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Sedimentation Trend and Behavior of Turbid Water in the Reservoir

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Abstract: A half of the water demand for agriculture and urban water supply is covered by surface water resources even in arid land, however the capacity of the reservoirs is gradually degraded due to sedimentation. Therefore, sedimentation control in reservoirs is an important issue in the sense of sustainable surface water resource management. In the case of North African countries, due to the clear precipitation difference between rainy season in winter and dry season in summer, the flood water in rainy season is stored for irrigation and potable use in the dry season. This longer retention time than humid area causes more rapid sedimentation.

In this study, the detailed behavior of turbid water which is discharged from upper catchment in rainy winter season is discussed with a numerical simulation model applied to a reservoir in northern Tunisia. Because of the low solar irradiance, thermal stratification was not found in the water body in winter and turbid water flowed along the bottom of the reservoir as a density flow. Understanding the speed and thickness of this density flow is very important for proper management of reservoirs, whether the turbid flood water can be removed by opening the spill way or other measures. The numerical simulation was carried out with some different cases of density of inflow and intake rate at the dam, which define the thickness and speed of the bottom flow.

Key Words: Density flow, Flood, Reservoir, Sedimentation, Turbidity

1. Introduction

Securing stable water resources is the most important issue in arid areas. However, the degradation of surface water resources in arid land is very serious due to sedimentation in reservoirs. For example, in North African countries, the annual reduction rate of water storage capacity reaches 0.5% in Morocco and Algeria, and 1% in Tunisia (Remini, 2006).

The spatial distribution of sedimentation in a reservoir is important for the discussion of the countermeasures to sedimentation. The behavior of the turbid water in the water body determines the spatial distribution of sediment in the reservoir.

In this study, the effect of the change of the discharge amount from reservoir to downstream on the behavior of the turbid water is discussed by numerical experiment with a hydraulic simulation model.

2. Materials and Methods

2.1. Study site

Joumine dam is located on the northern side of Tunisia. This reservoir is known as where the environmental discharges were started 10 years ago for the conservation of Ichkeul wet land (Djebbi, 2009). Due to this change of the management of Joumine dam, it is inferred that behavior of turbid water which inflows to the reservoir when floods occur is changed and the subsequence spatial distribution of sedimentation was affected. The sedimentation on downstream side (P1-P5) was dominant from 2000 to 2009 (Irie *et al.*, 2011)

2.2.Simulation model

The behavior of turbid flood inflow in the reservoir is discussed with a numerical simulation model. ELCOM (Estuary and Lake Computer Model) developed by the Centre for Water Research at The University of Western Australia (Hodges, 2000) is a three-dimensional hydrodynamic model used for predicting the velocity, temperature and salinity distribution in natural water bodies subjected to external environmental forcing such as wind stress, surface heating or

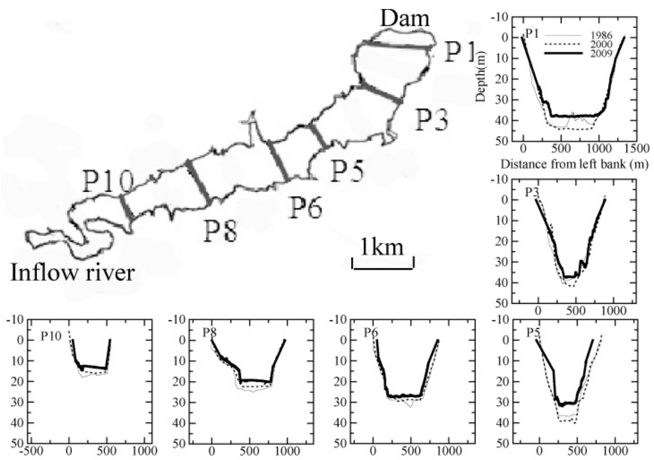

Fig. 1. Comparison of the cross sections of Joumine dam between 1986, 2000 and 2009.

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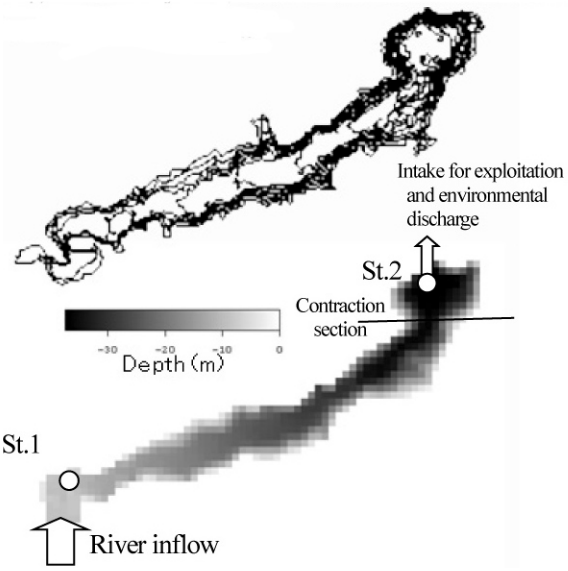

Fig. 2. Gridding of bathymetry data for simulation.

cooling. The bathymetry of Joumine dam is formed with a Cartesian 3-dimentional grid.

The above contour map is converted to the raster grid map with 100 m × 100 m square cells for running the numerical simulation model. The number of cells is V 40 × H 66.

2.3. Period for the numerical experiment

For the numerical simulation, the actual river inflow which was calculated from the record of water level fluctuation and water exploitation (outflow) of the dam was used as the boundary condition of inflow. The selected period was the beginning of 2010. **Figure 3** is the water level fluctuation of the dam and the inflow time series calculated from water level and water exploitation. This period is the water level rising phase in the rainy season in this area, especially in 2010, the water level reached to the maximum water level of the dam. Regarding thermal stratification due to the solar radiation, this period is transition phase from mixed cold single layer to development phase of stratification. Thus, the three floods shown in the time series of inflow might have different behavior depending on the stratification condition. In the model calculations, the three kinds of traces are released from inflow in the discharge increasing phase in order to evaluate the behavior of the flood water shown in Figure 3. The intensity of the tracers at the beginning of inflow is 1(dimensionless relative number) and keeps constant for 1-2 days. These experimental tracers are transferred with mixing and dispersion and draw the movement of the turbid water.

2.4. Assumption for simulation model application

The simulation model considers buoyancy effects of the difference of density as defined by temperature and salinity. Suspended solids are also one of the causes of density

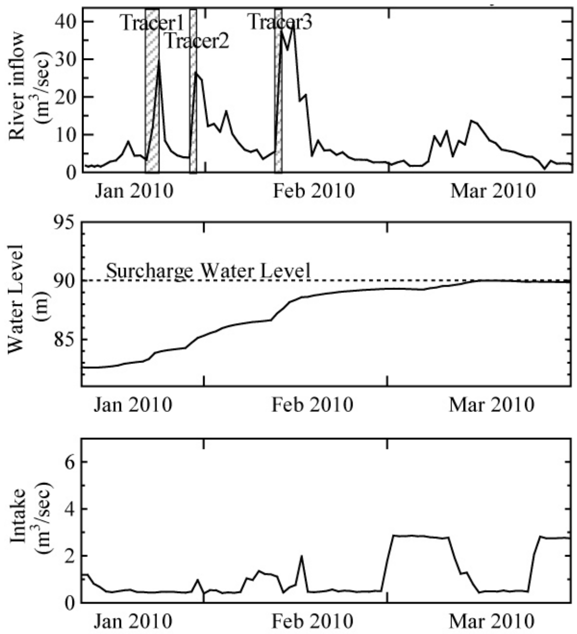

Fig. 3. Time series of water level, inflow rate and intake during the study period

differences especially in the flooding term, but this model doesn't include the effect of suspended solid. In this study, the salinity takes the place of the suspended solid for describing the difference of the density in the simulation model.

The density of turbid water is described as follows:

$$\rho = \rho_f \left[1 + \frac{c}{1000} \left(\frac{1}{\rho_f} - \frac{1}{\rho_s} \right) \right] \quad (1)$$

ρ_f (Mg/m^3): Density of water, ρ_s (Mg/m^3): Density of solid matter, c: Suspended solid (‰). Here it is assumed that the density of water and solid matter is 1.0 and 2.68 Mg/m^3 respectively. The density of saline water at t = 0°C is described as follows.

$$\rho = 1 + \sigma_0$$
$$= 1 - 0.069 + 1.4708Cl - 0.001570\,Cl^2 + 0.0000398Cl^3 \quad (2)$$

$$S = 0.030 + 1.805\,Cl \quad (3)$$

Where S is salinity (‰) and *Cl* is chloride concentration (‰). Calculating those equations and eliminating small factors (squared and cubed term in(3)), the equivalent salinity to the suspended solid density is described as follows.

$$S = 0.758c \quad (4)$$

The actual salinity of the inflow and the water body of the reservoir is almost the same, but the salinity concentration which is equivalent to the density of turbid river water is given for the flood inflow in this simulation.

The suspended solid and temperature of inflow have not been observed in the field. The temporal fluctuation of

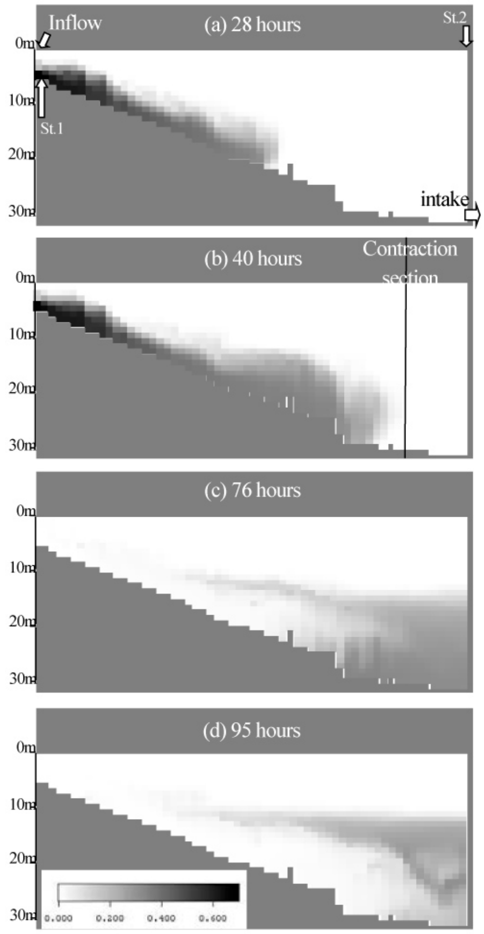

Fig. 4. Behavior of Tracer 3 seen on Lateral cross section along the deepest line of the reservoir. (a) 28hr, (b) 40hr, (c) 76hr, (d) 95hr from the start of flood. Inflow density and intake condition is A. a. of Table.1

salinity concentration which is given instead of suspended solid for describing the density difference in the model is based on the simple assumption that suspended solid is direct proportional to the inflow rate. Temperature of the inflow is given as the same as the air temperature which is measured at Beja city located in the catchment area of the inflow river and the distance between these two sites is about 40 km. The meteorological data of Beja are used for the simulation.

In this study, the dependency of the behavior of flood water on inflow density is discussed with the comparative experiment. The different cases of inflow density are prepared. **Figure 4** shows the standard time series of inflow salinity concentration. This series is equivalent to the turbidity level which is around 4000 ppm at the peak of the flood. Based on this standard time series of suspended solid, the cases of inflow conditions which are relative concentration of 0.75, 0.50 and 0.25 than the standard time series were prepared.

The other aim of this study is to determine the influence of the intake at the dam body on suspended solid transportation. Therefore, the different intake conditions were examined.

Table 1. Simulation cases of inflow density and intake rate.

Conc.	Relative Concentration	Intake	Intake rate (m^3/sec)
A	1	a	Actual intake (ave. 1.72)
B	0.75	b	2.5
C	0.5	c	5.0
D	0.25	d	10.0

Actual time series of the intake that of the average is 1.72 m^3/sec is shown in Figure 3. For the numerical experiment, the conditions of constant intake, 2.5 m^3/sec, 5 m^3/sec and 10 m^3/sec are also examined. The cases of the condition are shown in **Table 1**.

3. Results and Discussion

3.1. Outline of behavior of turbid flood water

Figure 4 shows the snap shots of the distribution of Tracer 3 released from the inflow river while the increasing phase of the inflow of the 3rd flood in the study period, in the case of A. a. of Table 1. It could be found that panel (a) the flood water inflows along the bottom. The thickness of the density low layer is around 6-8 m. In the reservoir, there is contraction narrow section. Panel (b) shows that the narrow point dams the density flow and thickness of the density flow is increased. After reaching the dam body, the water is reflected, found in panel (c) and raised up to the interface and reversed to the middle along it, shown as panel (d).

3.2. Dependency of behavior on inflow density

In order to evaluate the dependency of the turbid water behavior on the densities, the vertical profiles of different concentration conditions are compared in **Figure 5**. The effect of the difference looks not so strong except the case of Conc. D (0.25). This lowest concentration case has a weak interface effect of the density difference and diffusion and mixing vertically. In addition, the current of the bottom density flow is significantly slower than the others. The density flow doesn't reach at (iii). The difference of the density between pure water and the peak density of the Case (Conc. D) is estimated by the equation (1) as 4.66×10^{-4} Mg/m^3 at the peak. On the other hand, the difference of temperature between inflow water and water body in this season is around 2°C. It makes around 2.00×10^{-4} Mg/m^3 of density difference while there is the thermal difference of 10°C between the surface layer and the bottom layer of the stratification in summer season, which makes around 2.00×10^{-3} Mg/m^3 of density difference. Thermal stratification in summer makes significant relative buoyancy and river inflow intrude the interlayer of the thermal stratification. Comparing

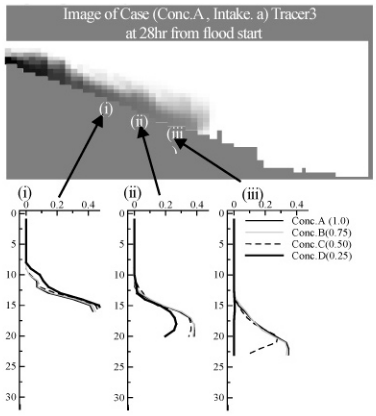

Fig. 5. Vertical profiles of the bottom density flow for the comparison of the bottom density flow behavior.

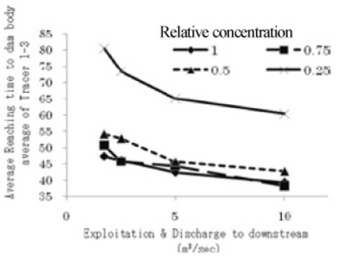

Fig. 6. Traveling time of flood water from St. 1 to St. 2.

with that situation, the relative buoyancy due to thermal difference in winter is not so strong and the density difference originated from suspended solid is dominant. If the difference of the density is less than 1.00×10^{-3} Mg/m^3, the interface effect of the density difference is degraded and the diffusion of the turbid flood water on the bottom slope of this reservoir might be developed gradually.

3.3. Effect of intake condition

Figure 6 shows the change of the reaching time of flood water from St.1 to St.2. The reaching time is measured by the traveling time of the tracers. The timings when the relative concentration of the tracers rises at the bottom of each point are observed in the simulation and its difference of the time at each point indicates the traveling time of the flood water.

As mentioned in 3.2., the case of Conc. D shows the different level of the interface strength, so that the traveling time is significantly longer than the others. However, in every case, the reduction of traveling time of around 12 hours (equivalent to 20-30% of the traveling time under actual intake) is found in the case of Intake. d (10 m^3/sec). With the consideration of average particle size of the sediment (Irie *et al.*, 2011), the precipitation rate of the sediment particle is around 12 hours/m depth at the same level as the reduced traveling time. Therefore, there is the possibility that the intake increment influences the suspended solid transportation of the reservoir and enhances the sedimentation on the lower side.

In addition, there is a possibility of another effect of intake on the sediment transportation. After flooding, the turbid water remains the deepest point beside the dam body and builds the density stratified layers. As mentioned in 3.1, flood water is raised up to the interface which is produced by the preceding flood and reversed to the middle part of reservoir. On the other hand, the intake shrinks the size of the stratified lower layer. It shortens the distance of the interface and the reversed flow which might transport suspended solid. As a result, suspended solid might precipitate on the near side of the reservoir.

4. Conclusion

In this study, the overview of the turbid flood water behavior in the study site reservoir is described by the numerical simulation. It clarified the spatial and temporal scale of the bottom density flow in the reservoir. However, the detail of the suspended solid transportation cannot be discussed due to the capability of the simulation model. Based on the results, in further study, the field observation such as fixing sediment trap will be carried out and the numerical simulation including sedimentation process will be applied.

Acknowledgements

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