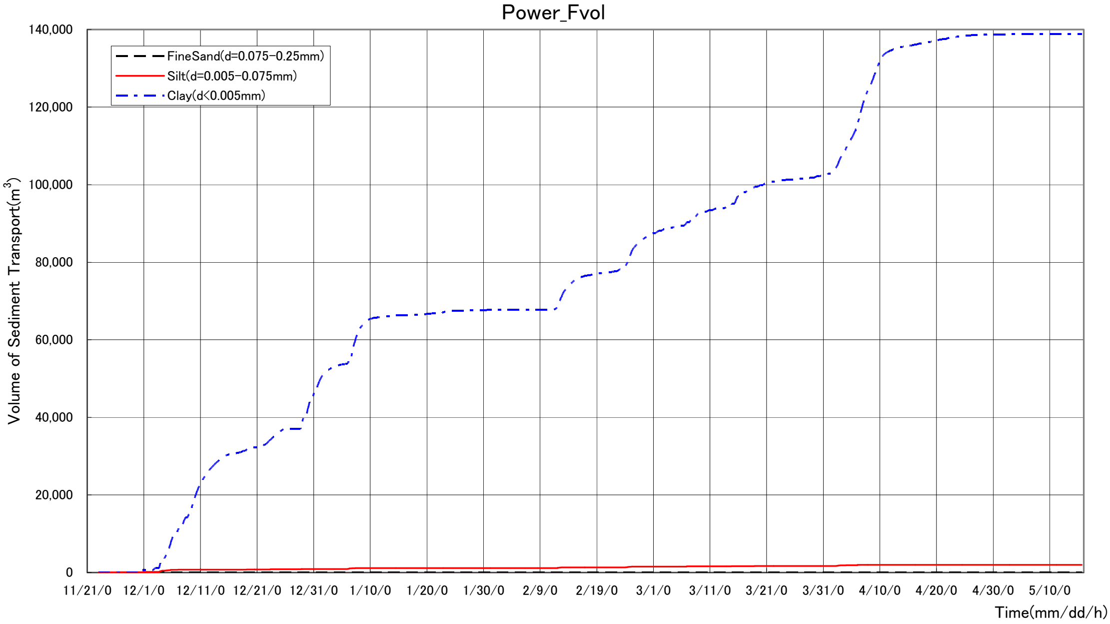


Figure 3.4.30 Computational Transport Volume of SS Through the Intake (2004/11/23-2005/5/15)

3.5 Verification of the Reservoir Sedimentation during 1993-2004

Applying equation (2.27) and the parameters in Table 3.3.2 for the sediment inflow in 2004-2005 to that in 1993-2004, sedimentation in the reservoir during 1993-2004 (11 years) is also simulated by NKhydro2D model. For shortening the computing time, the simulation is mainly conducted in the rainy seasons of the period. 150,000 m^3 of the sediment inflow (the total 35,200,000 m^3, 0.5%) is lost because the simulation skips the dry seasons.

3.5.1 Initial and Boundary Conditions

Domain of the simulation and its grids are the same as that in Figure 3.1.1. The input conditions for simulation during 1993-2004 are listed in Table 3.5.1.

Table 3.5.1 Input Data for Simulation during 1993-2004

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 1993	Section interval was very wide
Inflow Discharge	Temporal discharge (hourly) is employed.	Year 1996 = drought year Year 1998 = flood year
Water Release	Records of both the spillway and the intake	
Water Level	The initial water level is specified as the measured reservoir water level at the starting of simulation.	The initial velocity is set to zero.
Bed Material	Data of particle size distribution at different locations sampled in October 2004. As non-uniform material (consists of 9 classes in simulation)	No data analyzed in 1993.
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.	

(1) Initial Bed level and Bed Material

Figure 3.5.1 shows the contour of bed level, measured in 1993, in the Wonogiri reservoir. This is specified as the initial bed level for the simulation in 1993-2004. Particle size distribution sampled in October 2004 is employed for the initial distribution of bed material in 1993 because there was no data analyzed in 1993. Non-uniform sediment, consists of 9 classes as shown in Table 3.2.3, is considered in the simulation.

Comparing with the bed level in Figure 3.4.1, the bed level in 1993 was deeper because of less sedimentation at that time.

(2) Water Inflow and Outflow

Hydrographs during 1993-2004 in Keduang river, Tirtomoyo river, Temon river, Bengawan Solo river, Alang river, Wuryantoro river are estimated by a hydrological model according to rainfall, evaporation, water level in the reservoir and water release from both the intake and the spillway, and are specified as the water inflow conditions. Because of the observation error and less information, it is believed that precision of the estimated hydrograph is lower. However, the total inflow is correct because the variation of reservoir water level balanced with the variation of inflow and outflow.

Total inflow hydrograph, outflow hydrograph through the intake and the existing spillway from 1993 to 2004 are shown in Figure 3.5.2 ~ 3.5.23.

During 1993-2004, maximum inflow, about 1.5 billion m^3, occurred in 1998 and minimum inflow, about 0.8 billion m^3, occurred in 1996. Difference on the water inflow in a year was great.

The water outflows are the water release from both the intake and the spillway, and are specified according to the observation in the reservoir. In 1996-1997 and 2003-2004, which were hydrological drought years, there was no water release through the spillway.

For shortening the computing time, the simulation is mainly conducted in the rainy seasons of the period.

(3) Sediment Inflow and Outflow

Sediment inflows in 1993-2004 in the rivers are specified by equation (2.27) and the parameters in Table 3.3.2. As stated in the above, 150,000 m^3 of the sediment inflow (the total 35,200,000 m^3, 0.5%) is lost because the simulation skips the dry seasons.

Sediment outflow is the sediment release from both the spillway and the intake. In simulation, its volume is estimated by the outflow discharge of water and the computational concentration of SS near the facilities.

3.5.2 Computational Results

(1) Bed deformation (Sedimentation)

Bed deformations (sedimentation) in accumulation from the bed in 1993 are shown in Figure 3.5.24 for 1993-(1994~2003), and Figure 3.5.25 for 1993-2004. Figure 3.5.26 and Figure 3.5.27 show the longitudinal profiles of deepest bed in Bengawan Solo river (Solo ~ Dam) and in Keduang river (Keduang ~ Dam), respectively.

As the computational result in the calibration, the simulation from 1993 to 2004 also shows that in Bengawan Solo river, the sedimentation progressed gradually to the center of the reservoir from the river area. The fore-set bed had been reached to Temon river area and the sedimentation depth was about 2m in the fore-set bed during the period. In center of the reservoir, the sedimentation depth was about 0.1 ~ 0.3m. In Keduang area, the sedimentation was more severe and the maximum depth of sedimentation was about 4m. The deepest bed level rose about 2m in 11 years. The fore-set bed invaded to the center of reservoir from Keduang river and the sedimentation in dam area (near the intake) was about 2m.

(2) Sedimentation Volume and Trap Ratio in the Reservoir

Estimated sediment inflow, computational sedimentation volume in the reservoir and sediment release during 1993 ~ 2004 are listed in Table 3.5.2. Computational total sedimentation volume in the reservoir during 1993 ~ 2004 (11 years) is 29,840,000m^3, and the annual average is 2,710,000 m^3.

Due to skip of dry season in the simulation, estimated sediment inflow during the simulation period is about 35,100,000 m^3 in total, although the estimated sediment inflow during 1993 ~ 2004 was about 35,200,000 m^3 in total. Therefore, the annual average of sediment inflow for the simulation is about 3,190,000 m^3. Among the others, 1993, 1998 and 1999 were hydrological flood year, and the sediment inflow in the year was over 4,000,000 m^3. On the other hand, in hydrological drought year 1996 and 2003, the sediment inflow in the year was less than 2,000,000 m^3.

Table 3.5.2 Estimated Sediment Inflow, Measured Sedimentation, Computational Sedimentation in the Reservoir and Sediment Release during 1993 ~ 2004 (Deposition Base, m^3)

Year	Sediment Inflow (m3)		Simulation (m3)			Reservoir Sediment Trap Ratio	Measured Sedimentation in the reservoir (m3)
	Total	Keduang only	Sedimentation in the reservoir	Sediment Release by Spillway	Sediment Release by Power Plant		
1993-1994	4,063,000	1,665,000	3,353,000	223,000	463,000	0.825	
1994-1995	3,825,000	1,435,000	3,186,000	192,000	376,000	0.833	
1995-1996	3,651,000	1,362,000	3,064,000	155,000	412,000	0.839	
1996-1997	1,698,000	579,000	1,520,000	0	156,000	0.895	
1997-1998	2,907,000	1,016,000	2,704,000	94,000	100,000	0.930	
1998-1999	4,355,000	1,721,000	3,561,000	338,000	365,000	0.818	
1999-2000	4,124,000	1,774,000	3,393,000	351,000	327,000	0.823	
2000-2001	2,643,000	902,000	2,315,000	70,000	214,000	0.876	
2001-2002	3,450,000	1,566,000	2,749,000	317,000	317,000	0.797	
2002-2003	2,607,000	769,000	2,324,000	120,000	154,000	0.891	
2003-2004	1,765,000	504,000	1,672,000	0	73,000	0.947	
Total (1993-2004)	35,088,000	13,293,000	29,841,000	1,860,000	2,957,000	0.850	32,306,000
Yearly average	3,190,000	1,209,000	2,713,000	170,000	269,000	0.850	2,937,000

Note: deposition base for the volume, including the void

The measured sedimentation volume in the 11 years is also listed in the table. The measured sedimentation during 1993 ~ 2004 (11 years) is about 32,310,000 m^3 in total and the annual average is 2,940,000 m^3.

During the 11 years, total difference of the sedimentation between the measurement and the computation is about 2,470,000 m^3. The annual average difference is about 225,000 m^3 and the discrepancy ratio is about 8%. This is partly caused by the numerical simulation due to the input conditions which are estimated based on less information. Moreover, the measured sedimentation volume was estimated by using the measurement of cross-section in 1993, in which the interval of section was 1km or more. Furthermore, there was no section data in the dam area. Therefore, it can be judged that from the engineering viewpoint, the simulation result corresponds to the measurement of sedimentation. The correlation function and parameters for sediment transport rate with inflow discharge in the rivers, which are derived based on the observation data in the rainy season of 2004-2005, could be applied to the sediment inflow from 1993 as well.

Computational total sediment release from the reservoir during 1993 ~ 2004 (11 years) is 4,820,000 m^3, in which 1,860,000 m^3 by the intake and 2,960,000 m^3 by the spillway. The annual average is 440,000 m^3, and 170,000 m^3 by the intake and 270,000 m^3 by the spillway. The simulation shows that much sediment was released by both the spillway and the intake during flood year, and annually released sediment was over 700,000 m^3. The spillway was not run in drought year, and sediment release by the intake was little, 150,000 m^3 in 1996 and 70,000 m^3 in 2003, respectively.

Sediment trap ratios are calculated in Table 3.5.2. According to the simulation, mean sediment trap ratio by the reservoir is 0.85. The trap ratio is relative lower in flood year and higher in drought year.

3.5.3 Conclusion of the Simulation for Verification

According to the simulation for the sedimentation in the reservoir during 1993 ~ 2004, the following conclusion are obtained.

- By comparison of the computational sedimentation with the measurement during 1993 ~ 2004, it is judged that NKhydro2D model can be employed to simulate the sedimentation in Wonogiri reservoir.
- The correlation function and parameters for sediment transport rate with inflow discharge in the rivers, which are derived based on the observation data in the rainy season of 2004-2005, could be applied to the sediment inflow from 1993 as well.
- Estimated total sediment inflow during the simulation period is about 35,100,000 m^3, and annual average of sediment inflow is about 3,190,000 m^3.
- Computational total sedimentation volume in the reservoir during 1993 ~ 2004 (11 years) is 29,840,000m^3, and the annual average is 2,710,000 m^3.
- In Bengawan Solo river, the sedimentation progressed gradually to the center of the reservoir from the river area. The fore-set bed had been reached to Temon river area and the sedimentation depth was about 2m in the fore-set bed during the period. In center of the reservoir, the sedimentation depth was about 0.1 ~ 0.3m.
- In Keduang area, the sedimentation was more severe and the maximum depth of sedimentation was about 4m. The fore-set bed invaded to the center of reservoir from Keduang river and the sedimentation in dam area (near the intake) was about 2m.
- Annual average of sediment release from the reservoir is 440,000 m^3, in which 170,000 m^3 by the intake and 270,000 m^3 by the spillway.
- Mean sediment trap ratio by the reservoir is 0.85. The trap ratio is relative lower in flood year and higher in drought year.

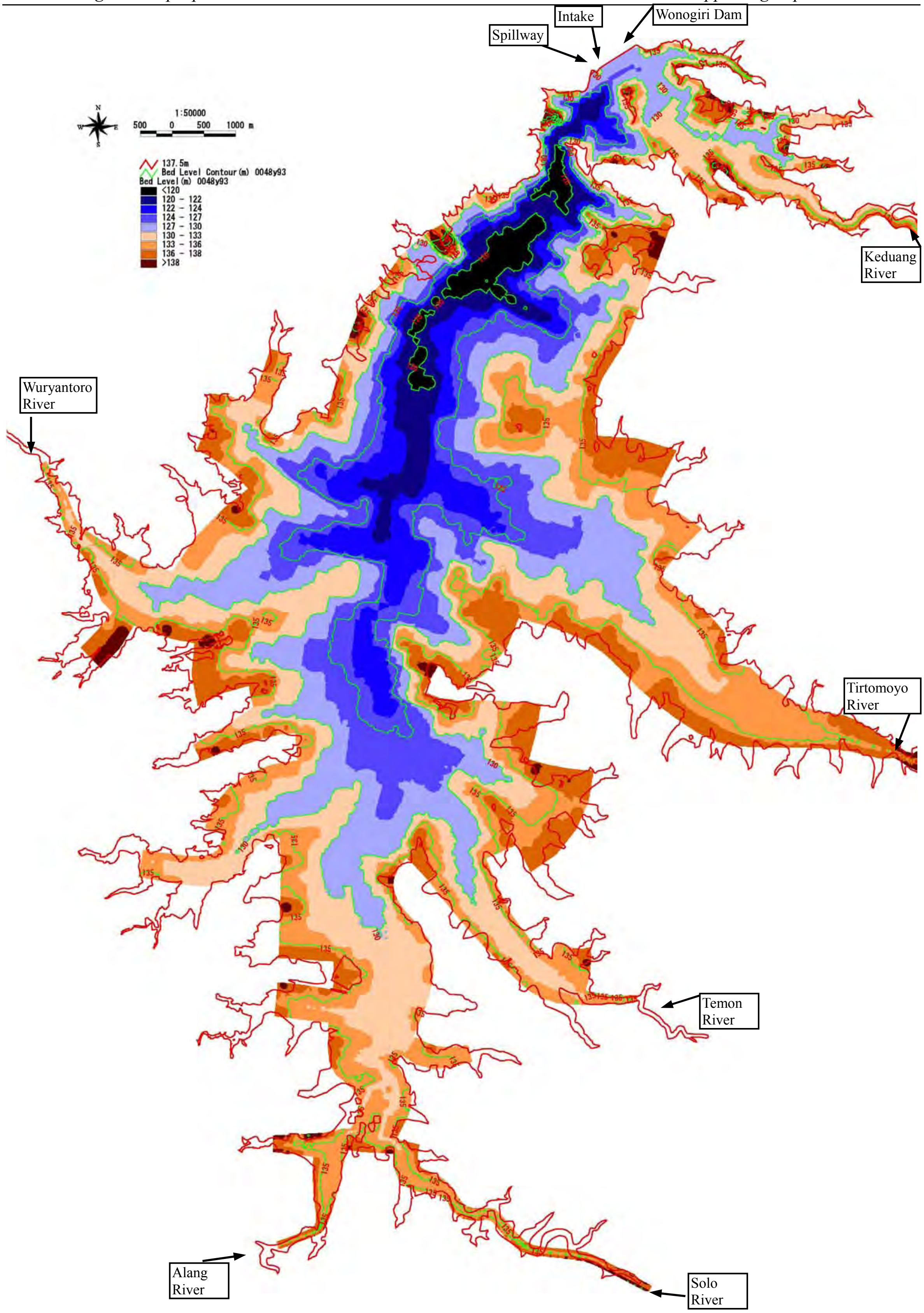


Figure 3.5.1 Bed Level Contour in the Reservoir (Measured in 1993, Contour Unit: m)

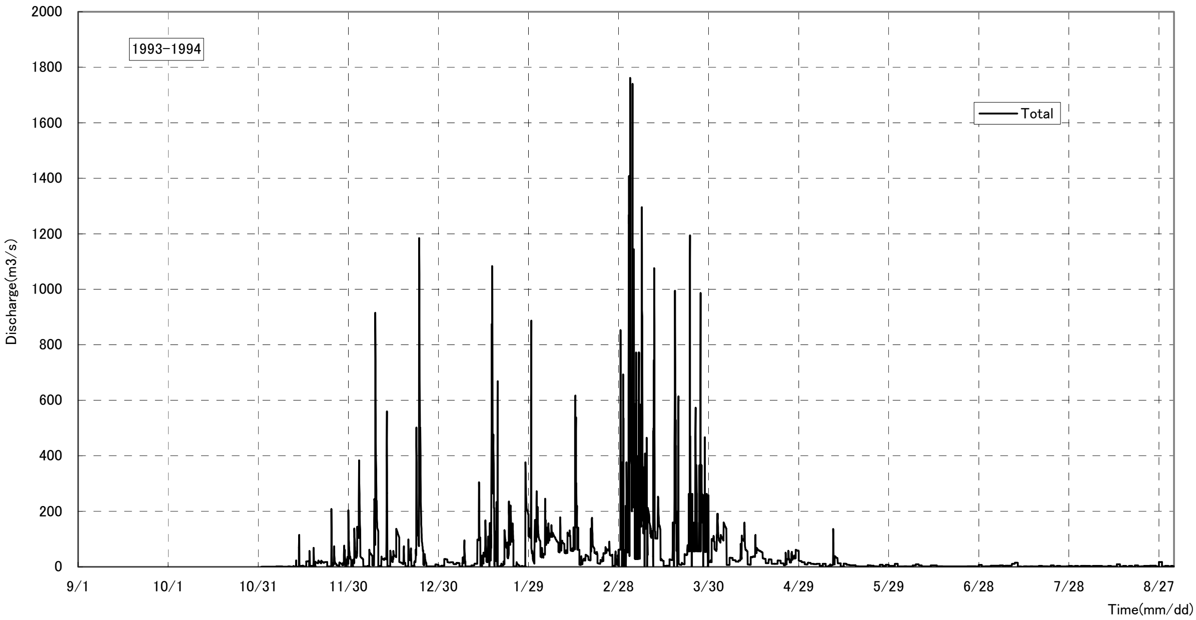
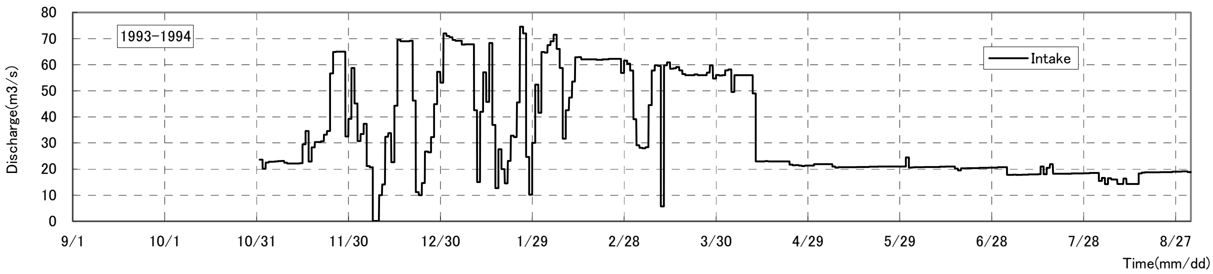
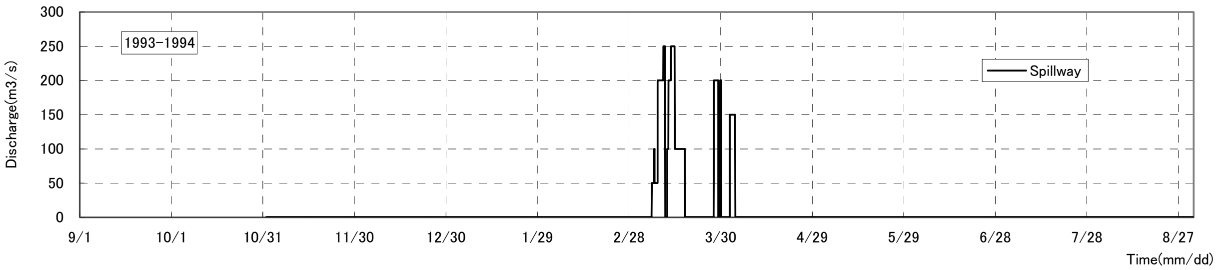


Figure 3.5.2 Discharge Hydrograph of Total Inflow in 1993-1994



(a) Intake



(b) Spillway

Figure 3.5.3 Discharge Hydrograph of Outflow in 1993-1994

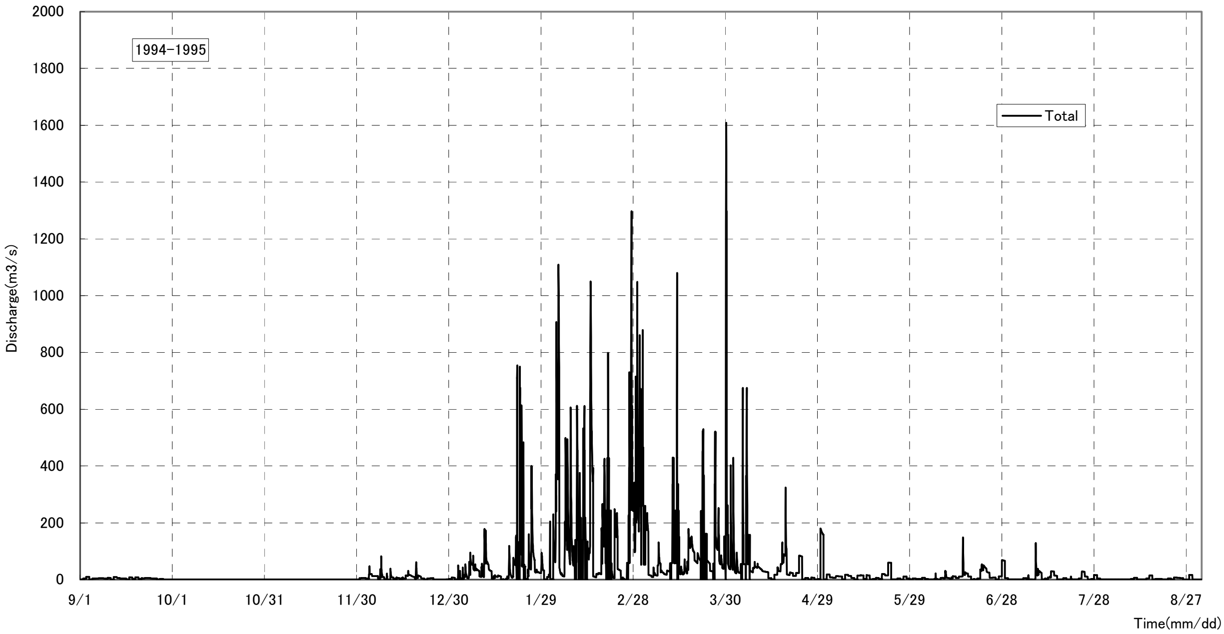
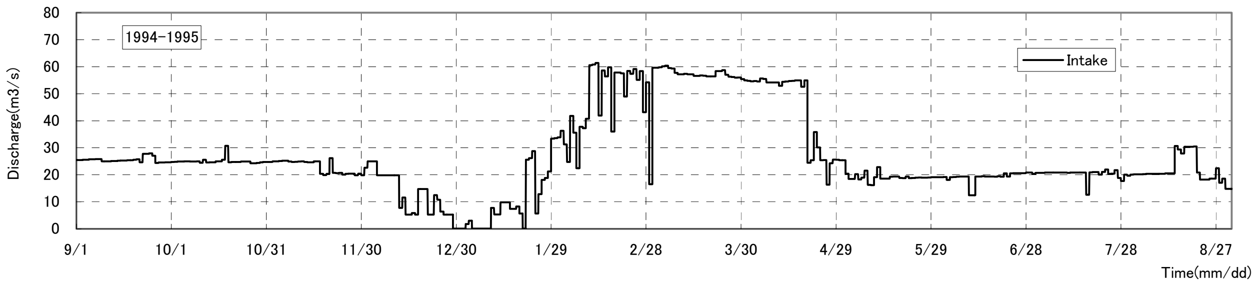
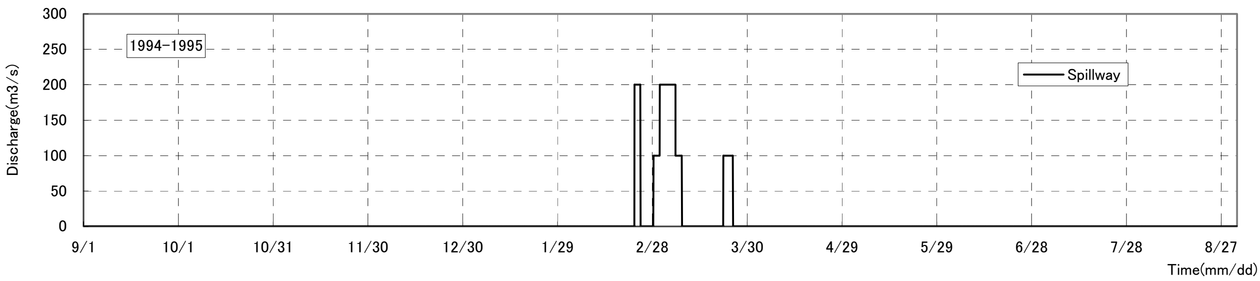


Figure 3.5.4 Discharge Hydrograph of Total Inflow in 1994-1995



(a) Intake



(b) Spillway

Figure 3.5.5 Discharge Hydrograph of Outflow in 1994-1995

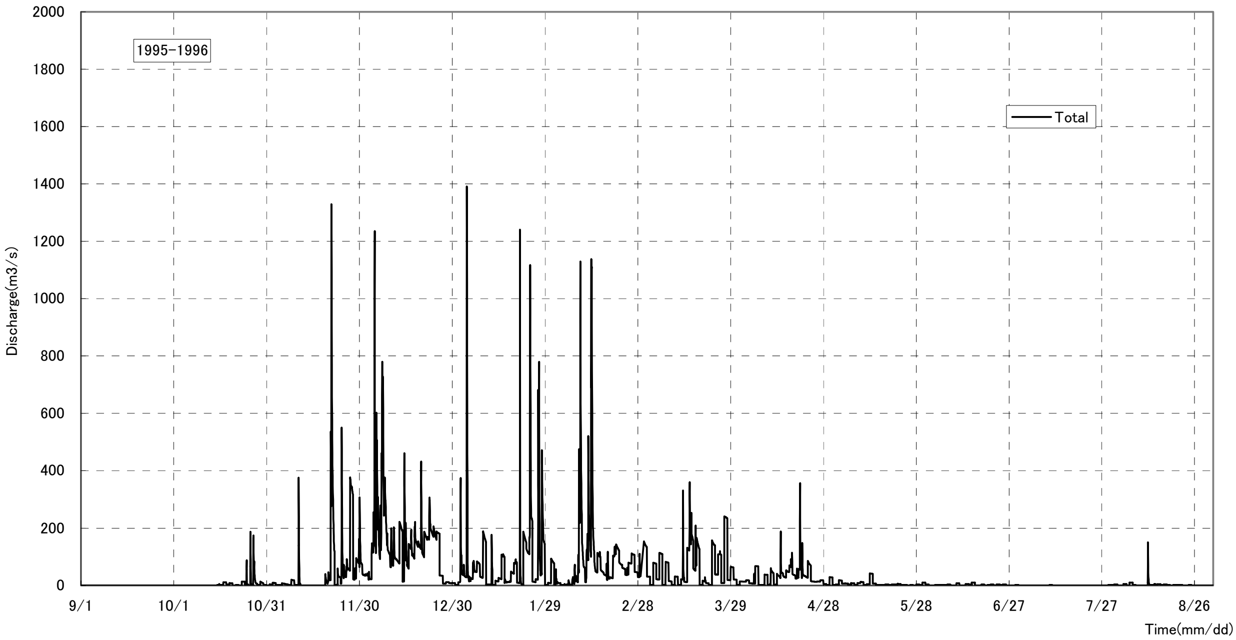
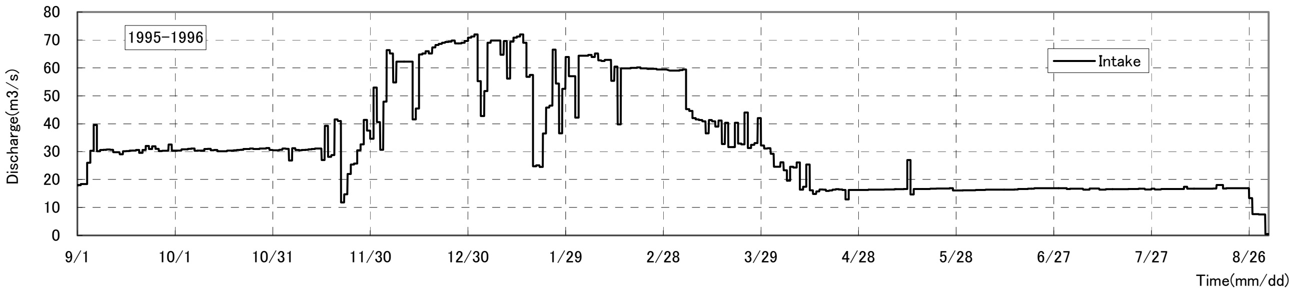
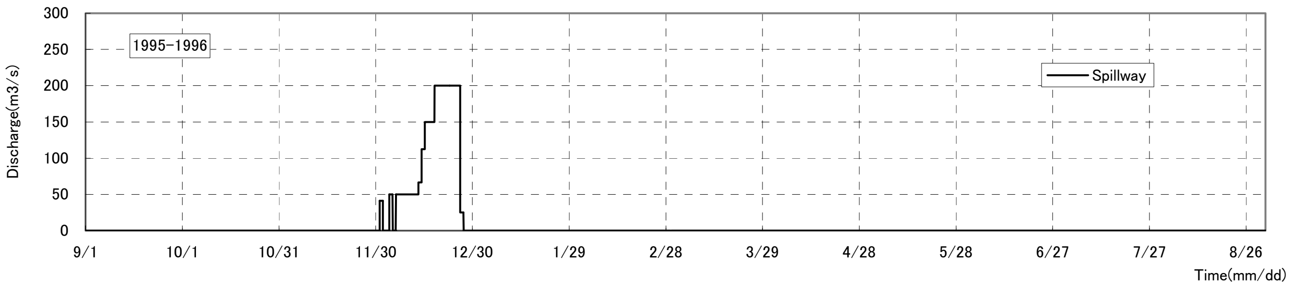


Figure 3.5.6 Discharge Hydrograph of Total Inflow in 1995-1996



(a) Intake



(b) Spillway

Figure 3.5.7 Discharge Hydrograph of Outflow in 1995-1996

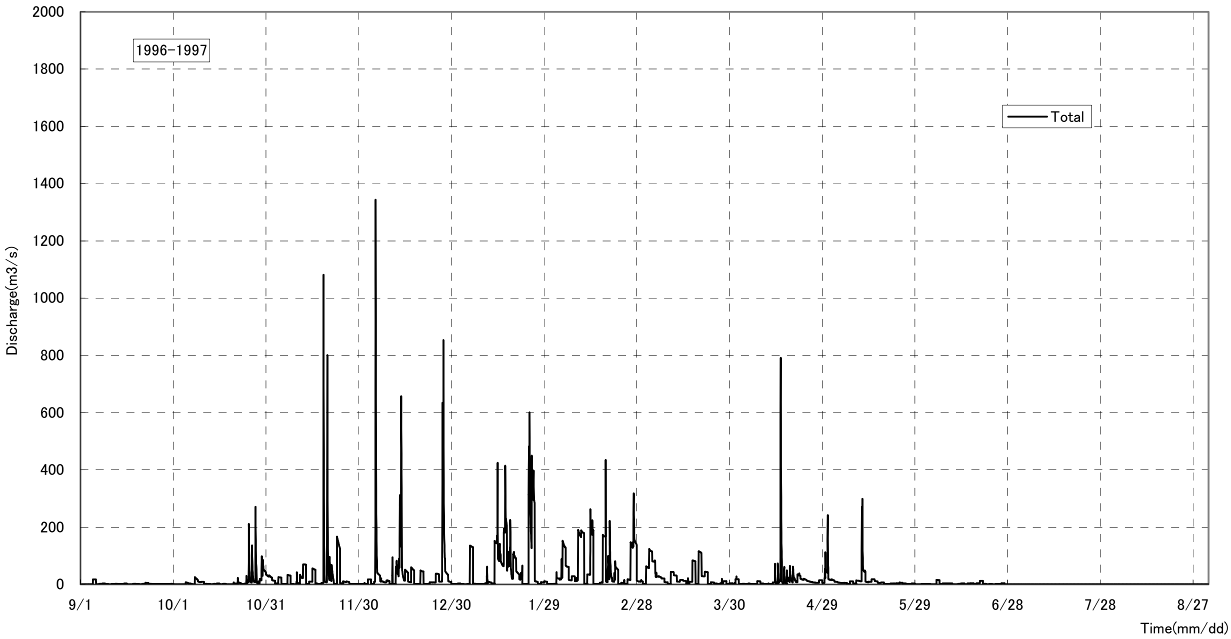
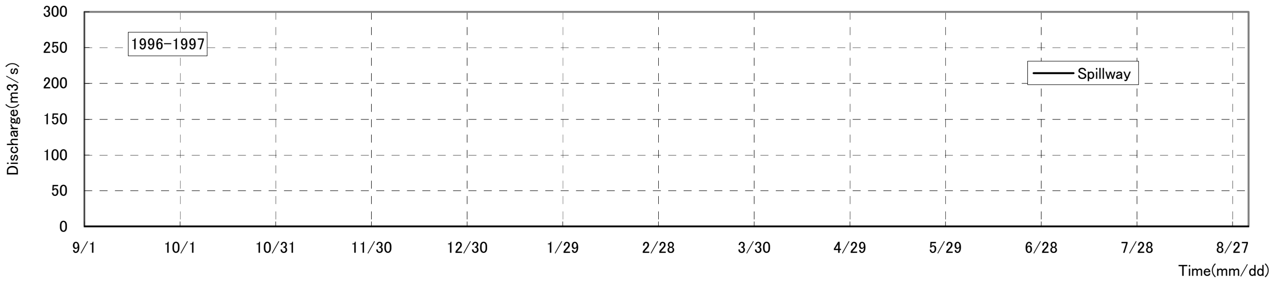
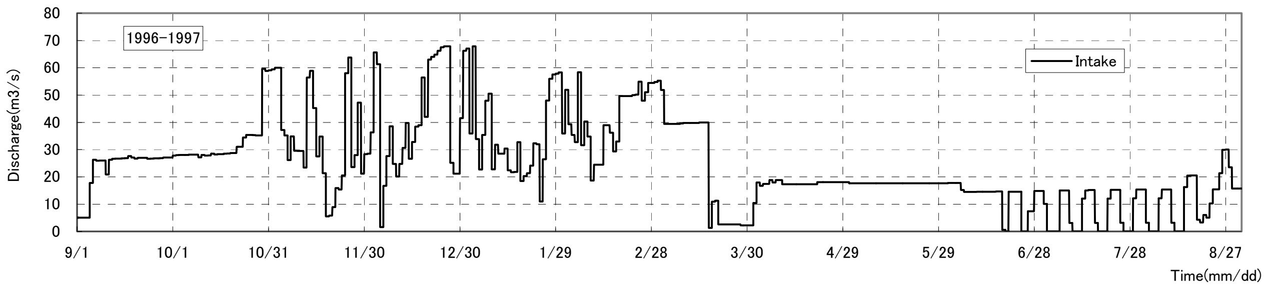


Figure 3.5.8 Discharge Hydrograph of Total Inflow in 1996-1997



(a) Intake



(B) Spillway

Figure 3.5.9 Discharge Hydrograph of Outflow in 1996-1997

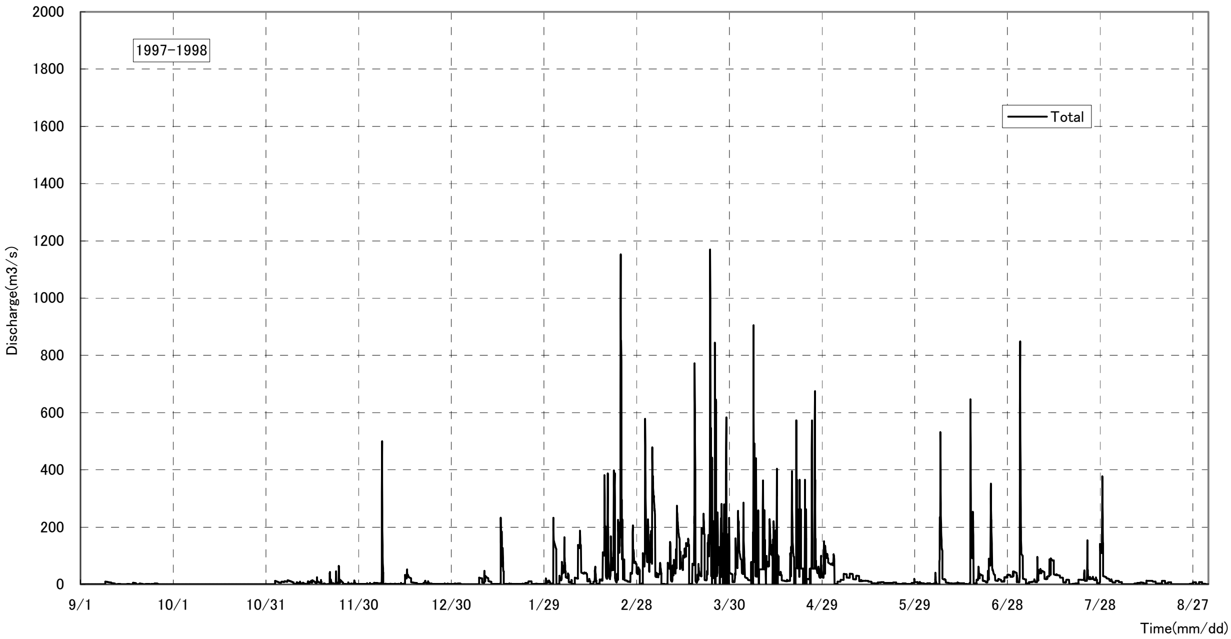
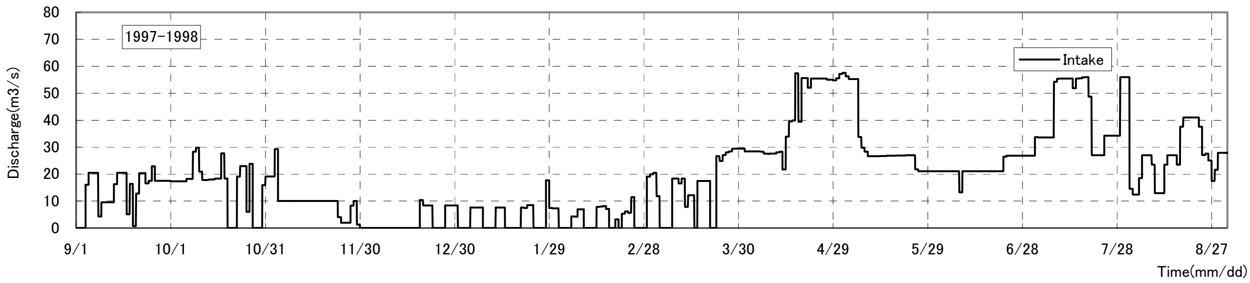
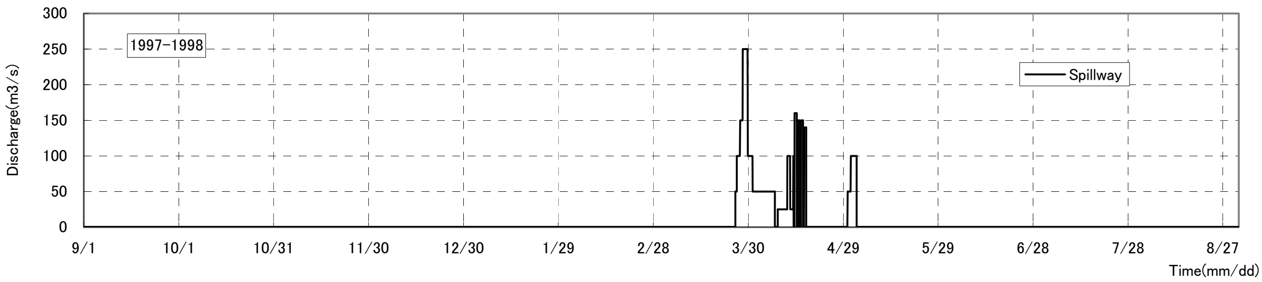


Figure 3.5.10 Discharge Hydrograph of Total Inflow in 1997-1998



(a) Intake



(b) Spillway

Figure 3.5.11 Discharge Hydrograph of Outflow in 1997-1998

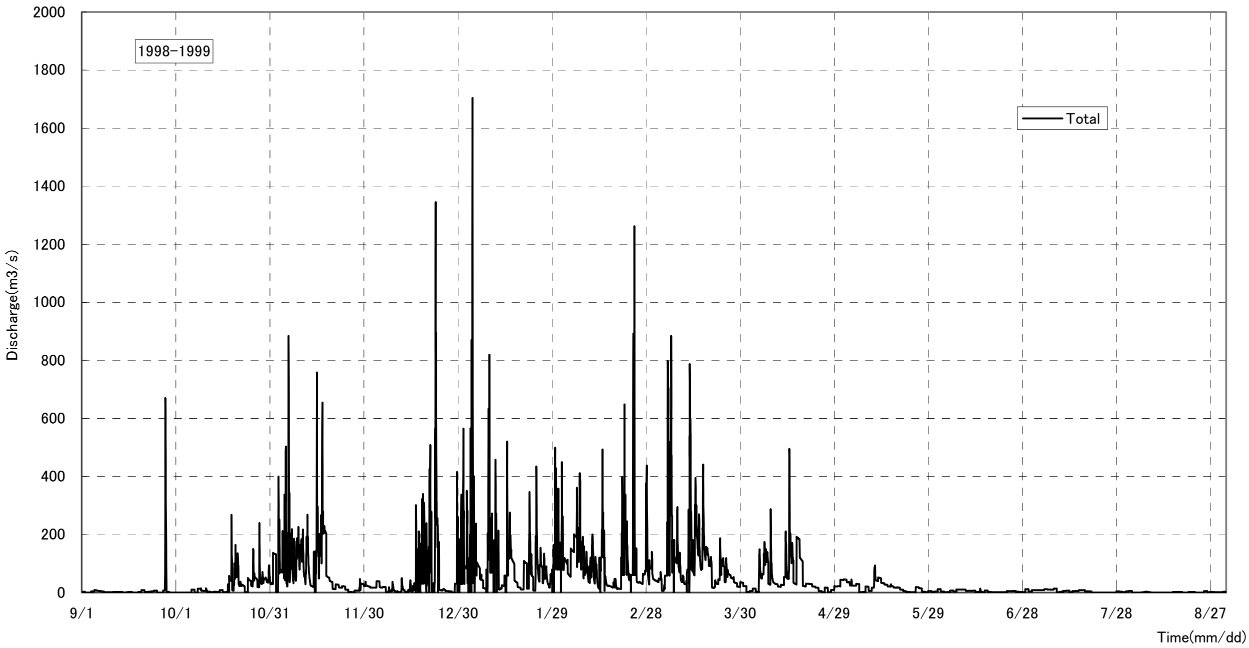
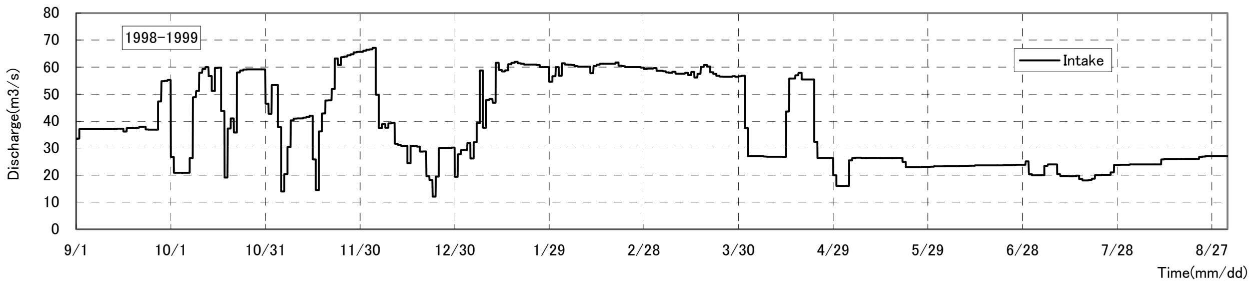
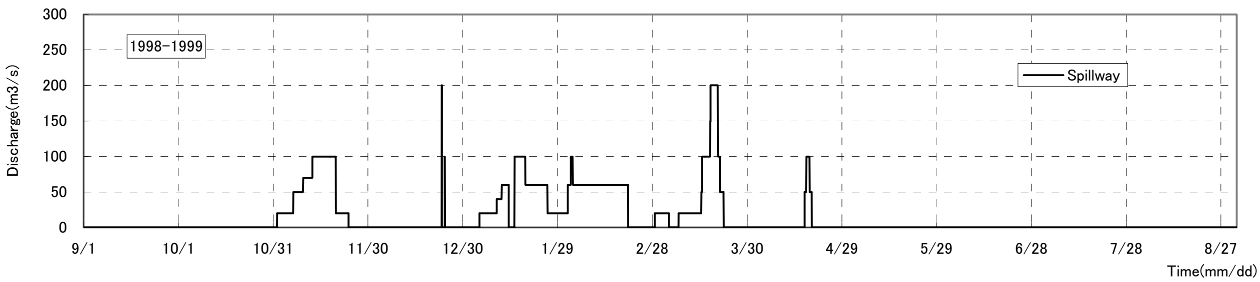


Figure 3.5.12 Discharge Hydrograph of Total Inflow in 1998-1999



(a) Intake



(b) Spillway

Figure 3.5.13 Discharge Hydrograph of Outflow in 1998-1999

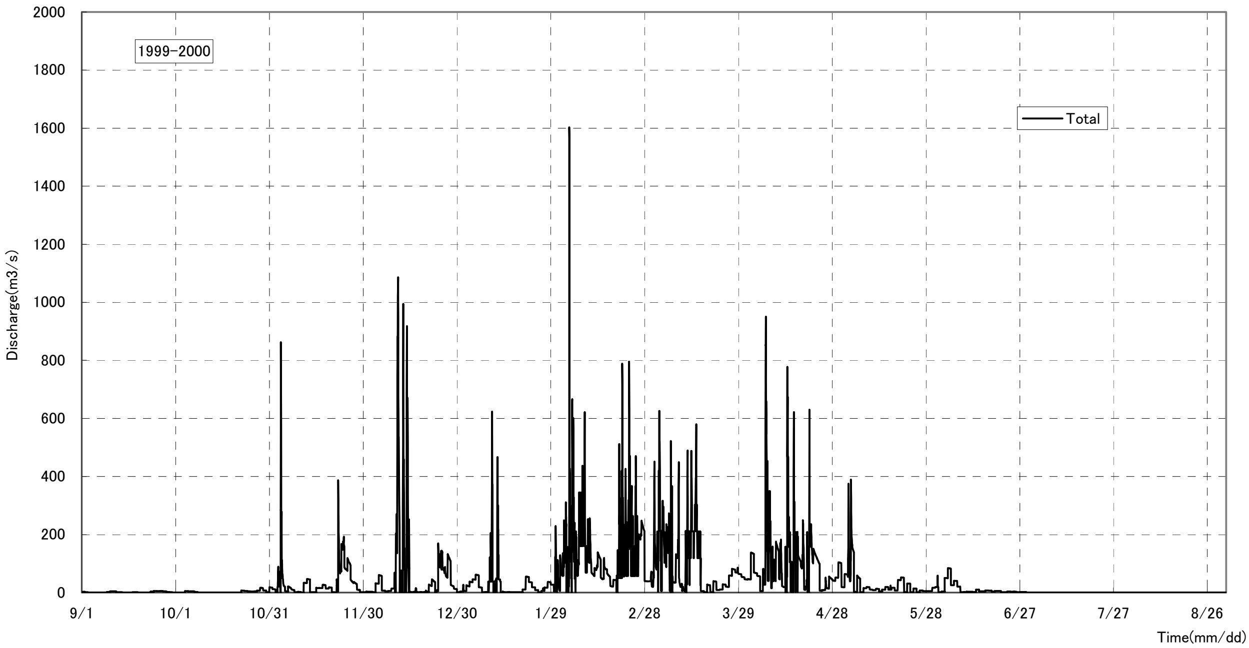
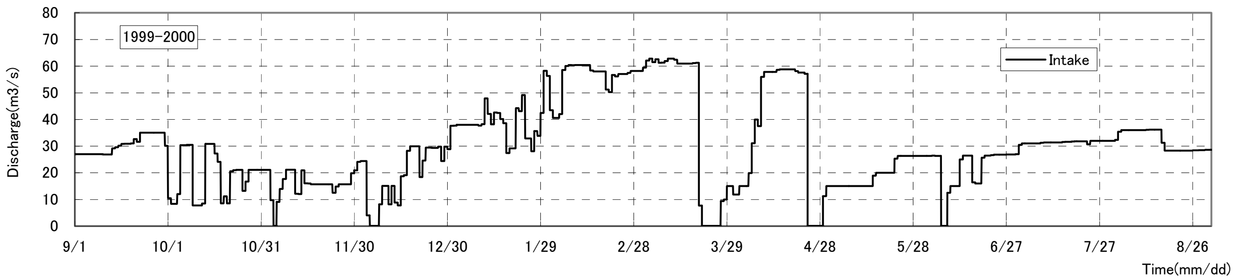
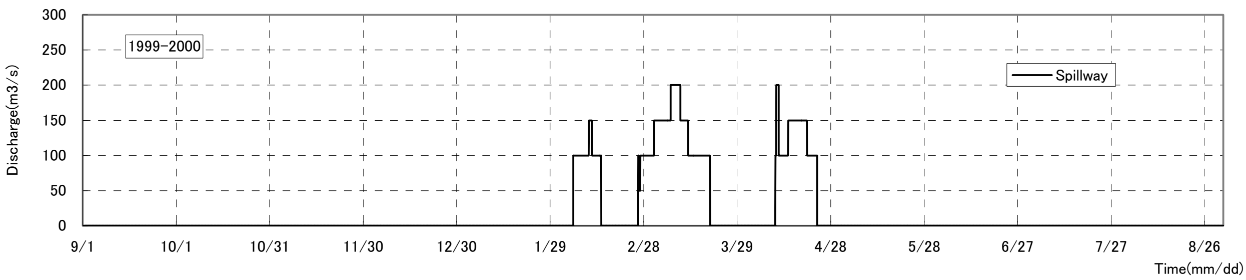


Figure 3.5.14 Discharge Hydrograph of Total Inflow in 1999-2000



(a) Intake



(b) Spillway

Figure 3.5.15 Discharge Hydrograph of Outflow in 1999-2000

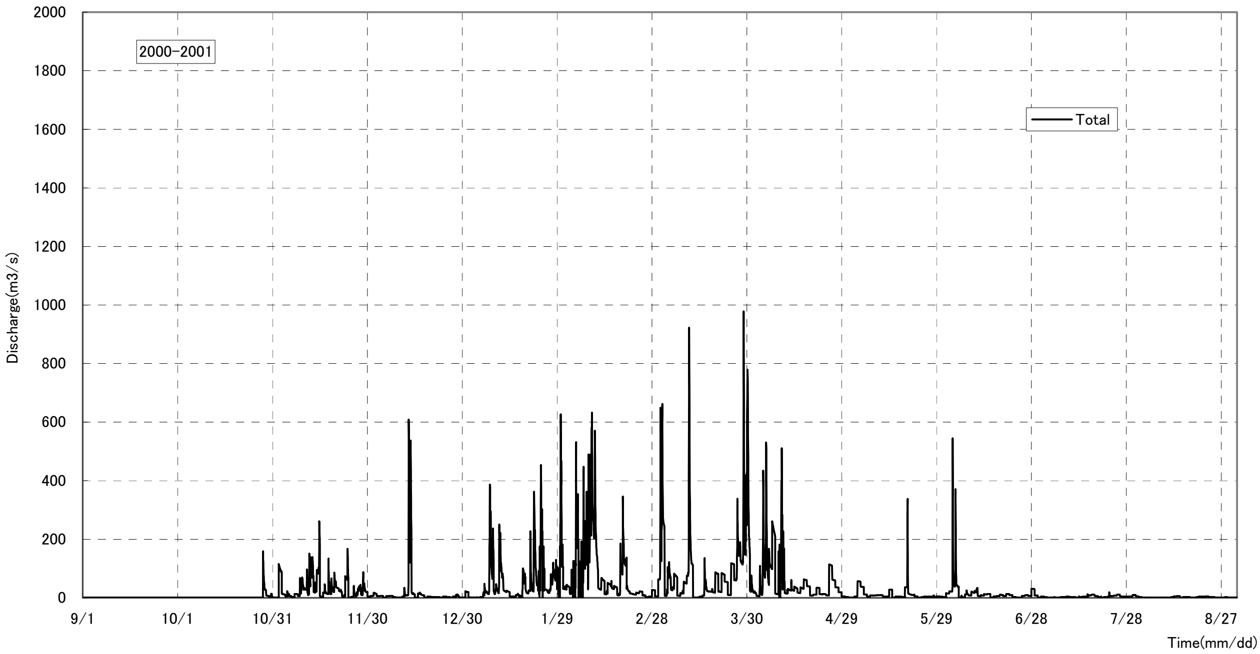
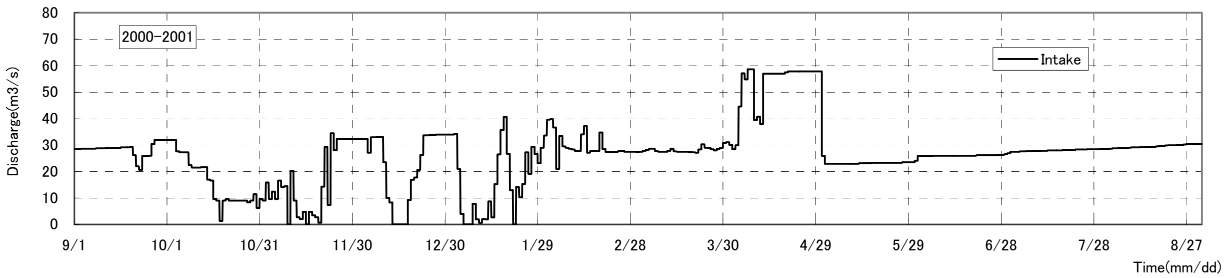
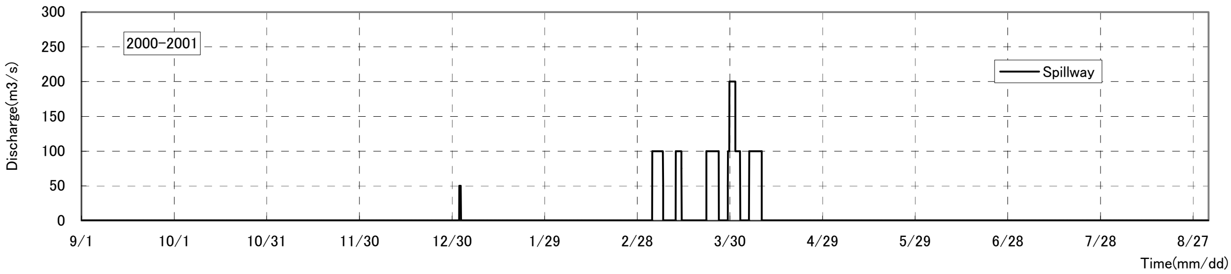


Figure 3.5.16 Discharge Hydrograph of Total Inflow in 2000-2001



(a) Intake



(b) Spillway

Figure 3.5.17 Discharge Hydrograph of Outflow in 2000-2001

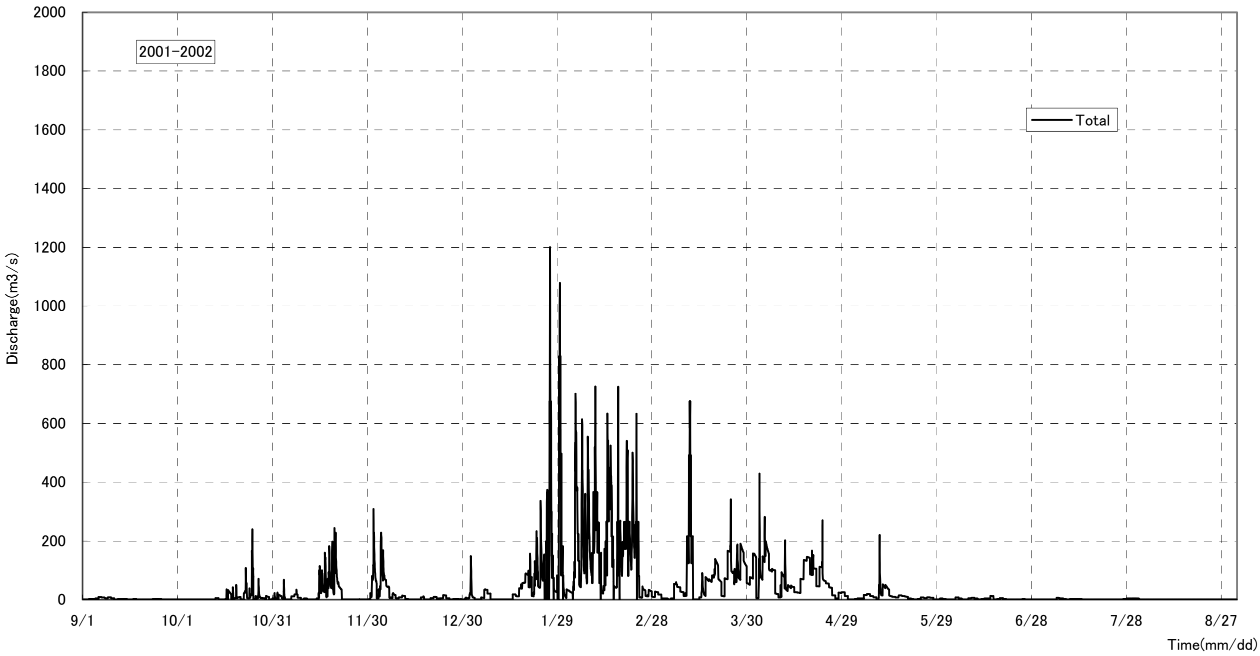
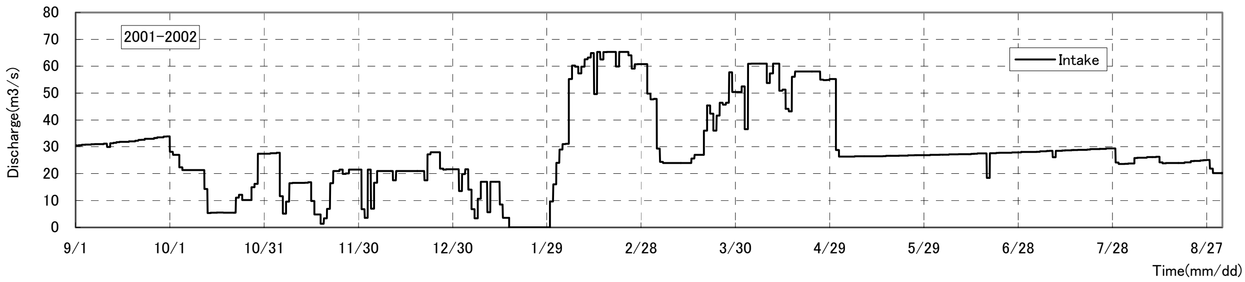
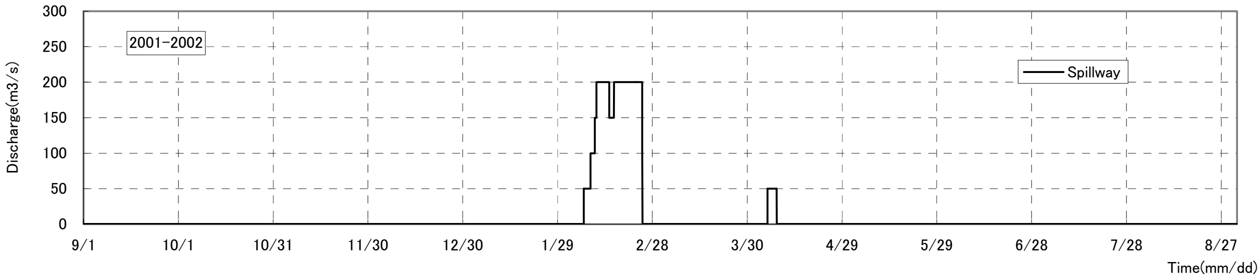


Figure 3.5.18 Discharge Hydrograph of Total Inflow in 2001-2002



(a) Intake



(b) Spillway

Figure 3.5.19 Discharge Hydrograph of Outflow in 2001-2002

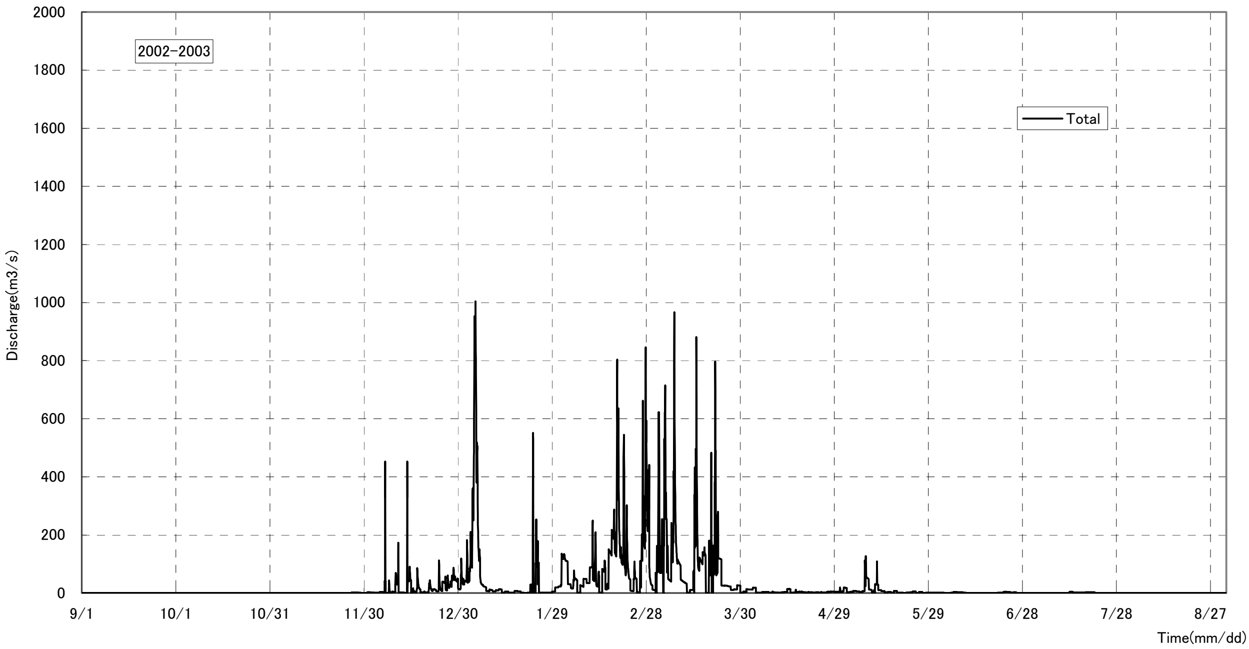
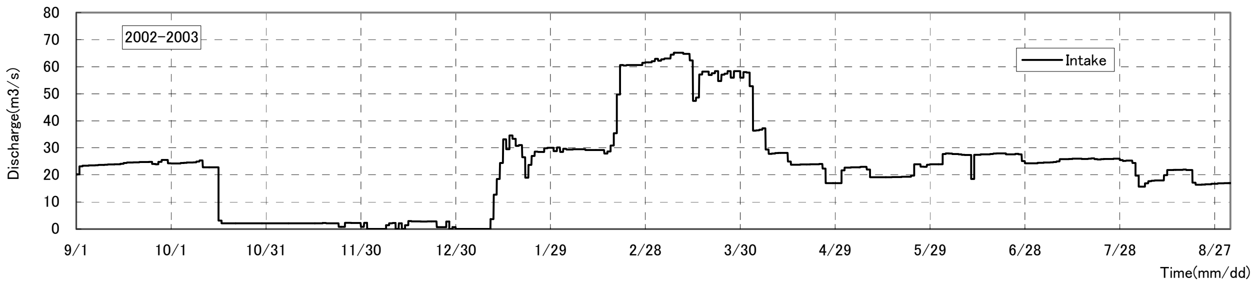
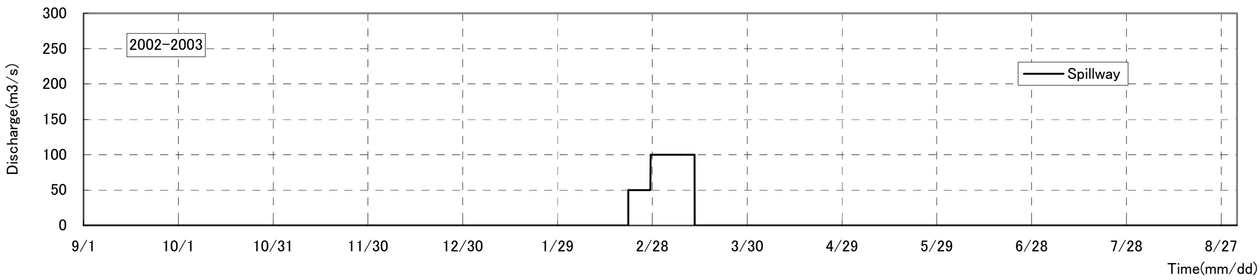


Figure 3.5.20 Discharge Hydrograph of Total Inflow in 2002-2003



(a) Intake



(b) Spillway

Figure 3.5.21 Discharge Hydrograph of Outflow in 2002-2003

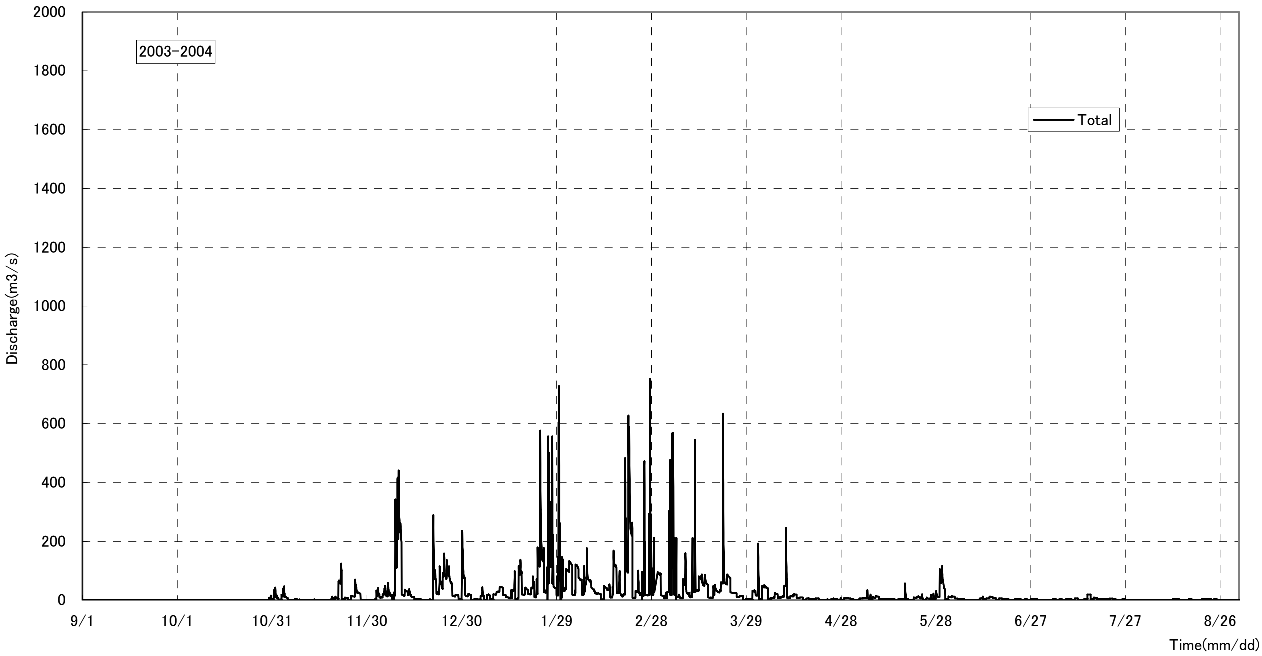
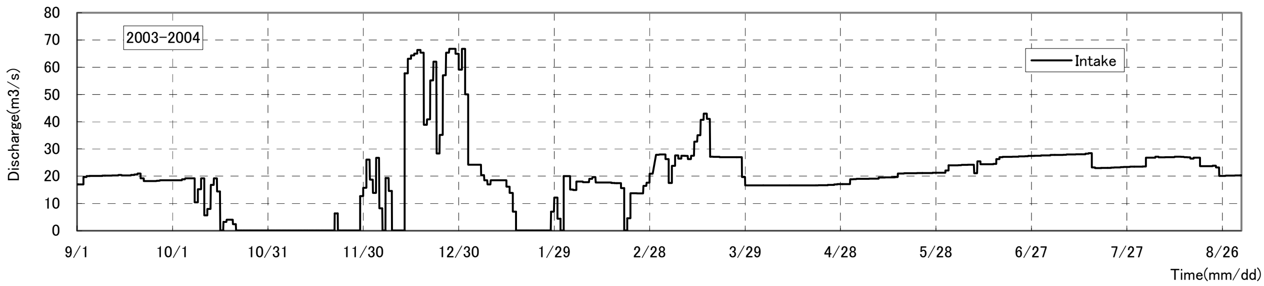
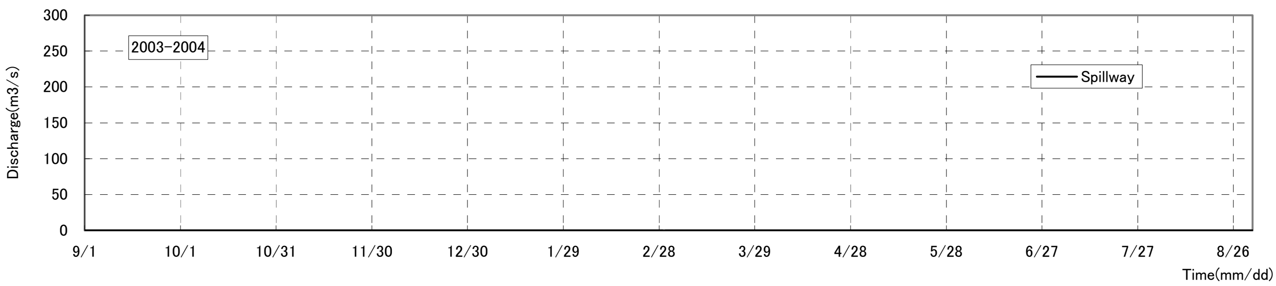


Figure 3.5.22 Discharge Hydrograph of Total Inflow in 2003-2004

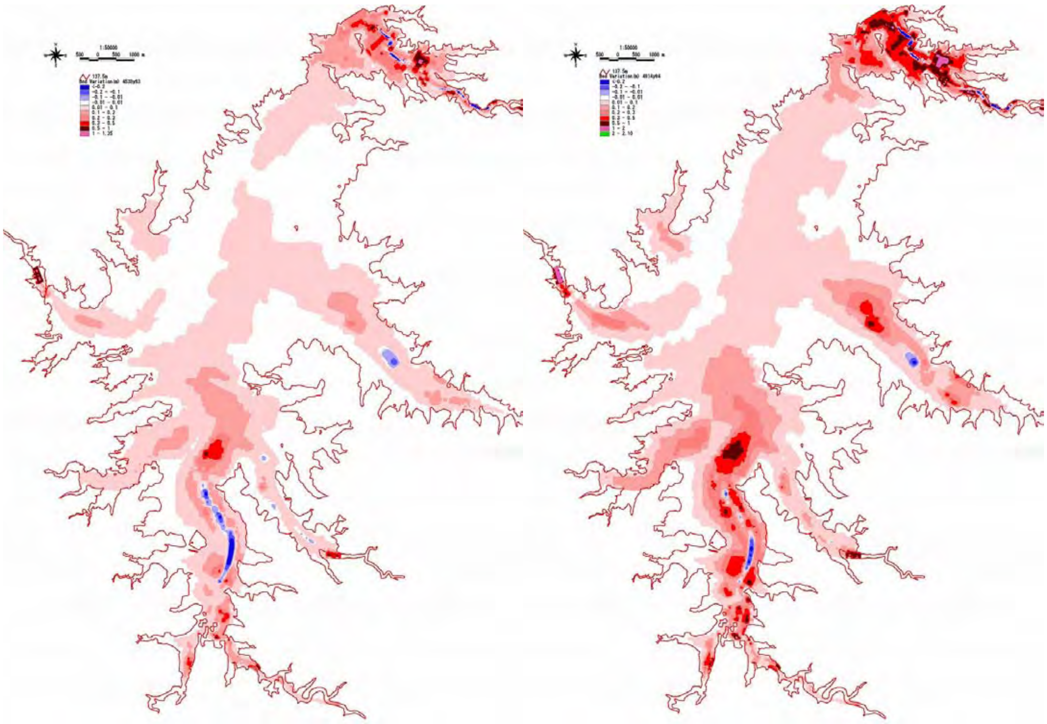


(a) Intake



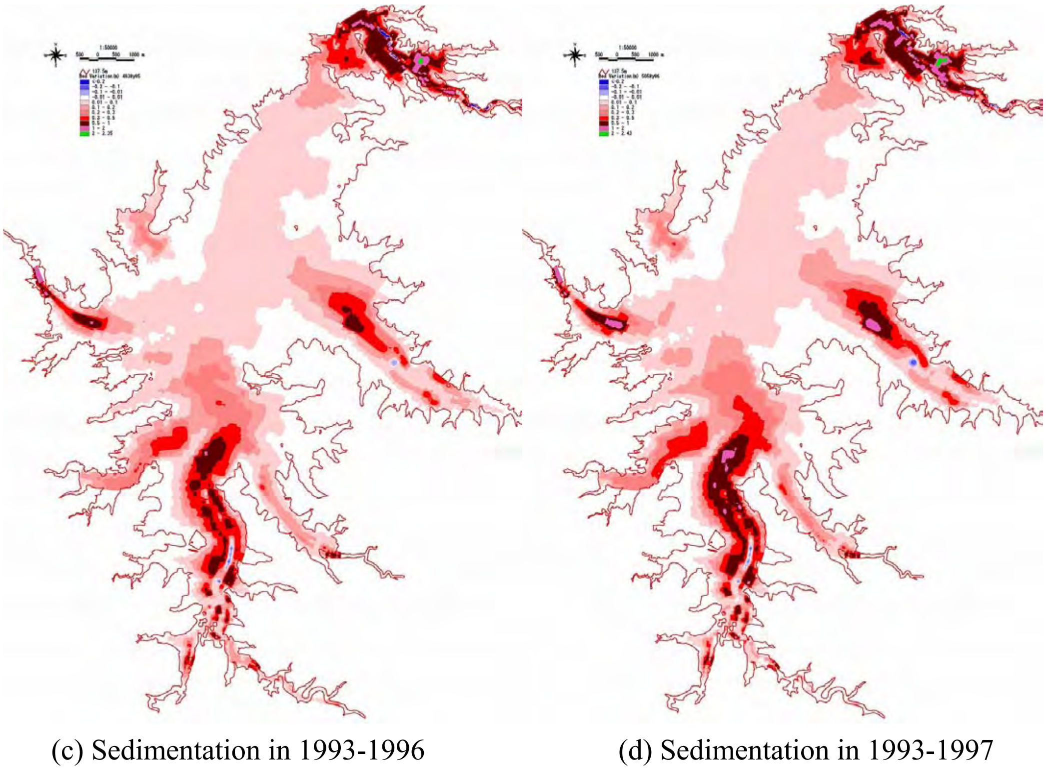
(c) Spillway

Figure 3.5.23 Discharge Hydrograph of Outflow in 2003-2004



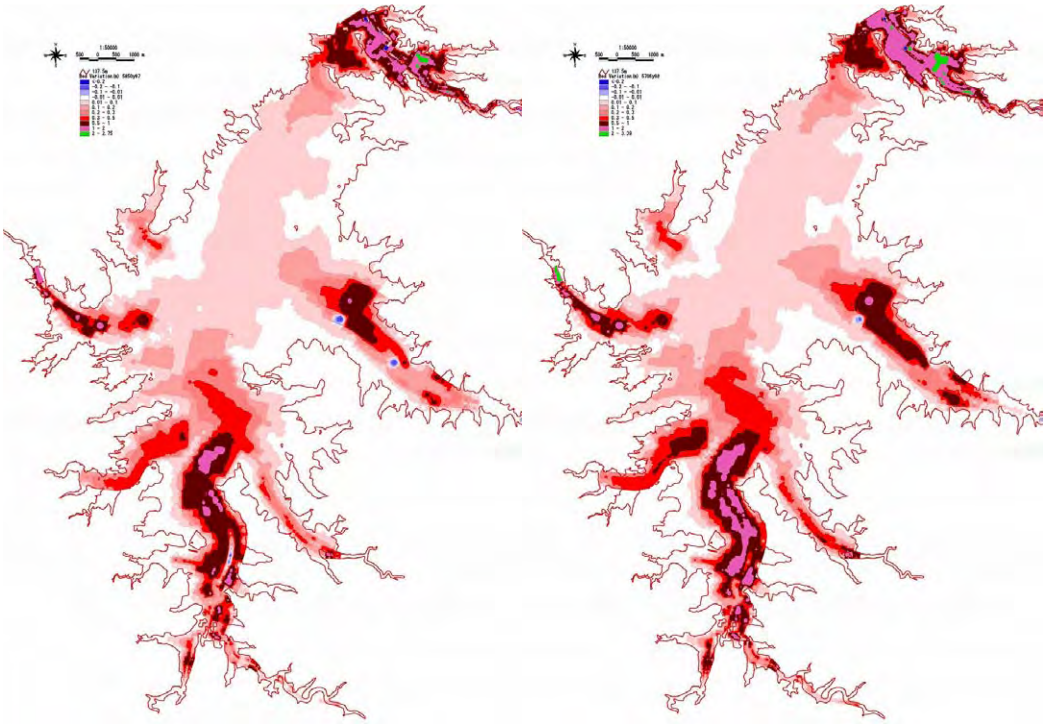
(a) Sedimentation in 1993-1994 (b) Sedimentation in 1993-1995

Figure 3.5.24(1) Bed Variation (Sedimentation) in the Reservoir from the Bed in 1993



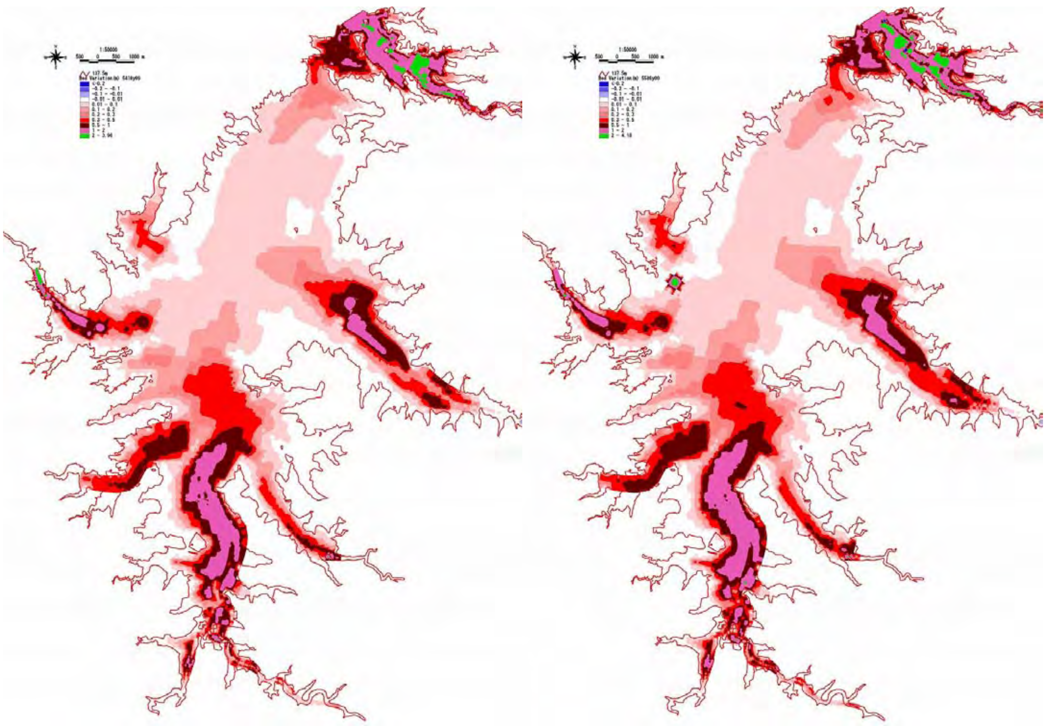
(c) Sedimentation in 1993-1996 (d) Sedimentation in 1993-1997

Figure 3.5.24(2) Bed Variation (Sedimentation) in the Reservoir from the Bed in 1993



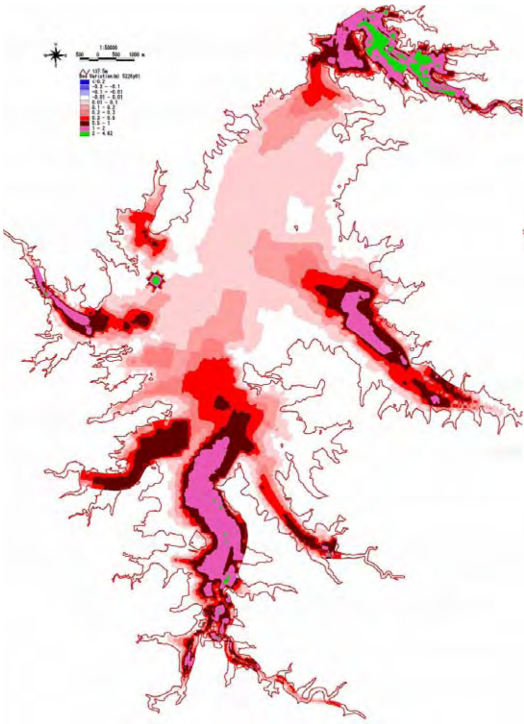
(e) Sedimentation in 1993-1998 (f) Sedimentation in 1993-1999

Figure 3.5.24(3) Bed Variation (Sedimentation) in the Reservoir from the Bed in 1993

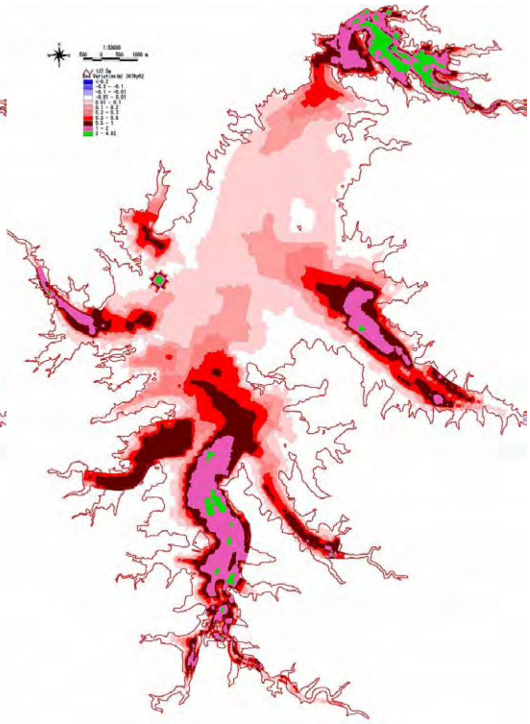


(g) Sedimentation in 1993-2000 (h) Sedimentation in 1993-2001

Figure 3.5.24(4) Bed Variation (Sedimentation) in the Reservoir from the Bed in 1993



(i) Sedimentation in 1993-2002



(j) Sedimentation in 1993-2003

Figure 3.5.24(5) Bed Variation (Sedimentation) in the Reservoir from the Bed in 1993

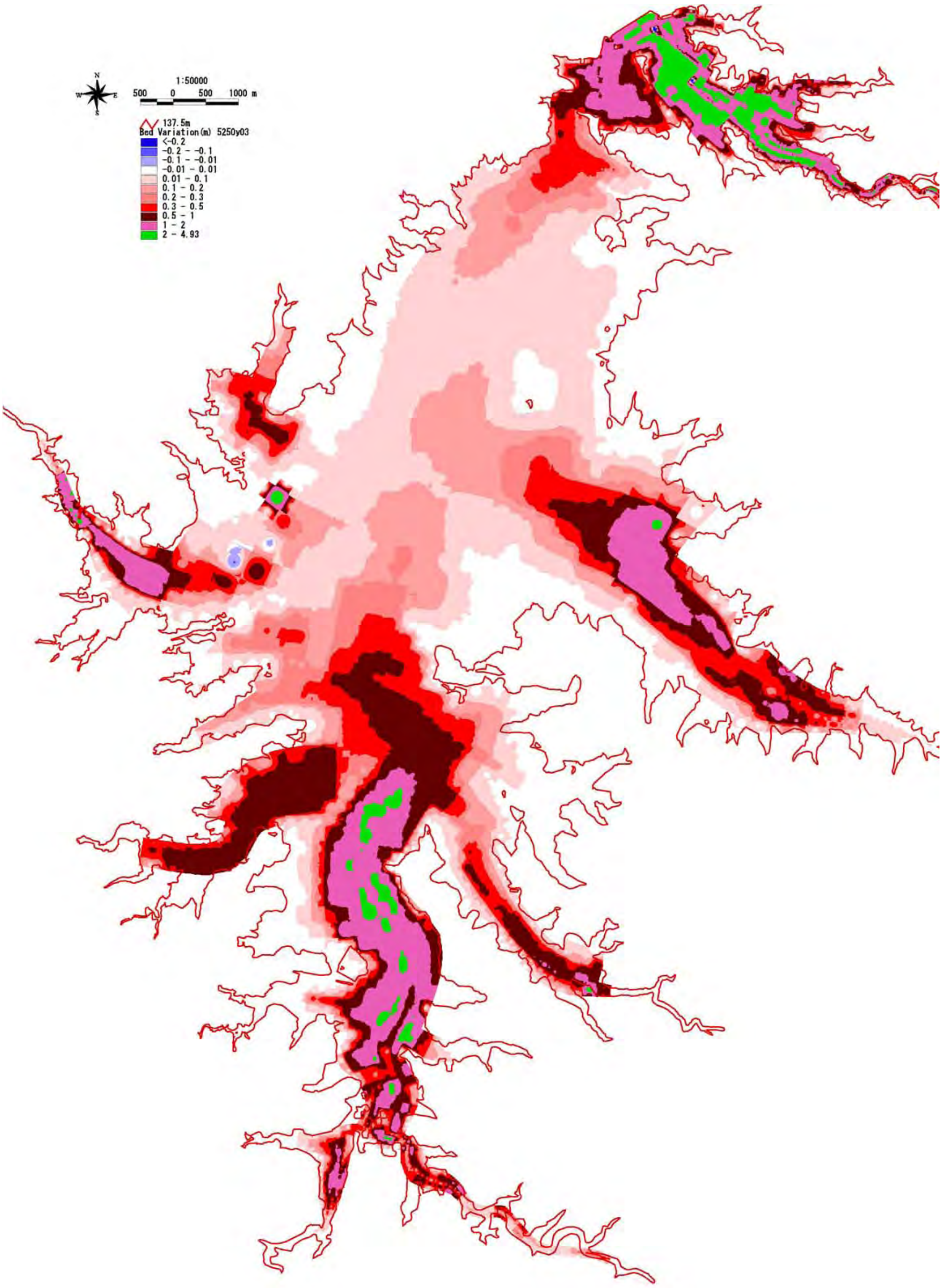


Figure 3.5.25 Bed Deformation (Sedimentation) during 1993-2004 (11 Years) in the Reservoir

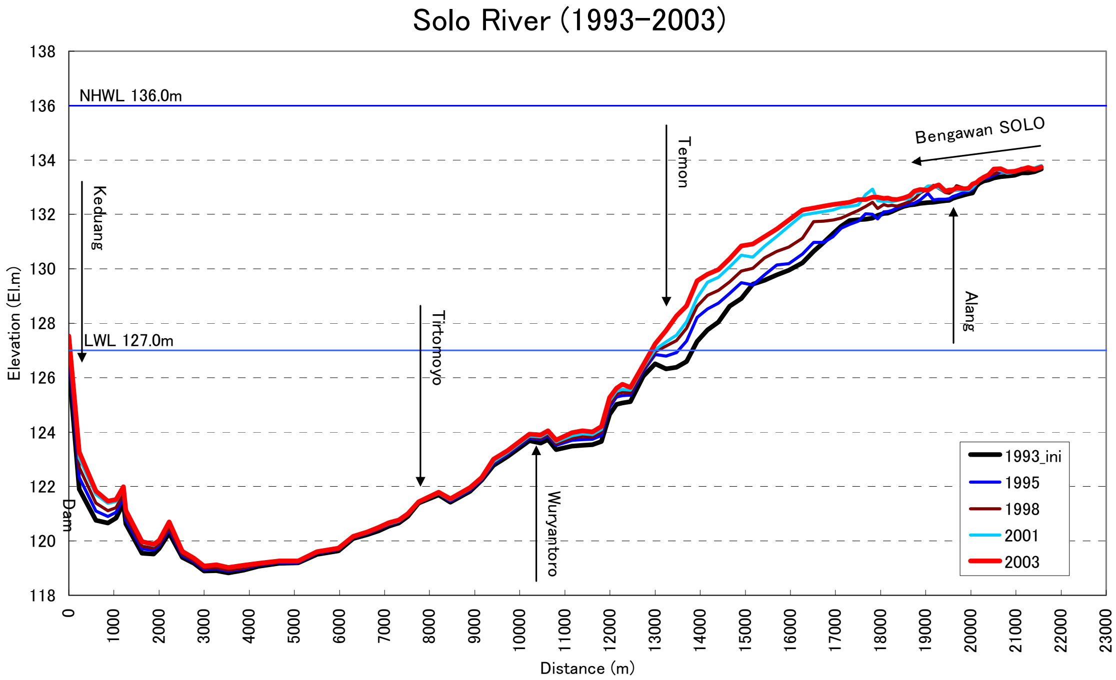


Figure 3.5.26 Longitudinal Profile of Deepest Bed in Bengawan Solo River (Solo ~ Dam left) during 1993-2004

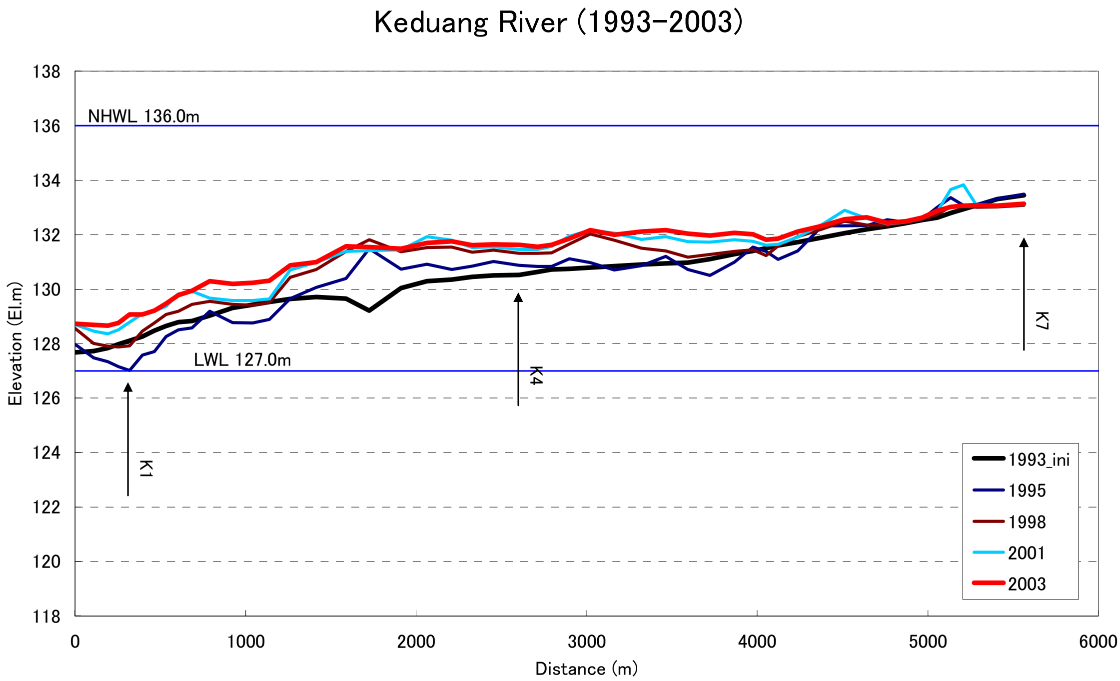


Figure 3.5.27 Longitudinal Profile of Deepest Bed in Keduang River (Keduang ~ Dam right) during 1993-2004

3.6 Conclusions

As analyzed above, it is concluded that estimation of sediment inflow and its allocation to the rivers in the past 12 years (1993~2005) is reasonable, and NKhydro2D model can be employed to simulate both the sedimentation in Wonogiri reservoir and the sediment release (outflow) from the reservoir.

The estimated sediment inflow, sedimentation in the Wonogiri reservoir and sediment release (outflow) from the reservoir in the past 12 years (1993~2005) are concluded in Table 3.6.1. Figure 3.6.1 shows the annual variation of the sediment release by both the spillway and the intake of power plant.

Table 3.6.1 Sediment Inflow, Sedimentation in the Reservoir and Sediment Release during 1993 ~ 2005

Year	Sediment Inflow (m3)		Sedimentation in the reservoir (m3)	Sediment Release (m3)			Reservoir Sediment Trap Ratio
	Total	Keduang only		by Spillway	by Power Plant Intake	Total	
1993-1994	4,063,000	1,665,000	3,353,000	223,000	463,000	686,000	0.825
1994-1995	3,825,000	1,435,000	3,186,000	192,000	376,000	568,000	0.833
1995-1996	3,651,000	1,362,000	3,064,000	155,000	412,000	567,000	0.839
1996-1997	1,698,000	579,000	1,520,000	0	156,000	156,000	0.895
1997-1998	2,907,000	1,016,000	2,704,000	94,000	100,000	194,000	0.930
1998-1999	4,355,000	1,721,000	3,561,000	338,000	365,000	703,000	0.818
1999-2000	4,124,000	1,774,000	3,393,000	351,000	327,000	678,000	0.823
2000-2001	2,643,000	902,000	2,315,000	70,000	214,000	284,000	0.876
2001-2002	3,450,000	1,566,000	2,749,000	317,000	317,000	634,000	0.797
2002-2003	2,607,000	769,000	2,324,000	120,000	154,000	274,000	0.891
2003-2004	1,765,000	504,000	1,672,000	0	73,000	73,000	0.947
2004-2005	2,392,000	811,000	2,250,000	0	140,000	140,000	0.941
Total (1993-2005)	37,480,000	14,104,000	32,091,000	1,860,000	3,097,000	4,957,000	0.856
Annual average	3,124,000	1,176,000	2,675,000	155,000	259,000	414,000	0.856

Note: deposition base for the volume, including the void

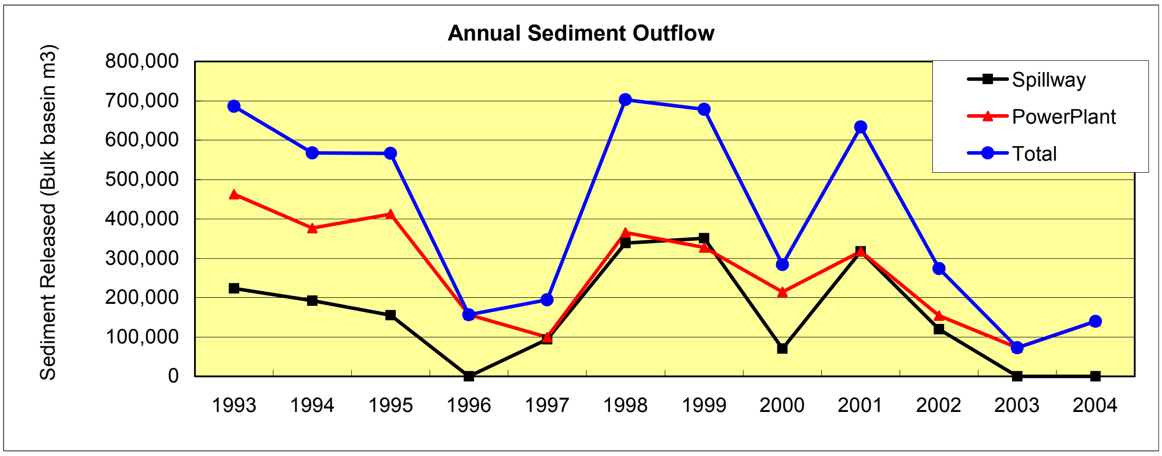


Figure 3.6.1 Estimated Sediment Release from the Reservoir during 1993~2005

In the past 12 years (1993~2005), the annual average of sediment inflow into Wonogiri reservoir was 3,120,000m^3, in which the sediment inflow from Keduang river was 1,180,000m^3 (about 38% of the total). The annual average of sediment release (outflow) was 414,000m^3, in which 155,000m^3 by the spillway and 259,000m^3 by the intake of power plant. Therefore, the annual average of sedimentation in Wonogiri reservoir was 2,680,000m^3, and the sediment trap ratio of the reservoir was about 0.856 (85.6%).