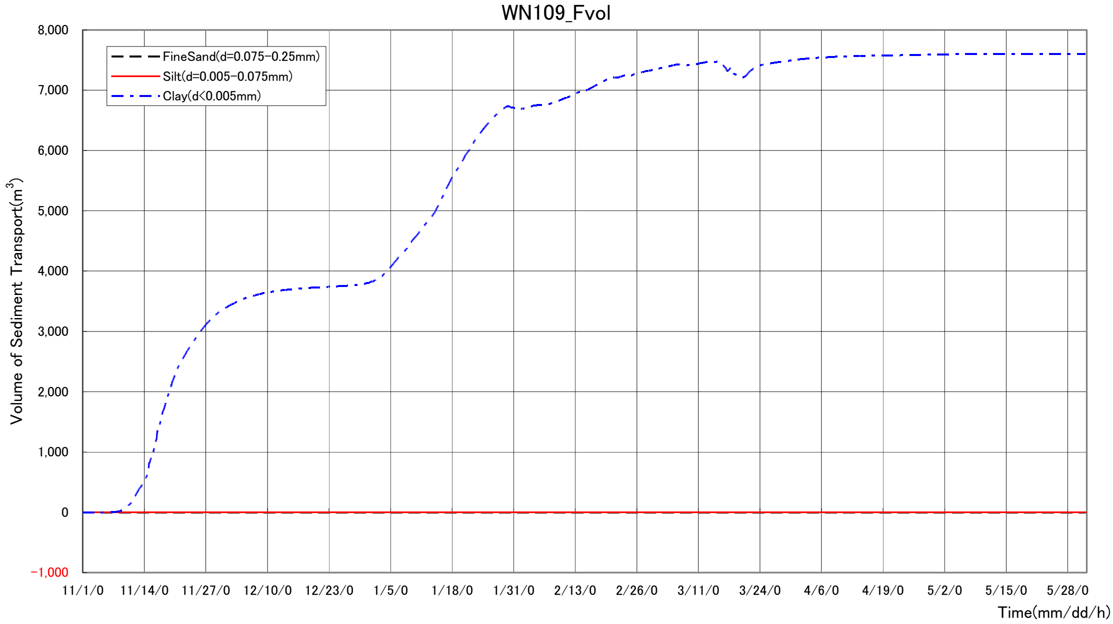

Figure 4.4.43 Sediment Transport Volume through Cross Section No.1 in the Wonogiri Reservoir in Hydrological Flood Year (Deposition Volume) (New Gate)

4.4.4 Compartmented Reservoir with New Flushing Gate

This method is to create a small component reservoir for the sediment inflow form the Keduang River inside the reservoir by installation of closure dike, thereby to allow two reservoir portions to be operated separately. The separated portions are named the Keduang reservoir and main Wonogiri reservoir. For the sediment sluicing during flood in Keduang river, a new gate will be installed on the same location as the above case (right side of the dam). Thus, through the new gate, sediment-laden flood inflow from Keduang River can be passed through before deposition in the reservoir.

In case of the Wonogiri Dam, as turn-over rate of reservoir per year is only 2-3 times, it is very difficult to lower the water level until free flow for sediment flushing in the view of securing enough water for irrigation and power generation.

Storage capacity-elevation curve of Keduang portion of the reservoir is shown in Figure 4.4.44. Storage capacity of the Keduang reservoir is 14 million m^3 at EL.136.0 m and average annual Keduang inflow in 1992 - 2005 is about 353 million m^3. Hence, the Keduang reservoir turn-over rate is 25 times a year on average. Therefore, it is believed that this compartmented reservoir system can flush out the deposited sediments by empting the Keduang reservoir.

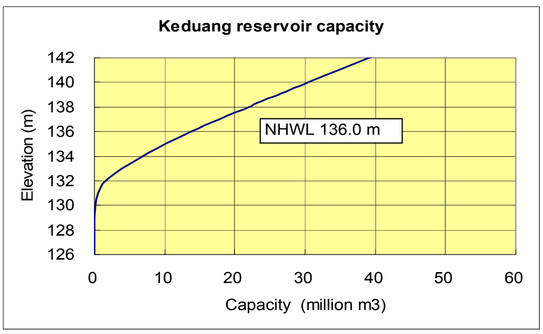

Figure 4.4.44 Storage Capacity- Elevation Curve of Keduang Reservoir Area

(1) Layout of Facility and the Operation

Layout and alignment of facilities are shown in Figure 4.4.45. Facility items is listed in Table 4.4.7.

A closure dike will be installed in the reservoir connecting the right side abutment of the Dam and the small peninsula in front of the Dam as shown in Figure 4.4.45. New flushing gate will be installed at the right side abutment of the Dam in the Keduang reservoir. In addition, an overflow weir with the crest level 135.3m is installed in the peninsula (between the Keduang reservoir and the main reservoir). Water exchange occurs between the Keduang reservoir and the main reservoir when the water level in one of or both sides excesses 135.3m. No water is released from the existing spillway.

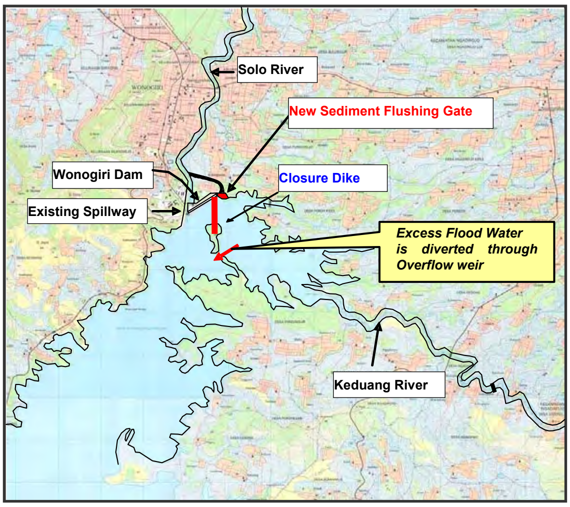

Figure 4.4.45 Layout and Alignment of Compartmented Reservoir with New Flushing Gate

Table 4.4.7 Facility Plan of Compartmented Reservoir with New Flushing Gate

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

Source : JICA Study Team

The same operation procedure as the above sediment sluicing is applied. In evaluating the efficiency on sediment release, the gate is assumed to be fully opened from the beginning of wet season to the end of next January whenever flood discharge in Keduang river exceeds $10m^3/s$. The total outflow volume is limited to maximum 200 million m^3. In addition, the release flow through the new gate is controlled to not exceed 400 m^3/s according to the current reservoir operation rule.

(2) Reservoir Sedimentation Simulation

a) Computational Conditions

Computational conditions are listed in Table 4.4.8.

Table 4.4.8 Input Data for the Simulation (Compartmented Reservoir with New Gate)

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 existing spillway	No water released through the existing spillway	
Water Release through a new gate	The gate is fully opened by the end of next January when flood discharge in Keduang river is greater than $10m^3/s$. The total outflow volume is limited to maximum 200 million m^3. In addition, the release flow through the new gates is controlled to not exceed 400 m^3/s.	The crest is at the level 127m
Water Exchange by overflow weir	Water exchange by the overflow weir occurs when water level in one of or both sides excesses 135.3m.	The crest is at the level 135.3m
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.	

b) Computational Results: Water Release from the New Gate, Reservoir Water Level and Discharge at the Overflow Weir

Water release discharge and its total volume through the new gate, reservoir water level under different inflow conditions are shown in Figure 4.4.46 ~ 4.4.51. Minus discharge on overflow at the weir means the flow from the Keduang reservoir to the main reservoir, the plus means that from the main to the Keduang.

Similar to the above cases, 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 in hydrological drought year. In the Keduang reservoir, the water level reaches to the NWL in the season but its capacity volume is small.

In both hydrological average year and hydrological flood year, the water level in the reservoir can be recovered to NWL in the rainy season.

Before the end of next January, water level is lower and almost no flow from Keduang river through the overflow weir occurs. After that, the flow occurs. Furthermore, in both hydrological average year and hydrological flood year, flow from the main reservoir to Keduang reservoir through the overflow weir also occurs.

Velocity vectors with or without overflow flow at the weir are shown in Figure 4.4.52 ~ 4.4.56. When overflow at the weir occurs, recirculation flow is induced around the intake.

c) 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 4.4.57 ~ 4.4.59.

The maximum SS concentrations through the new gate in the early stage (first month) of the season are about 14.9g/l in hydrological drought year, 11.4g/l in hydrological average year and 11.3g/l in hydrological flood year, respectively. After the first stage, the SS concentration becomes lower and the maximum is lower than 4g/l. The SS concentration is lower than that in the above case.

In the early stage of the rainy season, SS concentration at the existing spillway and the intake is very low. Comparing to the case with new gate only, SS concentration at the new gate is little a bit lower because water level in the Keduang reservoir is higher due to existence of the closure dike. This may cause the reduction on efficiency of sediment release through the new gate.

Contours of SS concentration with or without overflow flow at the weir are shown in Figure 4.4.60 ~ 4.4.65. Sediment flow exchange through the overflow weir is completely stopped when water level is lower. When water level rises and overflow at the weir occurs, SS concentration around the intake increases.

d) Computational Results: Sedimentation Distribution

Sediment release volume through the intake and the new gate and sediment transport volume through cross section No.1 (Figure 3.1.1) are shown in Figure 4.4.67 ~ 4.4.75.

In the early stage of the season, there is almost no sediment release through the intake because the water is quite clear due to the closure dike between the Keduang reservoir and the main reservoir.

Sediment transport volumes through cross section No.1 in hydrological drought year, hydrological average year and hydrological flood year are 32000m^3、11000m^3、7000m^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 4.4.9. By the results, it can be calculated that sediment trap ratios under different inflow conditions are 79.5%、83.8%、83.2%, respectively. Comparing to those in the above cases with the new gate only, the sediment trap ratios in the reservoir increase slightly. The reason is that SS concentration at the new gate is little a bit lower because water level in the Keduang reservoir is higher due to the closure dike.

Sediment release volumes from the intake and the new gate are 261,400 m^3 and 233,200 m^3 in hydrological drought year, 229,100 m^3 and 364,900 m^3 in hydrological average year, and 294,800 m^3 and 418,200 m^3 in hydrological flood year, respectively.

Except that in Keduang area, sedimentation distribution in the reservoir is almost the same as that in the case with the new gate only. Sedimentation in Keduang area increases about 90,000m^3 in hydrological flood year.

In hydrological drought year, sedimentation in the effective storage zone and in the area near the intake is less because the reservoir water level is lower. However, water level in the reservoir is lower in the season, even lower than that in the above case, and the level cannot be recovered to the NWL (Normal Water Level: 136m) in the rainy season. The dam operation should be careful.

Total sediment release from the reservoir decreases about 20,000~100,000m^3 because water level in the Keduang reservoir is higher due to the closure dike.

Sediment flushing effect is related to the operation method of the new gate for flood releasing in Keduang river and can be improved. The most attractive point of this alternative is that sediment-laden flood flow from the Keduang river can be sluiced without lowering the water level in the main reservoir.

It will be evaluated in details in next Chapter.

Table 4.4.9 Sedimentation Distribution and Sediment Release Volume (Compartmented Reservoir with New Gate)

Area	Sedimentation Volume (m3)		
	Drought Year	Average Year	Flood Year
Dam	17,400	81,100	104,500
Keduang	358,700	675,600	863,400
Tirtomoyo	182,900	500,500	630,800
Temon	58,400	76,600	151,500
Solo&Alang	−227,300	558,200	692,300
CenterUP+ Wuryantoro3	648,900	590,400	570,000
Center	866,100	339,000	291,500
Wuryantoro	−12,900	193,000	186,000
Wuryantoro2	23,600	52,200	47,500
PowerPlant	261,400	229,100	294,800
SandGate	233,200	364,900	418,200
Total	2,410,000	3,660,000	4,250,000

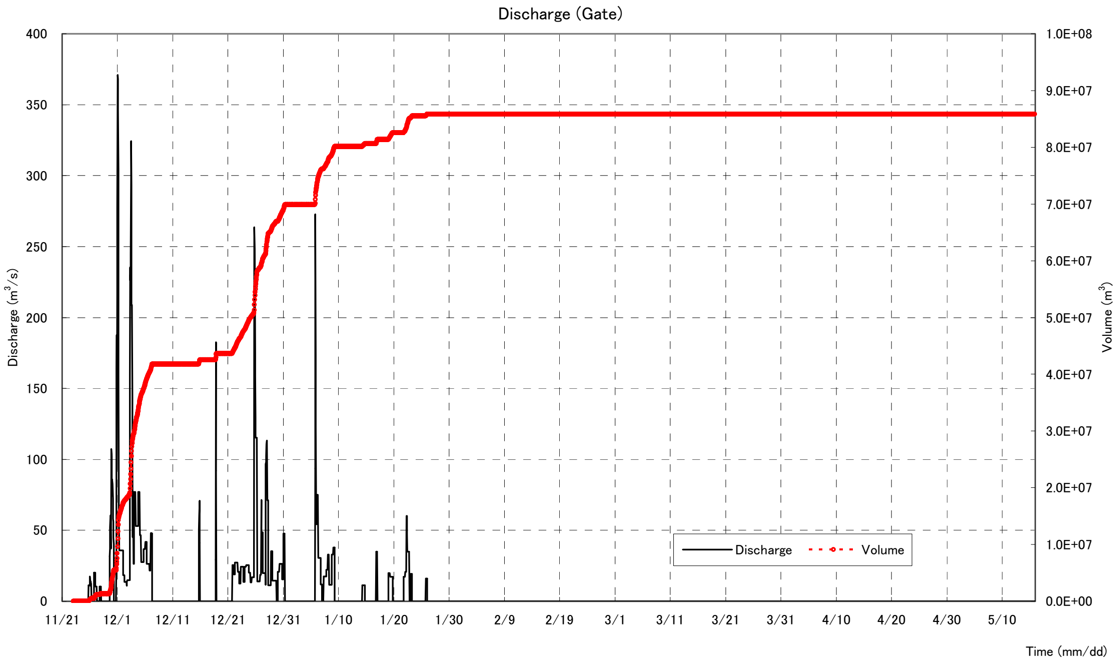

Figure 4.4.46 Release Discharge and its Total Volume through the New Gate in Hydrological Drought Year (Compartmented Reservoir with New Gate)

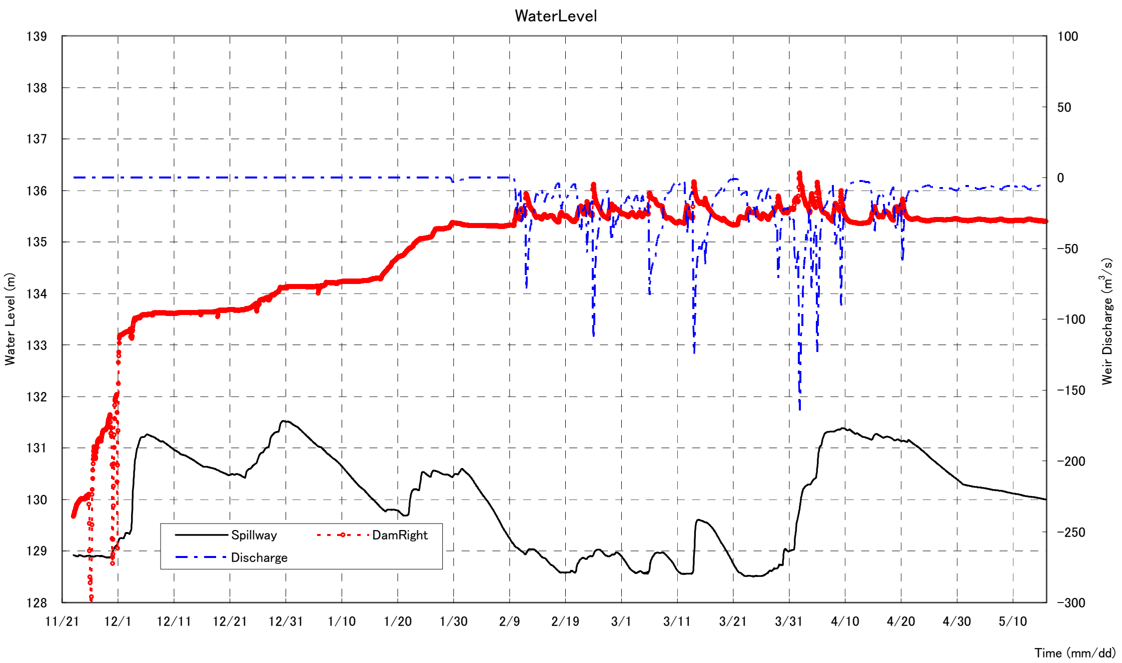

Figure 4.4.47 Water Level in Two Sides of the Wonogiri Reservoir and Discharge at Overflow Weir in Hydrological Drought Year (Compartmented Reservoir with New Gate)

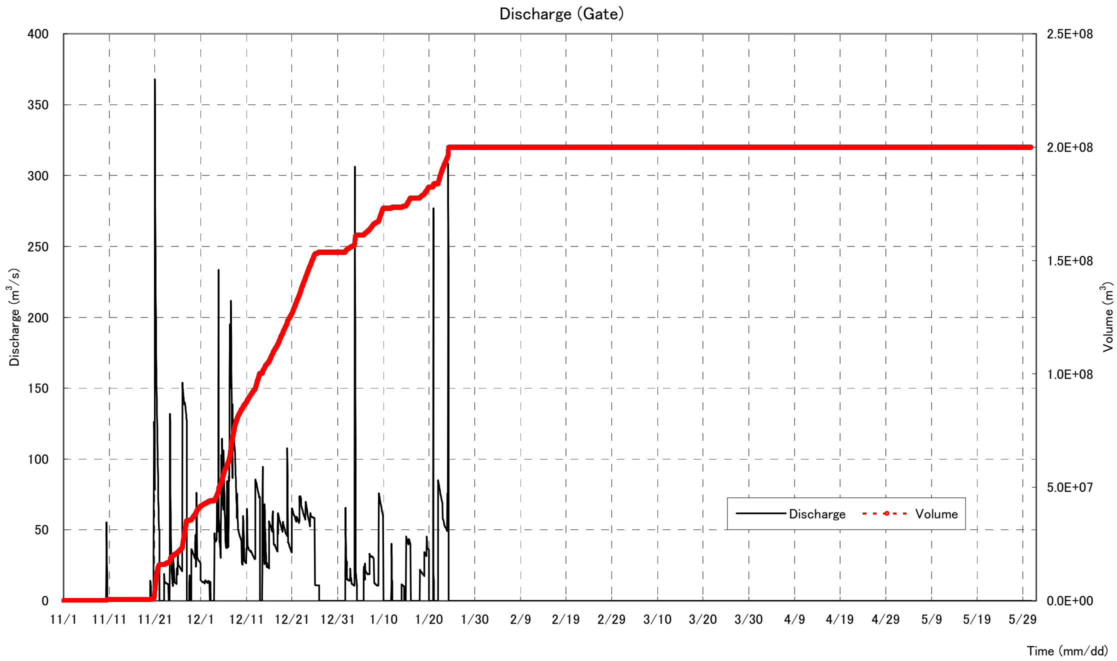

Figure 4.4.48 Release Discharge and its Total Volume through the New Gate in Hydrological Average Year (Compartmented Reservoir with New Gate)

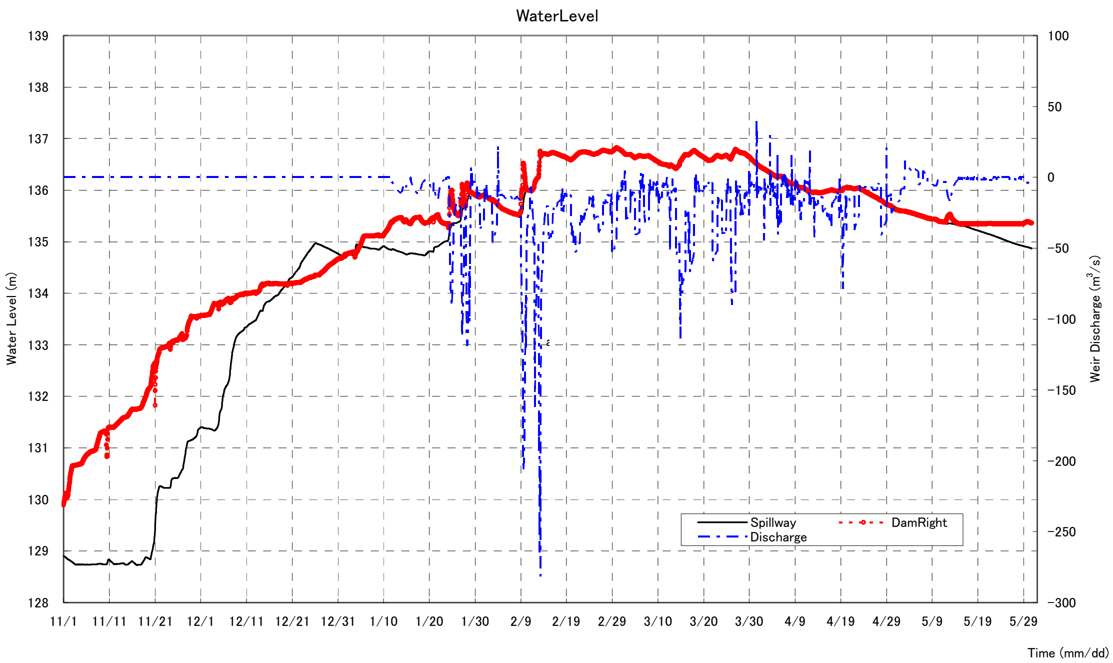

Figure 4.4.49 Water Level in Two Sides of the Wonogiri Reservoir and Discharge at Overflow Weir in Hydrological Average Year (Compartmented Reservoir with New Gate)

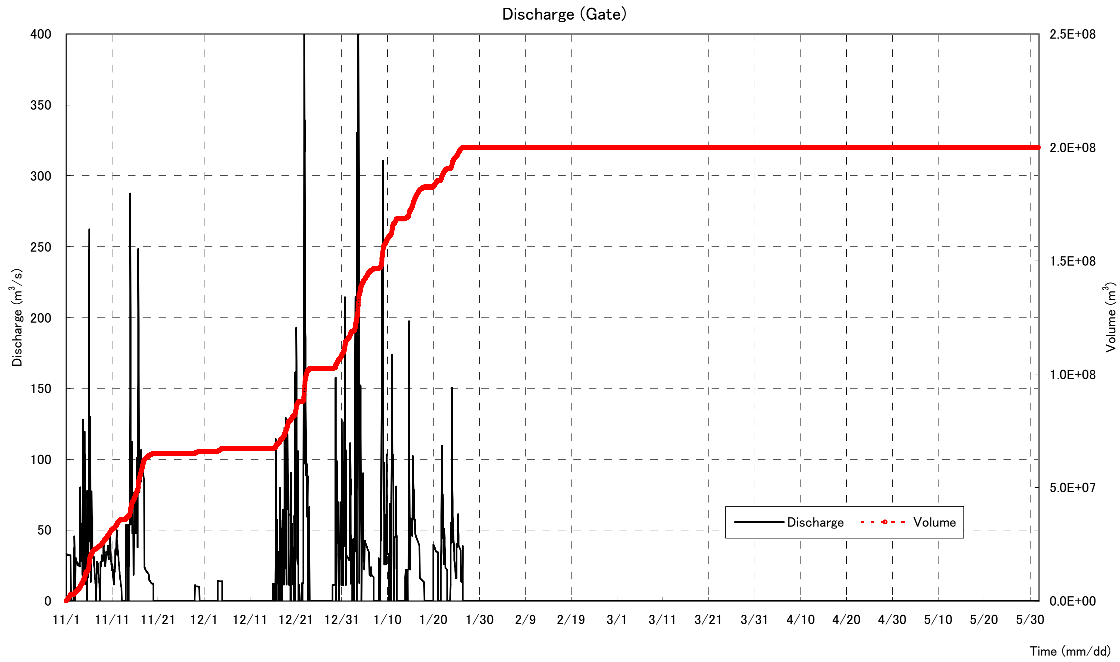

Figure 4.4.50 Release Discharge and its Total Volume through the New Gate in Hydrological Flood Year (Compartmented Reservoir with New Gate)

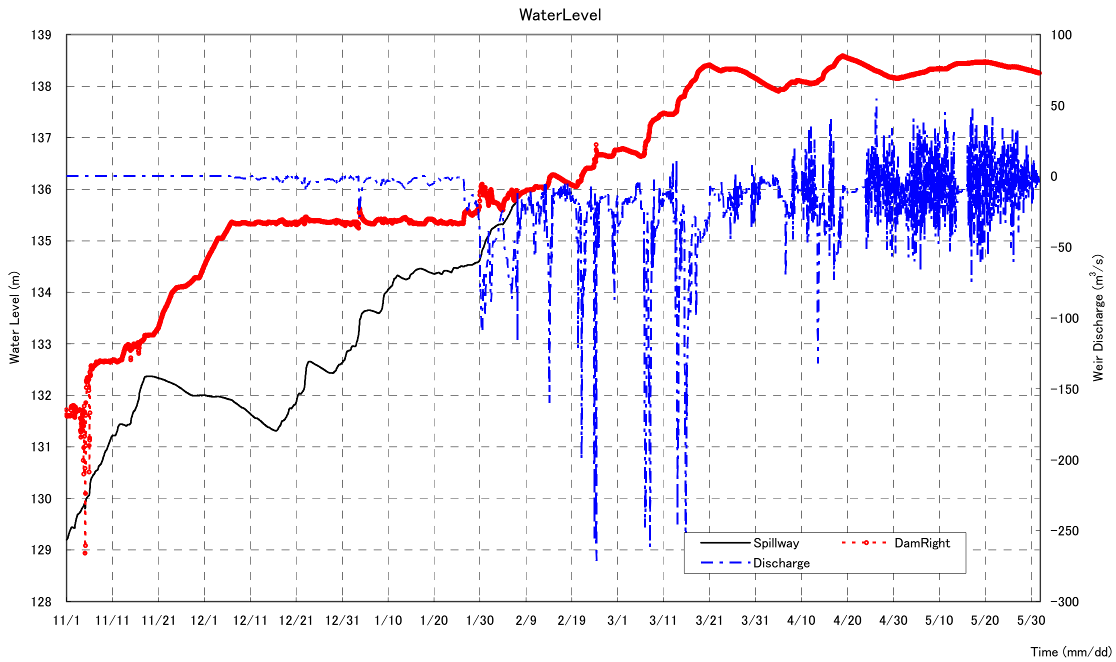

Figure 4.4.51 Water Level in Two Sides of the Wonogiri Reservoir and Discharge at Overflow Weir in Hydrological Flood Year (Compartmented Reservoir with New Gate)

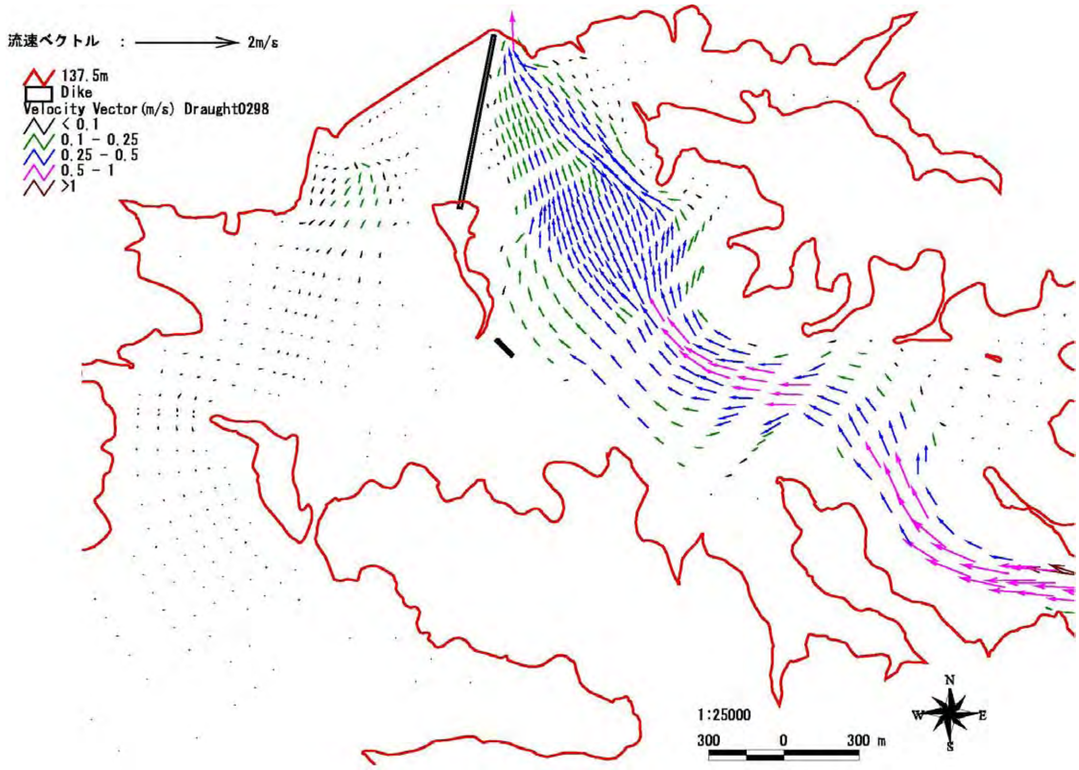

Figure 4.4.52 Velocity Vector in Hydrological Drought Year (at 10:00, December 3, Lower Water Level) (Compartmented Reservoir with New Gate)

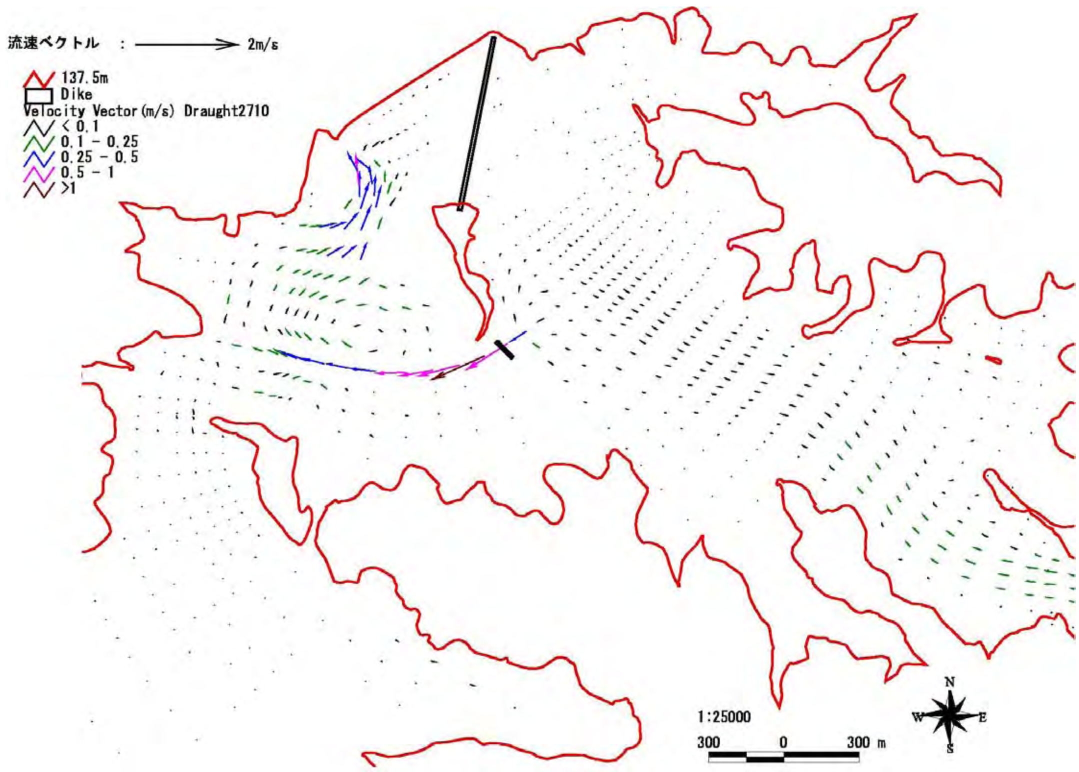

Figure 4.4.53 Velocity Vector in Hydrological Drought Year (at 23:00, March 23, Higher Water Level) (Compartmented Reservoir with New Gate)

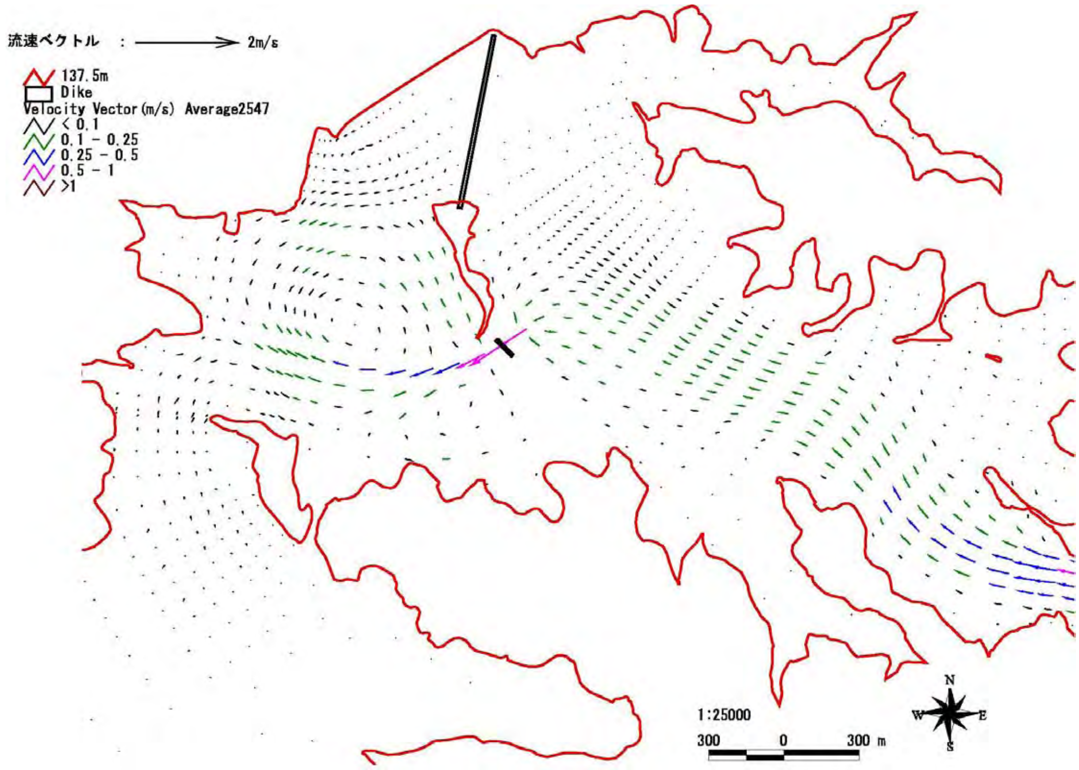

Figure 4.4.54 Velocity Vector in Hydrological Average Year (at 3:00, February 3, Higher Water Level) (Compartmented Reservoir with New Gate)

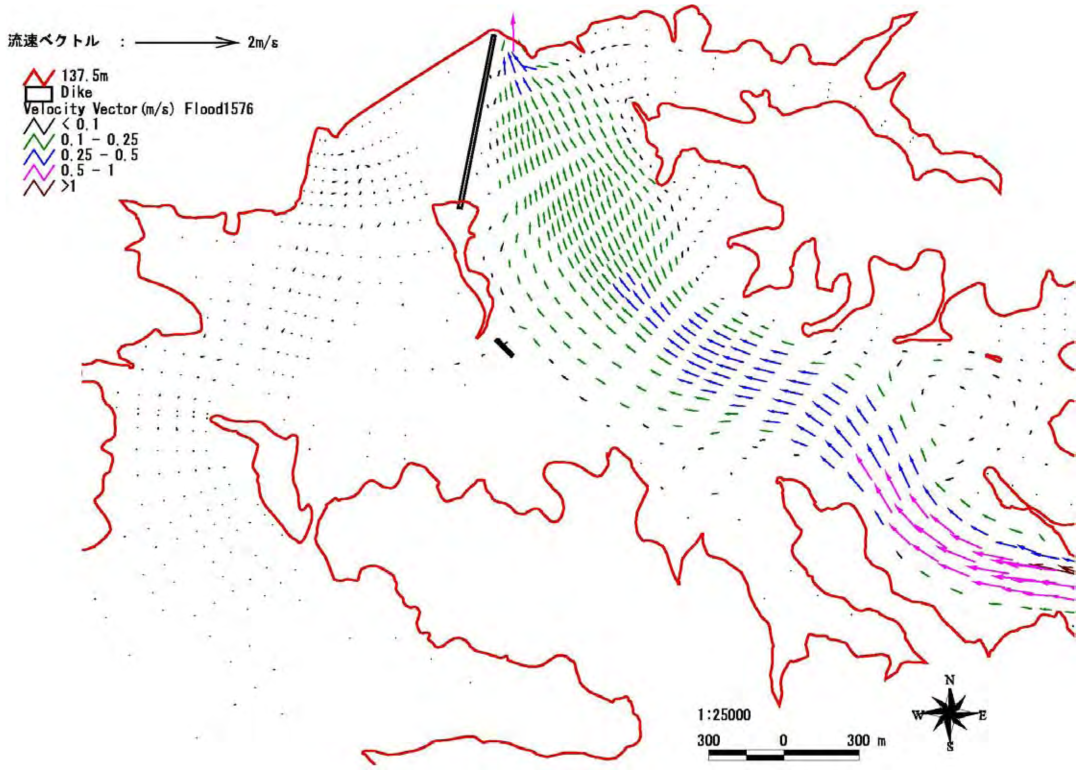

Figure 4.4.55 Velocity Vector in Hydrological Flood Year (at 16:00, January 3, Lower Water Level) (Compartmented Reservoir with New Gate)

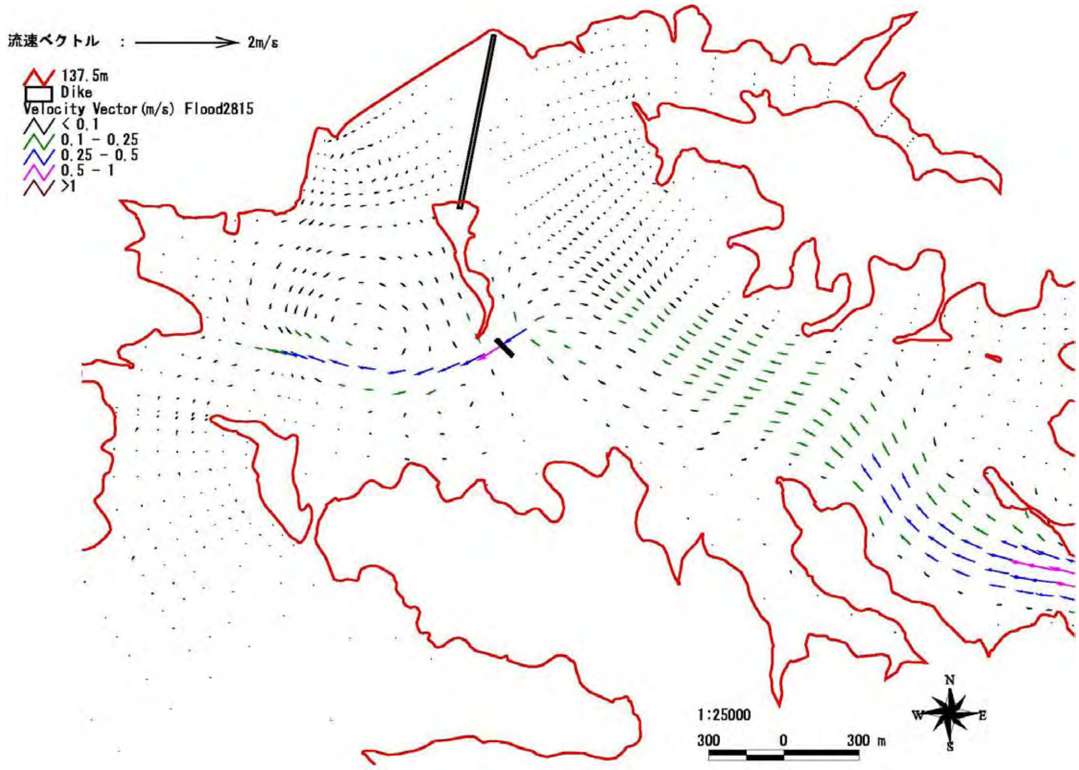

Figure 4.4.56 Velocity Vector in Hydrological Flood Year (at 7:00, February 24, Higher Water Level) (Compartmented Reservoir with New Gate)

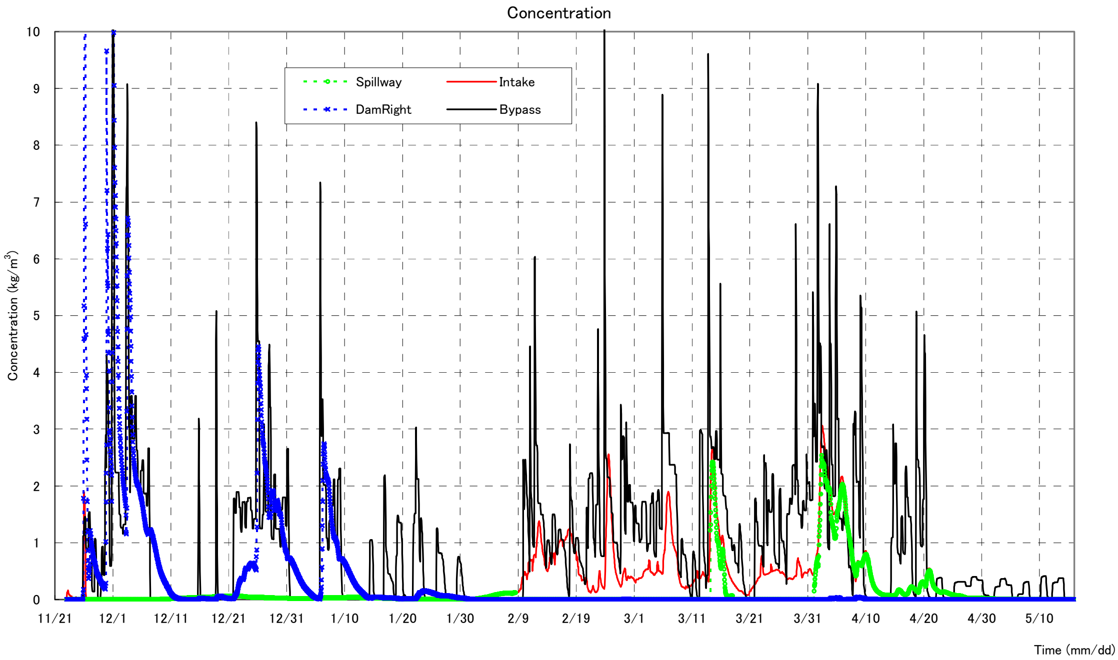

Figure 4.4.57 SS Concentration at Different Locations in the Wonogiri Reservoir in Hydrological Drought Year (Compartmented Reservoir with New Gate)

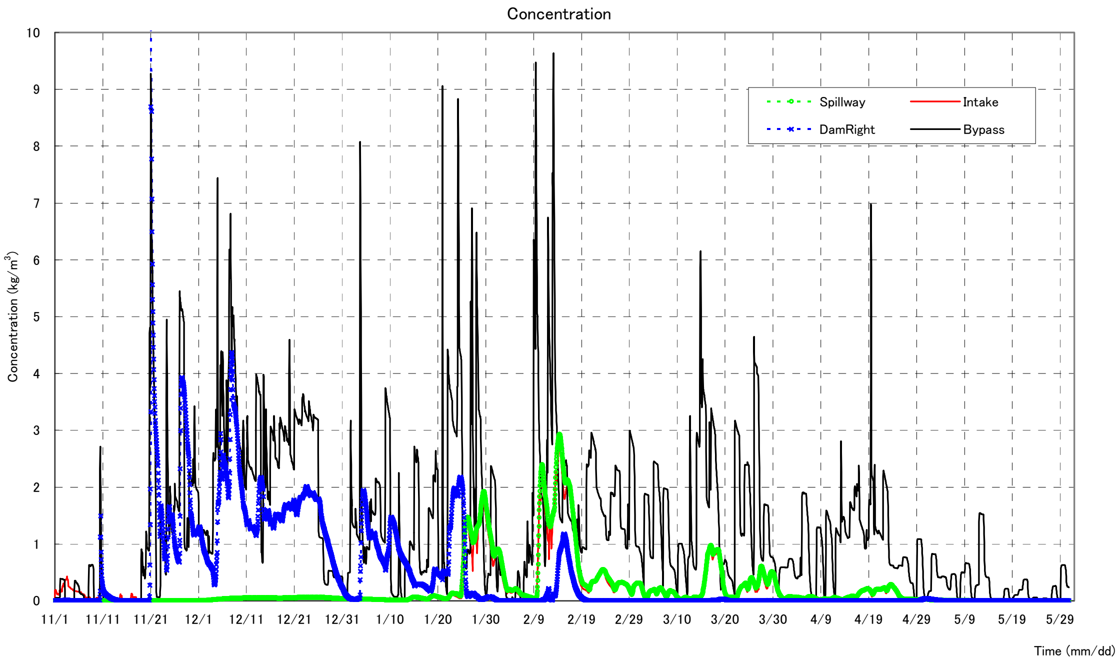

Figure 4.4.58 SS Concentration at Different Locations in the Wonogiri Reservoir in Hydrological Average Year (Compartmented Reservoir with New Gate)

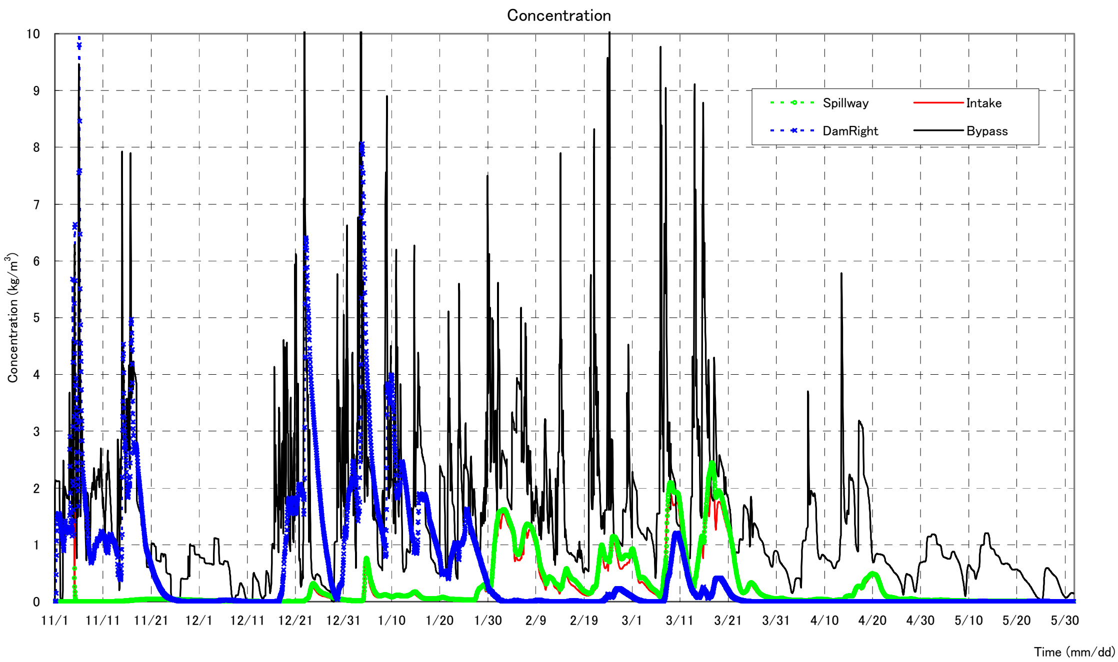

Figure 4.4.59 SS Concentration at Different Locations in the Wonogiri Reservoir in Hydrological Flood Year (Compartmented Reservoir with New Gate)

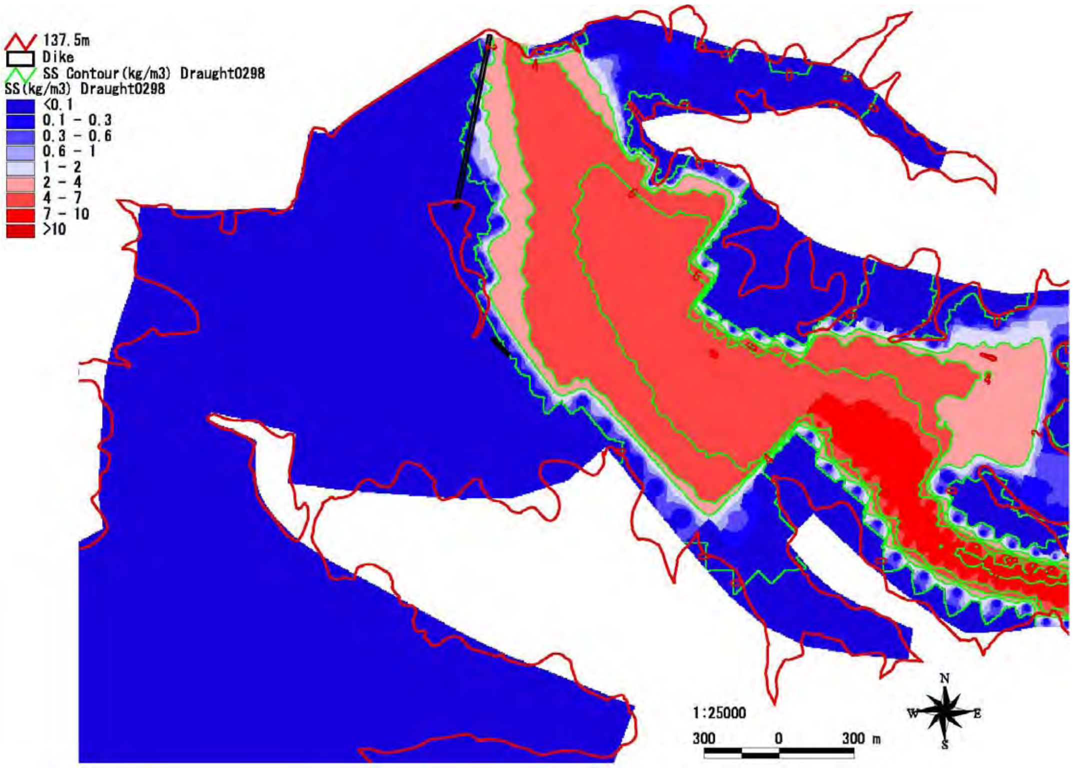

Figure 4.4.60 SS Contour in Hydrological Drought Year (at 10:00, December 3, Lower Water Level) (Compartmented Reservoir with New Gate)

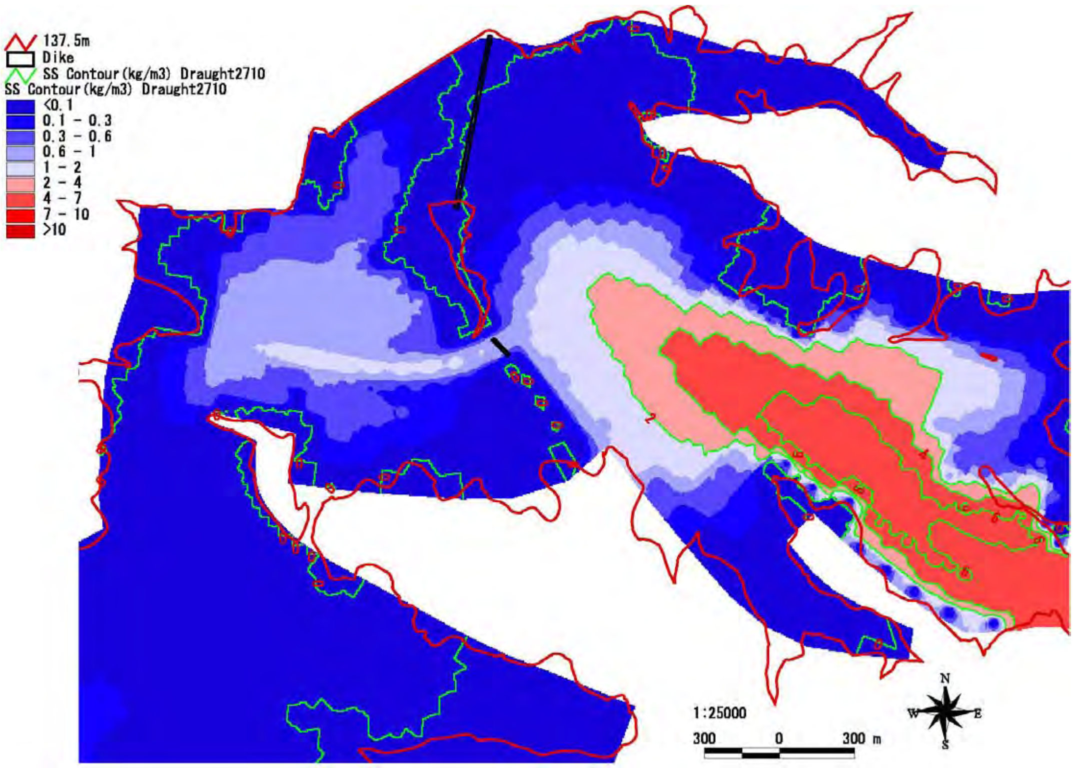

Figure 4.4.61 SS Contour in Hydrological Drought Year (at 3:00, February 13, Higher Water Level) (Compartmented Reservoir with New Gate)

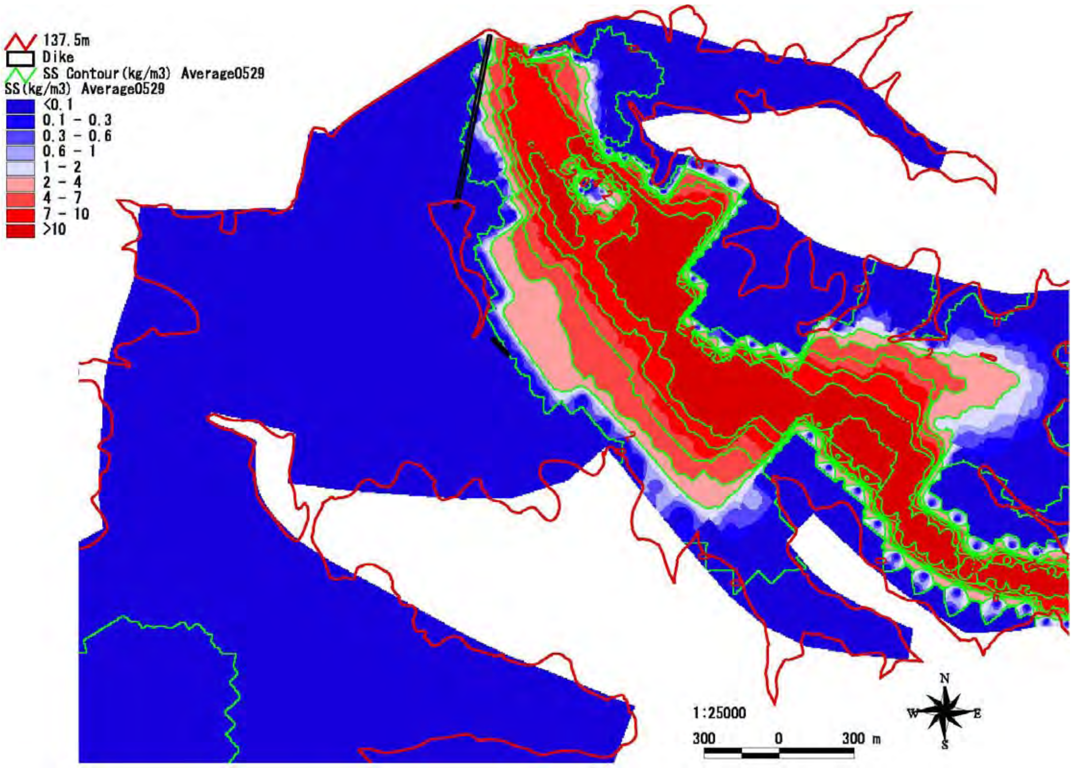

Figure 4.4.62 SS Contour in Hydrological Average Year (at 1:00, November 21, Lower Water Level) (Compartmented Reservoir with New Gate)

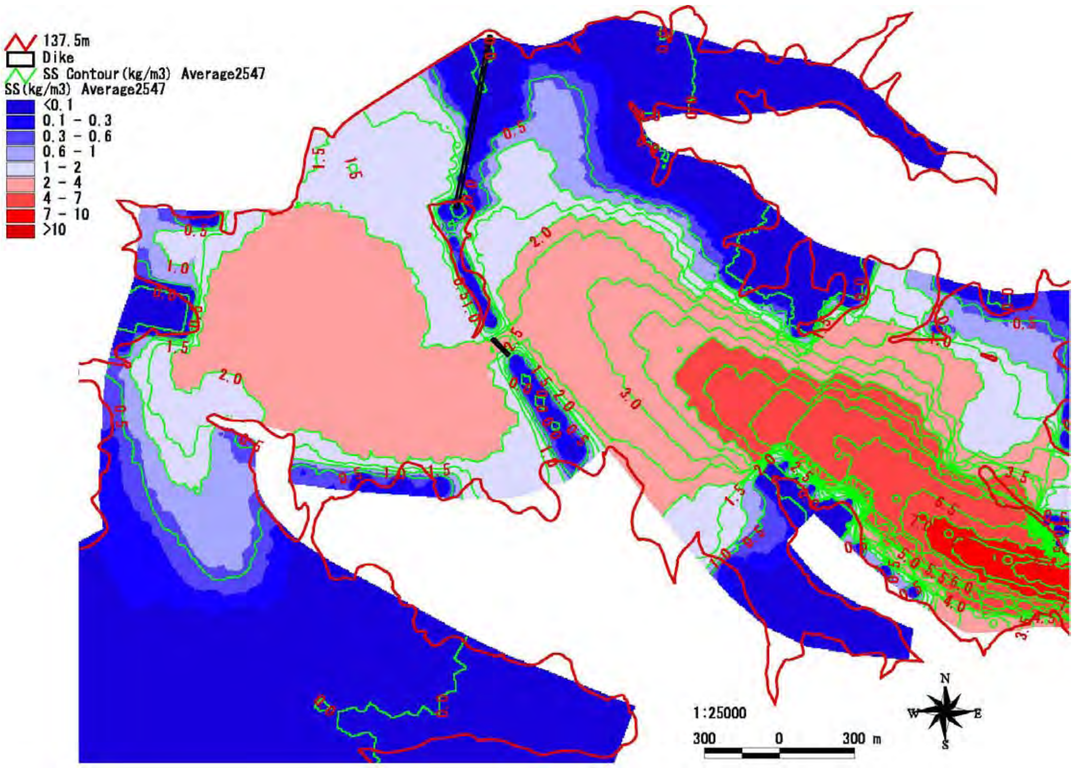

Figure 4.4.63 SS Contour in Hydrological Average Year (at 3:00, February 13, Higher Water Level) (Compartmented Reservoir with New Gate)

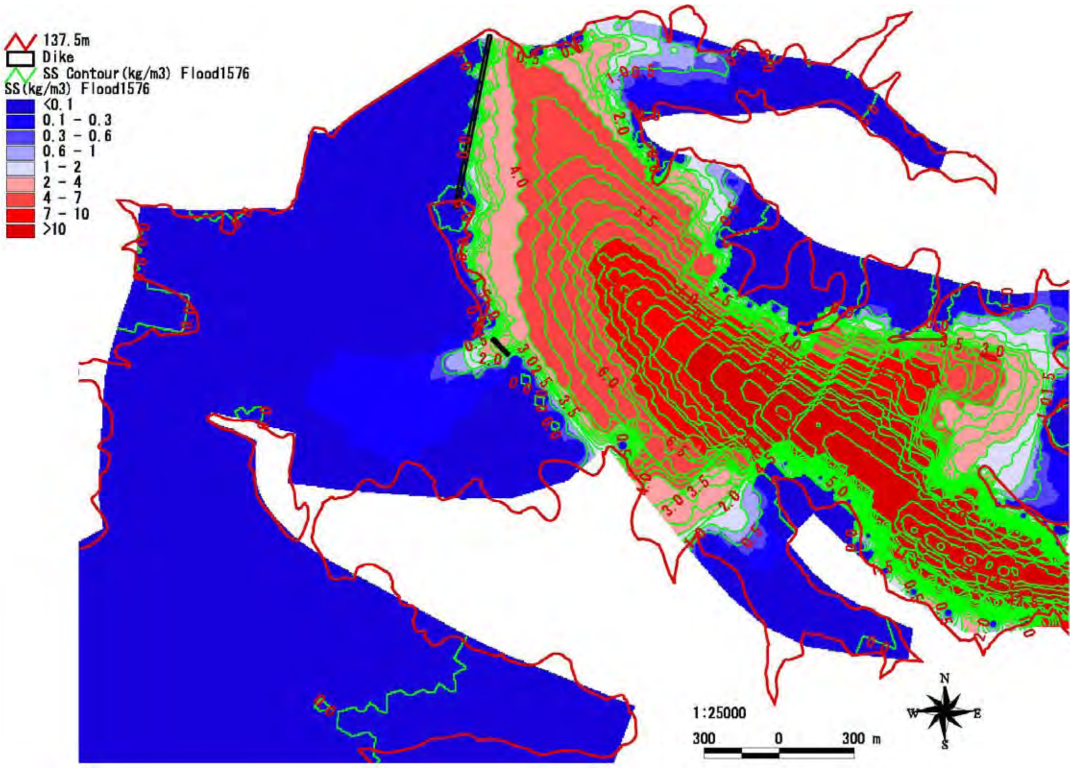

Figure 4.4.64 SS Contour in Hydrological Flood Year (at 16:00, January 3, Lower Water Level) (Compartmented Reservoir with New Gate)

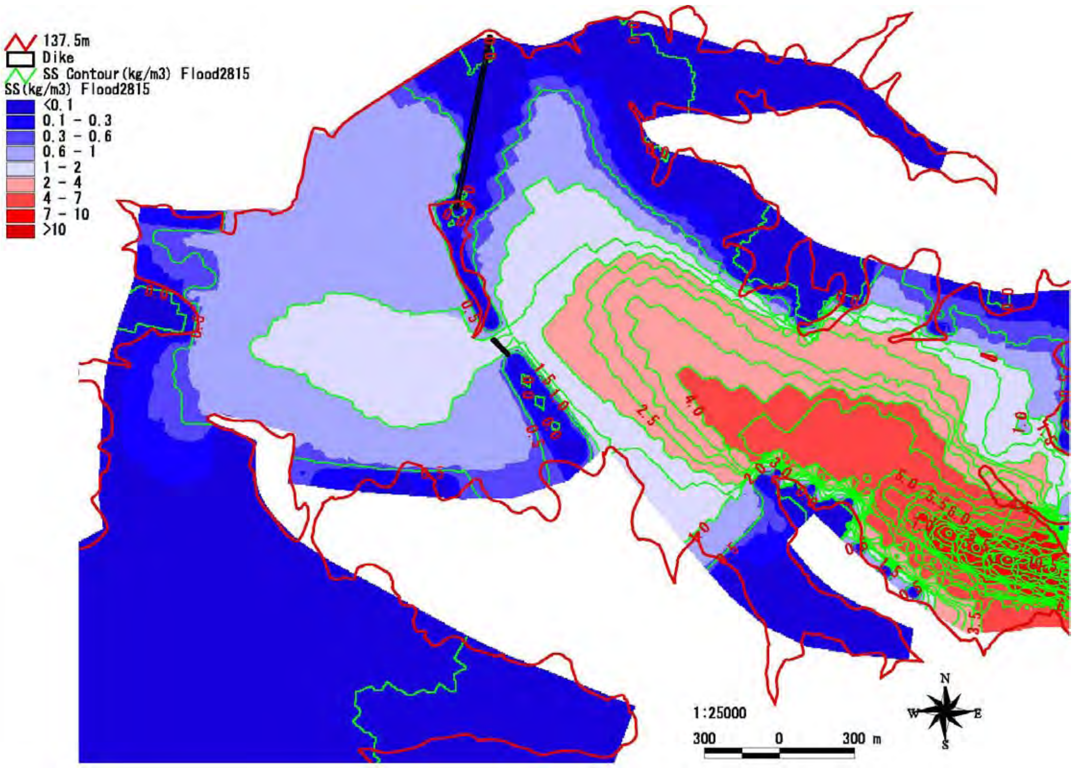

Figure 4.4.65 SS Contour in Hydrological Flood Year (at 7:00, February 24, Higher Water Level) (Compartmented Reservoir with New Gate)

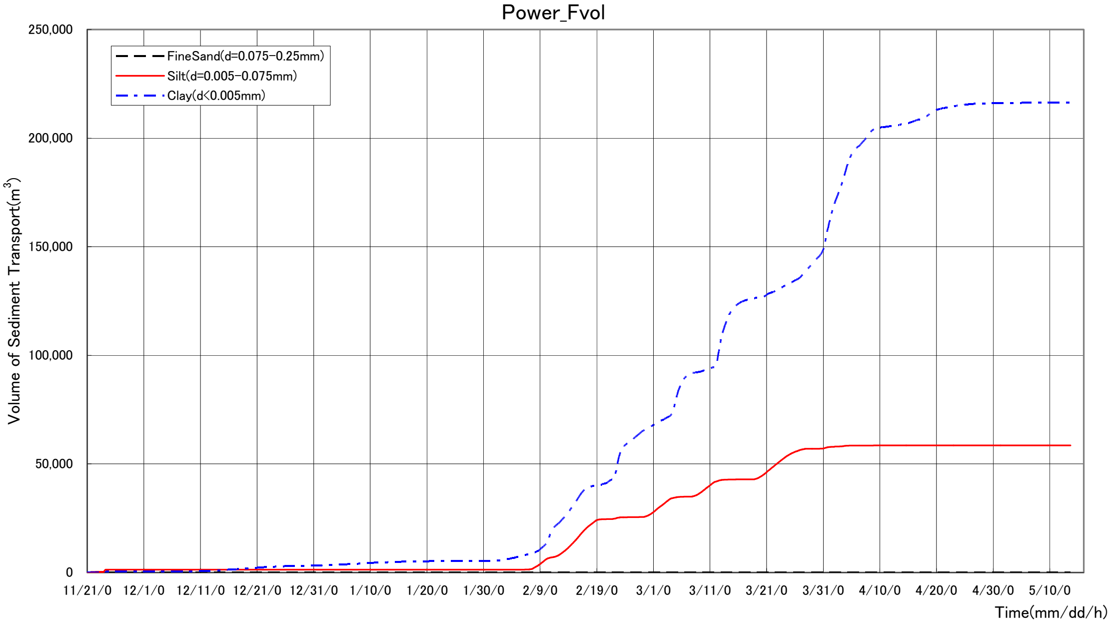

Figure 4.4.66 Sediment Release through the Intake in the Wonogiri Reservoir in Hydrological Drought Year (Deposition Volume) (Compartmented Reservoir with New Gate)

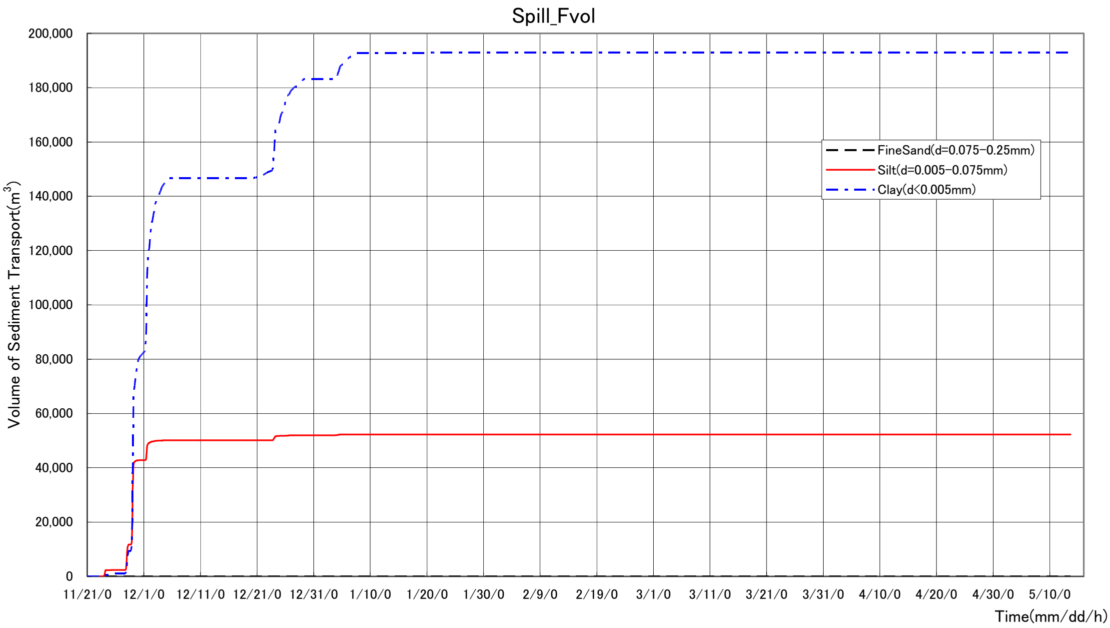

Figure 4.4.67 Sediment Release through the New Gate in the Wonogiri Reservoir in Hydrological Drought Year (Deposition Volume) (Compartmented Reservoir with New Gate)

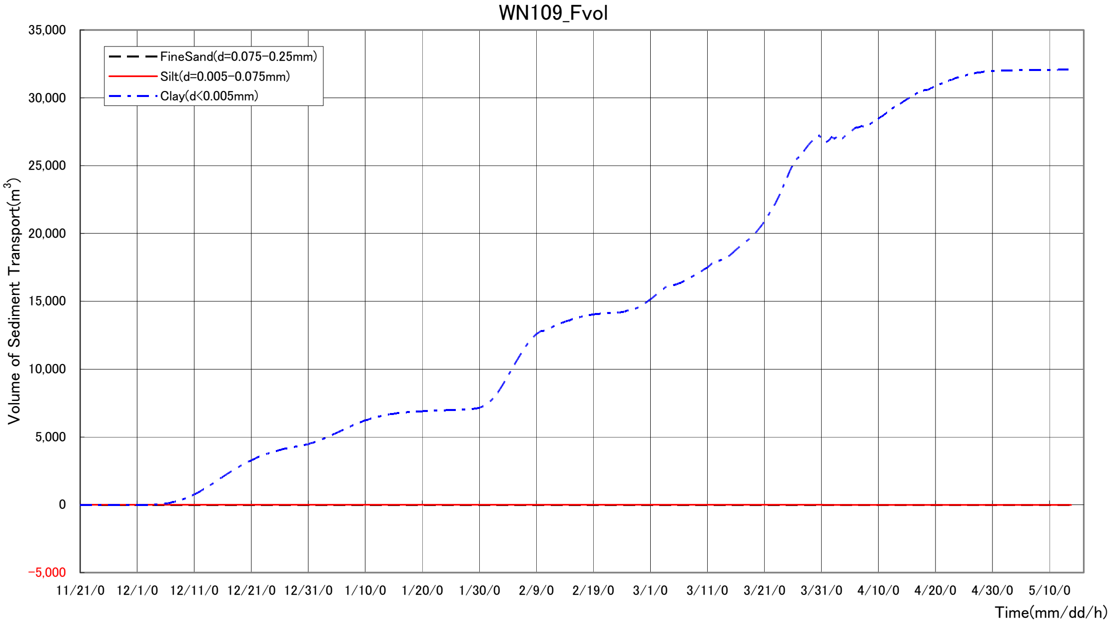

Figure 4.4.68 Sediment Transport Volume through Cross Section No.1 in the Wonogiri Reservoir in Hydrological Drought Year (Deposition Volume) (Compartmented Reservoir with New Gate)

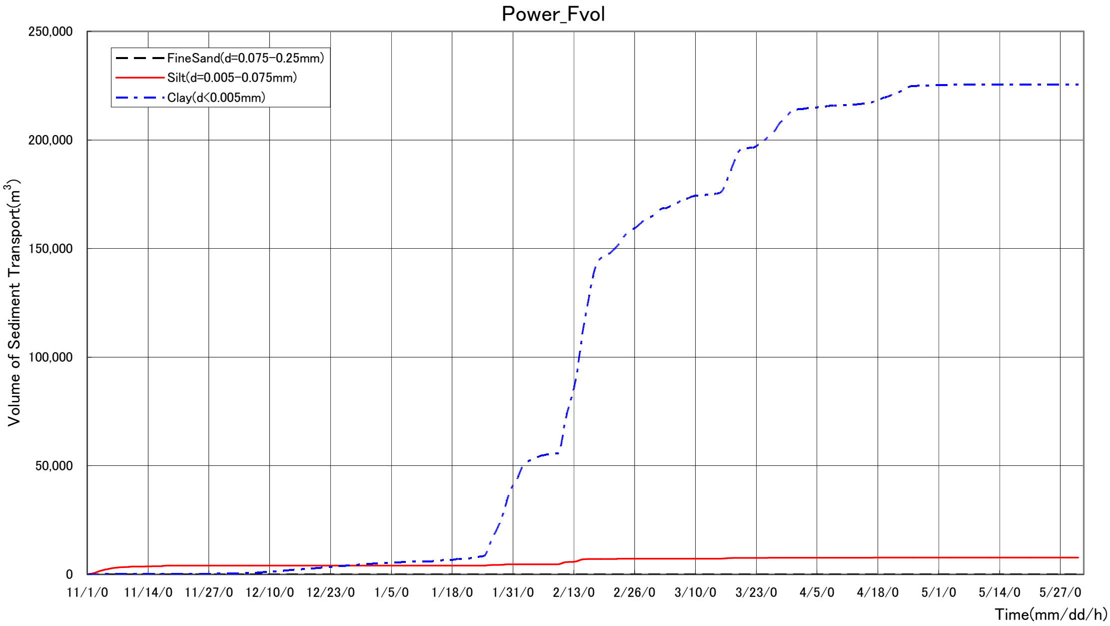

Figure 4.4.69 Sediment Release through the Intake in the Wonogiri Reservoir in Hydrological Average Year (Deposition Volume) (Compartmented Reservoir with New Gate)

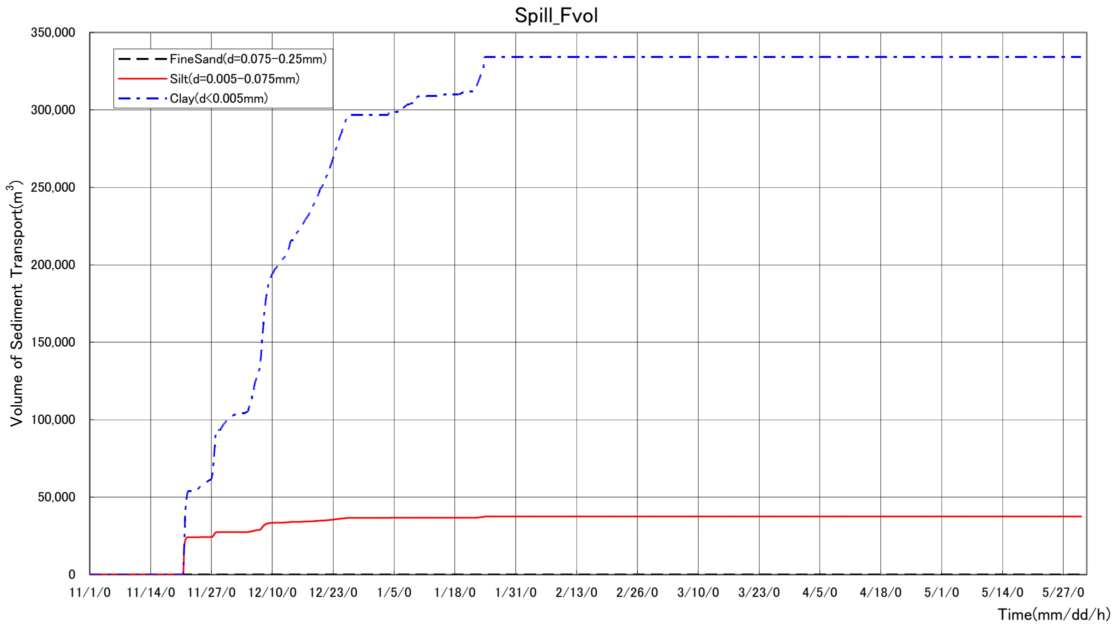

Figure 4.4.70 Sediment Release through the New Gate in the Wonogiri Reservoir in Hydrological Average Year (Deposition Volume) (Compartmented Reservoir with New Gate)

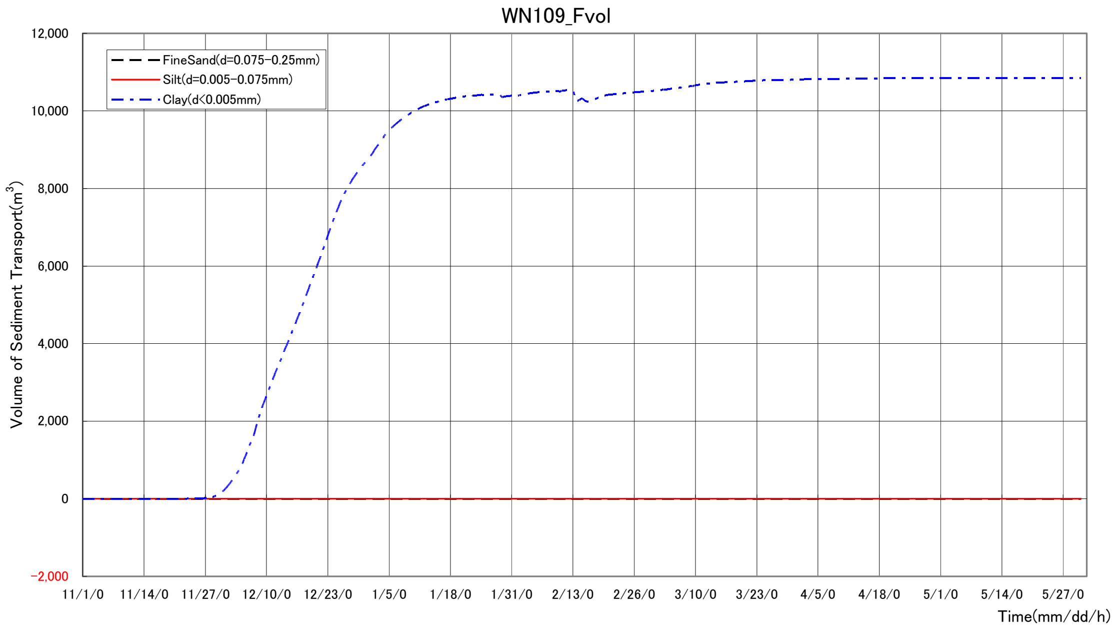

Figure 4.4.71 Sediment Transport Volume through Cross Section No.1 in the Wonogiri Reservoir in Hydrological Average Year (Deposition Volume) (Compartmented Reservoir with New Gate)

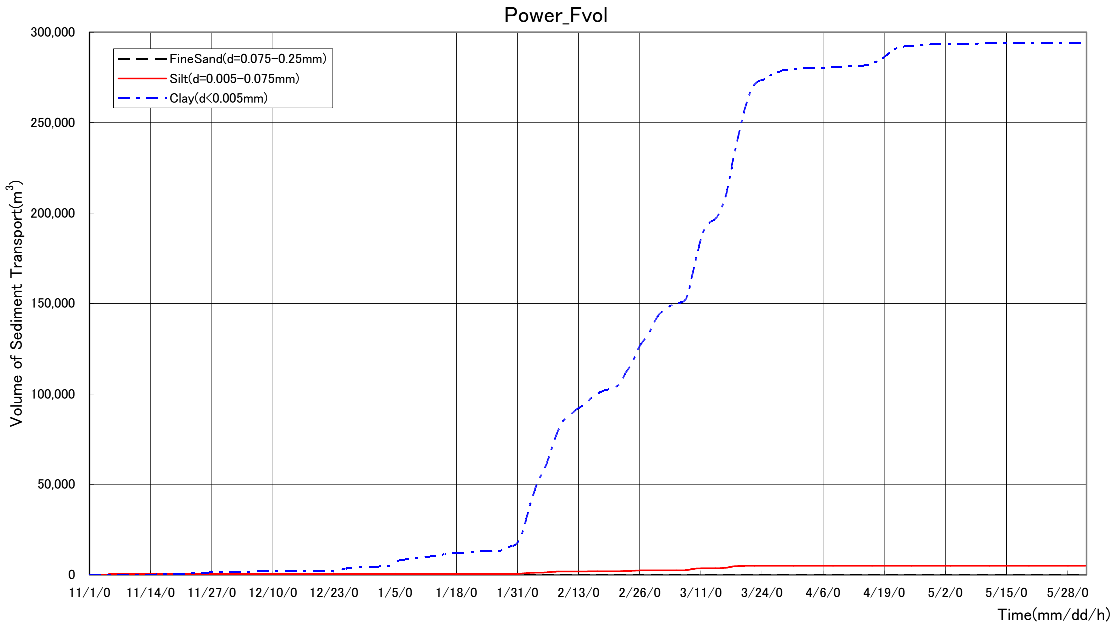

Figure 4.4.72 Sediment Release through the Intake in the Wonogiri Reservoir in Hydrological Flood Year (Deposition Volume) (Compartmented Reservoir with New Gate)

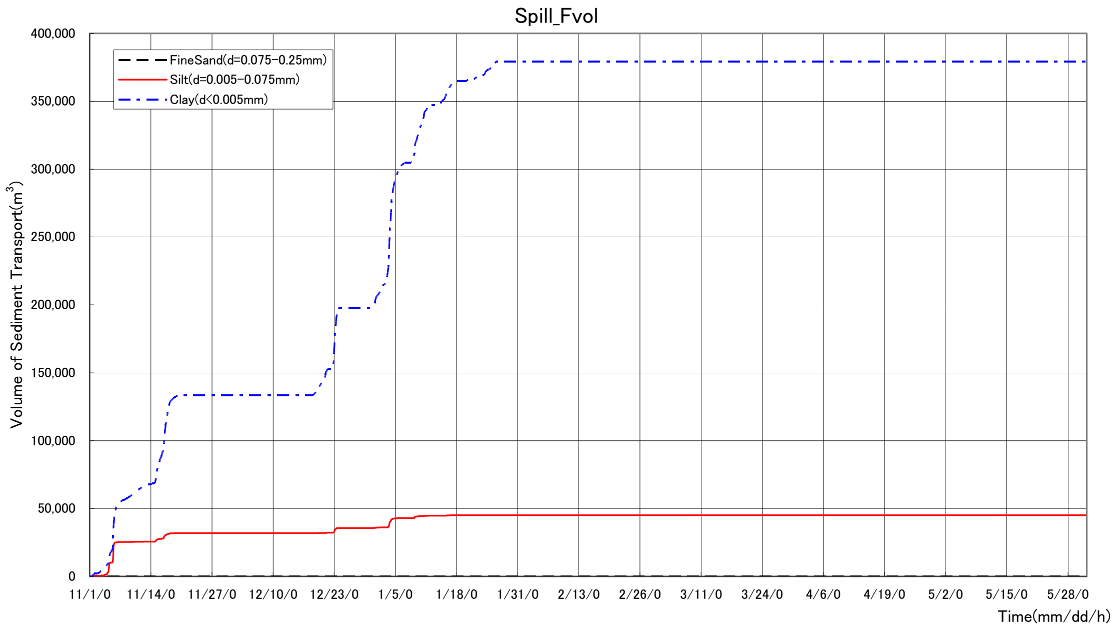

Figure 4.4.73 Sediment Release through the New Gate in the Wonogiri Reservoir in Hydrological Flood Year (Deposition Volume) (Compartmented Reservoir with New Gate)

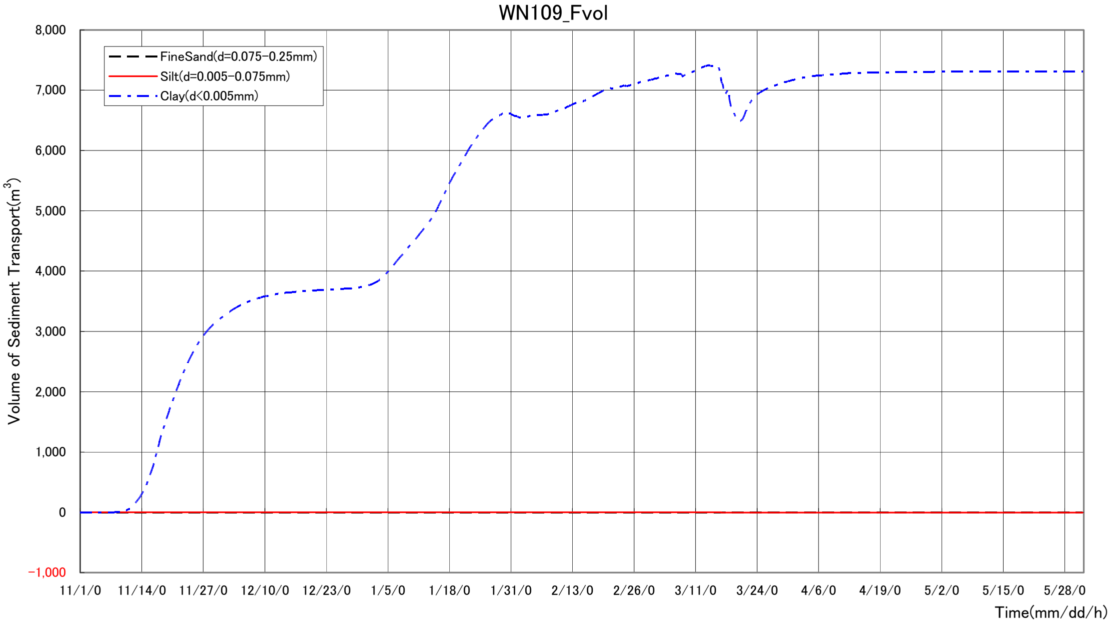

Figure 4.4.74 Sediment Transport Volume through Cross Section No.1 in the Wonogiri Reservoir in Hydrological Flood Year (Deposition Volume) (Compartmented Reservoir with New Gate)

4.4.5 Keduang River Sediment Bypass

Sediment bypassing is the method that part of the inflowing sediment-laden flood inflow from the Keduang River is diverted into a bypass tunnel to the downstream river of the Dam. This method is effective in case that it would be difficult to lower the water level and the reservoir is relatively small. The construction cost is usually very expensive. For its details, please refer to Chapter 6 of the Interim Report in the Study.

Herein, bypass route B (Figure 4.4.1) is discussed. Considering the efficiency between sediment release volume and discharge, the capacity of bypass tunnel is determined to 50 m^3/s.

(1) Layout of Facility and the Operation

The sediment bypassing is composed of four (4) facilities, a diverting weir, control gates, a bypass tunnel and river improvement. Dimensions of each facility are shown in Table 4.4.10 and Figure 4.4.75.

Diverting channel gates are installed on the right side abutment of the diverting weir. When flood discharge exceeds 30 m^3/s, the gates are fully opened to divert flood of 50 m^3/s at maximum into the bypass tunnel directly. When flood declines to 30 m^3/s, the gates are closed. Consequently, parts of flood flow of less than 30 m^3/s and more than 50 m^3/s directly enter into the reservoir. Operation of sediment bypassing is illustrated in Figure 4.4.76.

Table 4.4.10 Facility Plan of Keduang River Sediment Bypass

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

Source : JICA Study Team

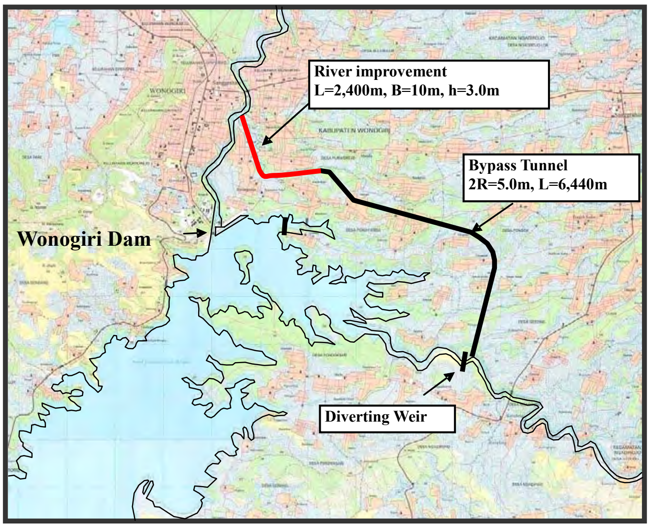

Figure 4.4.75 Layout and Alignment of Keduang River Sediment Bypass

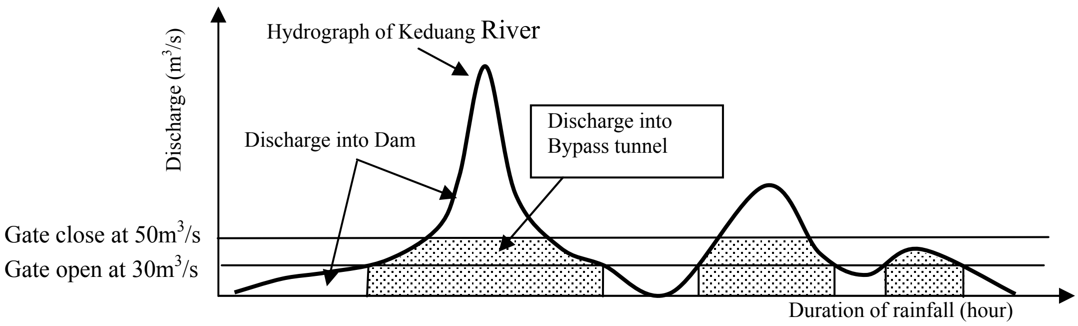

Figure 4.4.76 Illustration of Design Discharge of Bypass Tunnel

(2) Reservoir Sedimentation Simulation

a) Computational Conditions

Computational conditions are listed in Table 4.4.11.

Table 4.4.11 Input Data for the Simulation (Keduang River Sediment Bypass)

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 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 Release through bypass	When flood discharge exceeds 30 m^3/s, the gates are fully opened to divert flood of 50 m^3/s at maximum into the bypass tunnel directly. When flood declines to 30 m^3/s, the gates are closed.	Parts of flood flow of less than 30 m^3/s and more than 50 m^3/s directly enter into the reservoir.
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

Result of sediment balance in wet season under flow condition of hydrological flood year is listed in Table 4.4.12.

- The diverted sediment volume is around 476,000 m^3 which is 28% of the total inflow volume of 1,710,000 m^3.
- Diverted water volume is 181.6 million m^3 and average sediment concentration is 2,789 ppm.
- On the other hand, sediment outflow from the existing outlets is reduced to 289,000 m^3 from 638,000 m^3. Reduction of released sediment volume reaches to 349,000 m^3.
- Consequently, effectiveness of sediment removal by sediment bypass is only 118,000 m^3, which is only 6.9% of the sediment inflow from the Keduang River.

Cost of construction and O&M will be highest among alternatives. With considering its cost and benefit, this countermeasure, i.e., Keduang river sediment bypass, is not recommended.

Table 4.4.12 Sediment Balance of Keduang River Sediment Bypass

Facility	Unit	Sediment outflow				Sediment Deposit in the Reservoir	Total Sediment Inflow from Keduang
		Intake	Existing spillway	Bypass tunnel	Total		
Existing System	1000 m^3	394	244	-	638	1071	1710
Bypassing	1000 m^3	189	91	476	757	953	1710
(Difference)	1000 m^3	-205	-152	476	118	-118	
Outflow water	MCM	806	90	182	1078	-	
Concentration	ppm	250	1077	2789	747	-	

Source : JICA Study Team

4.5 Conclusion of Evaluation on Structure Countermeasures for Sediment Inflow from Keduang River

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

By the above simulations, Structure countermeasures for sediment inflow from the Keduang river can be concluded as follows.

- In hydrological drought year, sedimentation in the effective storage zone and in the area near the intake is less because the reservoir water level is lower. However, water level in the reservoir is lower in the season and the level cannot be recovered to the NWL (Normal Water Level: 136m). The dam operation should be careful.
- More sediment can be released from the reservoir by a new gate installed in right abutment of the dam than that by the existing spillway only.
- By constructing a closure dike connecting the peninsula (in front of the dam) to the dam, the reservoir can be divided into two (2) areas, the Keduang reservoir and the main reservoir. Water level in the Keduang reservoir can be lowered with keeping the main reservoir at NWL or CWL level so that flushing and/or sluicing of sediment-laden flood flow from the Keduang river can be carried out. In this case, sediment release efficiency is related to the operation method of the new gate for flood releasing in Keduang river and can be improved.
- Cost of construction and O&M will be highest among alternatives.

The most attractive point of the alternative --- Compartmented Reservoir with New Gate is that sediment-laden flood flow from the Keduang river can be sluiced without lowering the water level in the main reservoir. It is worth to be evaluated in details.