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SUSTAINABLE SEDIMENT MANAGEMENT PLAN OF THE WONOGIRI MULTIPURPOSE RESERVOIR IN INDONESIA*

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1. INTRODUCTION

The Wonogiri Multipurpose Reservoir on the Bengawan Solo River, the largest river on the Java Island in Indonesia, was constructed in 1980. The total watershed of the Reservoir covers 1,350 km^2, consisting of around 90 km^2 of reservoir surrounded by 1,260 km^2 of watershed (Fig. 1).

The Wonogiri Reservoir has been suffering from massive sediment inflows transported from the watershed. Intensive farming with poor land use practices on the highly erosive and steep sloped uplands is the main cause of the sedimentation of the reservoir. To cope with the sedimentation problems, the Government of Indonesia requested the Government of Japan (GOJ) to provide the technical cooperation by JICA (Japan International Cooperation Agency) on countermeasures for sedimentation issues of the reservoir. In response to the

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request, a study on countermeasures for sedimentation in the Wonogiri Reservoir[1)] had been conducted from August 2004 to July 2007. The primary purpose of the Study is to establish a master plan for sustainable countermeasures for sedimentation problems of the Wonogiri Reservoir.

Fig.1

The Wonogiri Reservoir Watershed and its Major Tributaries

Ligne de partage des eaux du réservoir de Wonogiri et ses principaux affluents

In the Study, the current status and issues due to the sedimentation in the reservoir were first outlined and analyzed. Then, a reservoir sedimentation analysis model was employed to evaluate the transport volume and distribution of sedimentation in the reservoir. The analyses showed that there was almost no sediment exchange between the area near the dam and the upstream area in the reservoir. Based on the distribution feature of the sedimentation, mitigation countermeasures against the sedimentation are evaluated by the model. Finally, an effective countermeasure against the Wonogiri Reservoir sedimentation was proposed.

1. CURRENT ISSUES DUE TO SEDIMENTATION

The Wonogiri Dam is a center impervious core type rock-fill dam. The reservoir provides 220 million m^3 of flood control capacity to regulate the design flood with peak discharge of 4,000 m^3/s to the constant outflow of 400 m^3/s and 440 million m^3 of capacity to supply irrigation water (30,000 ha) and hydropower generation. Principal feature, allocation of storage capacity and designated water levels of the Wonogiri Multipurpose Dam are presented in Fig. 2.

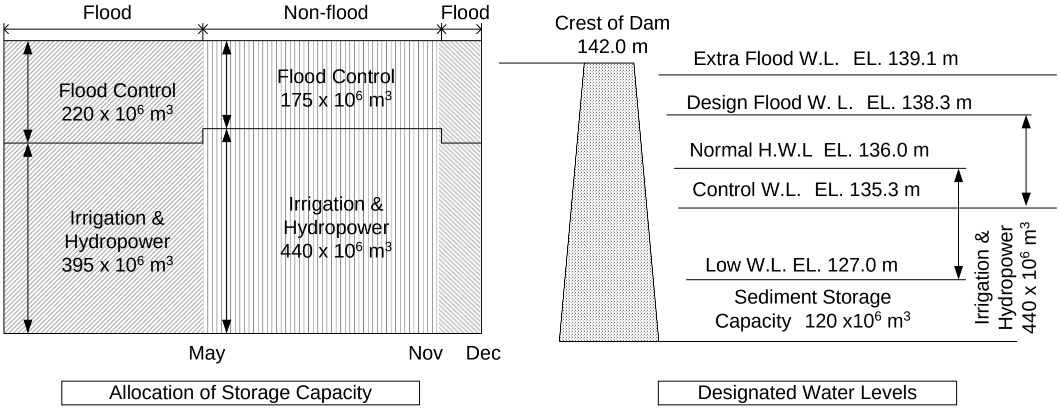


Fig. 2

Allocation of Storage Capacity and Designated Water Levels of the Wonogiri Dam

Distribution de la capacité de stockage et les niveaux d'eau correspondants au barrage de Wonogiri

Sedimentation problems in the Wonogiri Reservoir are; i) sediment deposits and garbage problems at/around the intake (Photos 1 and 2), ii) decrease of effective storage capacity, and iii) high sediment yield from its watershed.

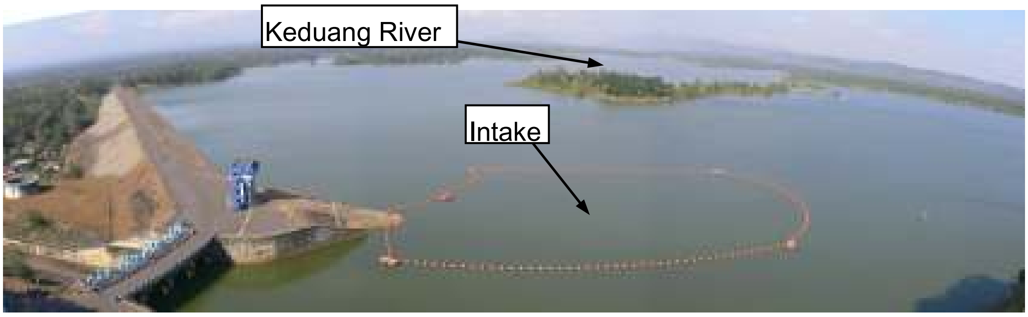


Photo 1

Panoramic View of the Wonogiri Reservoir at the Beginning of Dry Season

Vue panoramique du réservoir de Wonogiri en début de la saison sèche

Photo 2

Panoramic View of the Wonogiri Reservoir at the Beginning of Wet Season (The Keduang River enters the reservoir just upstream right of the dam)

Vue panoramique du réservoir de Wonogiri en début de la saison humide (La rivière Keduang débouche dans le réservoir en amont et juste à droite du barrage)

As shown in Fig. 1, the Wonogiri watershed is drained by 6 major rivers. Among them the Keduang River is the largest tributary with a catchment area of 421 km^2, or 33% of the Wonogiri watershed (1,260 km^2) and the primary cause of the current sediment- related problems at/around the intake. The Keduang River enters the reservoir just upstream right of the dam and conveys large quantities of sediment close to the dam. Further, the considerable quantity of vegetative debris and garbage washes into the intake fore-bay area at the beginning of the wet season. Partial blockage of intake by garbage has been frequently occurring.

2. CURRENT STATUS OF WONOGIRI RESERVOIR SEDIMENTATION

In the Study, reservoir sounding survey was undertaken in 2004 and 2005, respectively, in order to estimate the current status of the sedimentation as well as incremental sediment deposits in the wet season from December 2004 to April 2005. It appeared that approximately 114 million m^3, or 16% of the total capacity of 730 million m^3, was lost due to sedimentation in 1980-2005. The estimated current loss of capacity due to sedimentation in the three storage zones between 1980 and 2005 is summarized in Table 1.

Table 1
Wonogiri Reservoir Capacity Loss by Storage Zone between 1980 and 2005

Reservoir Zone	Reservoir Capacity (10^6 m^3)		Capacity Lost due to Sedimentation	
	1980	2005	Volume (10^6 m^3)	of Original (%)
Flood Control Storage	232	230	2	0.9
Water Use Storage	433	375	58	13.4
Dead Storage	114	58	56	49.1

Note; Reservoir capacities in 1980 above are re-estimated in the Study based on the topographical maps of the reservoir area before construction.

Around 13% of the original effective storage zone (between El. 127.0 m and El. 136.0 m) has been filled with sediment deposits by 2005. In other words, around 87% of the original effective storage zone is still usable.

Sediment in the reservoir is mainly composed of silt and clay. The profile of the Keduang River shows that massive quantities of sediment have deposited along the lower reach of river channel and in the reservoir over LWL El. 127.0 m (Photo 2). Sediment deposit materials on the Solo River gradually become finer in the downstream direction and form sandy to clayey reservoir bed in the vicinity of the upstream end of the reservoir. Profile of the Solo River shows the delta-like shape has been formed. Silt and clay sediments are deposited below the LWL in the main body of the reservoir.

3. SOURCES OF SEDIMENT DEPOSITS IN RESERVOIR

Low-lying flat lands in the Wonogiri Dam watershed have been widely developed for paddy cultivation. Upland fields with an elevation of 200-1,000 m have been also developed for agricultural uses. Major portion of hilly areas has been cultivated almost up to the ridge of hilly areas. About 90% of the watershed comprises paddy field, home settlement area, upland field (dry-land framing). These home settlement area and upland field are categorized as highly fragile to surface erosion. Forests cover less than 1% of the dam watershed. These values reflect a high population density. (Photos 3 and 4)

Preliminary estimation of the annual sediment yields for the existing gullies, landslides, river banks and slope of roadsides within the Wonogiri watershed were conducted based on the field investigations. Soil erosions from cultivated lands were analyzed by using the Universal Soil Loss Equation (USLE)[2)], that is the method widely used in Indonesia to predict rates of rill erosion from field or farm size unit subject to different management practices. In summary, it was estimated that around 93% of the annual sediment inflow originates in soil erosion from the cultivated uplands, which is very fine, mainly clay and silt. In the Wonogiri Reservoir, suspended load is absolutely dominant in the sediment transport.

Photo 3

Forest Area

Photo 4

Subsistence Cultivation

4. RESERVOIR SEDIMENTATION ANALYSIS

In order to take mitigation countermeasures against the sedimentation phenomenon, it is important to evaluate current situation of the sedimentation and to predict its future change in the reservoir. A sediment transport model is a right tool to predict the reservoir sedimentation because the phenomenon is one kind of bed deformation [3)], in which sediment deposition is dominant. By the model, transport volume and distribution of sedimentation in the reservoir and effect of mitigation countermeasures against sedimentation can be evaluated.

4.1. MODEL OF RESERVOIR SEDIMENTATION ANALYSIS

Maximum surface area of the Wonogiri Reservoir is around 90 km^2, and the water depth is shallow and its maximum is less than 18 m at the NHWL El. 136.0 m. In the reservoir, transport of very fine sediment, i.e., wash load, which is usually clay and silt, is dominant due to slower flow. Herein a depth-integrated two-dimensional numerical model, NKhydro2D sediment transport model developed by Nippon Koei Co., Ltd., is employed to study the flow condition and potential of sedimentation in the Wonogiri Reservoir under different conditions.

The reservoir planform is complicated with some coves and inflow tributaries. A model based on a boundary-fitted curvilinear coordinate system is preferable for analyzing the reservoir sedimentation phenomenon. Furthermore, computational grid in curvilinear coordinate system is flexible in grid size, by which effective simulation for long-term phenomenon becomes possible. Therefore, the present model is based on numerically generated boundary-fitted curvilinear grids (Fig.3). Depth-integrated 2D Reynolds' equations for water flow and advection-diffusion equation for sediment concentration are solved by a control volume based finite difference scheme. Both bed load and suspended load transport are taken into account. Bed load transport rate is evaluated by Ashida-Michiue’s formula in consideration of both the flow direction and bed slope. The concentration of suspended sediment (SS) is obtained by solving the equation of the sediment. Starting from certain initial conditions and under specified boundary conditions, the simulation is carried out step by step and the time varying velocity fields, water surface level, sediment transport rate and sedimentation (bed level variation) are evaluated. For the details of the model, please refer to the paper by authors[4)].

Figure 3 shows the Wonogiri Reservoir and the computational grids, which includes 6 major inflow rivers. The upstream ends of the inflow river are located at where effect due to backwater from the reservoir could almost be ignored. The total grids are about 3,700 and the grid size is about 3 - 330 m for the effective and accurate simulation. The grids are set to be finer in area of the inflow river and near the dam, while coarser grids are set in center of the reservoir.

Besides the information of computational mesh, other input conditions for the sediment transport model, including the inflow discharge, sediment supply and bed conditions, are necessary as the initial and boundary conditions. They are specified from the field investigations. Among the others, transport of fine sediment, including washload, is generally independent of local hydraulic conditions and is hardly evaluated directly by general empirical formula. Herein, suspended sediment concentration in inflow is assumed to be a function of the corresponding flow discharge as follows.

$$Q_s = a \cdot Q^b \qquad (1)$$

in which Q_s = transport rate of volumetric suspended sediment (m^3/s), Q = discharge (m^3/s) in river, a and b are the parameters. Based on the observed concentration and its particle distribution in inflow, the measured sedimentation in reservoir and sediment release from the reservoir and other related information, the parameter a and b are determined. The particle size distribution of suspended sediment with the inflow is taken into account in the simulation.

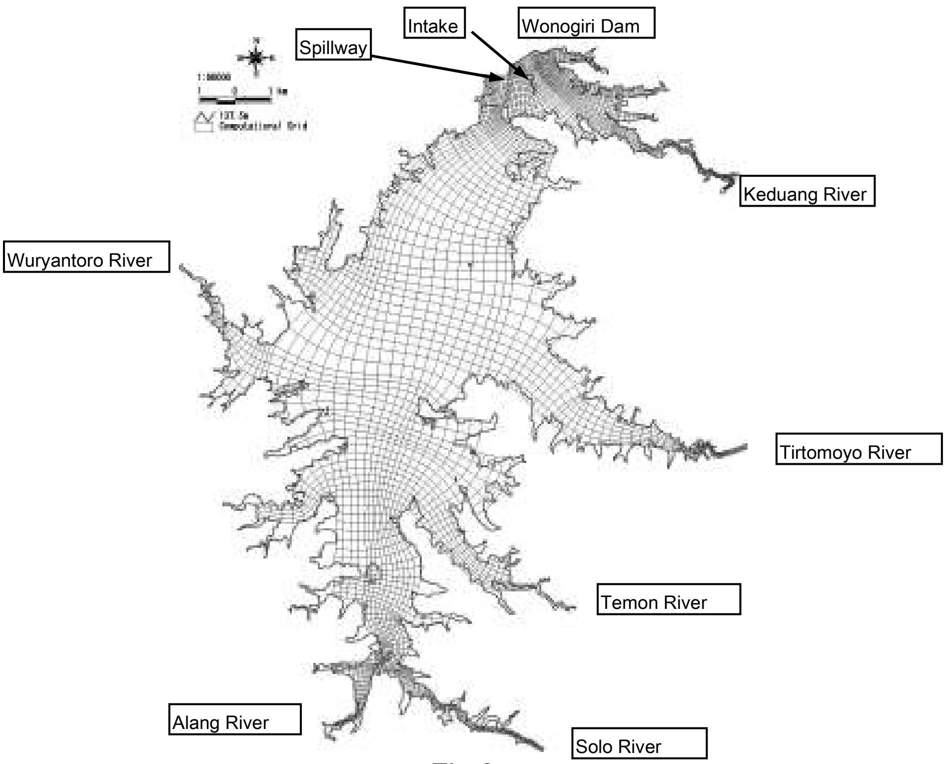


Fig.3

Wonogiri Reservoir and Computational Mesh

Le réservoir de Wonogiri et maillage

4.2. VERIFICATION OF SIMULATION

The model was verified first by the field data surveyed during the wet season of 2004-2005. Figure 4 shows the contour of bed level, measured in October 2004, which is specified as the initial bed level for the simulation.

The computational results show that the flow in river area was fast during the flood, while that in center of the reservoir was very much slowly, about 1cm/s or below. Furthermore, counter flow to the center from the dam area due to flood in Keduang River occurred, especially at lower water level in the reservoir.

Both the measured and the computed SS concentration at the intake from November 2004 to May 2005 are shown in Figure 5. Though there is a deviation in the time (phase lag) because of the inflow conditions, the computed SS concentration well corresponds to the observation.

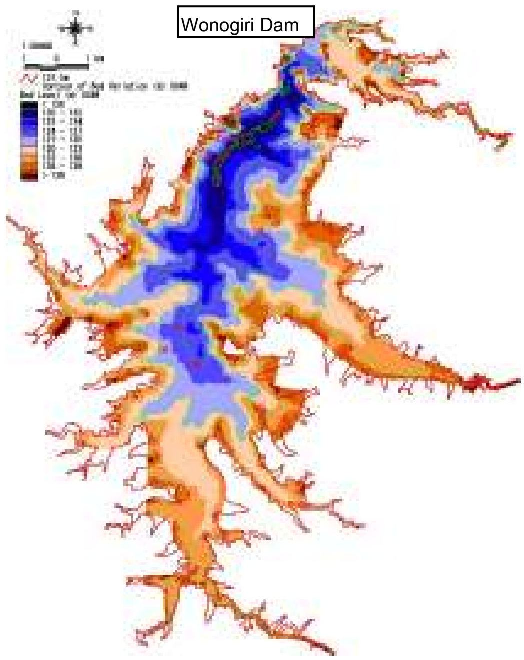


Fig. 4
Bed Level Contour of Wonogiri Reservoir in October 2004
Le contour du niveau du lit du réservoir de Wonogiri en Octobre 2004

Figure 6 shows SS concentration at the peak of flood and the sedimentation (bed level variation) in the rainy season of 2004 - 2005. It was found that SS concentration in river area during flood was higher and the muddy current transported inversely into the center of the reservoir from the Keduang River, consistent with the trajectory of the main flow. Much sedimentation occurred in the river area (top-set and fore-set bed) and the sedimentation progressed gradually to the center of the reservoir (bottom-set bed) from the river area. During the season, sedimentation in the river area (fore-set bed) was about 0.1 ~ 0.3m, while that in the center of the reservoir was less than 0.02m. Distribution of the computed sedimentation, including the particle size distribution, agrees with the measurement. For the details, please refer to the paper[4].

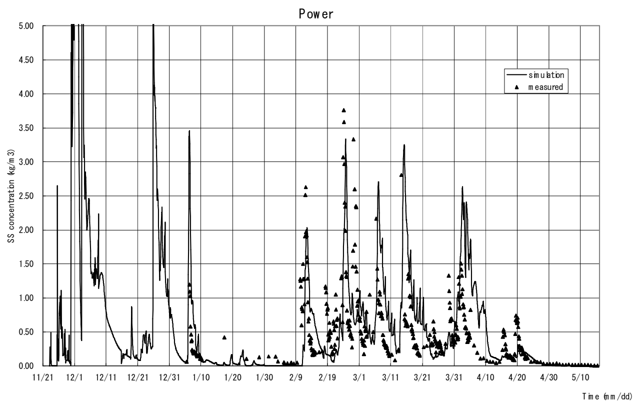
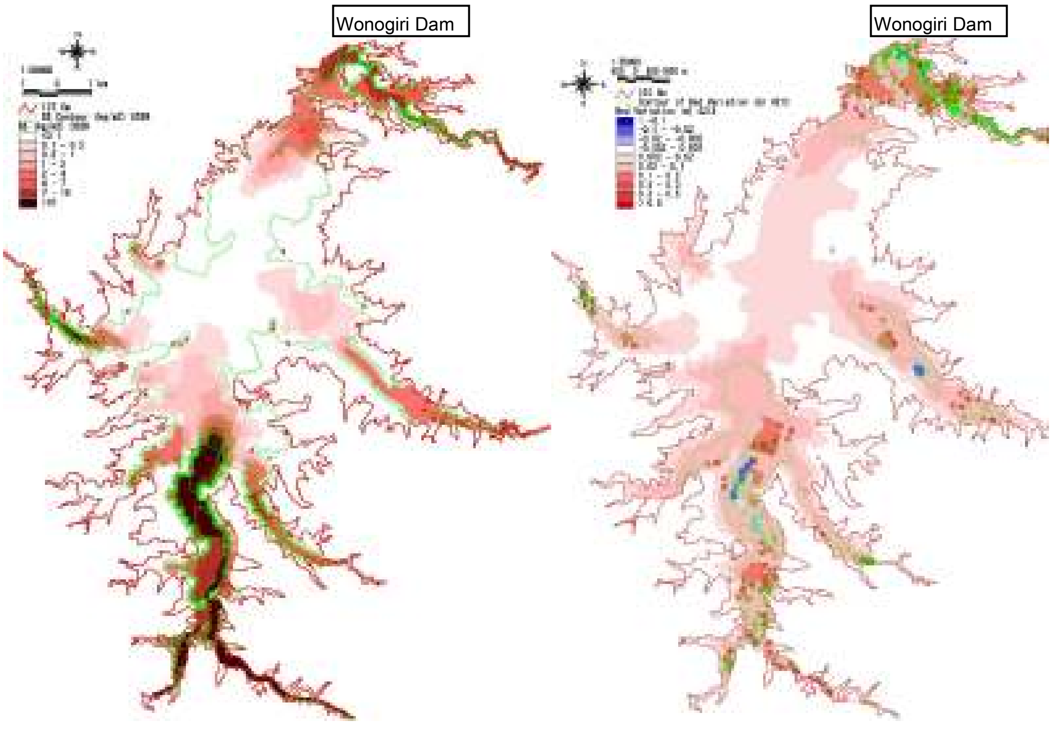


Fig. 5

Measured and Computed SS Concentration at the Intake

Concentration des SS mesurées et calculées au niveau des prises d'eau



(a) SS concentration (b) Sedimentation (bed level variation)

Fig. 6

SS Concentration at Flood Peak and Sedimentation during the Season

Concentration des SS durant les pointes de crues et de la sédimentation durant la saison

4.3. ANNUAL SEDIMENT BALANCE IN 1993-2004

Furthermore, sedimentation in the reservoir during 1993-2004 (11 years) is also simulated by the model and the results are shown in Figure 7. The sedimentation progressed gradually to the center of the reservoir from the river area. In center of the reservoir, the sedimentation depth was about 0.1 - 0.3 m. In the Keduang River area, sedimentation was severe and the maximum depth of sedimentation was about 4 m. The deepest bed level rose about 2 m in 11 years. The fore-set bed invaded to the center of reservoir from the Keduang River and the sedimentation near the intake was about 2 m. The total sediment inflow in 1993-2004 was about 35.2 million m^3. The annual average sediment inflow was 3.2 million m^3. The total computational sediment volume released from the reservoir during 1993-2004 was 4,820,000 m^3, in which 1,860,000 m^3 by the intake and 2,960,000 m^3 by the spillway. According to the simulation, mean sediment trap ratio by the Wonogiri Reservoir was 0.85. The trap ratio was relative lower in the wet year and higher in the dry year.

The simulation results show that counter flow to the center due to the flood in Keduang River occurred and there was only little sediment to be transported from Keduang (near the dam) area to center area. It is concluded that there was almost no sediment exchange between Keduang area and the upstream area in the reservoir. This is important for planning the mitigation countermeasures against the sedimentation.

The above results show that the present model can be employed to simulate the sedimentation in the Wonogiri Reservoir. The model is then applied to evaluate the mitigation countermeasures against the sedimentation

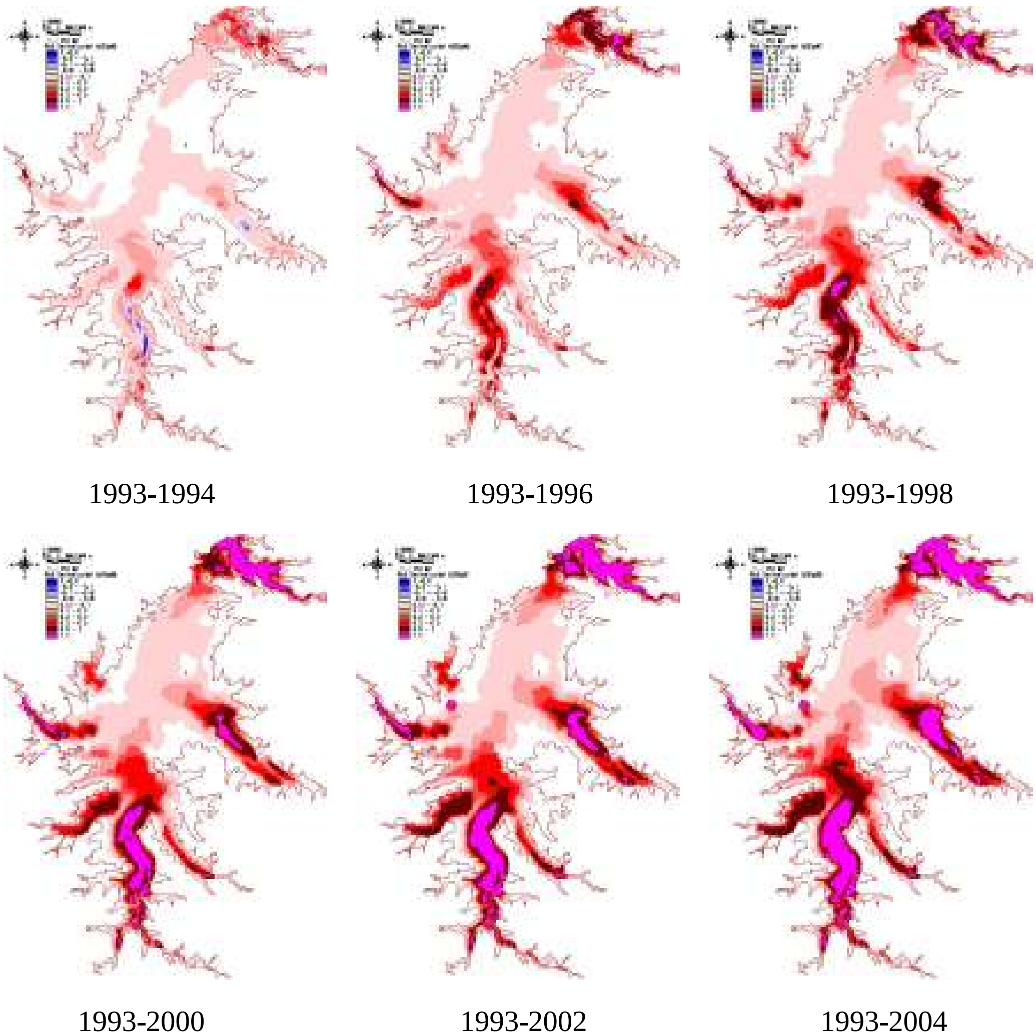


Fig. 7

Bed Variation (Sedimentation) in the Wonogiri Reservoir from 1993 to 2004

Variation de la sédimentation du lit dans le réservoir de Wonogiri de 1993 jusqu'à 2004

5. OUTLINE OF THE PROPOSED SEDIMENT STORAGE RESERVOIR

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

5.1. PROJECTION OF RESERVOIR LIFETIME

Based on the annual sediment balance, the future state of Wonogiri Reservoir sedimentation without any countermeasures for the sedimentation problems is projected. By year 2051, the Wonogiri Reservoir will lose around 28% of its effective storage capacity and completely lose its dead storage capacity. Furthermore, the Wonogiri Reservoir will lose about 62% of the effective storage capacity by the year 2105. In general, impact or severity of reservoir sedimentation problems is represented by the years taken to lose half the initial reservoir volume. It is generally recognized that reservoirs often experience the serious operational constraints by the time when half its original capacity is lost[5)]. The Wonogiri Reservoir will lose half of the capacity around by the year 2062.

5.2. STRATEGY FOR MASTER PLAN FORMULATION

Complete restoration of the Wonogiri Reservoir would be a very hard task. Sustainable management of the reservoir function is crucial. Thus it was recommended to enable the sustainable operation of the Wonogiri Reservoir through provision of the effective reservoir sediment management system to prolong the reservoir lifetime as illustrated in Fig. 8.

The layout of the Wonogiri Reservoir looks somewhat unusual because the Keduang River enters the reservoir just upstream right of the dam. As mentioned earlier the Keduang River is the largest tributary with a catchment area of 421 km^2 or 33% of the total Wonogiri watershed. However, the reservoir area accommodating the Keduang sediment inflow is only 5 km^2 or 6% of the whole reservoir area. Because of the relatively small storage volume of the Keduang reservoir area, progress of sedimentation in this area is much faster than those of other tributaries. As a result, a large quantity of sediments has been deposited in the portion close to the dam, especially in the forebay adjacent to the intake.

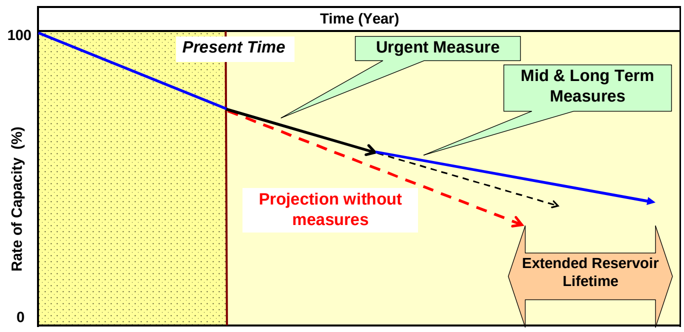


Fig. 8

Illustration of Prolonging the Reservoir Lifetime

Illustration du Prolongement de la Durée de Vie du Réservoir

Around 66% of the effective storage zone in the Keduang reservoir area (estimated total original capacity in 1980 is around 74 million m^3) has been lost due to sedimentation between 1980 and 2005. It was estimated that the storage capacity in the Keduang reservoir area would be lost around by the year 2022. The sediment and garbage inflow from the Keduang River is the primary cause of the current sediment-related problems on the intake. Thus countermeasure for the problems on the intake needs to handle the sediment and garbage inflow from the Keduang River as the top priority. Sediments from other tributaries are deposited forming a delta at each mouth of tributary. Although each delta has a tendency to extend in the downstream deeper and wider portions of the reservoir, the longitudinal growth rate seems to be slow. It will take a long time until the delta approaches to the area causing serious impacts on the intake. For the other tributary basins, it was judged to be practical to adopt the watershed management and conservation so as to reduce the sediment yield rate as the mid- and long-term countermeasures.

5.3. Proposed Sediment Storage Reservoir

Various structural alternative measures were worked out for technical and economical evaluation. Technical effects on mitigation of sedimentation in the reservoir with provision of respective alternatives were evaluated by the reservoir sedimentation analysis model. As the result of comparative study, a sediment storage reservoir with new gates was proposed in view of sediment releasing ability and efficiency.

This plan is to create a small sediment storage reservoir inside the Wonogiri Reservoir for the sediment inflow form the Keduang River by installation of closure dyke, thereby to allow two reservoir portions to be operated separately. The separated portions are named the Keduang reservoir and main Wonogiri Reservoir. New gates will be installed on the right side of the dam. Thus, through the new gates, sediment-laden flood inflow from the Keduang River would be passed through before deposition in the reservoir. Structural layout is illustrated in Fig. 9.

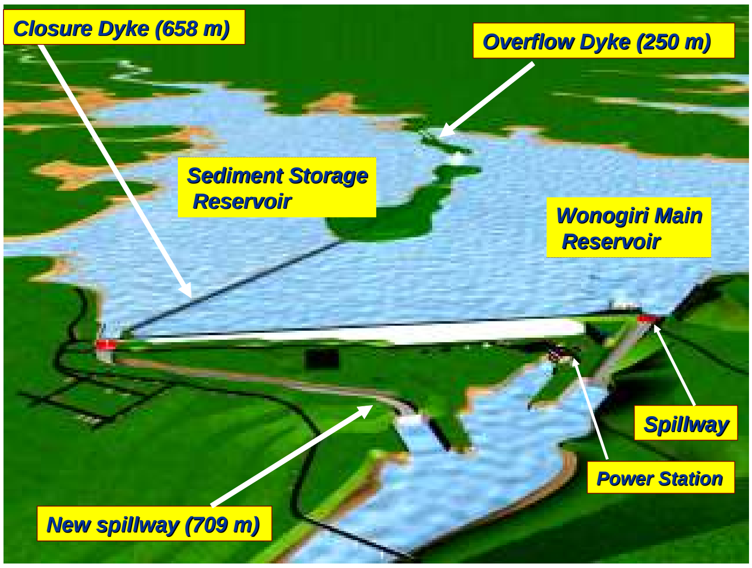


Fig. 9
Illustration of Layout of Sediment Storage Reservoir
Illustration du plan de site du stockage des sédiments du Réservoir

As a turn-over rate of the Wonogiri Reservoir is only 2-3 times/year, it is difficult to lower the water level for sediment sluicing. However, storage capacity of the created sediment storage reservoir is 14 million m^3 at the NHWL and mean annual Keduang inflow is about 353 million m^3. Hence, the sediment storage reservoir turn-over rate is 25 times/year on average. The new sediment storage reservoir can flush out the deposited sediments by empting the reservoir.

Almost all of the garbage inflow from the Keduang River would be completely retained within the sediment storage reservoir area. The existing intake structure will become completely relieved from the current garbage issues. Because of creation of the small sediment storage reservoir, besides the sediment sluicing to pass through the incoming Keduang sediment inflow, sediment flushing can be made independently without releasing water stored in the main Wonogiri Reservoir.

Simulation analysis was conducted based on the current reservoir operation rule. The results are summarized in Table 2. The total reservoir water inflow volumes are around 0.8 billion m^3 in the dry year, 1.3 billion m^3 in the normal year and 1.5 billion m^3 in the wet year, respectively. The mean annual inflow volume is around 1.2 billion m^3. As seen in the table, sediment release volumes from the intake (power generation) and the new gate are 200,000 m^3 and 60,000 m^3 in the dry year, 100,000 m^3 and 1,100,000 m^3 in the normal year, and 100,000 m^3 and 1,300,000 m^3 in the wet year, respectively. Sediment release through the new gate increases a lot although that through the intake decreases. The sediment release is little in the dry year because the inflow is extremely small as compared with that in the normal year. Accordingly, the frequency of flushing operation becomes very scarce in the dry year.

Table 2
Simulation Results of Sediment Storage Reservoir by Hydrological Year

Released Sediment Volume (1,000 m^3)	Present Average (1993- 2005)	Sediment Storage Reservoir		
		Dry Year (2004-2005)	Normal Year (1995- 1996)	Wet Year (1998-1999)
Existing Spillway	150	0	0	0
Power Generation	260	200	100	100
New Gates	-	60	1,100	1,300
Total	410	260	1,200	1,400

Note: Radial gate H12.6m x B7.5m x 4 nos. are conceived.

Water level in two sides of the Wonogiri Reservoir and discharge at overflow dyke in wet (hydrological flood) year is shown in Figure 10. The result shows that during the operation of the new gate in the Kuduang side, the water level in main part of the reservoir can be kept in desired level. Furthermore, the water level in the Keduang side can be restored by the end of flood season.

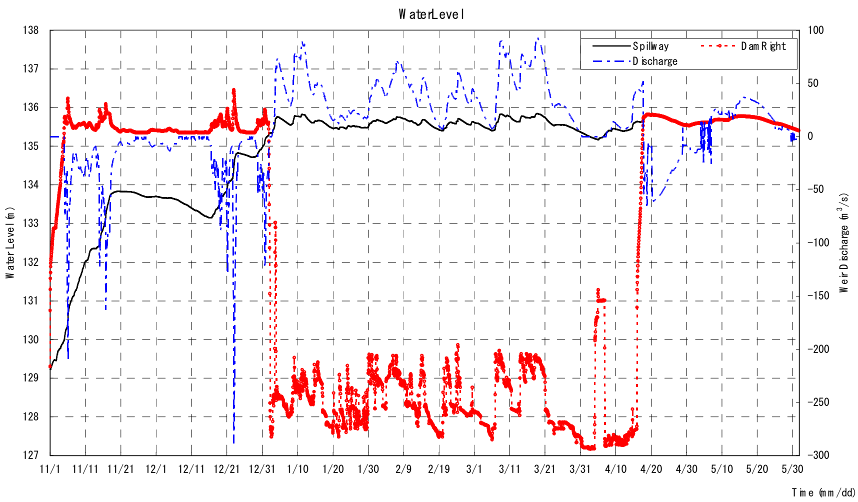


Fig.10
Water Level in Two Sides of the Wonogiri Reservoir and Discharge at Overflow Dyke in Hydrological Flood Year
Niveau d'eau des deux cotés du réservoir de Wonogiri et débit de déversement à partir du déversoir durant l'année hydrique de crue

Results of velocity vector, SS concentration and sedimentation for both the countermeasure condition and the present condition in the wet (hydrological flood) year are presented in Figure 11. In Sediment Storage Reservoir with New Gate, sediment-laden flood flow from the Keduang river is shut out by the closure dyke. Therefore, there is no sediment-laden flow passed through the area around the intake. On the other hand, in the current situation with the existing spillway only, sediment-laden flow from the Keduang river passes through the area around the intake. This feature of the flow will inevitably affect the sedimentation in the area. The feature of SS concentration distribution is similar with that of the velocity. In the Keduang reservoir, SS concentration is quite high while that near the intake in the main reservoir is lower than that in the current condition. Therefore, comparing to the current situation, sedimentation in the area around the intake is improved.

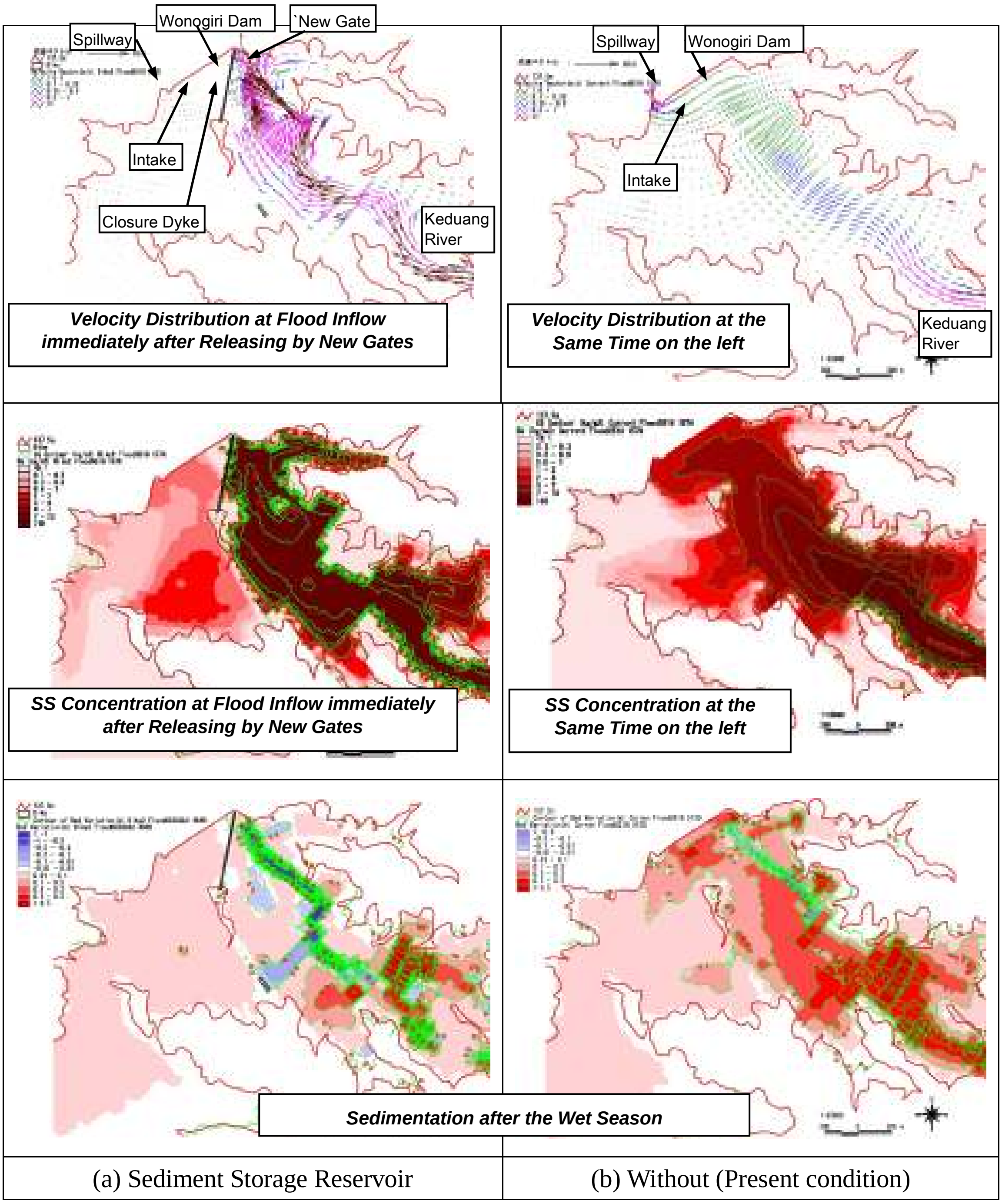


Fig. 11
Comparison of the Results with and without the Countermeasure
(Case: Hydrological Wet Year in 1998-1999)
Comparaison des résultats avec et sans contre-mesures
(Cas de l'année hydrique humide de 1998-1999)

5.4. OPERATION OF SEDIMENT CONTROL

Figure 12 illustrates future operation of the sediment storage reservoir compared to current operation of the Wonogiri Reservoir. The Wonogiri Reservoir is divided into two reservoirs by the closure dyke; a sediment storage reservoir and the Wonogiri main reservoir. The storage capacity of the sediment storage reservoir is small at around 11 million m^3 at the CWL 135.3 m. Both reservoirs are to be operated independently. The current reservoir operation rule of the Wonogiri dam is unchanged and thus will be applied to the operation of Wonogiri main reservoir.

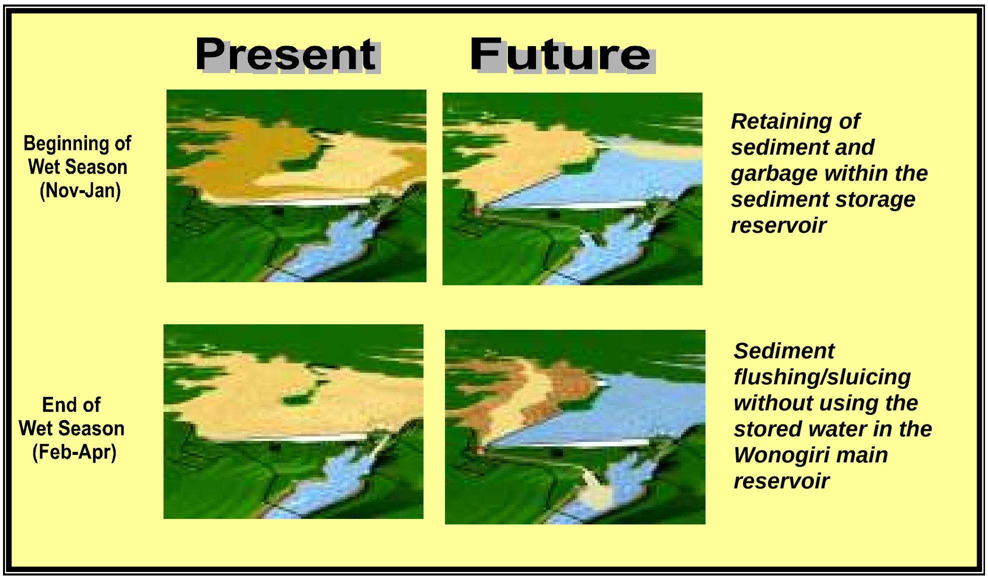


Fig. 12

Comparison of Operation of Current Wonogiri Reservoir and Sediment Storage Reservoir

Comparaison de l'exploitation actuelle du réservoir de Wonogiri et du réservoir de stockage des sédiments

Watershed conservation will be implemented for the Keduang River with a total area of 11,260 ha covering 83 villages. After implementation, around 0.42 million m^3 of sediment inflow is expected to be reduced every year on the average. The majority of annual sediment inflow 1.22 million m^3/year from the Keduang River could be released in combination with the design sediment releasing capacity 0.70 million m^3/year of the proposed sediment storage reservoir (the number of gates was finally reduced from 4 to 2 nos. in view of cost effectiveness). From the reservoir sedimentation simulation, sediment volume overflow into the main Wonogiri Reservoir from the sediment storage reservoir and released from hydropower generation were estimated 0.10 million m^3/year and 0.14 million m^3/year. Annual sediment deposits in the Wonogiri Reservoir are thus 1.92 million m^3/year.

As mentioned in Section 6.2, for the continuing sediment inflow from other tributary basins, it was proposed that the best and practical way is to reduce the sediment yield rate by implementing watershed conservation works with a total area of 23,120 ha. After the completion of the works, the annual sediment inflow into the reservoir from other tributaries is expected to be reduced from 1.96 million m^3 to 1.04 million m^3. Consequently the annual sediment deposits in reservoir would be less than the original design sedimentation rate of 1.2 million m^3/year.

CONCLUSION

The Wonogiri Reservoir has been suffering severe sedimentation problem because of massive sediment inflows from the watershed. A study for sustainable countermeasures on the sedimentation had been conducted. The annual average sediment inflow was 3.2 million m^3, of which 85% was trapped in the reservoir. The study showed that approximately 114 million m^3, or 16% of the total capacity of 730 million m^3, was lost due to sedimentation in 1980-2005. Around 93% of the annual sediment inflow originates in soil erosion from the cultivated uplands, which is very fine, mainly clay and silt.

In the study, a depth-integrated 2D numerical analysis model was developed to predict sedimentation in the Wonogiri Reservoir. This sediment transport model is a strong tool to evaluate the sedimentation phenomenon in reservoir. By use of this model, transport volume and sedimentation distribution in reservoir with provision of various mitigation measures were predicted for technical evaluation. The Wonogiri watershed is drained by 6 major rivers. Among them the Keduang River, which enters the reservoir just upstream right of the dam, is the largest tributary with a catchment area of 421 km^2, or 33% of the Wonogiri watershed (1,260 km^2). The simulation results show that counter flow to the center due to the flood in Keduang River occurred and the sedimentation in the area near the dam was mainly resulted from the sediment supply from the Keduang River. This is important for planning the mitigation countermeasures against the sedimentation.

According to the sedimentation feature in the reservoir and based on evaluation by simulation for various structure measures, a countermeasure with a sediment storage reservoir was proposed. The Wonogiri Reservoir is divided into two reservoirs by the closure dyke; a sediment storage reservoir and the Wonogiri main reservoir. Both reservoirs are to be operated independently. The simulation result shows that comparing to the current situation, the sedimentation in the reservoir will be reduced and moreover the sedimentation in the intake area is dramatically improved. For the continuing sediment inflow from other tributaries, watershed conservation was proposed to reduce the sediment yield. After the completion of the watershed conservation works, the annual sediment deposits in reservoir would be less than the original design sedimentation rate of 1.2 million m^3/year.

It is highly expected that our study would provide solutions and technical approaches for the similar sedimentation problems in other reservoirs in Indonesia.

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SUMMARY

This paper introduces the results of a study to cope with serious sedimentation issues in the Wonogiri Reservoir, Indonesia. The annual average sediment inflow was 3.2 million m^3, of which 85% was trapped in the reservoir and the materials are very fine, mainly clay and silt. Besides the field investigation and data analysis, a depth-integrated two-dimensional numerical analysis model was developed to simulate the reservoir sedimentation and to evaluate alternative structural countermeasures. The simulation results show that the sedimentation in the area near the dam was mainly due to the sediment supply from the Keduang River which enters the reservoir just upstream right of the dam.

According to the sedimentation feature in the reservoir and based on evaluation by simulation for various structural alternatives, a master plan for sustainable countermeasures for sedimentation problems, including structural and non-structural measures, was proposed. Besides watershed conservation as the non-structural measures, construction of sediment storage reservoir with new gates was recommended as the urgent countermeasure. This sediment storage reservoir will be created inside the Wonogiri Reservoir by installation of closure dyke, allowing two reservoir portions to be operated separately. Sluicing gates will be also installed in the sediment storage reservoir portion to pass-through the sediment-laden flood inflows. Comparing to the current situation, the sedimentation near the intake will be dramatically improved. Together with the watershed conservation works, the annual sediment deposits in reservoir would be less than the original design sedimentation rate of 1.2 million m^3/year.

RÉSUMÉ

Cet article présente les résultats d'une étude effectuée sur la manière de remédier aux problèmes majeurs liés à la sédimentation dans le réservoir de Wonogiri, en Indonésie. La moyenne annuelle du débit entrant des sédiments était de 3,2 millions de m^3, dont 85 % étaient piégés dans le réservoir et constitués de très fines particules, principalement d'argile et de boue. En plus de l'enquête menée sur le terrain et de l'analyse des données, un modèle d'analyse numérique bidimensionnel à profondeur intégrée a été développé afin de simuler la sédimentation du réservoir et d'évaluer d'autres contre-mesures structurelles. Les résultats de la simulation montrent que la sédimentation dans la zone proche du réservoir provient surtout de l'apport en sédiments de la rivière Keduang qui pénètre dans le réservoir juste à droite en amont du barrage.

Selon le caractère de la sédimentation dans le réservoir et en se basant sur l'évaluation en fonction de la simulation des différentes possibilités structurelles, un plan directeur pour l'introduction de contre-mesures durables pour les

problèmes de sédimentation, dont des mesures structurelles et non-structurelles, a été proposé. En plus de la préservation de la ligne de partage des eaux en tant que mesure non-structurelle, la construction du réservoir de stockage des sédiments avec de nouvelles vannes a été recommandée comme contre-mesure urgente. Ce réservoir de stockage de sédiments sera créé à l'intérieur du réservoir de Wonogiri en y installant une digue de fermeture, permettant l'exploitation de deux parties du réservoir d'une manière séparée. Des vannes de chasse des sédiments seront installées dans la partie du réservoir de stockage des sédiments afin de permettre le passage des sédiments causés par le débit entrant des crues. La sédimentation aux abords des prises d'eau connaitra un changement radical par rapport à la situation actuelle. Avec les travaux de conservation des lignes de partage des eaux, la disposition annuelle des sédiments dans le réservoir serait inférieur au taux de sédimentation prévu initialement (1,2 millions de m^3/an.)