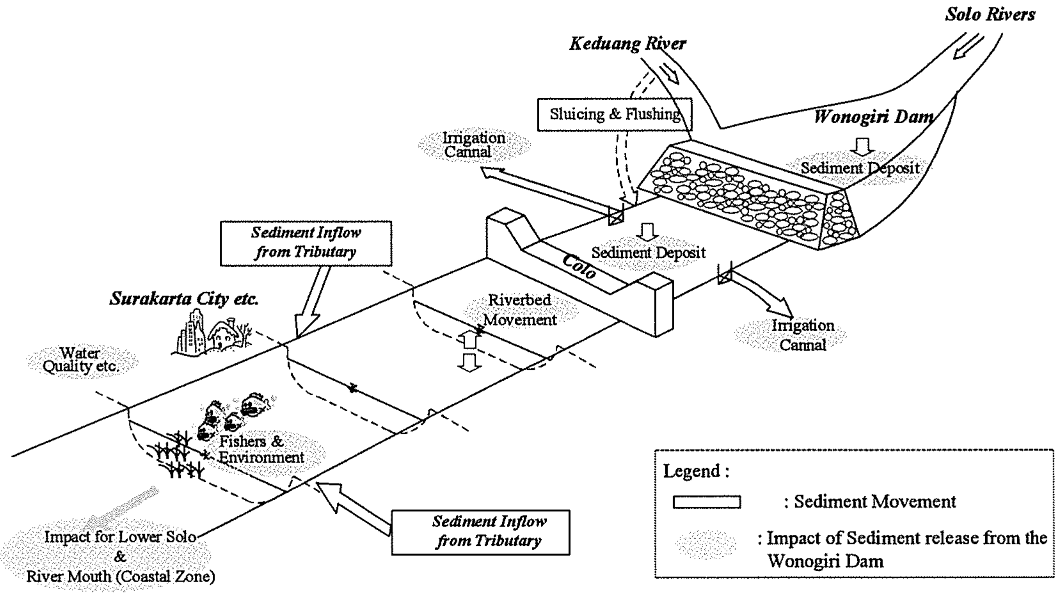
CHAPTER 3 TURBIDITY ANALYSIS FOR DOWNSTREAM REACHES

3.1 Objective of Analysis

In the master plan, construction of a sediment storage reservoir with new gates was proposed as one of the urgent measures. This measure aims at securing the existing intake function through a sediment sluicing/flushing system on the sediment storage reservoir without using the stored water in the main reservoir. Through this operation, a sustainable use of the Wonogiri reservoir and an appropriate sediment balance in the Bengawan Solo River basin may be achieved in the future. However, while the sediment sluicing/flushing system is operated, plenty of highly turbid water will be released to downstream reaches for a period of time. There would be a threat of adverse impacts on social and natural environments in the downstream reaches. The allowable volume of sediment release would be the technical factor to control to mitigate adverse impacts.

In this section, aimed at examination of suitable operation to minimize the impacts to the downstream reaches, sediment hydraulic analysis was carried out to simulate the fluctuation of turbidity due to release of highly turbid water from the sediment storage reservoir.



Source: JICA Study Team

Figure 3.1.1 Impacts for Downstream River Caused by Sediment Release from Dam

Table 3.1.1 Impacts for Downstream River Caused by Sediment Release from Dam

Impact	*Short Term*	*Middle and Long Term*
Negative Impact	Impact of high concentration of SS - Irrigation water - domestic water - Ecological system - Fishers, etc. Impact of river discharge - Irrigation water - domestic water	Change of sediment balance in the basin - Riverbed aggradation - Decrease of flow capacity - Clogging of river mouth - Change of discharge duration - Change of ecological system

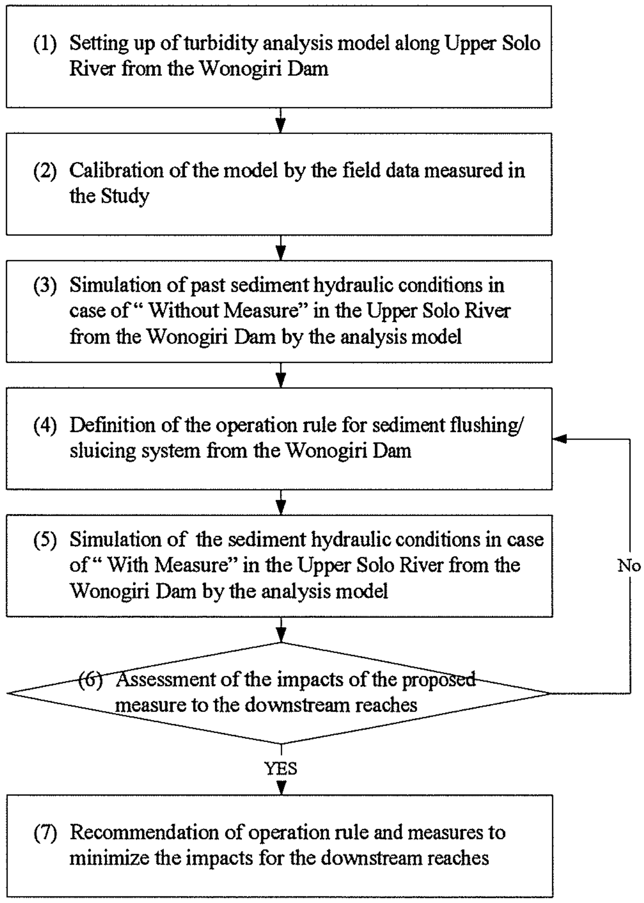
Impact	Short Term	Middle and Long Term
	- Ecological system - Fishers - Navigation, etc.	
Positive Impact		- Formulation of sustainable basin-wide sediment management system - Mitigation of riverbed degradation - Secure the Wonogiri dam Sedimentation

Source: JICA Study Team

3.2 Approach of Analysis

The objective area is the Upper Solo mainstream from the Wonogiri dam to the Ngawi, the confluence of the Madiun River, in total 200 km long.

Basic approach is presented in Figure 3.2.1 on the right. A turbidity analysis model was setting up to simulate the sediment hydraulic condition in the objective area. After calibration of the model by the field data measured in the Study, the past sediment hydraulic conditions in the Upper Solo mainstream was reproduced by .the model. Subsequently, the impacts of the proposed urgent measure (a sediment storage reservoir with new gates) to the downstream reaches were predicted under conditions in some distinct hydrological wet, normal and dry year. Finally, sediment management criteria to mitigate the impacts for downstream were discussed based on results of turbidity analysis.



Source: JICA Study Team

Figure 3.2.1 Basic Approach of Turbidity Analysis

3.3 Setting-up of Turbidity Analysis Model

3.3.1 Objective Area

The objective area for turbidity analysis is the mainstream of Upper Solo River from the Wonogiri dam to Ngawi, the confluence with the Madiun River. The objective river stretch is 200 km long. The location map of the Upper Solo basin applicable for the turbidity analysis model is presented in Figure 3.3.1 in the next page. The design was based on the model where there are 16 main tributaries entering into the mainstream between the Wonogiri dam and Ngawi, and the Colo intake weir and five (5) groundsills were constructed between Jurug and Colo, which help stabilize the river bed.

In this stretch, two (2) water level gauging stations have been installed at the Jurug (51 km downstream of the dam) and the Kajangan (131 km downstream of the dam). SS concentration in the mainstream has been periodically observed by JICA Study Team at four (4) locations, i) the bridge immediately downstream of the Wonogiri dam, ii) the Colo weir, iii) Jurug bridge and iv) Tangen bridge.

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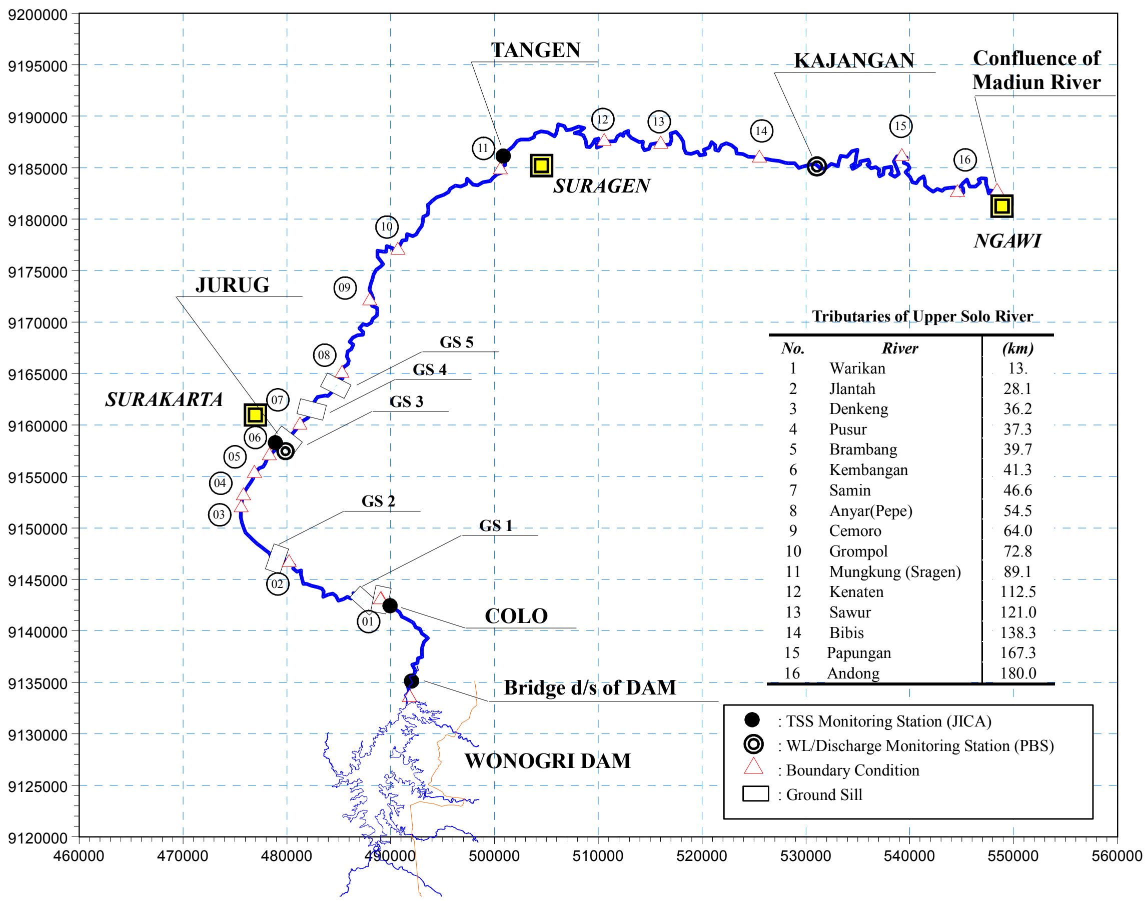


No.	River	(km)
1	Warikan	13.
2	Jlantah	28.1
3	Denkeng	36.2
4	Pusur	37.3
5	Brambang	39.7
6	Kembangan	41.3
7	Samin	46.6
8	Anyar(Pepe)	54.5
9	Cemoro	64.0
10	Grompol	72.8
11	Mungkung (Sragen)	89.1
12	Kenaten	112.5
13	Sawur	121.0
14	Bibis	138.3
15	Papungan	167.3
16	Andong	180.0

Source: JICA Study Team

Figure 3.3.1 Location Map for Turbidity Analysis Model

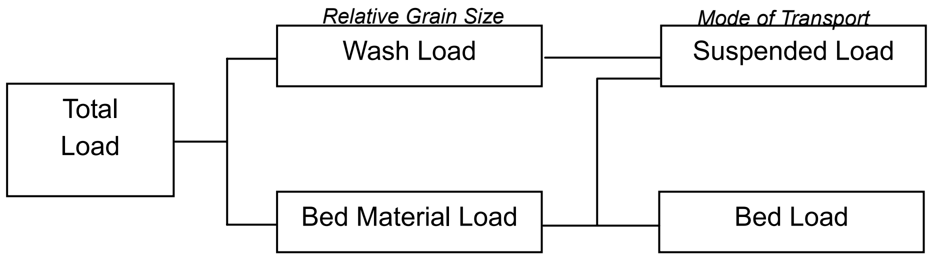
3.3.2 Analysis Model

For the turbidity analysis model the MIKE 11, which is in wide usage as commercial software, was used because of its high versatility. The calculation method on the turbidity analysis model used basically the same equations as the reservoir sedimentation model as described in the Supporting Report II Annex No.4 “Reservoir Sedimentation Analysis”.

In this model, basic hydraulic parameters could be calculated by the one-dimensional unsteady flow calculation. Applying the results of the hydraulic parameters, the turbidity (suspended sediment concentration) in the river was calculated from the conservation equation and the advection-diffusion equation. For the downstream reaches, one-dimensional model was applied because the fluctuations of flow in the cross sectional direction become negligibly small.

Generally turbidity in the river was dominant on not only advection and diffusion of the steam but also settling and re-suspension between the bed materials and suspended sediments. It is, however, convenient to assume the fixed bed conditions on this turbidity analysis model because the sediment hydraulic conditions in the Upper Solo River has a distinguish characteristics as below. Important issue to be considered in the analysis is the impact to the downstream reaches by wash load not bed material road.

- ***Fixed Bed Condition:*** The Colo weir and five groundsills have been placed from the Colo to Jurug, and the hard bed rocks/soils without erosion widely appeared over the objective stretch such as Lawu. They make stabilize the riverbed from degradation. By this effect, suspended loads supplying from the bed materials is relatively much smaller than those supplying from the dam outflow and from the tributaries.
- ***Washload***: Washload would be main composition of the released sediments from the Wonogiri dam and they tend not to be deposited with river flow velocity in the river channel. Important issue to be considered in the analysis is the impact to the downstream reaches by wash load not river bed movement.



Source: Reservoir Sedimentation Hand Book

Figure 3.3.2 Classification of Sediment Transport by Grain Size and by Mode of Transpote

The outline of calculation method is presented in the Table 3.3.1 below.

Table 3.3.1 Calculation Method of Turbidity Analysis Model

Item	Condition	Remarks
i) Riverbed Movement	Fixed bed condition	
ii) Sediment Transportation	Advection-Diffusion Equation of Concentration	
iii) Interaction between bed materials and suspended load	Re-suspension and settling velocity of non-cohesive sediment	

Source: JICA Study Team

3.3.3 Conditions of Analysis

(1) Cross Section, Structures and Riverbed

The basic condition such as river structures, cross sections, bed materials in the Upper Solo mainstream were already described in Chapter 1. Based on these data, initial conditions on the turbidity analysis model were produced as listed in the Table 3.2.2 below.

(2) Boundary Condition

Boundary conditions are set out at three locations as presented in Table 3.2.3 below. In view of accuracy of the simulation, the boundary condition of sediment inflows and outflow over the stretch are vitally important. However, as for the SS concentration data of the Wonogiri dam outflow, no field measurement data had been available since its completion. In this model, SS concentration of the dam outflow were applied the simulation results of the reservoir sedimentation analysis. For the inflow from tributaries, SS concentration was calculated applying a sediment rating curves which was created based on the past field data measured in tributaries by PBS in 1988 – 1995 as presented in Figure 3.3.2.

Table 3.3.2 Applied Cross Section, Structure and Riverbed for Turbidity Analysis Model

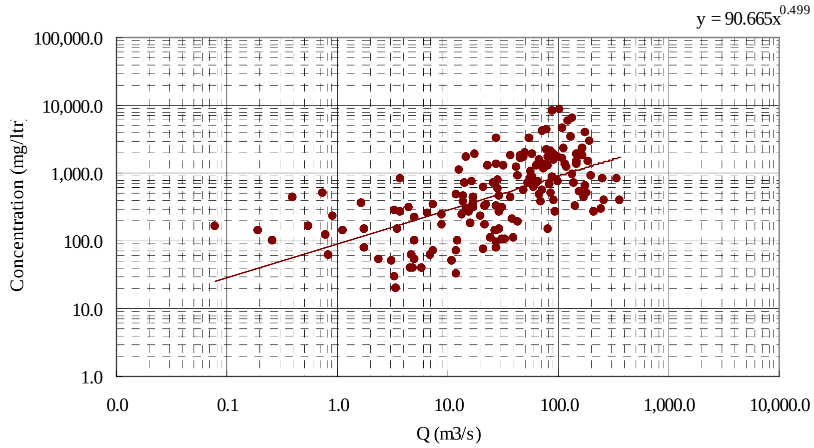
Item	Data Type	Source
i) Cross Section	Totally 163 cross sections in Upper Solo River mainstream from Wonogiri dam to the Madiun River confluence with the interval of 500 m	Cross Section Survey from 2004 JICA, 2004 WECFR&CIP
ii) Existing River Structures	Colo weir and Ground Sills no.1 to no.5 of fixed weir.	Cross Section Survey from 2004 WECFR&CIP
iii) Riverbed material	Totally 17 samples taken with interval of 10 km and analyzed it grain size distribution	2004 JICA, WECFR&CIP

Source: JICA Study Team

Table 3.3.3 Boundary Conditions of Dam Outflow and Inflow from Tributaries

Item	Data Type	Interval	Source
i) Dam Outflow	Available records of hourly power discharge and spillout discharges released from the Wonogiri dam.	hourly	PJT-1
ii) Colo Intake	Available discharge records of intake discharge to west canal, east canal and overflow discharge at Colo weir.	Monthly(1986-1999) Hourly(2000-2005)	PJT-1
iii) Inflow from tributaries	Using the unit discharge per catchment area estimated from the observation discharge at Jurug sta. and Kajangan sta., inflows from major 16 tributaries between Wonogiri - Ngawi were determined.	Daily (1986-1999), 3 times per day at 6:00, 12:00, 18:00 (2000-2005)	JICA Study Team
iv) SS Concentration of dam outflow	Reservoir sedimentation analysis results of SS concentration at both intake and spillway	hourly	JICA Study Team
v) SS Concentration of inflow from tributaries	Computed from sediment rating curve of tributaries based on the field data at major tributaries in 1988 to 1995	Daily (1986-1999), 3 times per day at 6:00, 12:00, 18:00 (2000-2005)	JICA Study Team

Source: JICA Study Team



Source: JICA Study Team

Figure 3.3.3 Sediment Rating Curve of Tributaries in Upper Solo River Basin

3.3.4 Output of the Model

After set-up of the above conditions, a dry run was conducted. The results showed that this model could be adaptable and sufficient for the analysis of the hydraulic parameters of water level, discharge, velocity, shear velocity and sediment parameters of SS concentration, mass transportation and deposition of SS, etc. in the Upper Solo River mainstream below the Wonogiri dam.

3.4 Calibration of Analysis Model

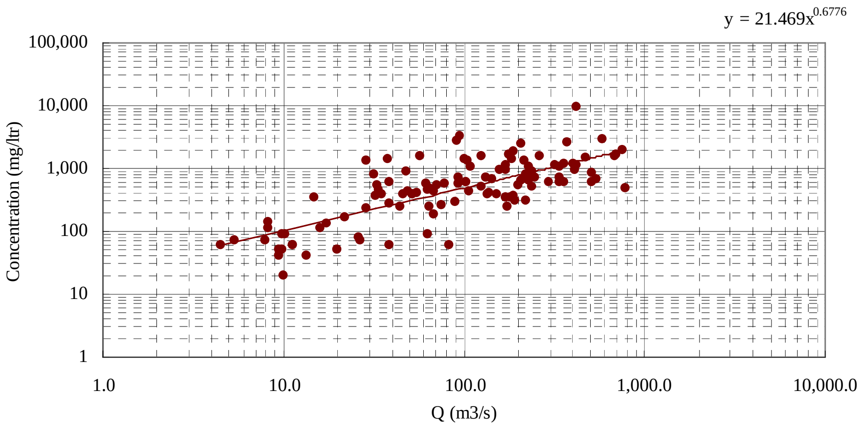
3.4.1 Data for Calibration

The turbidity analysis model was calibrated based on the field observation data on both discharge and SS concentration in the wet season in 2004/2005 as presented in Figures 3.4.2 and 3.4.3. The data for calibration are listed in Table 3.4.1 below. At Jurug and at Tangen, calibration data for SS concentration are applied the data which was created from a sediment rating curve at Jurug as shown in Figure 3.4.1.

Table 3.4.1 Data List for Calibration

Item	Location	Date Source	Interval
Discharge	Jurug (52 km)	i) field monitoring data	three times per day (6:00, 12:00, 18:00)
	Tangen (97 km)	i) calculated discharge data based on the unit discharges per area at both Jurug and Kajanagan station.	ditto
SS	D/S of the dam (0.7km)	i) field measurement data by Study Team	3 hours in flood and every day in non-flood
	Colo weir (14km)	i) field measurement data by Study Team	every two weeks
	Jurug (52km)	i) calculated SS data based on the sediment rating curves at Jurug ii) field measurement data by Study Team	three times per day (6:00, 12:00, 18:00) every two weeks
	Tangen (97km)	ditto	ditto

Source: JICA Study Team



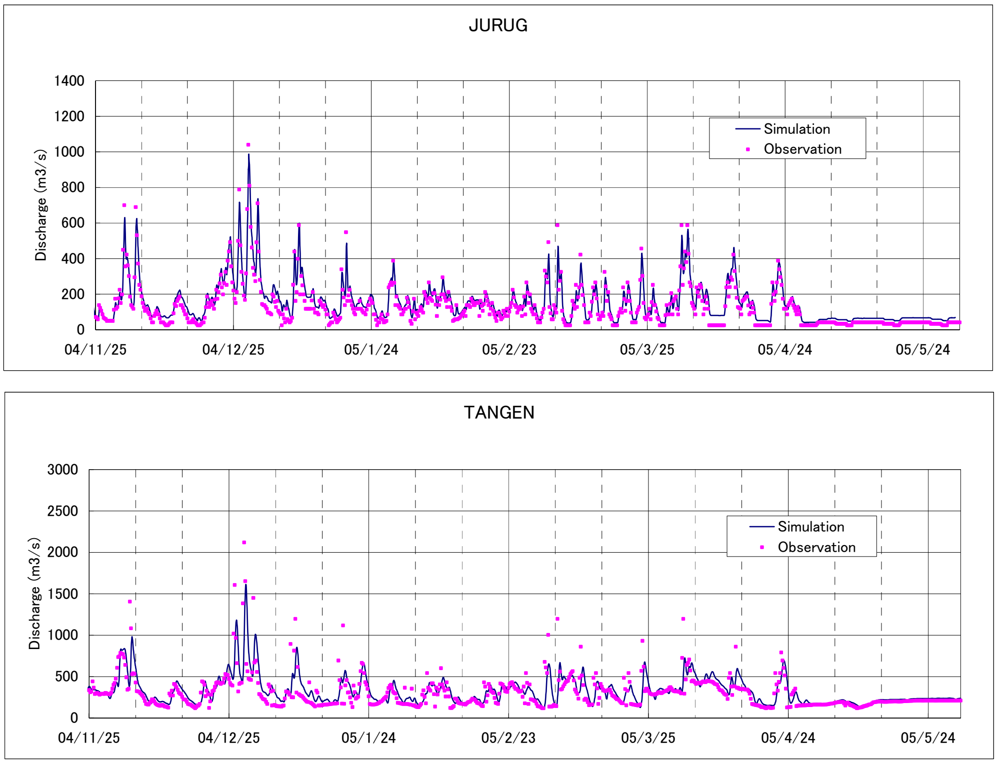
Source: JICA Study Team

Figure 3.4.1 Sediment Rating Curve at Jurug in Upper Solo River Basin

3.4.2 Calibration Result

(1) Discharge

The hydrographs at Jurug and Tangen from December 1, 2004 to May 31, 2005 are presented in Figures 3.4.1 together with the observation data and simulation data. As shown in the figure, the simulated discharges were well reproduced the field observation data at both stations.



Source: JICA Study Team

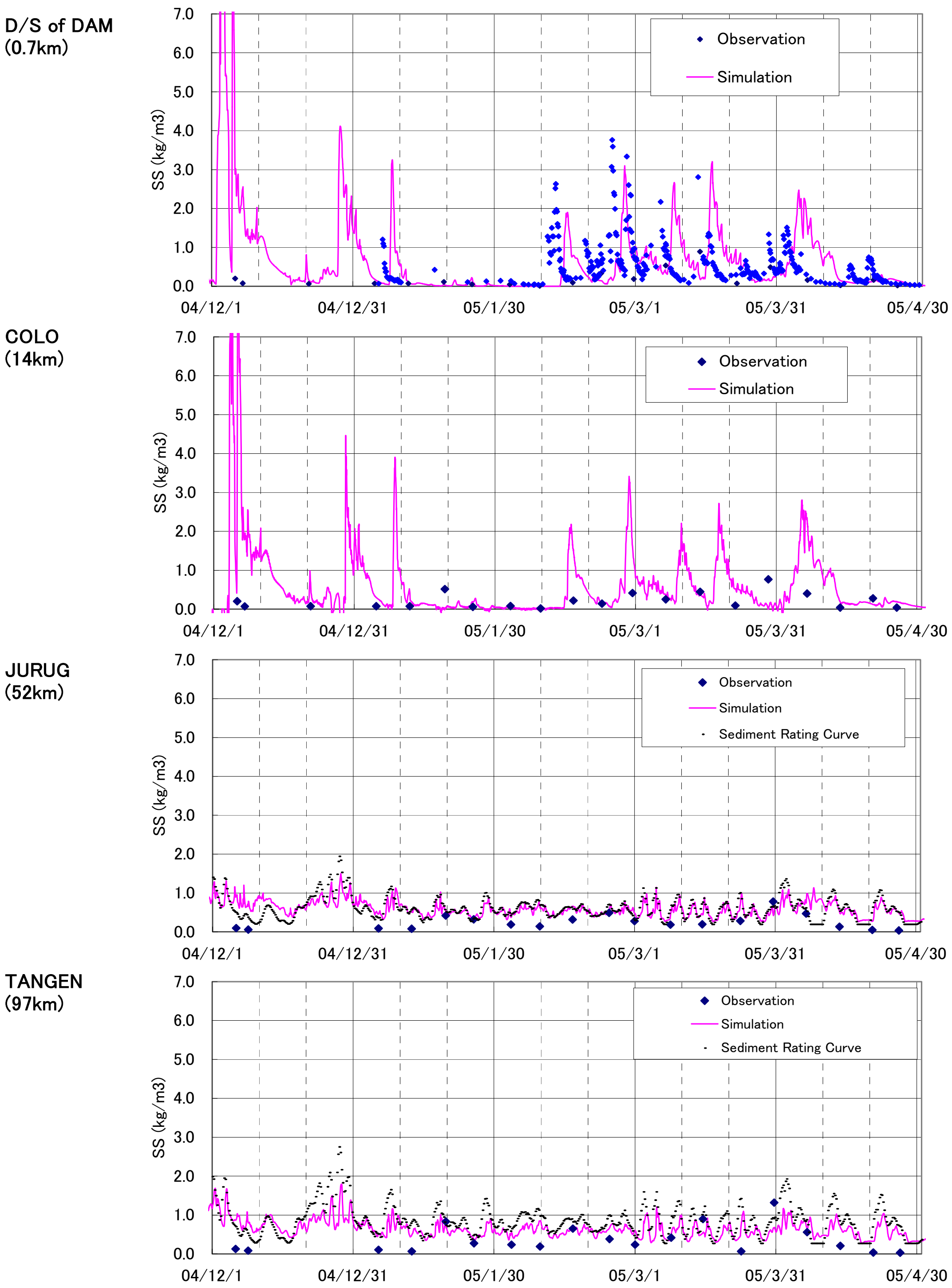
Figure 3.4.2 Simulation Result for Discharge at Jurug and Tangen in 2004/05 Wet Season

(2) SS Concentration

The hourly SS hydrographs at four locations are presented in Figures 3.4.2. The results of calibration for SS concentration on the turbidity analysis model are summarized below:

- The simulated hourly SS hydrographs at the immediately downstream of the Wonogiri dam is well reproduced the field observation data. There are slightly delays of peak values in the simulation results due to the boundary conditions of reservoir sedimentation analysis model as described in the Annex No.4.
- At the Colo weir, only weekly field observation data was available. In this sense, the simulated SS hydrographs at Colo are well reproduced the *weekly* fluctuation.
- The simulated hourly SS hydrographs at Jurug and Tangen stations are well reproduced both the short term fluctuation that was calculated from the sediment rating curves and the weekly field observation data.

Judging form the above calibration results, this model can be applied for a estimation for hourly basis fluctuation of SS concentration in the Upper Solo mainstream.



note : 1) "Observation" is the field measurement results of water samples.
2) "Simulation" is the result obtained by turbidity analysis model.
3) "Calculation" is the result obtained from the sediment rating curve at Jurug.

Source: JICA Study Team

Figure 3.4.3 Simulation Result for SS Concentration in 2004/05 Wet Season

3.5 Case of Turbidity Analysis

3.5.1 Analysis Case for Current Condition

To assess i) the current sediment hydraulic conditions "*Without Measure*", ii) the impacts of the proposed urgent measure (a sediment storage reservoir with new gates) to the downstream reaches "*With Measure*", turbidity analysis was carried out using the boundary conditions in three distinct hydrological years as shown in Table 3.5.1.

Table 3.5.1 Annual Reservoir Inflow and Outflow of Selected Hydrological Years

(Unit : million m^3)

Hydrological Year	Period	Reservoir Inflow	Reservoir Outflow
Wet Year	1998/99	1,385	1,545
Normal Year	1995/96	1,176	1,254
Dry Year	2004/05	668	469

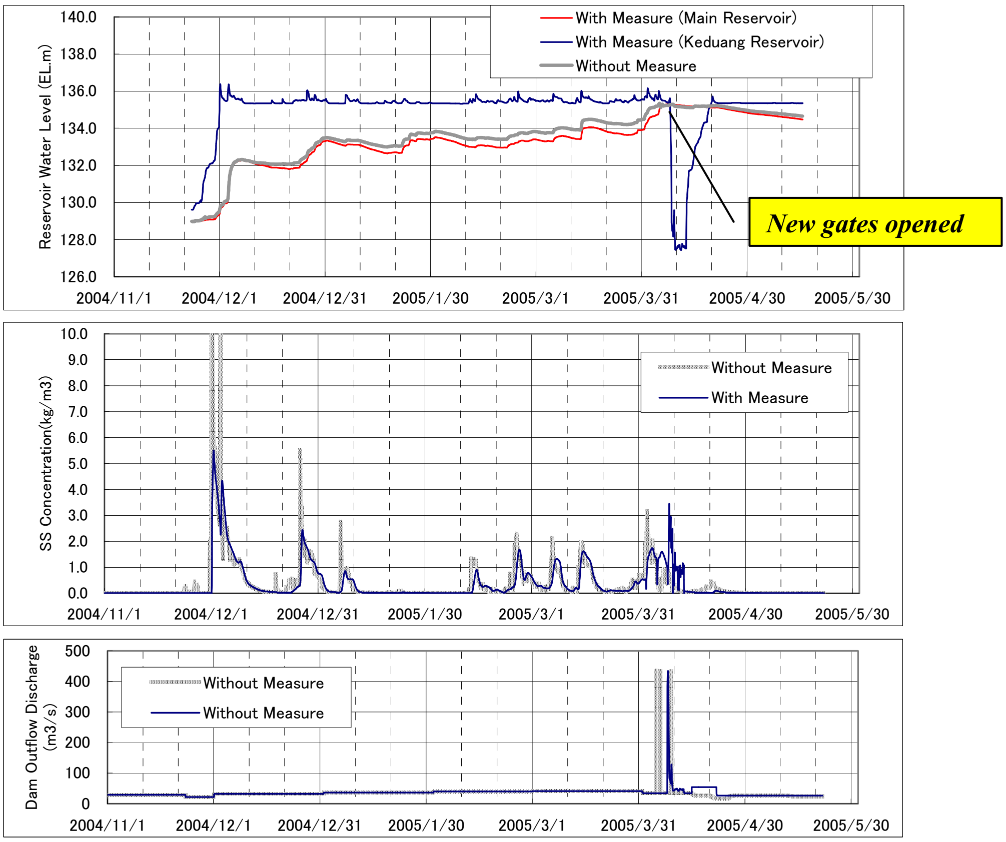
Note : Above data is a hydrological year from November 1 to October 31. The data of 2004/2005 is up to June 2005
Source : JICA Study Team

3.6 Results of Analysis

3.6.1 Result of Dry year (2004/2005)

(1) Outflow and SS Concentration from Wonogiri Dam

The hourly outflow from the reservoir and its SS concentration are presented in the Figure 3.6.1 below together with the hydrograph of reservoir water level. In this case, the new gates are fully opened from the beginning of April.

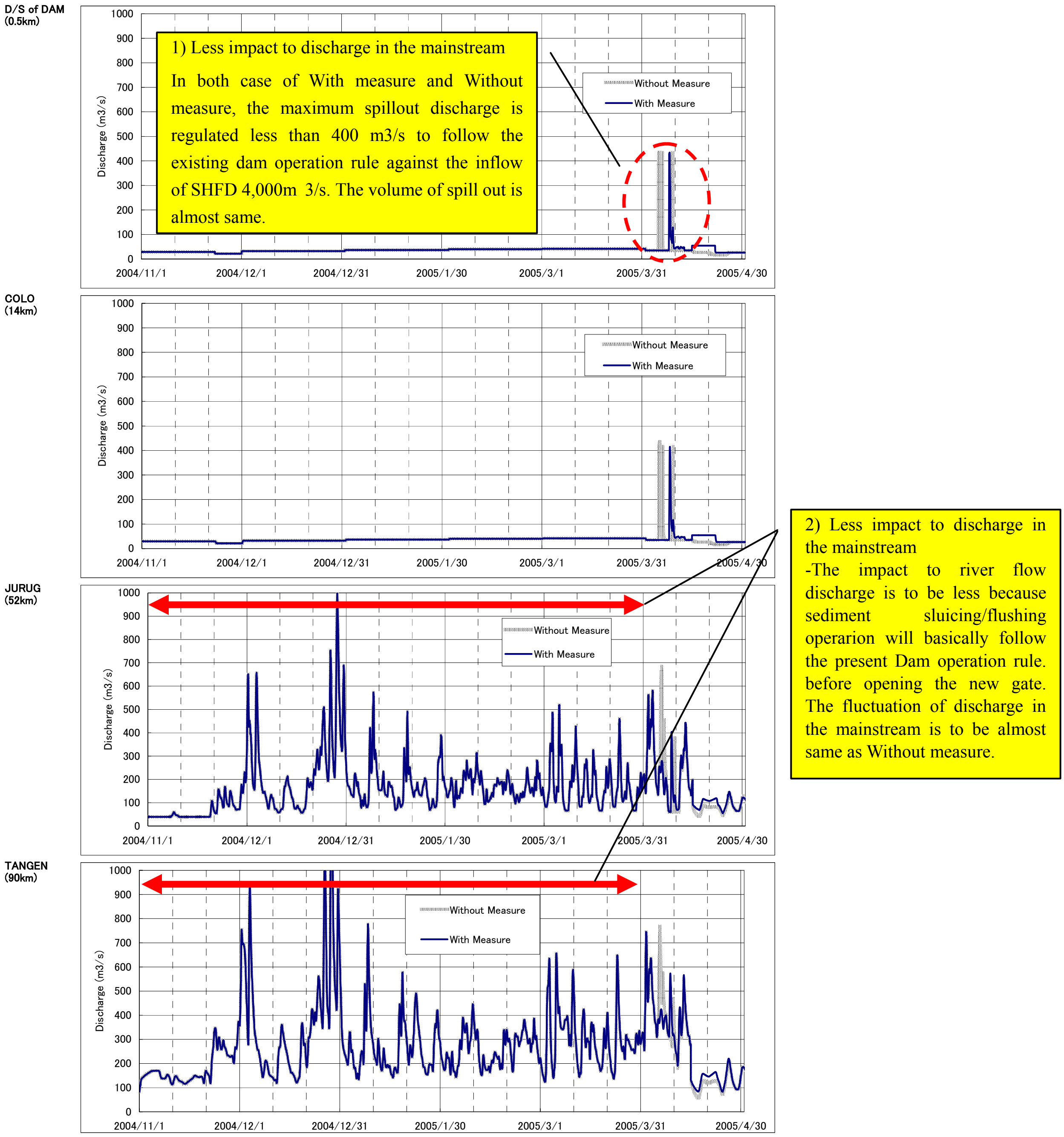


Note:" Without Measure" is the result of the reservoir sedimentation analysis assuming for dam operation to follow the existing rule curve. "With Measure" is the result of the reservoir sedimentation analysis assuming after implementation of the measure (Sediment storage reservoir with new gates).
Source : JICA Study Team

Figure 3.6.1 Comparison of Reservoir Water Level, SS concentration and Discharge of Dam Outflow between With and Without measure In Dry Year (2004/2005)

(2) SS Concentration and Discharge in the Upper Solo Mainstream

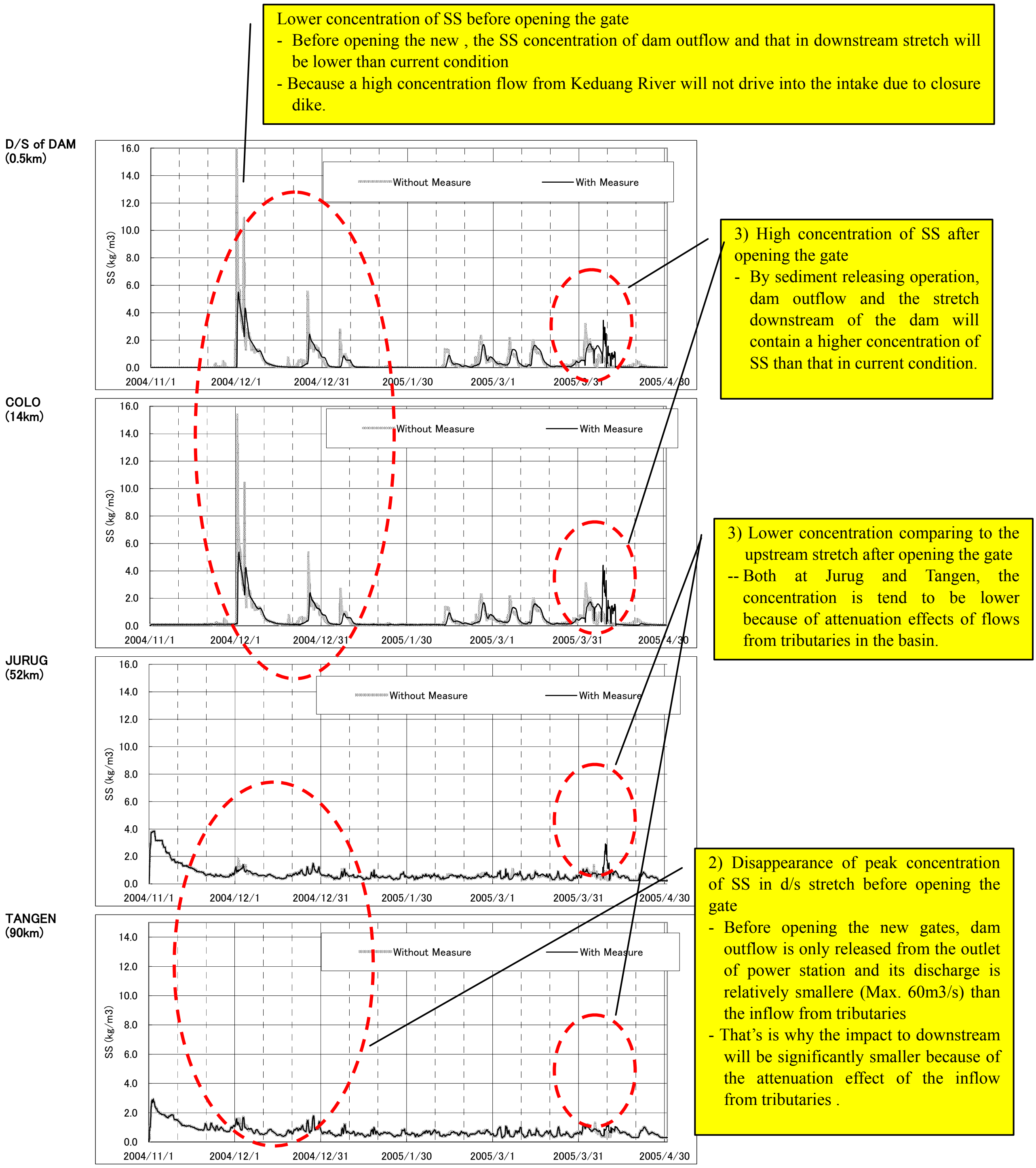
The fluctuation of discharge and SS concentration in the Upper Solo mainstream are presented together with the comments in the Figures 3.6.2 to 3.6.3.



Note:" Without Measure" is the case in present condition assuming for dam operation to follows the existing rule. "With Measure" is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.2 Comparison of Discharge in Upper Solo Mainstream between With and Without measure In Dry Year (2004/2005)



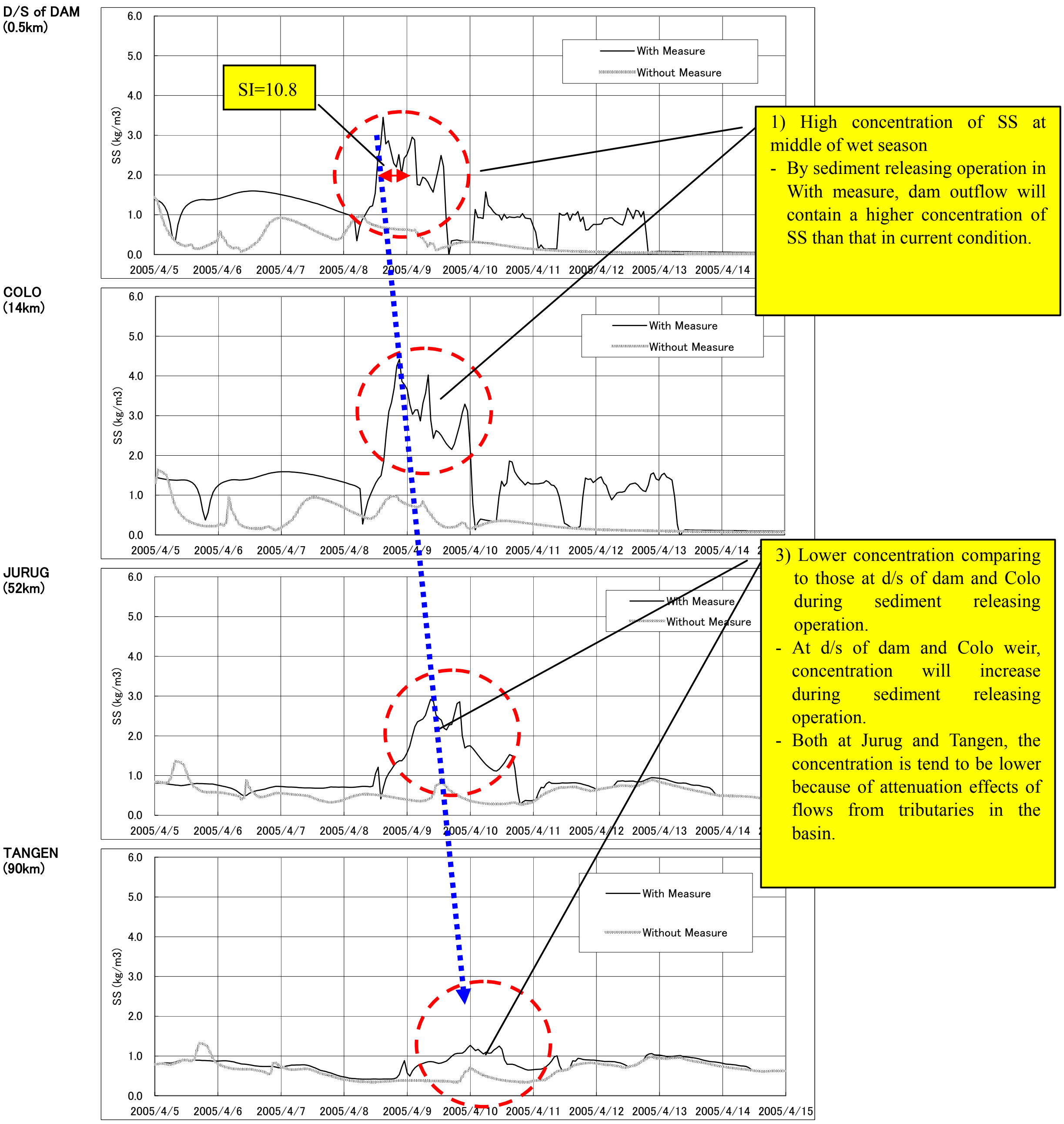
Note:" Without Measure" is the case in present condition assuming for dam operation to follows the existing rule. "With Measure" is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.3 Comparison of SS concentration in Upper Solo Mainstream between With and Without measure In Dry Year (2004/2005)

(4) Peak SS Concentration in the Upper Solo Mainstream（2004/04/05 – 2004/04/15）

Focused on the transportation of a peak SS concentration, its characteristics was examined in detail comparing to both cases Without measure and With measure as presented in the comments in the Figure 3.6.4 below.



Note:” Without Measure” is the case in present condition assuming for dam operation to follows the existing rule. “With Measure” is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.4 Comparison of Peak SS Concentration in Upper Solo Mainstream between With and Without measure In Dry Year (2004/2005)

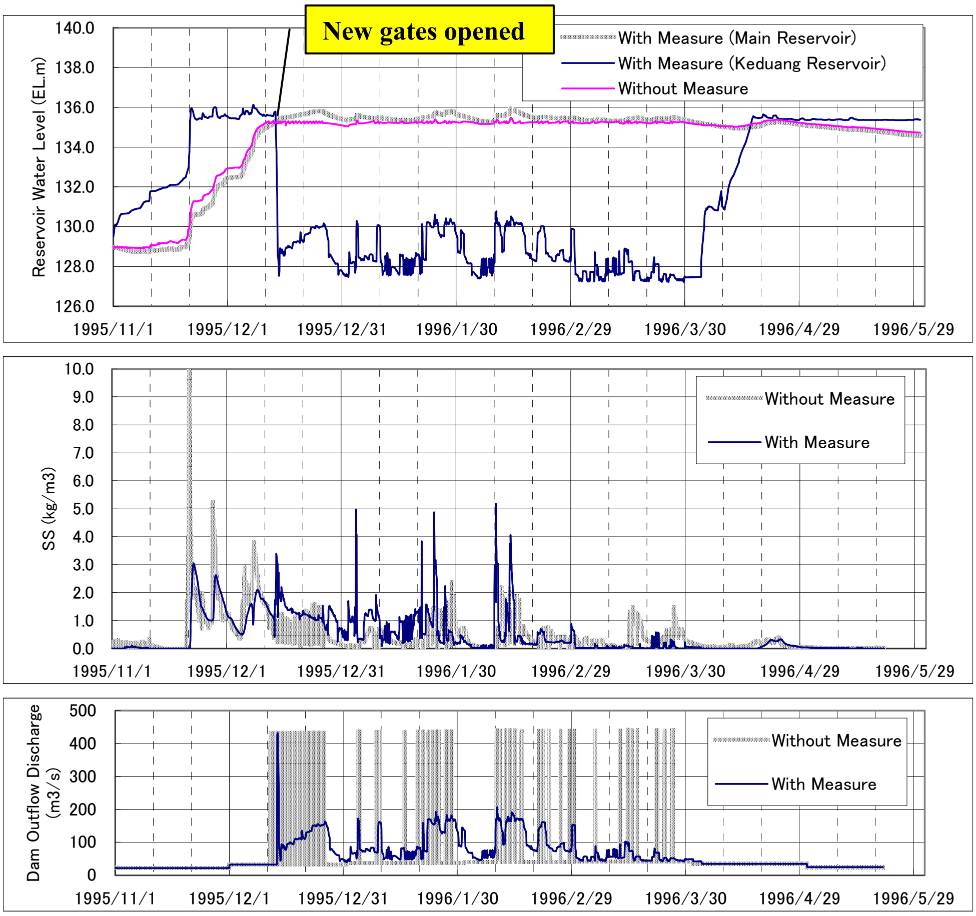
3.6.2 Result of Normal Year (1995/1996)

(1) Outflow and SS Concentration from Wonogiri Dam

The hourly outflow from the reservoir and its SS concentration are presented in the Figure 3.6.5 below together with the hydrograph of reservoir water level. In this case, the new gates are fully opened from the middle of December to End of March.

Before opening the new gate, SS concentration of the With measure was significantly lower than that of the Without measure. It was because that a high concentration flow from Keduang River do not reach to the intake due to closure dike.

After opening the new gate the SS concentration of the With measure was adversely to be higher than that of the Without measure with the peaks of 5.0 kg/m^3. The frequency of releasing a high SS concentration water was increased. The spillout discharge was 400 m^3/s immediately after opening the new gates then to be lower than 400 m$^{3/}$s. While the Keduang reservoir water level was lower and new gate was opened, the spillout discharge was the same as the inflow discharge from the Keduang River because of sluicing operation.



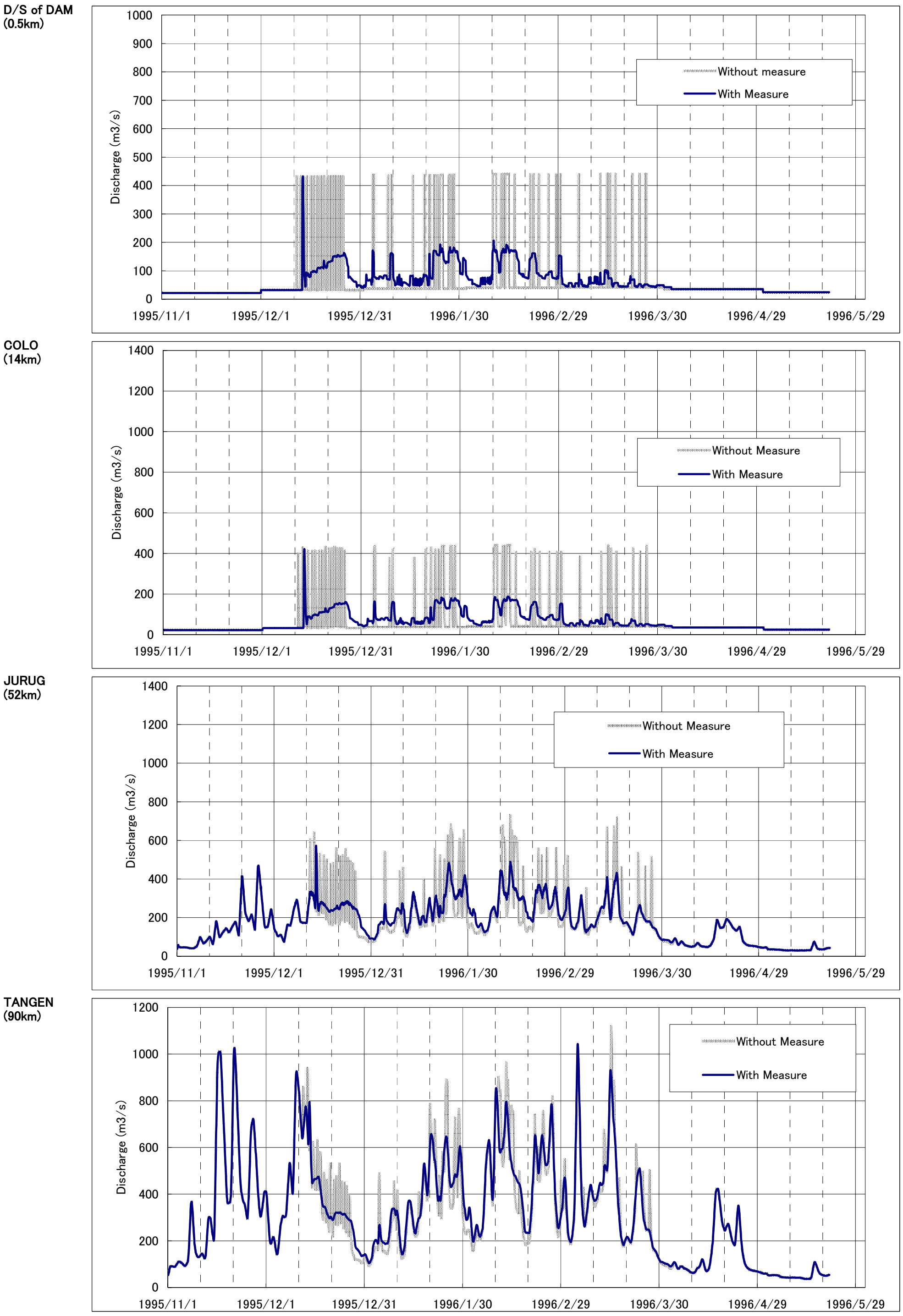
Note:" Without Measure" is the result of the reservoir sedimentation analysis assuming for dam operation to follow the existing rule curve. "With Measure" is the result of the reservoir sedimentation analysis assuming after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.5 Comparison of Reservoir Water Level, SS concentration and Discharge of Dam Outflow between With and Without measure In Normal Year (1995/19965)

(2) SS Concentration and Discharge in the Upper Solo Mainstream

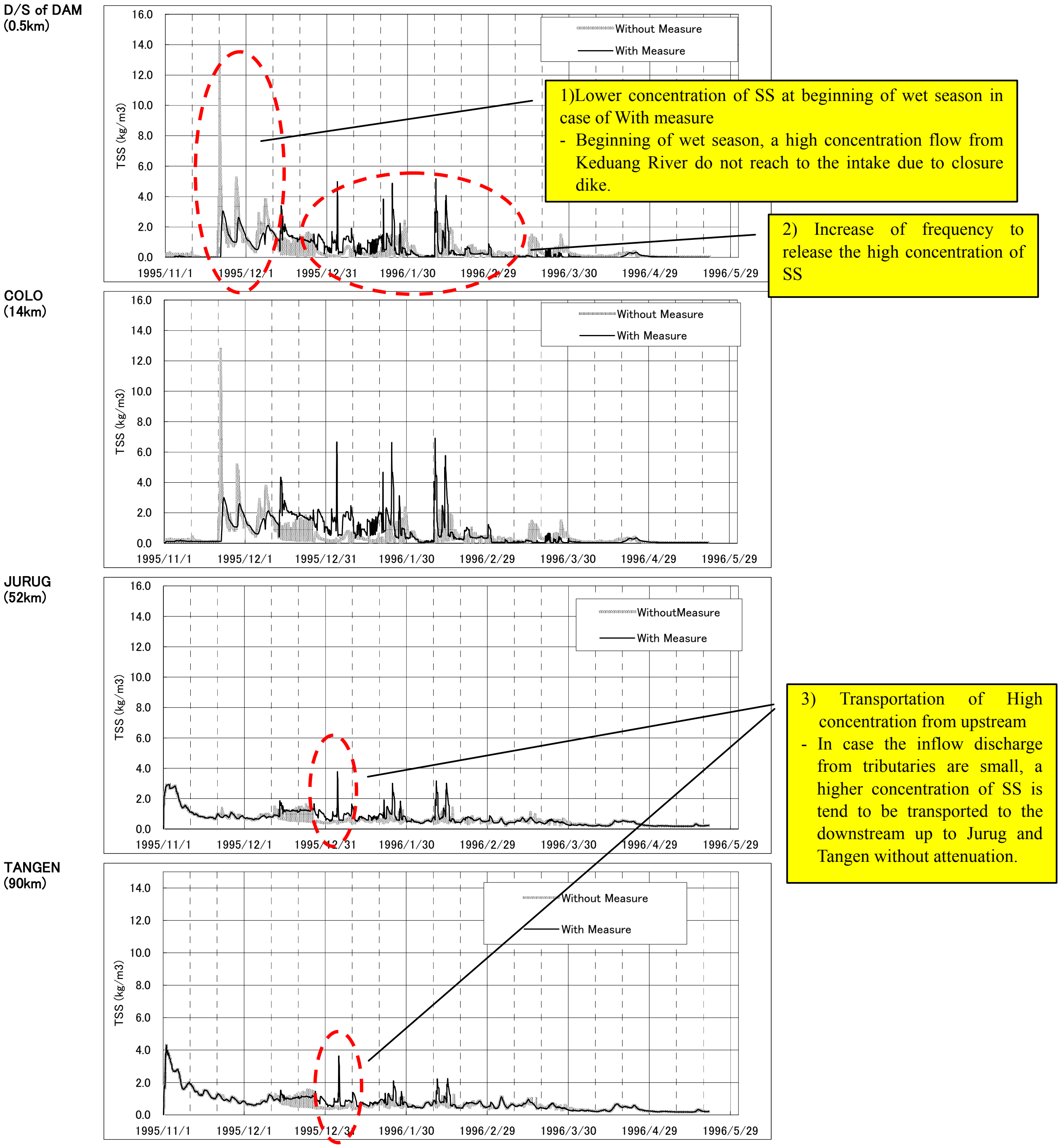
Main findings on the discharge and SS concentration at four locations in the downstream of the Wonogiri dam by the turbidity analysis were presented in the comments in the Figures 3.6.6 and 3.6.7 respectively.



Note:" Without Measure" is the case in present condition assuming for dam operation to follows the existing rule. "With Measure" is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.6 Comparison of Discharge in Upper Solo Mainstream between With and Without measure In Dry Year (1995/1996)



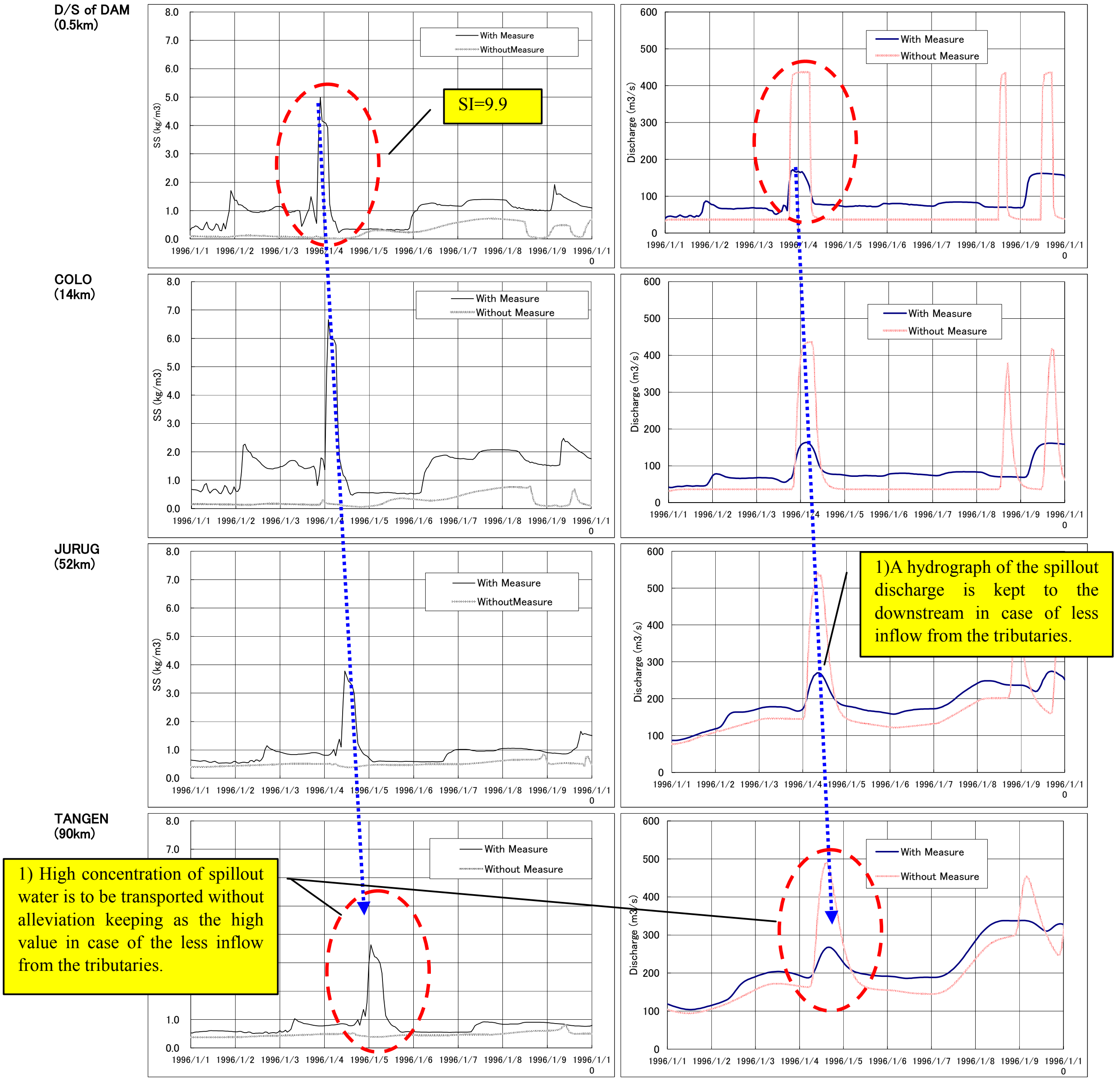
Note:" Without Measure" is the case in present condition assuming for dam operation to follows the existing rule. "With Measure" is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.7 Comparison of SS concentration in Upper Solo Mainstream between With and Without measure In Dry Year (1995/1996)

(4) Peak SS Concentration in the Upper Solo Mainstream (1996/01/01 - 1996/01/10)

Focusing on the propagation of a peak SS concentration along the mainstream, its characteristics was examined in detail comparing to both cases Without and With measures as presented in the Figure 3.6.8 below.



Note:" Without Measure" is the case in present condition assuming for dam operation to follows the existing rule. "With Measure" is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

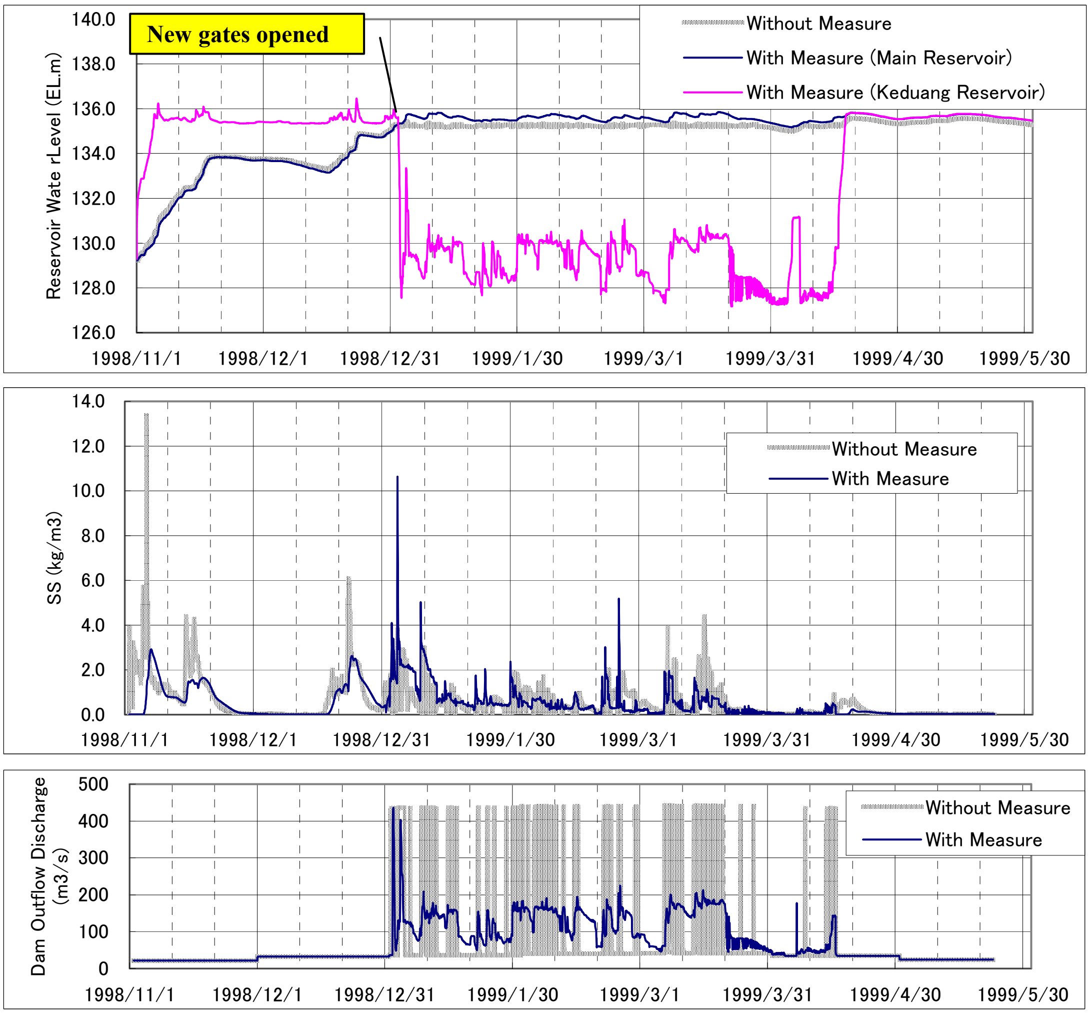
Figure 3.6.8 Comparison of Peak SS Concentration in Upper Solo Mainstream between With and Without measure In Dry Year (1995/1996)

3.6.3 Result of WET Year (1998/1999)

(1) Dam Outflow and SS Concentration

The hourly outflow from the reservoir and its SS concentration are presented in the Figure

3.6.9 below together with the hydrograph of reservoir water level. In this case, the new gates are fully opened from the beginning of January to the middle of April.

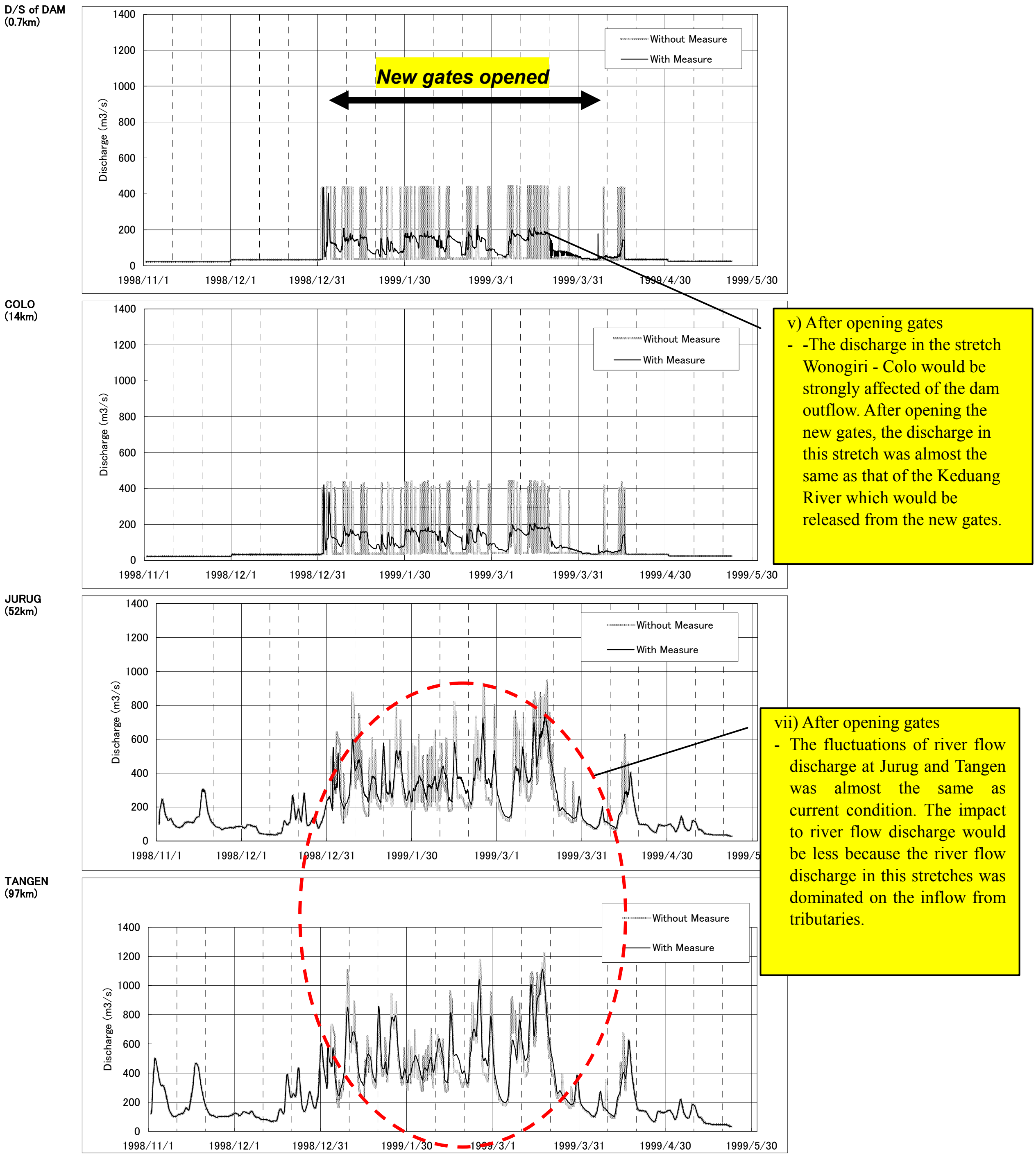


Source : JICA Study Team

Figure 3.6.9 Comparison of Reservoir Water Level, SS Concentration and Discharge of Dam Outflow between With and Without Measures in Wet Year (1998/1999)

(2) SS Concentration and Discharge in the Upper Solo Mainstream

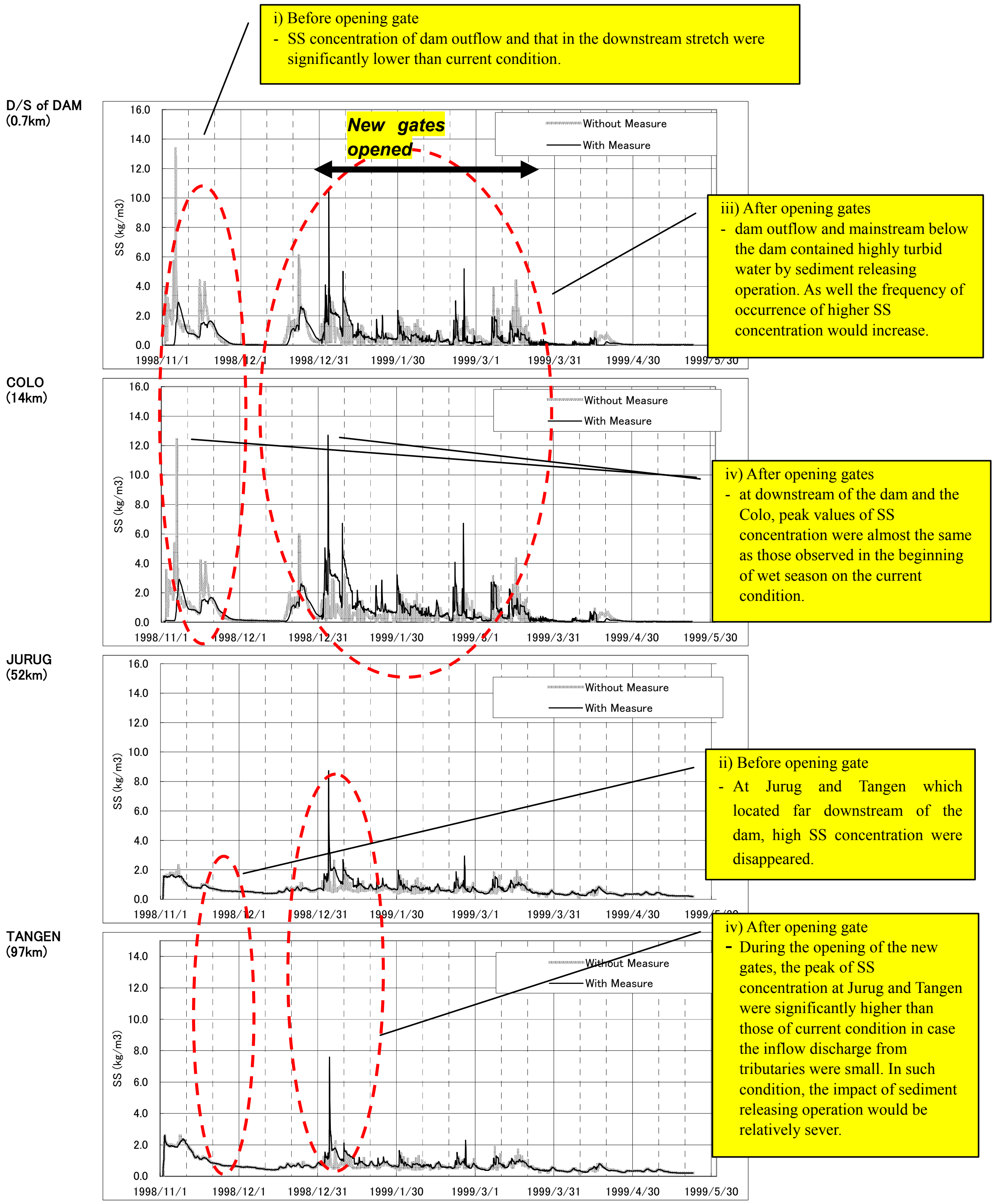
Main findings on the discharge and SS concentration at four locations in the downstream of the Wonogiri dam by the turbidity analysis were presented in the comments in the Figures 3.6.10 and 3.6.11 respectively.



Note:" Without Measure" is the case in present condition assuming for dam operation to follows the existing rule. "With Measure" is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.10 Comparison of Discharge in Upper Solo Mainstream between With and Without measure in Wet Year (1998/1999)



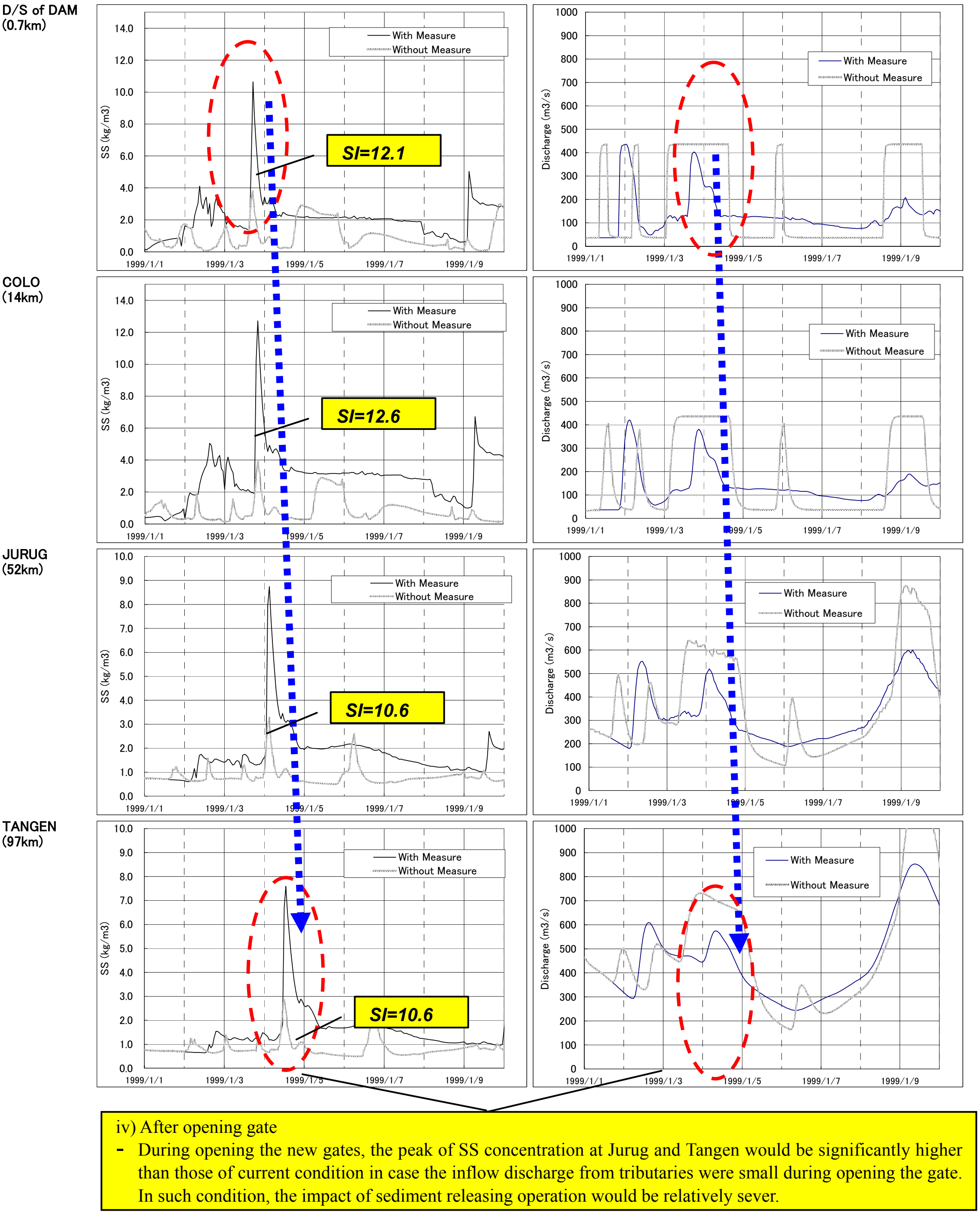
Note:” Without Measure” is the case in present condition assuming for dam operation to follows the existing rule. “With Measure” is the case after implementation of the measure (Sediment storage reservoir with new gates).

Source : JICA Study Team

Figure 3.6.11 Comparison of SS concentration in Upper Solo Mainstream between With and Without Measure in Wet Year (1998/1999)

(4) Peak SS Concentration along the Upper Solo Mainstream (1999/01/01 - 1999/01/10)

Focusing on the propagation of a peak SS concentration along the mainstream, its characteristics was examined in detail comparing to both cases Without and With measures as presented in the Figure 3.6.12 below.



Note:" Without Measure" is the case in present condition assuming for dam operation to follows the existing rule. "With Measure" is the case after implementation of the measure (Sediment storage reservoir with new gates).
Source : JICA Study Team

Figure 3.6.12 Comparison of Peak SS Concentration in Upper Solo Mainstream between With and Without measure in Wet Year (1998/1999)

3.6.4 Summary of Analysis Result

As a result of the turbidity analysis in the three hydrological years mentioned above, similar characteristics were obtained the conditions of "With" and "Without" measures. The results of wet year are discussed in detail below:.

(1) Before Opening New Gates (beginning of Wet Season)

i) Before opening the new gates, the SS concentrations of dam outflow and that in the downstream stretch were significantly lower than current condition (case of Without measure). This was due to the highly turbid inflow from the Keduang River retained in the sediment storage reservoir.

ii) At Jurug and Tangen, the high SS concentration at the beginning of wet season disappeared. Before opening the new gates, the dam outflow was only released from the outlet of power station and its discharge was relatively small (Max. 60 m^3/s) compared to the inflow from the tributaries. The impact to downstream reaches would be significantly smaller due to the attenuation effect on the inflow from tributaries.

(2) After Opening the New Gate

D/S of Dam and Colo weir

iii) After opening the new gate, the dam outflow and mainstream below the dam contained highly turbid water from the sediment releasing operation. The frequency of occurrence of higher SS concentration increased as well.

iv) It was, however, revealed that downstream of the dam and Colo, the peak value of SS concentration was almost the same as those observed at the beginning of wet season on the current conditions.

v) The discharge in the stretch Wonogiri - Colo was strongly affected by dam outflow. After opening the new gates, the discharge in this stretch would be almost the same as that of the Keduang River, which would be released from the new gates.

Jurug and Tangen

vi) During the opening of the new gates, the peak of SS concentrations at Jurug and Tangen were significantly higher than those of current conditions in the case when inflow from the tributaries is small. In such condition, the impact of the sediment releasing operation would be relatively severe.

vii) Fluctuations of river flow discharge at Jurug and Tangen were almost the same as current conditions. The impact on the river flow discharges would be less because the river flow discharges in these stretches are dominated by the inflow from the tributaries.

(3) After Closing the New Gates (end of Wet season)

ⅷ) No impact would be observed in the downstream reaches.

3.7 Evaluation of Impact for Downstream

Based on the results of turbidity analysis, the impacts of the proposed urgent measure (a sediment storage reservoir with new gates) to the downstream reaches were predicted under conditions in some distinct hydrological wet, normal and dry year. The characteristics of the impact to the downstream reaches were assessed on the following criteria:

Monthly fluctuations:

(1) Impact for discharge
- monthly mean discharge
- monthly maximum discharge
- discharge duration curve

(2) Impact for SS concentration
- monthly mean SS concentration
- monthly maximum SS concentration
- frequency of high concentration of SS

Short term fluctuations:

(3) SI (Stress Index)

3.7.1 Impact on Discharge

Based on the results of turbidity analysis, the impacts of the proposed urgent measure (a sediment storage reservoir with new gates) to the downstream reaches were assessed on the following criteria:

i) Impact on discharge (monthly mean, monthly maximum, and discharge duration curve)
ii) Impact on SS concentration (monthly mean, monthly maximum, and duration curve of SS concentration)
iii) SI (Stress Index)

The results of assessment by above criteria are presented in Figures 3.7.1 to 3.7.6 and summarized below:

<u>Monthly Mean Discharge</u>

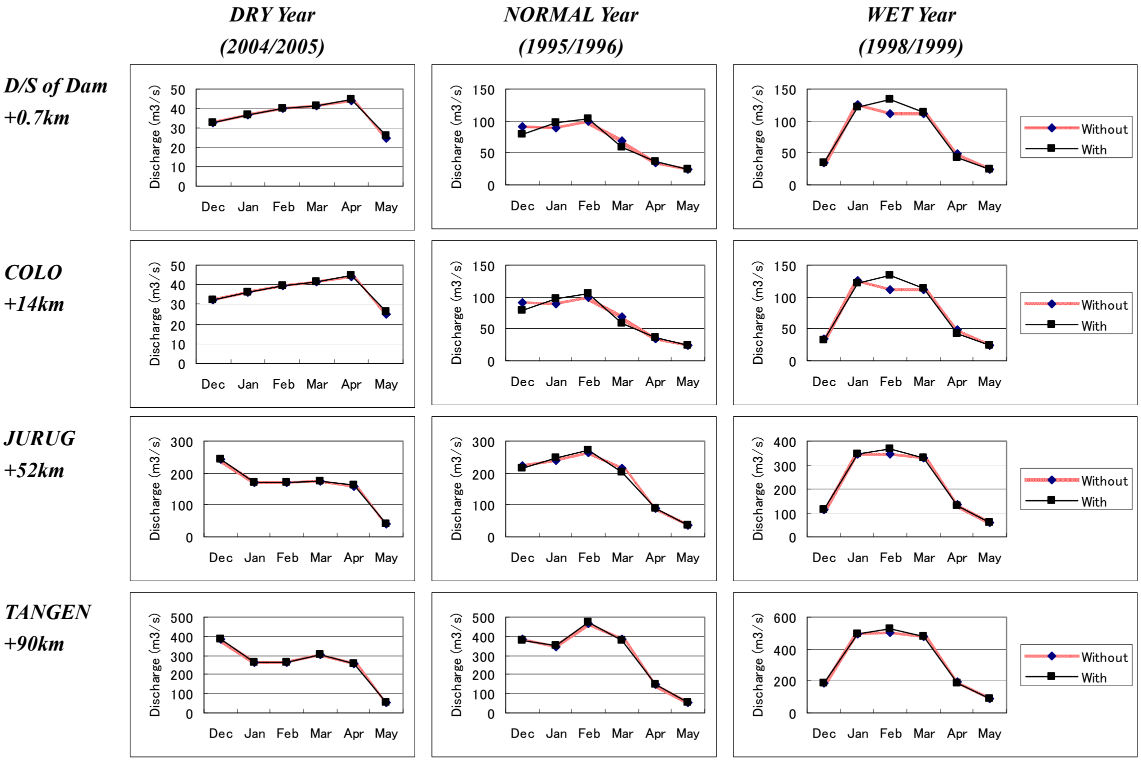
i) In each of dry, normal and wet year and at each station in the Upper Solo River downstream of the Wonogiri dam, no significant impact would occur.

<u>Monthly Maximum Discharge</u>

ii) In dry years, no impact would occur because the spillout discharge would be minimal or zero.
iii) In normal and wet years in the stretch of the Wonogiri - Jurug, the monthly maximum discharges would be slightly decreased due to operation of the proposed measure.
iv) At Tangen, the impact would be less because the river flow discharge in this stretch is dominated by the inflow from tributaries.

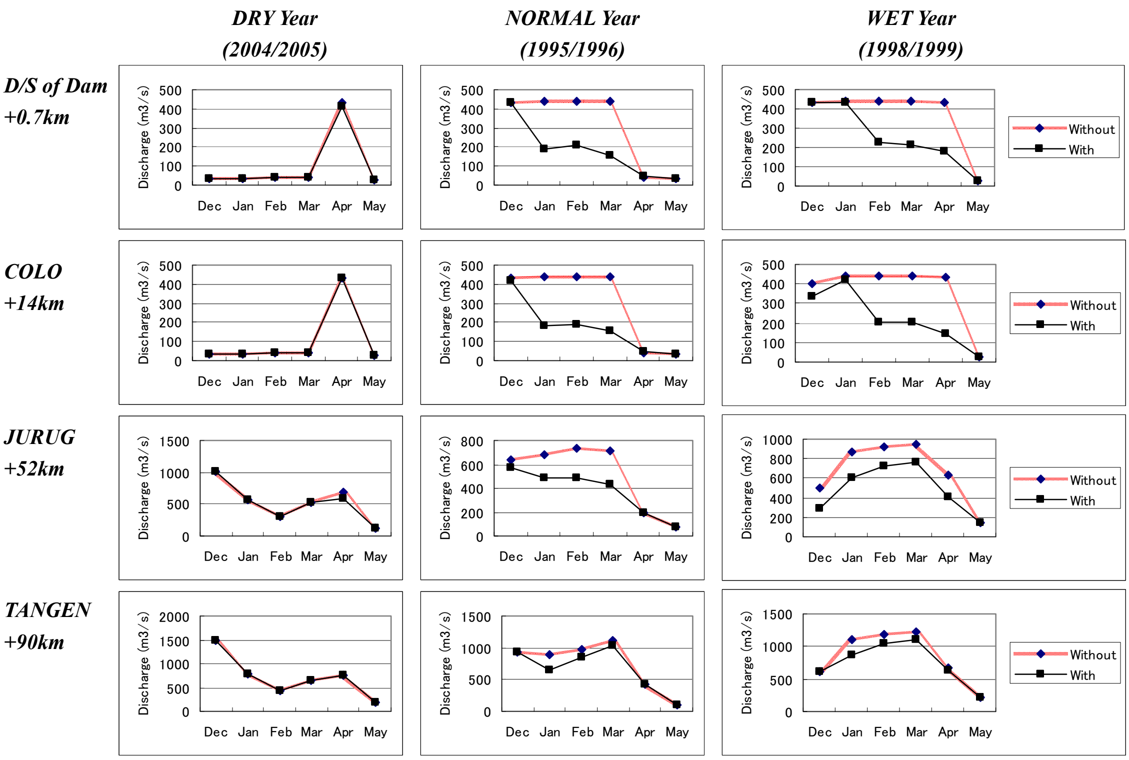
<u>Discharge-Duration Curve</u>

v) In the stretch of Wonogiri – Colo, the discharge duration curve would be a little smoother due to operation of the proposed measure. In the stretch of Jurug – Tangen, no significant impact would occur.



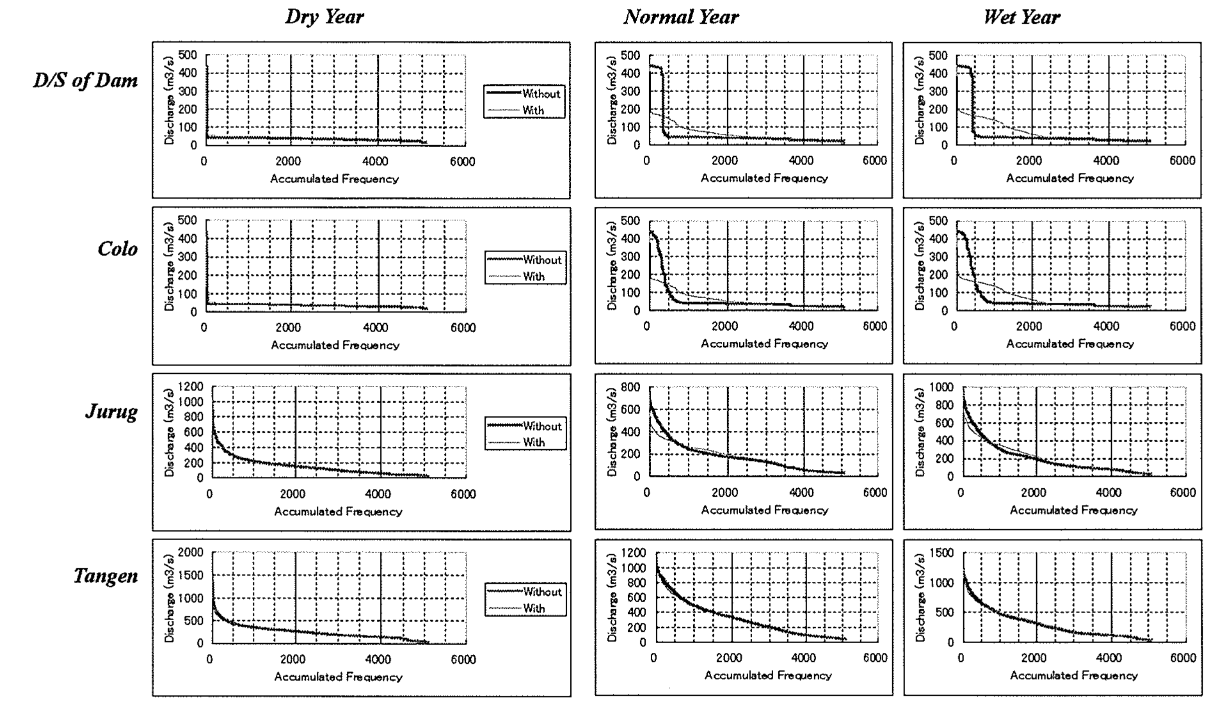
Source : JICA Study Team

Figure 3.7.1 Comparison of Monthly Mean Discharge in Upper Solo Mainstream bewteen With/Without Measures



Source : JICA Study Team

Figure 3.7.2 Comparison of Monthly Maximum Discharge in Upper Solo Mainstream bewteen With/Without Measures



Source : JICA Study Team

Figure 3.7.3 Comparison of Discharge-Duration in Upper Solo Mainstream bewteen With/Without Measures

3.7.2 Impact on SS Concentration

The comparison of monthly mean SS concentration, monthly maximum SS concentration and frequency of high concentration of SS between the cases of With measure and Without measure are presented in Figures 3.7.4 to 3.7.6 respectively. The main findings are presented in Table 3.6.1 and summarized below:

Monthly Mean SS Concentration

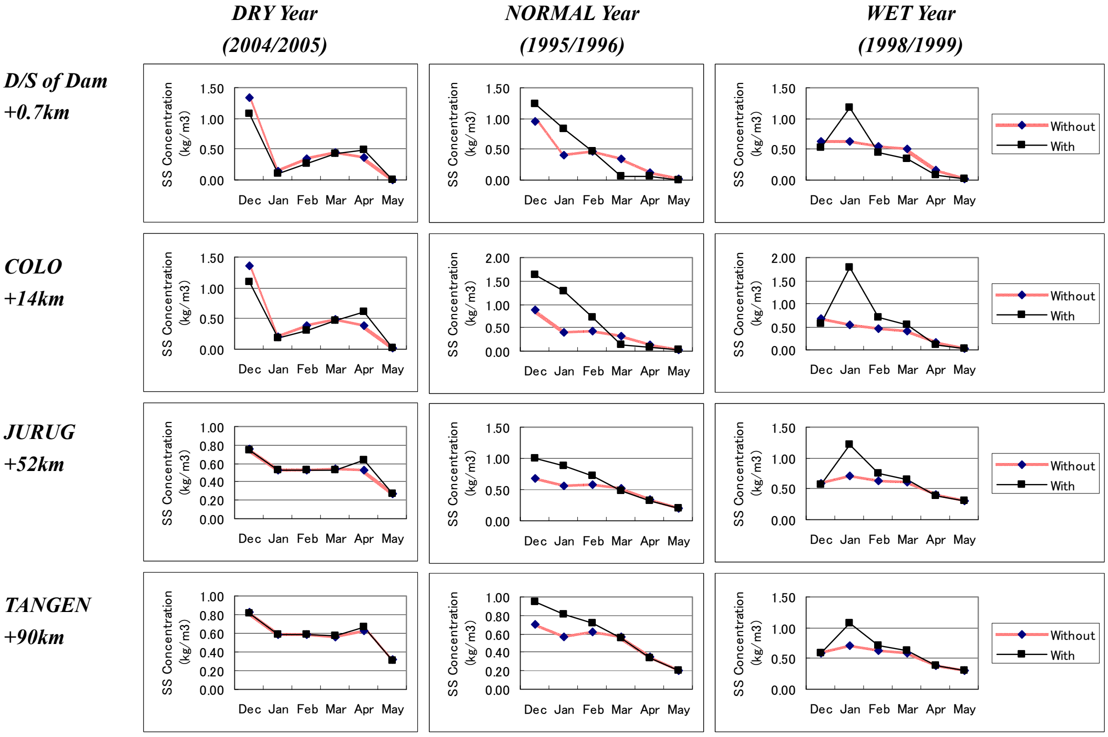
i) In dry years at each station, no significant impact would occur as the monthly mean and monthly maximum discharge would be the same because the spillout discharge would be minimal or zero.
ii) In normal and wet years at each station, the monthly mean SS concentrations would increase by 1.3 - 2.9 times while the new gates are opened.

Monthly Maximum SS Concentration

iii) Before opening the new gates, the monthly maximum SS concentration would decrease due to the effect of the proposed measure by which the existing intake would be protected from turbid inflow from the Keduang River.
iv) During opening of the new gates, the monthly maximum SS concentrations would increase by 2 - 3 times due to the released turbid water from the sediment storage reservoir.

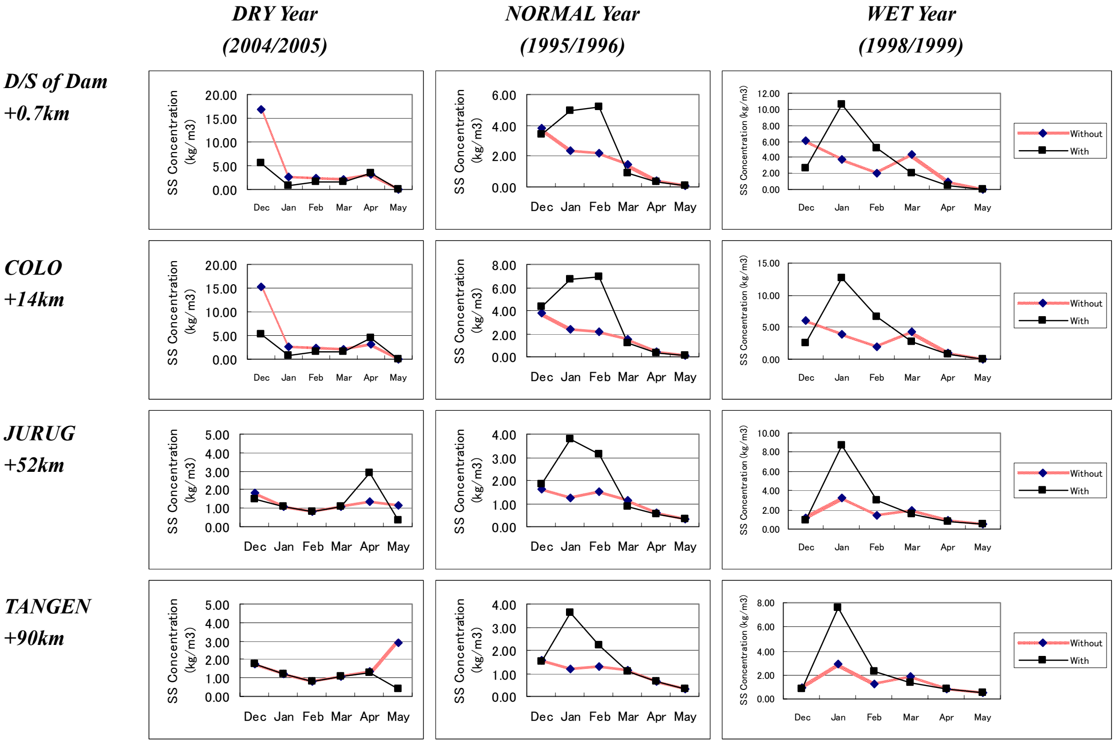
Duration Curve of SS Concentration

v) In dry years at each station, no impact would occur.
vi) In normal and wet years in the stretch of Wonogiri - Colo, the duration of SS concentration would slightly increase from 0.5 to 2.5 kg/m^3.
vii) In each year at Tangen, the duration curve of SS concentration would be unchanged because the SS concentration in this stretch would be dominated by the sediment inflow from tributaries, not the dam outflow.



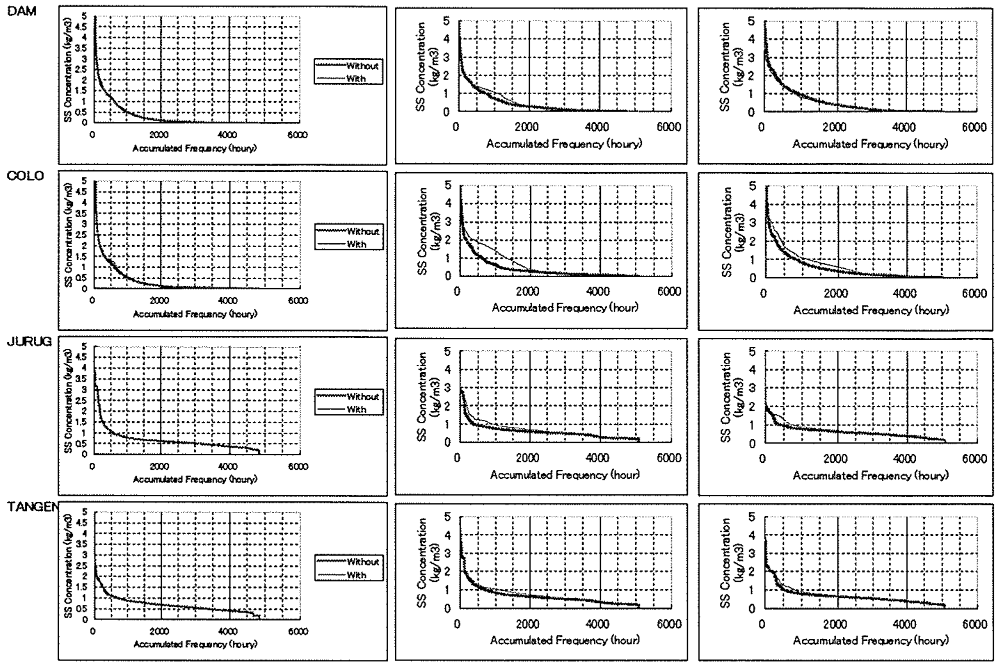
Source : JICA Study Team

Figure 3.7.4 Comparison of Monthly Mean Discharge in Upper Solo Mainstream bewteen With/Without Measures



Source : JICA Study Team

Figure 3.7.5 Comparison of Monthly Maximum Discharge in Upper Solo Mainstream bewteen With/Without Measures



Source : JICA Study Team

Figure 3.7.6 Comparison of Frequency of High SS Concnetration in Upper Solo Mainstream bewteen With/Without Measures

3.7.3 Impact for Stress Index

There is a criteria named Stress Index (SI) that is used to assess a short time impact of a sediment flushing/sluicing operation in the downstream stretch. The Stress Index is given by following equation:

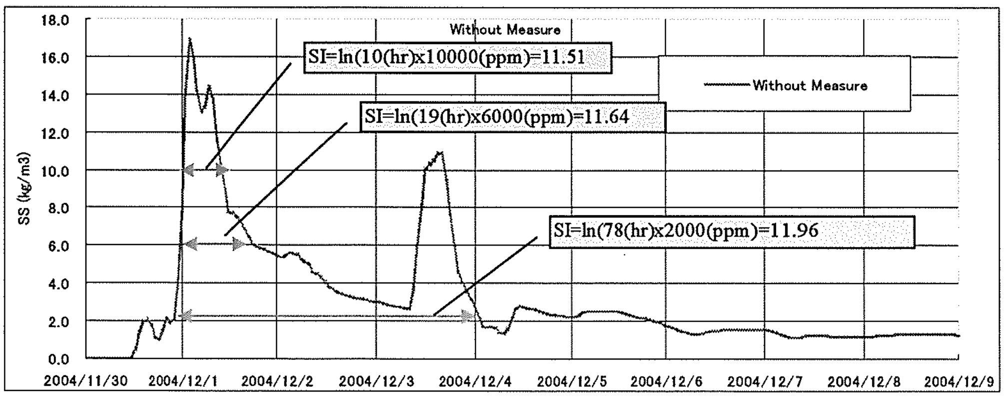
$SI = \log_e (SS \times T)$

where, SI : Stress Index

SS : Suspended Solid Concentration (mg/l)

T : Duration (hr)

Applying this index to the result of the turbidity analysis, the preliminary assessment was that there would be a short-term impact to the downstream of the Wonogiri. For the calculation of SI the threshold value of SS was assumed to be 2,000 mg/ltr so that a few significant peak fluctuations could be selected for respective wet seasons. An example of SI on the hydrograph of SS concentration is shown in the Figure 3.7.7.



Source : JICA Study Team

Figure 3.7.7 Example of SI Calculation on Various Threshold Values of SS Concentration

For the calculation of SI, the value of SI are different among various threshold of SS concentration in spite of applying a same hydrograph of SS concentration as shown in the figure below. In this analysis the threshold value of SS was assumed to be 2,000 mg/ltr so that a few significant peak fluctuations could be selected for respective wet seasons. As the result of calculation of SI on the simulated SS hydrographs, monthly maximum SI at each location in each hydrological year are classified in Table 3.7.2 and plotted in Figure 3.7.8 below.

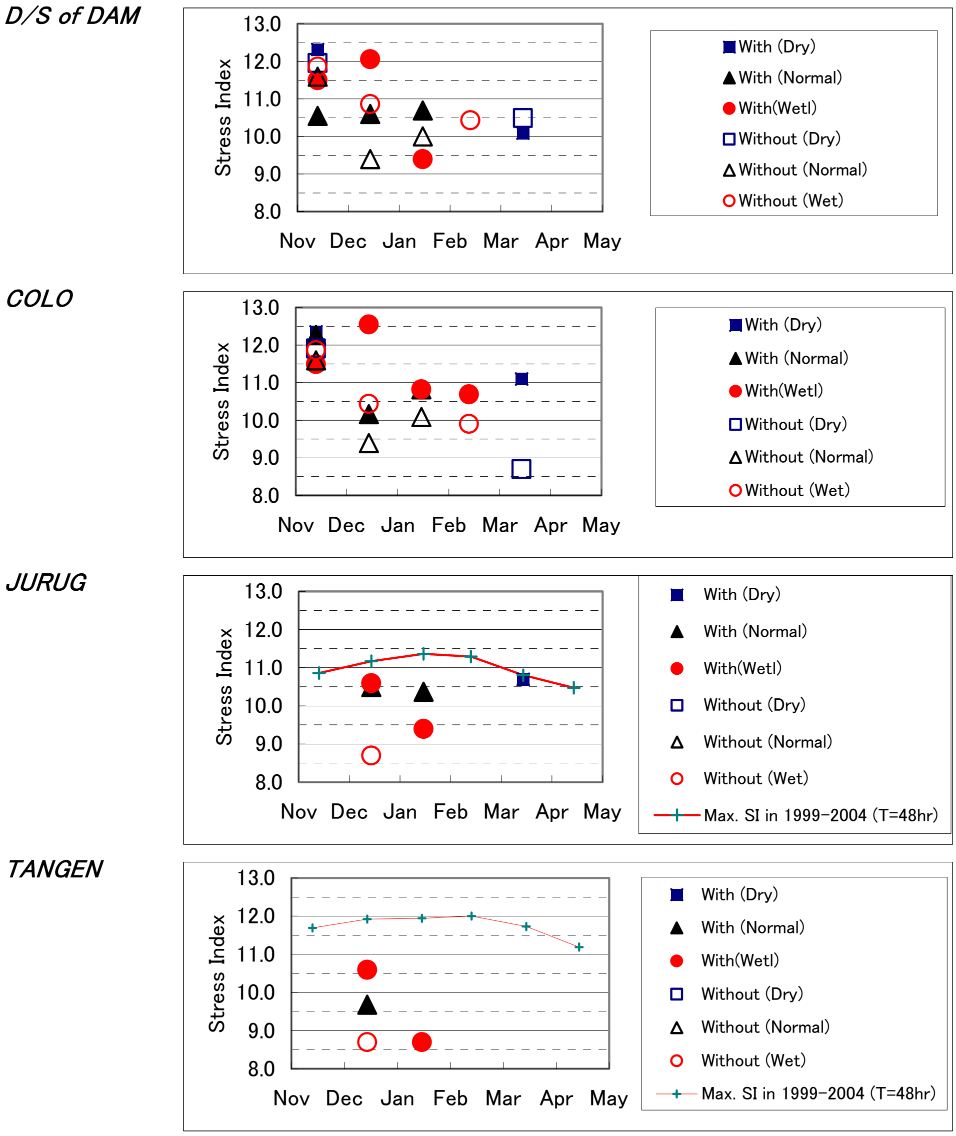
Though only three hydrological years were analyzed, SI varies in wider range along the upper Solo River mainstream depend on the duration and peak value of SS. From the overall points of view, it is indicated that the monthly maximum SI would slightly increase after implementation of the proposed measure.

The simulated monthly maximum SI was compared with the envelop curve of the estimated monthly maximum SI from the recorded SS at Jurug and Tangen in 1990 – 2004. The results were summarized in Figure 3.7.8. In this estimation, duration of SS was assumed 24 hour because the daily base data is available. As shown in the figure, all of the simulated monthly maximum SI from November to May were smaller than that on the recorded maximum. It is judged that short time impact to the downstream of the Wonogiri dam would be slightly small comparing to the recorded maximum SI in the stretch.

Table 3.7.1 Characteristics of Monthly Maximum of SI

Location	**Monthly Maximum SI (Dec.-May.)**					
	Without			**With**		
D/S of Dam	***9.4***	***-***	***12.0***	***9.4***	***-***	***12.3***
COLO	***8.7***	***-***	***11.9***	***10.2***	***-***	***12.5***
JURUG		***-***	***8.7***	***9.4***	***-***	***10.7***
TANGEN		***-***	***8.7***	***8.7***	***-***	***10.6***

Source : JICA Study Team



Source : JICA Study Team

Figure 3.7.8 Comparison of Monthly Maximu SI in Upper Solo Mainstream bewteen With/Without Measures

3.7.4 Impact of Sediment Loads

The accumulated volume of SS passing each station from November 1 to May 20 in each hydrological year was estimated as compared in Table 3.7.2. The average accumulated volume of SS passing was increased by 239,200 m^3 immediately downstream of the dam, 474,600 m^3 at the Colo, 478,500 m^3 at Jurug and 469,200 m^3 at Tangen. The increment in volume from the dam to the Colo was considered to be due to the high concentration of sediments supplied from tributaries and re-suspension of the riverbed materials. The decrease in the volume from the Colo to Tangen indicates that the sediment loads released from the sediment storage reservoir would become smaller with distance from the dam.

Even if the sediment load in the Upper Solo mainstream were to increase, sediments released from the Wonogiri reservoir would not be deposited in the river stretch because they are composed of 93-97% of wash load composed of clay and silt.

Table 3.7.2 Comparison of Accumulated Passing Volume of SS along Upper Solo River in Wet Season (November 1 to May 20)

(Unit: ton)

Location	Hydrological Year	Accumulated passing Volume of SS (November 1 – May 20)		
		Without	With	Increment
D/S of Dam	Dry	266,600	249,100	-17,500
	Normal	438,400	737,100	298,700
	Wet	437,900	874,300	436,400
	Average	***381,000***	***620,200***	***239,200***
COLO	Dry	297,700	291,900	-5,800
	Normal	501,300	1,074,800	573,500
	Wet	418,000	1,274,100	856,100
	Average	***405,700***	***880,300***	***474,600***
JURUG	Dry	1,861,000	1,862,800	1,800
	Normal	2,019,100	2,511,900	492,800
	Wet	2,262,400	3,203,400	941,000
	Average	***2,047,500***	***2,526,000***	***478,500***
TANGEN	Dry	3,441,900	3,449,200	7,300
	Norma	4,276,700	4,768,000	491,300
	Wet	3,727,200	4,636,200	909,000
	Average	***3,815,300***	***4,284,500***	***469,200***

Source: JICA Study Team