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Numerical Investigation on Effects of a Diversion Channel along a Meandering River Based on a 2D Model

NUMERICAL INVESTIGATION ON EFFECTS OF A DIVERSION CHANNEL ALONG A MEANDERING RIVER BASED ON A 2D MODEL

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ABSTRACT

Due to a heavy rainfall from July 15 to 24, 2006, the Sendai River basin, Japan, was severely and uniformly damaged from the upstream to the downstream areas. Around the Torai area, one of the most severely damaged areas, a diversion channel is to be constructed so that the water level of the Sendai River becomes lower for the same flood phenomenon. The reason of this project is that there is a meandering part of the Sendai River course just downstream of the Torai area, which is assumed to have encouraged rise of the water level. Therefore in this study, applying a two-dimensional numerical model, a flood simulation is conducted along the Sendai River and effects of this diversion channel are investigated. The two-dimensional numerical model used in this study is based on an inundation flow model using unstructured meshes. Lateral inflows from the 10 tributaries are also considered using a runoff analysis of the kinematic wave method. As the computational results, it is found that this diversion channel has an effect of decreasing the water level around Torai area to some extent, though there are still some problems to be revised.

Keywords: flood simulation, 2D numerical model, meandering, Sendai River

1. INTRODUCTION

From July 15 to 24, 2006, a front stagnated over Japan, and brought a heavy rainfall. Especially the Sendai River basin was severely and uniformly damaged from the upstream to the downstream areas. At four observatory stations, observed water levels of the Sendai River exceeded the design high water level. Around the Torai area, one of the most severely damaged areas, inundation water depth reached to 3m, and a diversion channel is to be constructed so that the water level of the Sendai River becomes lower for the same flood phenomenon. The reason of this project is that there is a meandering part of the Sendai River course just downstream of the Torai area, which is assumed to have encouraged rise of the water level. Therefore in this study, applying a two-dimensional numerical model, a flood simulation is conducted along the Sendai River and effects of this diversion channel are investigated.

2. NUMERICAL MODEL

In this study, numerical simulation of flood flow is carried out. The two-dimensional numerical model used in this study is based on an inundation flow model using unstructured meshes (Kawaike et al., 2004), which consists of river channel of the Sendai River and neighboring flood prone areas such as the Torai area. The governing equations are two-dimensional shallow water equations including horizontal friction terms as follows.

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \tag{1}$$

$$\frac{\partial M}{\partial t}+\frac{\partial (uM)}{\partial x}+\frac{\partial (vM)}{\partial y}=-gh\frac{\partial H}{\partial x}+\varepsilon\left(\frac{\partial^2 M}{\partial x^2}+\frac{\partial^2 M}{\partial y^2}\right)-\frac{gn^2 M\sqrt{u^2+v^2}}{h^{4/3}} \tag{2}$$

$$\frac{\partial N}{\partial t}+\frac{\partial (uN)}{\partial x}+\frac{\partial (vN)}{\partial y}=-gh\frac{\partial H}{\partial y}+\varepsilon\left(\frac{\partial^2 N}{\partial x^2}+\frac{\partial^2 N}{\partial y^2}\right)-\frac{gn^2 N\sqrt{u^2+v^2}}{h^{4/3}} \tag{3}$$

where h is water depth, u and v are flow velocity in x and y directions, respectively, M and N are flow discharge flux in x and y directions, respectively, H is water level, ε is eddy viscosity coefficient, n is Manning's roughness coefficient and g is gravitational acceleration. ε is expressed according to the following equation.

$$\varepsilon=\frac{\kappa u_* h}{6} \tag{4}$$

where κ is Karman coefficient and u_* is friction velocity expressed as the following equation.

$$u_*^2=ghi_e=\frac{gn^2\left(u^2+v^2\right)}{h^{1/3}} \tag{5}$$

where i_e is energy slope.

3. COMPUTATIONAL CONDITIONS

There are two computational cases; one is the case that the reproduction of the flood phenomenon at the disaster of 2006 is tried not considering the diversion channel; another one is that the diversion channel is considered and its effects are investigated using the same conditions as those of the previous case.

3.1 2D Flood Flow

The length of the Sendai River, which the computational model is applied to, is 15.8km from Yuda (41.8km from the river mouth) to Kuranobashi (26.0km from the river mouth) shown in Figure 1. The study area is divided into 16,926 unstructured meshes for computation. Figure 2 shows the elevation of those computational meshes, which is made from topographical data of river cross sections at every 200m and topographical maps of this area. Those computational meshes are classified into 3 categories; low water channel, high water channel and flood-prone area as shown in Figure 3, and their roughness coefficient are 0.025, 0.035 and 0.060, respectively, according to Watanabe, et al. (2002).

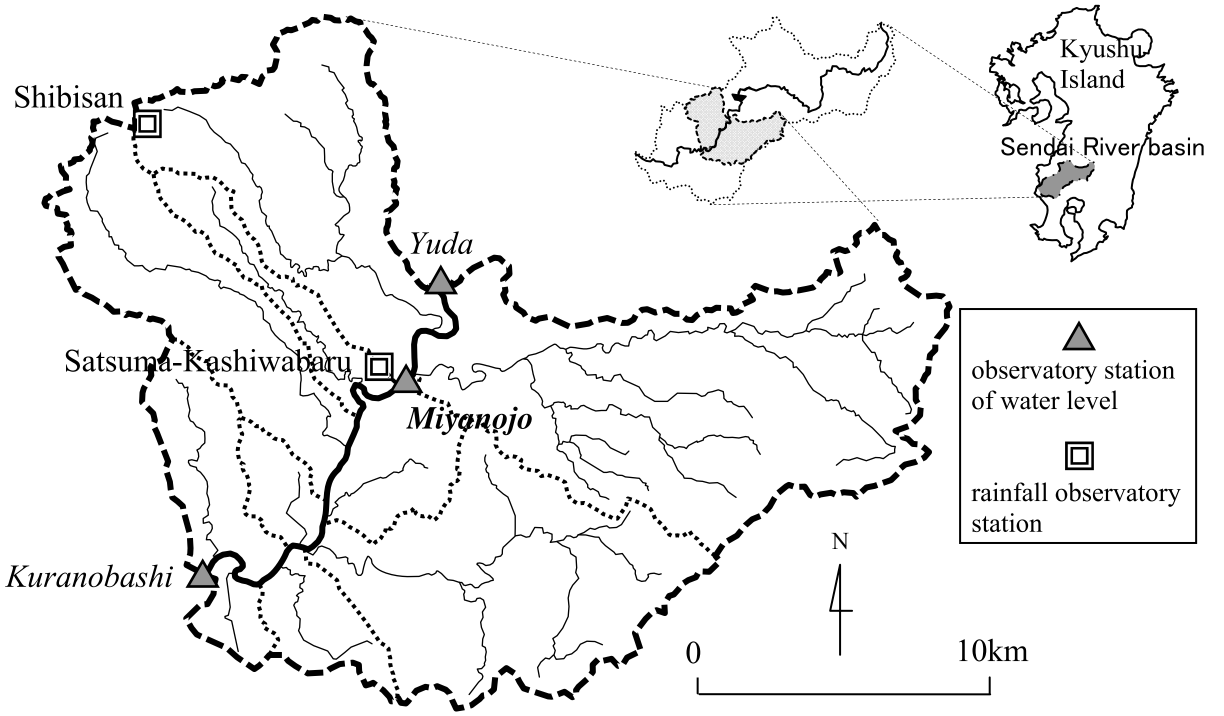


Figure 1 Study area of the Sendai River basin

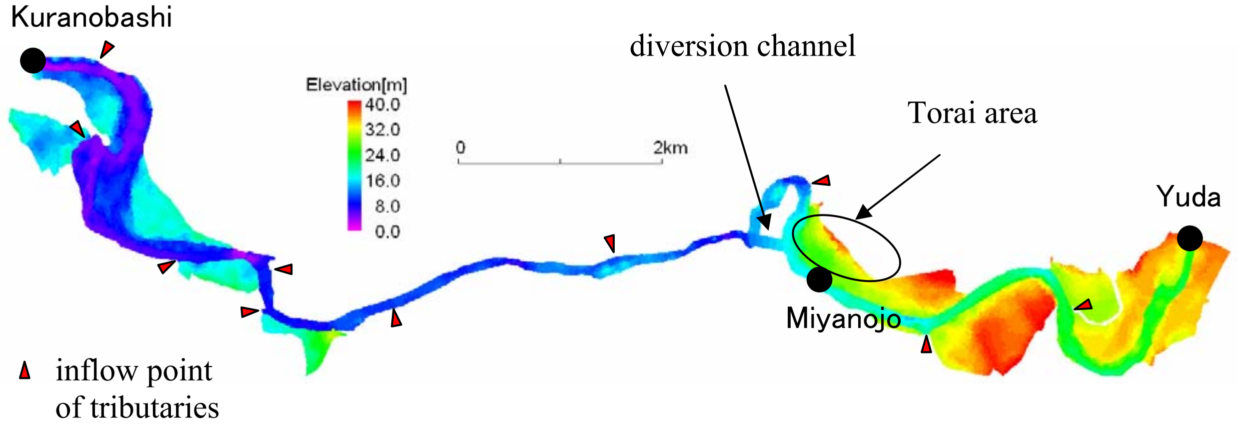


Figure 2 Elevation of the computational meshes

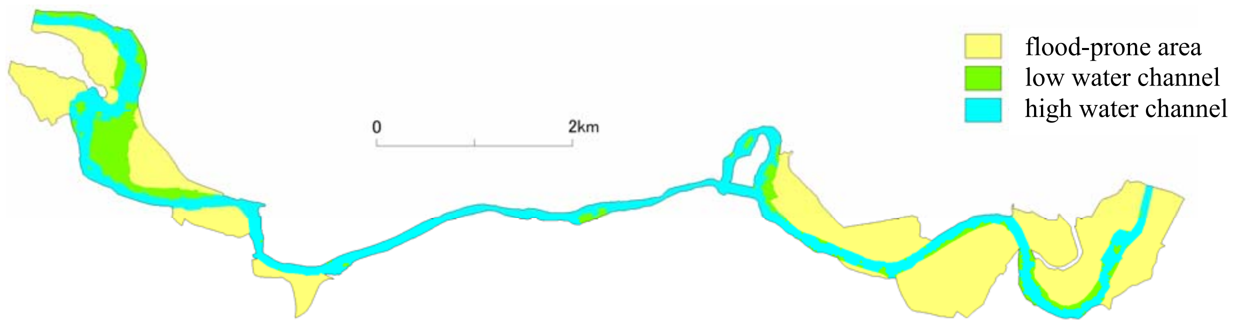


Figure 3 Categories of the computational meshes

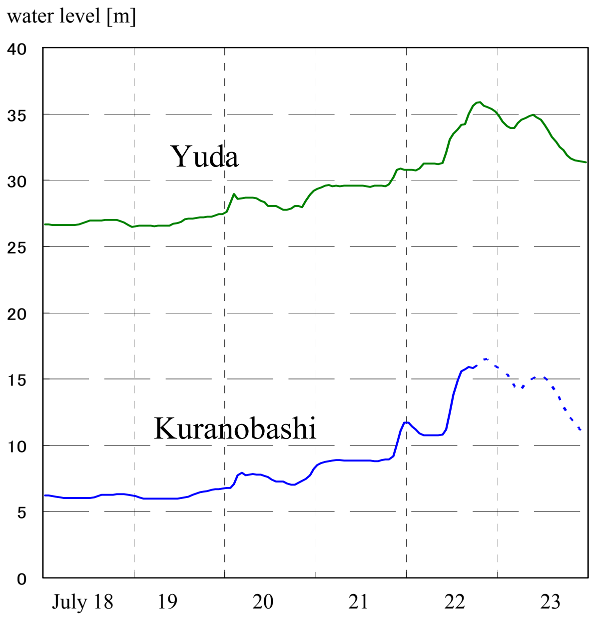


Figure 4 Observed water levels at Yuda and Kuranobashi

3.2 Upstream and Downstream Boundary Conditions

Figure 4 shows the observed water levels at Yuda and Kuranobashi used as the boundary conditions of river flow. At the downstream end, temporal change of the water level observed at Kuranobashi is used. After 21:00 of July 22, the observation had some trouble and water level data is not obtained, so some hypothetical water level is interposed as shown in Figure 4 as dashed line. And at the upstream end, a hydrograph of flow discharge is given, which was detected so that the observed water level at Yuda shown in Figure 4 can be reproduced.

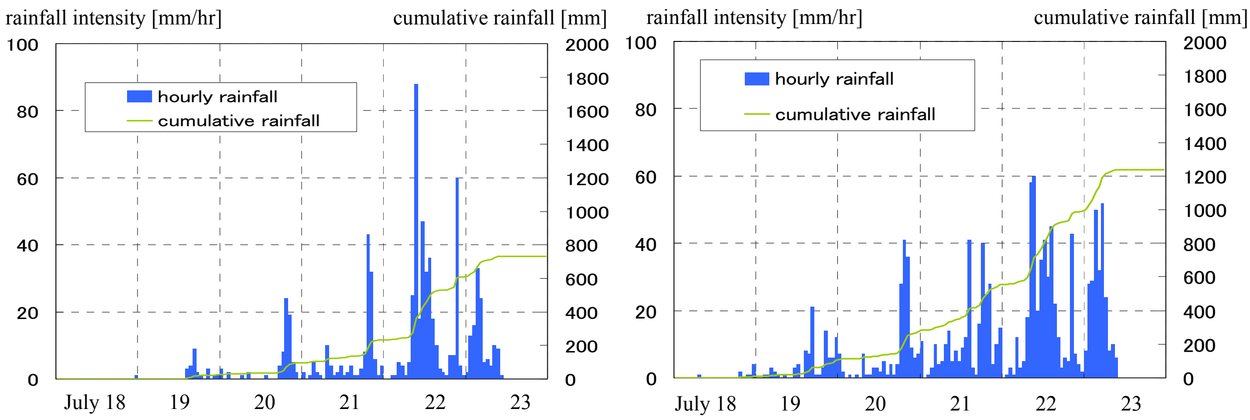
3.3 Inflow Discharge from Tributaries

The runoff discharge from tributaries affected much upon water level rise around the Trai area. Therefore lateral inflows from the 10 tributaries shown in Figure 1 are also considered using a runoff analysis of the kinematic wave method. The rain fall intensity observed at two observatory stations, Shibisan and Satsuma-Kashiwabaru, shown in Figure 5, is used for runoff analysis of the 10 tributaries. In the five tributary basins on the left side of the Sendai River, the rainfall intensity observed at Satsuma-Kashiwabaru is uniformly given, and in the five tributary basins on the right side, the rainfall intensity averaged from two observatory stations is given. Runoff analysis is carried out based on the kinematic wave method, and the obtained runoff discharge from each tributary basin area is inserted at inflow points shown in Figure 2.

4. RESULTS AND DISCUSSIONS

4.1 Reproduction of Flood Flow at the Disaster of 2006

In the case of reproduction of flood flow at the disaster of 2006, effects of the diversion channel are not considered, i.e. the elevation of computational meshes at the



(a) Satsuma-Kashiwabaru

(b) Shibisan

Figure 5 Rainfall intensity used in runoff analysis

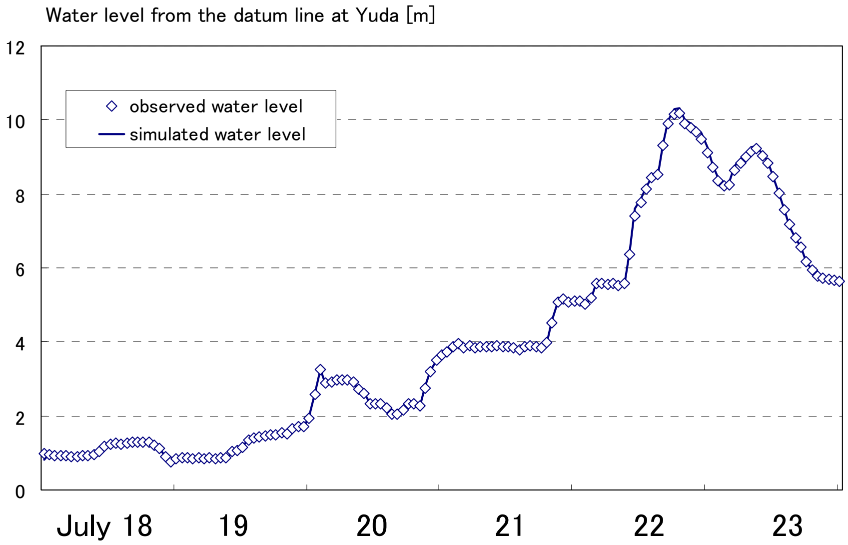


Figure 6 Comparison between observed and simulated water level at Yuda

location of the diversion channel is assumed sufficiently high. First, flow discharge at the upstream end (Yuda) must be determined. As the result of a simulation using the detected discharge described in **3.2**, the water level at the upstream end (Yuda) is reproduced as shown in Figure 6.

As the computational results, Figure 7 shows the comparison of temporal change of water level at Miyanojo (the observatory station in the vicinity of the Torai area) between the observed data and simulation results. From this figure, most part of the water level could be reproduced well by this simulation model, but the simulated water level did not always agree with the observed one. Especially around the time of peak discharge, the water level is underestimated.

4.2 Effects of the Diversion Channel

In the case considering effects of the diversion channel, the horizontal topography of computational meshes of the diversion channel is referred to the plan view map of the project,

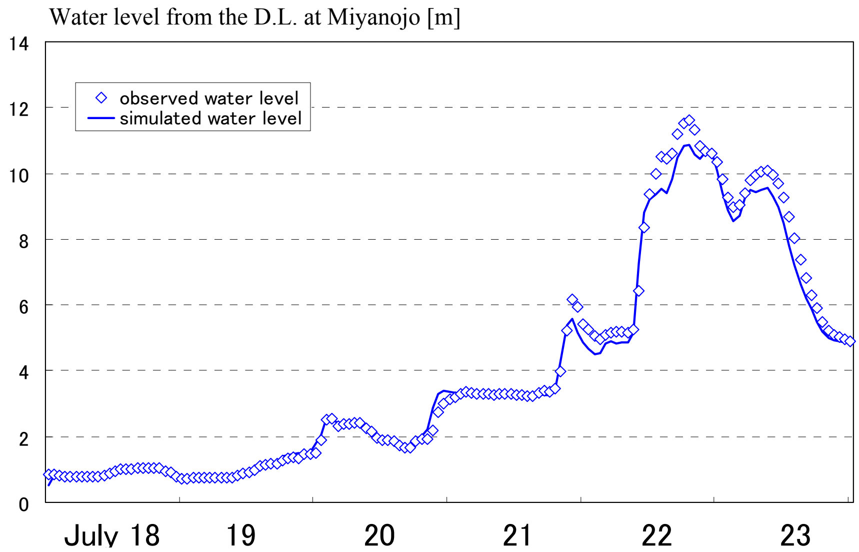


Figure 7 Comparison between observed and simulated water level

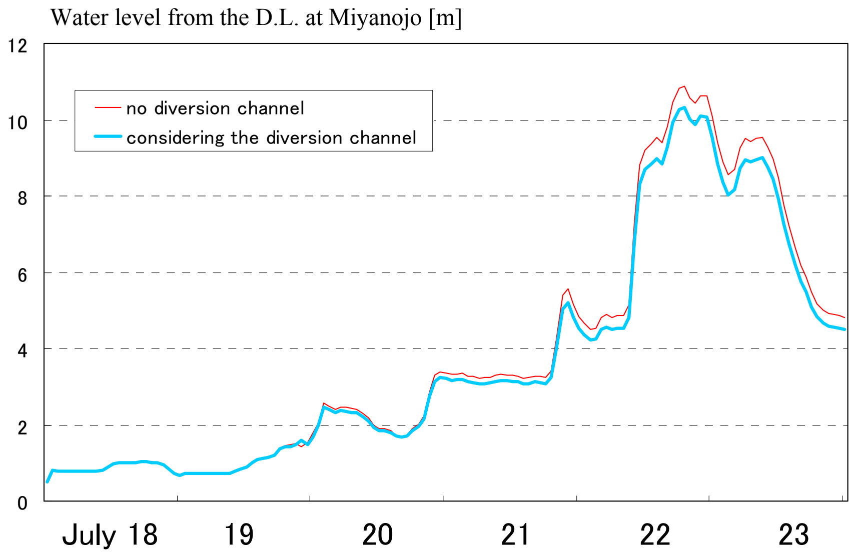


Figure 8 Water level difference at Miyanojo due to the effects of the diversion channel

and the elevation of those meshes are smoothly sloped between the elevations of upstream and downstream ends of the diversion channel. Figure 8 shows the difference of simulated water levels caused by effects of the diversion channel. The line of no diversion channel case in the figure is the results in the previous section **4.1** (shown in Figure 7). In the case considering the diversion channel, it is found that it has an effect of decreasing the water level by 0.6m at Miyanojo from this figure. Inundation damage around Torai area is also decreased according to the water level at Miyanojo, however, such small decrease of water level will not result in drastic solution to flood inundation, so dyke construction and excavation of river bed should be also necessary.

4.3 Simulation with Constant Value of Eddy Viscosity Coefficient

From Figure 7, the peak water level at Miyanojo is not well reproduced by using the model described in chapter **2**. Then the eddy viscosity coefficient is assumed to be constant,

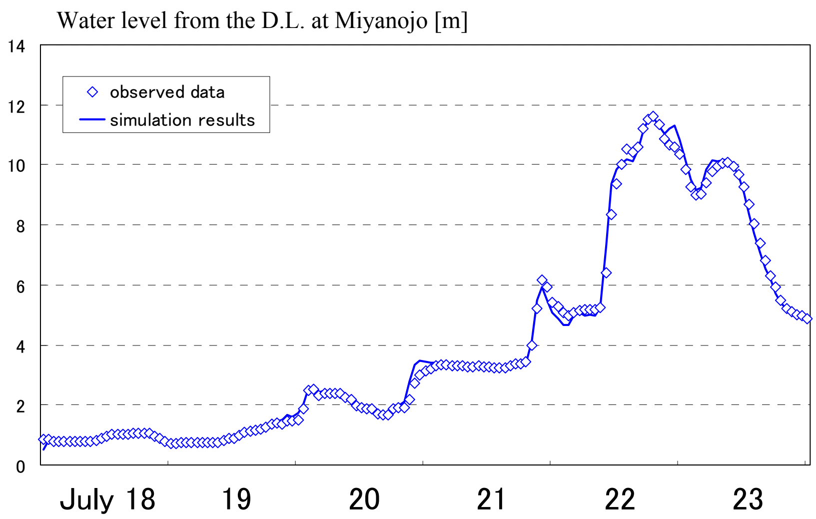


Figure 9 Comparison between observed and simulated water level ($\varepsilon = 2.0$)

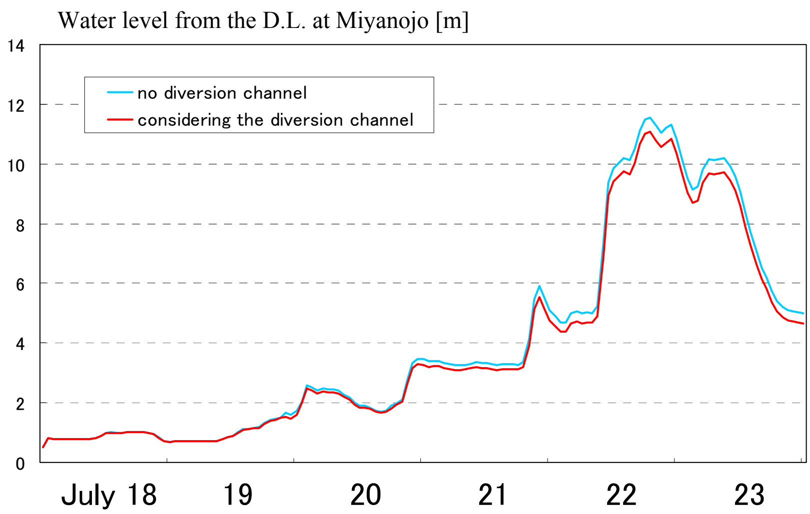


Figure 10 Water level difference at Miyanojo due to the effects of the diversion channel ($\varepsilon = 2.0$)

and its constant value is detected so that the peak water level at Miyanojo can be reproduced. From simulation results, the constant value is found to be $\varepsilon = 2.0$ [m^2/s], which will give the good agreement between the water levels of simulation results and observed data. Figure 9 shows the comparison of the water level at Miyanojo between simulation results and observed data when $\varepsilon = 2.0$. Furthermore, Figure 10 shows the difference of the water level at Miyanojo by effects of the diversion channel when $\varepsilon = 2.0$. From this figure, the maximum difference of the water level is also found to be 0.6m, which is almost the same as the result of **4.2**.

5. CONCLUSIONS

As the computational results, it is found that the planned diversion channel has an effect of decreasing the water level around Torai area to some extent, but only effects of this diversion channel is insufficient for the solution of inundation damage of this area.

In this simulation, rise of water level around Trai area is not always expressed very well. How to determine the values of parameters such as roughness of river bed and horizontal eddy viscosity coefficient would be revised in the future.

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