Conference Paper, Published Version

Kobayashi, Kenichiro; Takara, Kaoru

Comprehensive Analysis of Flooding in the Hinogawa River Catchment in Shiga, Japan

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/110139

Vorgeschlagene Zitierweise/Suggested citation:
Kobayashi, Kenichiro; Takara, Kaoru (2008): Comprehensive Analysis of Flooding in the Hinogawa River Catchment in Shiga, Japan. In: Wang, Sam S. Y. (Hg.): ICHE 2008. Proceedings of the 8th International Conference on Hydro-Science and Engineering, September 9-12, 2008, Nagoya, Japan. Nagoya: Nagoya Hydraulic Research Institute for River Basin Management.

COMPREHENSIVE ANALYSIS OF FLOODING IN THE HINOGAWA RIVER CATCHMENT IN SHIGA, JAPAN

Kenichiro Kobayashi[1]and Kaoru Takara[2]

[1] Assistant Professor, Institute of Sustainability Science, Kyoto University
Gokasho, Uji, Kyoto, 611-0011, Japan, e-mail: kobayashi.kenichiro@iss.iae.kyoto-u.ac.jp
[2] Professor, Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto, 611-0011, Japan, e-mail: takara@flood.dpri.kyoto-u.ac.jp

ABSTRACT

The Hinogawa river flows in southeastward of Shiga Prefecture, Japan. The middle to downstream region of the Hinogawa river has experienced heavy flood disasters several times in the past. Ryuou town is located in this flood disaster prone area. Thus, the town is, in general, eager to enhance the preparedness against flood disasters. To be a help for the town to realize the community-based flood management, the rainfall-runoff simulation in the catchment with the Hinogawa dam operational rule as well as the flood and inland-water inundation simulation focusing on Ryuou town are carried out. These results are to be used as the basic information in the future for the risk communication by showing them to the town people. The simulation results clarified that (1) the Hinogawa dam, although it is one of the smallest scale dams in Shiga, has a certain effect to mitigate the peak discharge in the river and the inundation area, (2) the dike-break induces a few times larger inundation than without the dike-break and (3) the inland-water causes severalfold more inundation than without the inland-water.

Keywords: the Hinogawa river, Ryuou Town, distributed rainfall-runoff model, flood and inland-water inundation

1. INTRODUCTION

The Hinogawa river is located in southeastward of Shiga Prefecture, Japan (Figure 1). The river starts from Watamukiyama mountain in Suzuka range, flows through three cities (Omi-hachiman, Higashi-omi, Yasu) and two towns (Hino, Ryuou) and ultimately reaches to Lake Biwa. The catchment size is 207.1 km^2 and its main channel length is 42.2 km. The middle to downstream region of the Hinogawa river is flood disaster prone because the river is ceiling river due to the land features and the result of the river improvement works. There is the Hinogawa dam at the upstream for the flood defence and water utilization.

Figure 2 shows Ryuou Town located in the Hinogawa river catchment. The area is approx. 44.52 km^2 and the population is 13674 (as of March 1, 2008). The main part of the town is surrounded by the Hinogawa river, Kagamiyama mountain in the west, Yukinoyama mountain in the east and hilly terrain in the south. Especially northern part of the town was damaged several times by flood disasters in the past.

To address the flood issues in the region, the physically-based distributed rainfall-runoff model with the Hinogawa dam function; and flood and inland water inundation model are developed. The risk assessment under different scenarios (e.g. 20-, 30-, 50-, 70-year rainfalls, with/without the dam, with/without the dike-break) is carried out using the models.

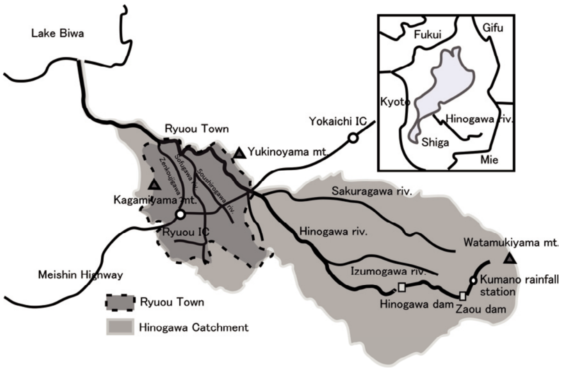

Figure 1 The Hinogawa river catchment

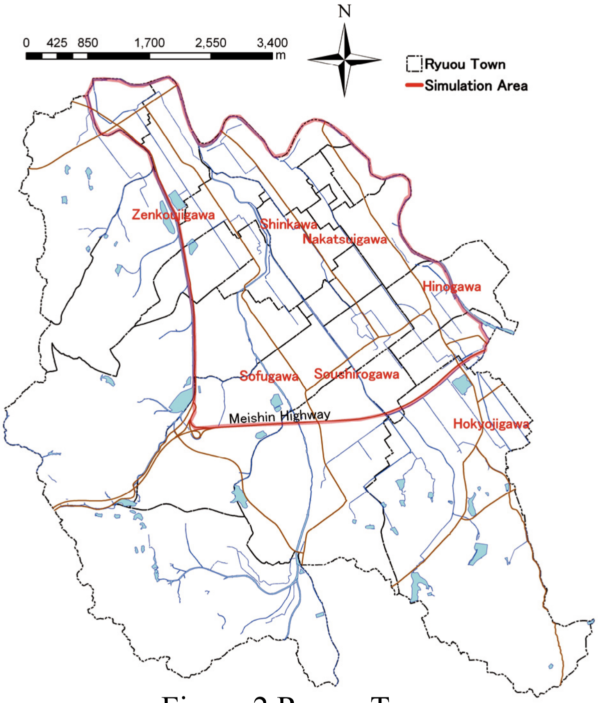

Figure 2 Ryuou Town

2. RAINFALL ANALYSIS

The return period of the daily rainfall in the Hinogawa river catchment is determined using the rainfall data for 42 years at the Kumano rainfall station (see Figure 1). Suimon-Tokei utility is used for the purpose (JICE, 2008). The result by Iwai method which showed the minimum SLSC among 8 different probability distributions is adopted. According to this, the 50-year daily rainfall, corresponding to the design rainfall level, is 491 mm. 10-, 20-, 30-, 70-year daily rainfalls are 258, 313, 347, 420 mm respectively. These values are used for the rainfall-runoff; and flood and inland-water inundation simulations.

3. HYDROLOGIC MODEL

A physically-based distributed rainfall-runoff model with the Hinogawa dam operational rule is constructed for the rainfall-runoff simulation. OHyMoS (Object-oriented Hydrological Modelling System; e.g. Ichikawa et al., 2001) is used for the model construction. The modelling of the Hinogawa catchment topography, the distributed rainfall-runoff model and the dam model are explained one by one in the following.

3.1 Topography Modelling

The procedure of the topography modelling is briefly summarized as follows: (1) The river network is expressed by the discrete dot sequence data obtained from Japan's digital national land information (river channel position file KS-272, river unit catchment ledger KS-271). (2) The coordinates of the dot sequence data are adjusted, using the digital elevation model (DEM) published by Geographical Survey Institute, Japan such that the coordinate is moved to the corresponding location of the DEM grid. (3) The slope element which belongs to each river segment and the flow direction over the slope is determined using the elevation of the grid. The flow direction is taken to the direction of the maximum grade calculated with the 8 points surrounding the flow origin and the origin point. Following this procedure, the topography of the Hinogawa river catchment is modelled at 250 m resolution.

3.2 Distributed rainfall-runoff model

The distributed rainfall-runoff model herein is constructed based on the kinematic wave theory of the river and slope flow.

(1) Slope flow

The governing equation of the slope flow is expressed as:

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=r(t) \tag{1}$$

where t is the time, x the distance from the top end of the slope, h the water depth, q the discharge per unit width over the slope, $r(t)$ the rainfall. Tachikawa's equation (2004) is used for the stage-discharge relation (see Figure 3).

$$q(h)=\begin{cases} v_m d_m\left(\dfrac{h}{d_m}\right)^{\beta}, & (0\le h\le d_m) \\ v_m d_m+v_a(h-d_m), & (d_m<h\le d_s) \\ v_m d_m+v_a(h-d_m)+\alpha(h-d_s)^{\frac{5}{3}}, & (d_s<h) \end{cases} \tag{2}$$

where D is the soil thickness, $d_a(=d_s-d_m)$ the thickness equivalent to the gravity flow zone, d_m the thickness equivalent to the capillary flow zone. $v_m=k_m i$, $v_a=k_a i$, $\alpha=\sqrt{i}/N_{slope}$, where v_m is the capillary flow velocity, k_m the hydraulic conductivity of the capillary flow, i the slope gradient, v_a the gravity flow velocity, k_a the hydraulic conductivity of the gravity flow, N_{slope} the equivalent roughness coefficient of the slope. The continuity condition for the stage-discharge relation yields $\beta k_m=k_a$ ($2\le\beta\le 6$). After

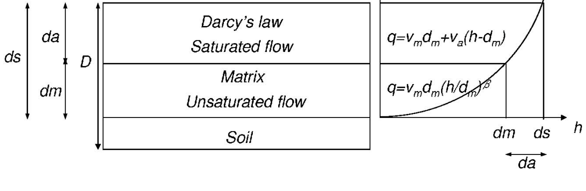

Figure 3 Stage-discharge relationship (Tachikawa et al., 2004)

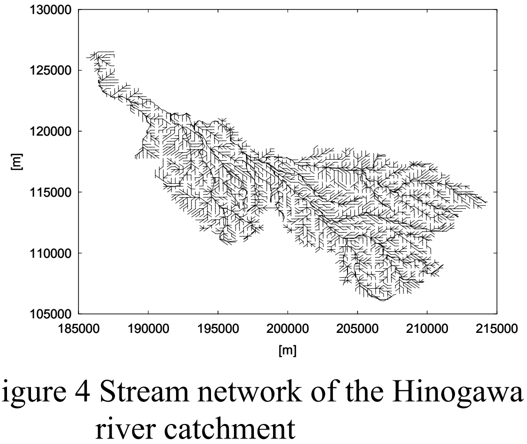

Figure 4 Stream network of the Hinogawa river catchment

all, D, d_a, d_m, k_a, N_{slope}, β are the parameters to be estimated.

(2) River flow

The governing equation of the river flow is expressed as:

$$\frac{\partial W}{\partial t}+\frac{\partial Q}{\partial x}=q(t) \tag{3}$$

where t is the time, x the distance from the top end of the river segment, W the flow area in the river channel, Q the river discharge, $q(t)$ the lateral inflow per unit length from the slope to the river channel. Provided that the stage-discharge relation follows the Manning's law, then we get

$$Q=\frac{WR^{\frac{2}{3}}I^{\frac{1}{2}}}{N_{river}} \tag{4}$$

where N_{river} is the equivalent roughness coefficient of the river channel, R the hydraulic radius, I the riverbed gradient. We substitute $R=K_1W^Z$ (K_1 and Z are constants) into Eq. (4) and with Eq. (3), we calculate Q by the Lax-Wendroff finite difference method. Here, N_{river} is the parameter to be estimated.

3.3 Dam Model

The Hinogawa dam is one of the smallest scale dams in Shiga, thus it is regarded that the flood defence capability is not so high. As we, in this paper, handles the rainfall event for one day, the pre-release from the dam based on the mid to long term weather prediction is not modelled this time (Ichikawa et al., 1999; Sayama et al., 2004). Instead, the water stage is initially set to the pre-release water stage (EL. 204 m). This approximately follows three real instances of the dam operation taken place in the past (Aug. 1971, Typhoon 23; Sep. 1972, Typhoon 20; Sep. 1990, Typhoon 19). The modelled dam operational rule is as follows: (1) Until the inflow from the upstream of the dam reaches the previously-defined flood discharge 160 m^3/s, the dam releases the amount equals to the inflow. (2) When the inflow exceeds the flood discharge 160 m^3/s , the dam releases 160 m^3/s constantly unless the water stage reaches to EL. 208.2 m. (3) When the water stage exceeds EL. 208.2 m, the dam starts the so-called Tadashigaki operation. In this case, the dam release the amount equals to the inflow. Only these three operational rules are modelled this time.

3.4 Parameter estimation and model validation

Figure 4 shows the stream network of the Hinogawa river catchment modelled (The origin of the coordinate system is where the latitude 34^o north and longitude 134^o east is converted into the point of the UTM coordinate system). The parameter identification of the distributed rainfall-runoff model and the validation of the dam model are carried out using the rainfall intensity (Figure 5), the observed inflow and outflow at the Hinogawa dam during the rainfall event of Sep. 1990 by Typhoon 19. However, this will be reported some other time. The parameter estimation is done with Levenberg-Marquardt algorithm (Kobayashi et al., 2004). The estimated parameters are D=1.14 m, d_a=0.229 m, d_m=0.452 m, k_a=0.029

m/s, β=4.04, N_{slope}=0.153 m$^{-1/3}$/s, N_{river} =0.01 m$^{-1/3}$/s. These parameters are uniformly given to the Hinogawa catchment in the following simulation.

4. FLOOD AND INLAND-WATER INUNDATION MODEL

This section explains the basics of the flood and inland-water inundation model. Inoue et al. (2000) , Kawaike et al. (2003) and JSCE (2001) are referred for the model construction.

4.1 River channel flow

The river channel flow is one-dimensionally routed by the continuity equation and St. Venant equation combined with Manning's law:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q \tag{5}$$

$$\frac{1}{g}\frac{\partial u}{\partial t}+\frac{u}{g}\frac{\partial u}{\partial x}+\frac{\partial h}{\partial x}=s_0-\frac{n^2 u\,|\,u\,|}{R^{4/3}} \tag{6}$$

where t is the time, x the distance from the top end of the river segment, A the flow area in the river channel, Q the discharge in the river channel, q the lateral flow per unit length (inflow is positive) , h the water depth, g the acceleration due to the gravity, $u=Q/A$ the average velocity over the cross section, s_0 the bed slope gradient, n the Manning's roughness coefficient, R the hydraulic radius. These are solved numerically by the characteristic curve method.

4.2 Flood and inland-water inundation model

The continuity equation and momentum equations based on Shallow water equation are used for the flood and inland-water inundation. The convective term of the momentum equations is omitted for the reduction of the computational time.

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=Q_{in} \tag{7}$$

$$\frac{\partial M}{\partial t}=-gh\frac{\partial H}{\partial x}-gn^2 u\frac{\sqrt{u^2+v^2}}{h^{1/3}} \tag{8}$$

$$\frac{\partial N}{\partial t}=-gh\frac{\partial H}{\partial y}-gn^2 v\frac{\sqrt{u^2+v^2}}{h^{1/3}} \tag{9}$$

where t is the time, h the water depth, H the water stage, Q_{in} the discharge over the dike. $M=uh$, $N=vh$ are the discharge fluxes in the x- and y-direction where u, v are the velocities in the x- and y-direction. To obtain the numerical solution, h, M, N are positioned on the staggered grid, and explicit scheme Leap frog method is used for the time differentiation.

4.3 Simulation condition for the river flow routing

Figure 2 shows 6 rivers modelled for the 1D river flow routing (i.e. the Hinogawa, Zenkoujigawa, Soushirogawa, Sofugawa, Shinkawa and Nakatsuigawa river). Due to lack of adequate information, the river cross section is represented by rectangle at around 100 m interval. The width of the rivers is read from the Ryuou Town map with a scale of 1 to 2500 (Hinogawa, 112.5 m; Zenkoujigawa, 20 m; Sofugawa, 20 m; Soushirogawa, 10 m; Shinkawa, 5 m; Nakatsuigawa, 5 m). The elevation of the river bed is analogically estimated from the surrounding land elevation. The height from the river bed to the bank crown is, for each river, set as: Hinogawa, 7m; Zenkoujigawa and Sofugawa, 5m; Soushirogawa, 4 m; Shinkawa and Nakatsuigawa, 3m. The discharge hydrograph calculated by the distributed rainfall-runoff model is used as the upstream boundary condition of the 1D river flow routing for the Hinogawa, Zenkouji, Soushiro and Sofugawa river. The Shinkawa and Nakatsuigawa rivers are relatively small and not modelled by the distributed rainfall-runoff model. Thus, small discharge is given at the upstream instead. The free flow boundary condition is given on the downstream boundary of the Hinogawa river.

4.4 Simulation condition for the flood and inland-water inundation

The computational domain is discretized with the square grid cells of 100 m side. The total number of the grid cells is 2958. The elevation of the land as well as Manning's coefficient according to the land use are given on the node of the grid cell (paddy and crop field, 0.025 $m^{-1/3}/s$; building land, 0.040 $m^{-1/3}/s$; mountain terrain, 0.060 $m^{-1/3}/s$). These are digitized from the Ryuou Town map with a scale of 1 to 2500. The computational area is limited to the area surrounded by the Hinogawa river, the Zenkoujigawa river and Meishin Highway which are regarded as water divides.

4.5 Discharge over the dike

The discharge of the bank overtopping is determined by the equation (JSCE, 1985).

$$Q_{in} = L\mu h_{in}\sqrt{2gh_{in}} \tag{10}$$

where $h_{in} = h_{river} - H_{Bank}$, h_{river} is the water depth in the river channel, H_{Bank} the height of the bank crown from the river bed, $\mu = 0.35$, L the length represented by a cross section.

The mechanism of dike-breaks is not yet perfectly known, thus how to deal with dike-breaks is a difficult problem. This time we assume as follows: The dike breaks when the bank overtopping occurs (the time lag between the bank overtopping and dike-break is not considered). Due to lack of adequate information to consider the elevation relation between the river bed, the land elevation inside the dikes and the height of the bank crown, 1/3 of the river depth (from the river bed to the bank crown) is regarded as the bank height from the corresponding land elevation inside the dyke. The discharge through the broken dike is determined also by Eq. (10). This time H_{Bank} is the height from the river bed to the position of the dike-break. The reverse flow from the inside of the dike to the river channel is not considered.

5 SIMULATION RESULTS

5.1 The result of the rainfall-runoff simulation

The rainfall of 19-20, Sep. 1990 by Typhoon 19 (Figure 5) is reduced or expanded

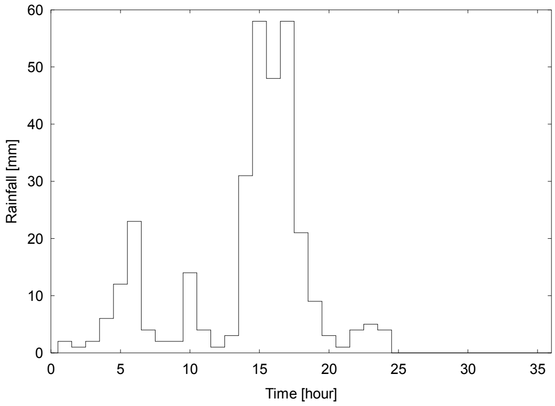

Figure 5 The rainfall evenf from 6:00 AM 19 to 18:00 PM 20, Sep. 1999

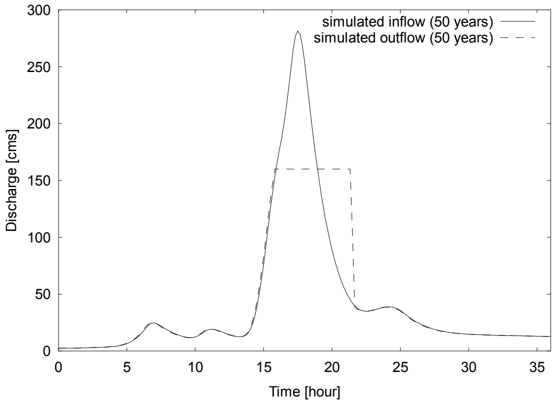

Figure 6 The simulated inflow and outflow at the Hinogawa dam by the 50-year rainfall

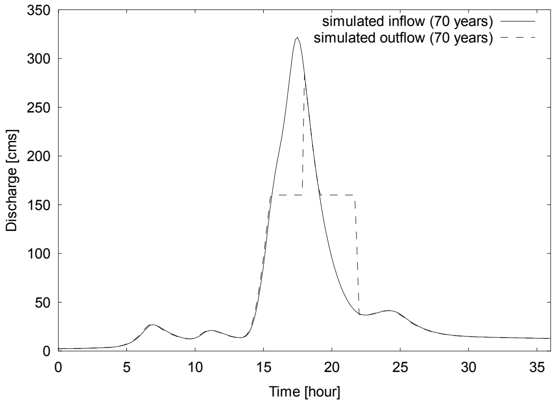

Figure 7 The simulated inflow and outflow at the Hinogawa dam by the 70-year rainfall

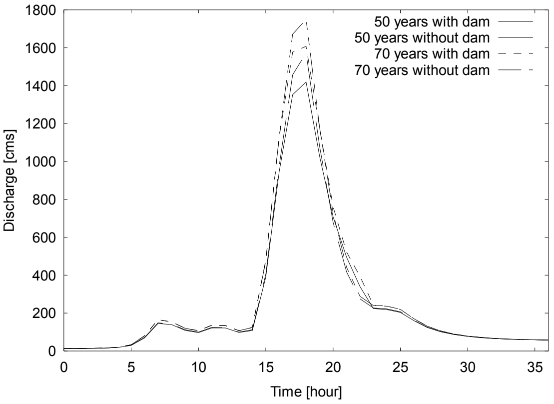

Figure 8 The simulated hydrogtraphs at the Hinogawa and Hokyojigawa river confluence

such that the total rainfall quantity becomes the amount of 20, 30, 50 and 70 year rainfalls estimated. And these reduced/expanded rainfalls are used as the input rainfalls to the distributed rainfall-runoff model. The total daily rainfall of the 1990 event is 318 mm and the return period is around 25 years.

Figures 6 and 7 show the inflow and outflow simulated by the distributed rainfall-runoff model with the Hinogawa dam function (50- and 70-year rainfalls respectively). In the simulations this time, the peak cut of the excessive inflow above 160 m^3/s is taken place for the cases of 20-, 30-, 50-year rainfalls. Regarding the 70-year rainfall, the water stage reaches to EL.208.2 m during the peak cut, thus it starts the Tadashigaki operation (see Sec. 3.3). For the 10-year rainfall, the inflow to the dam is smaller than 160 m^3/s, thus it releases directly the amount of the inflow.

In order to see the peak reduction effect by the dam at the downstream, Figure 8 shows the discharge hydrograph at the Hinogawa and Hokyojigawa river confluence (see Figure 1) with and without the Hinogawa dam. Table 1 shows the difference of the peak discharges with and without the dam regarding all the rainfall cases. The table also shows the relative size of each rainfall to the 10-year rainfall as well as the relative size of each peak discharge to the discharge by the 10-year rainfall. The relative size of the 70-year rainfall 420 mm to the 10- year rainfall 258 mm is 1.63, while the corresponding discharge with the dam is 2.07. This indicates that if the rainfall at the Hinogawa catchment increases due to e.g. the global warming, the increasing ratio of the discharge in the river channel is more than that of the

Table 1 T-year rainfalls and peak discharges according to the rainfalls

Return period [year]	70	50	30	20	10
Rainfall at Kumano [mm]	420	391	347	313	258
Relative size to the 10-year rainfall	1.63	1.51	1.34	1.21	
Peak discharge with dam[m^3/s]	1607	1420	1214	1055	775
Relative size to the 10-year discharge	2.07	1.83	1.57	1.36	
Peak discharge without dam [m^3/s]	1750	1572	1298	1088	775
Relative size to the 10-year discharge	2.26	2.03	1.66	1.40	
Difference of the peak discharges [m^3/s]	143	152	84	33	0

Table 2 Simulation scenario, the discharge over the dike, the inundation area with the water depth of more than 0.5m and the maximum water depth

Case number (Simulation Scenario; yrs=year rainfall)	Discharge [m^3]	Inundation area [km^2]	Maximum water depth [m]
Case 1 (20 yrs, bank overtopping, with dam, without inland-water)	99238	0.05	0.76
Case 2 (20 yrs, bank overtopping, without dam, without inland-water)	127790	0.11	0.75
Case 3 (20 yrs, bank overtopping, with dam, with inland-water)	99238	2.83	3.50
Case 4 (20 yrs, dike-break, with dam, without inland-water)	2879248	1.60	3.76
Case 5 (20 yrs, dike-break, with dam, with inland-water)	2879248	4.08	4.67
Case 6 (30 yrs, bank overtopping, with dam, without inland-water)	910751	0.62	2.25
Case 7 (30 yrs, bank overtopping, without dam, without inland-water)	1064423	0.68	2.32
Case 8 (30 yrs, bank overtopping, with dam, with inland-water)	910751	3.53	4.04
Case 9 (30 yrs, dike-break, with dam, without inland-water)	3651823	1.98	4.00
Case 10 (30 yrs, dike-break, with dam, with inland-water)	3651823	4.57	4.94
Case 11 (50 yrs, bank overtopping, with dam, without inland-water)	1984148	1.05	3.18
Case 12 (50 yrs, bank overtopping, without dam, without inland-water)	2199528	1.17	3.25
Case 13 (50 yrs, bank overtopping, with dam, with inland-water)	1984148	4.25	4.60
Case 14 (50 yrs, dike-break, with dam, without inland-water)	3784767	2.12	3.52
Case 15 (50 yrs, dike-break, with dam, with inland-water)	3784767	4.79	4.78
Case 16 (70 yrs, bank overtopping, with dam, without inland-water)	2782698	1.68	3.51
Case 17 (70 yrs, bank overtopping, without dam, without inland-water)	3089898	1.84	3.62
Case 18 (70 yrs, bank overtopping, with dam, with inland-water)	2782698	4.62	4.92
Case 19 (70 yrs, dike-break, with dam, without inland-water)	8404433	3.87	5.01
Case 20 (70 yrs, dike-break, with dam, with inland-water)	8404433	5.60	6.82

rainfall.

Looking at the differences of the peak discharges with and without the dam, the peak is reduced most at the case of the 50-year rainfall. This is around 153 m^3/s. About the 70-year rainfall, the peak reduction is adversely reduced because it reaches to the Tadagashigaki opearation. The peak reduction is around 142 m^3/s. As mentioned, the Hingoawa dam is one of the smallest scale dams in Shiga, thus the peak reduction capability have a limitation. However it shows a certain effect in the flood defence.

5.2 The result of the flood inundation simulation

Table 2 shows the scenarios for the flood inundation simulation (Case 1 to Case 20）. Figure 9 shows, as the representative cases, the results of the flood inundation simulation by

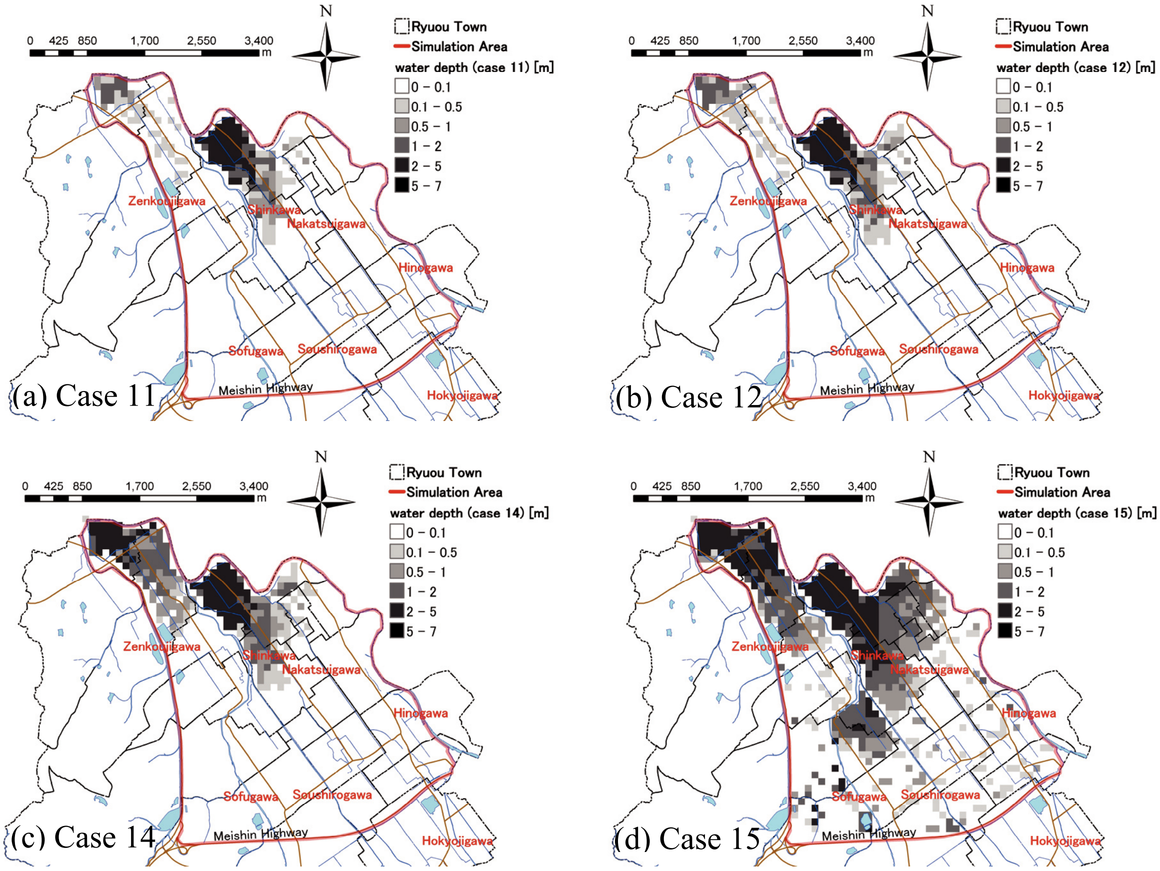

Figure 9 Results of the inundation simulation: (a) Case 11, after 21.4 hrs; (b) Case 12, after 21.3 hrs; (c) Case 14, after 22.2 hrs; and (d) Case 15, after 36.0 hrs

the 50-year rainfall (Case 11, 12, 14 and 15). The Case 15 simulation finishes after 36 hours (the rainfall event end time), while other cases do at the overtopping end time (irrespective of dike-break). Table 2 also shows the discharge over the dike, the inundated area with the inundation depth of more than 0.5 m and the maximum water depth at the simulation end.

Apparently, the water depth and the inundation area become maximum when both the inland-water and dike-break are considered (Case 5, 10, 15 and 20). Looking at the results of Case 11 and 15, the inundation area are 1.05 km^2 and 4.79 km^2. As both results are obtained by the 50-year rainfall, it may bring some misunderstainding to the hazard map users if they are used without notifiying the simulation condition.

To investigate the dam effect, the inundation area with and without the dam (without the dike-break and inland-water) are compared for all the cases (e.g. Case 11 and 12 for the 50-year rainfall). This comparison tells that, from the 20- to 70-year rainfalls, the dam reduced the inundation area by approx. 0.06, 0.06, 0.12, 0.16 km^2 . This is around 10 % reduction from the inundation area without dams. For all the discharges by the 20- to 70-year rainfalls, the ratio of the discharge over the dike without the dam to with the dam is calculated. This is around 1.11 to 1.29. On the other hand, the ratio of the peak discharge without the dam to with the dam at the Hinogawa and Hokyojigawa river confluence is around 1.03 to 1.11. In the simulation this time, the water stage in the Hinogawa river increases; and the Zenkoujigawa and Nakatsuigawa river are not able to drain the flow into the Hinogawa river. In other words, the overtopping/dike-break occurs in the tributaries due to the backwatering effect. This corresponds to the past events in the region. Therfore, it is considered that as the dam works mostly for the Hinogawa river (e.g. the peak reduction in the main stream), the reduction effect is reduced to some extent for the inundation from the tributraries.

Comparing Case 14 (50-year rainfall, with the dike-break) and Case 11 (50-year rainfall, without the dike-break), the inundation of Case 14 (2.12 km^2) is around twofold larger than that of Case 11 (1.05 km^2). As this is more for the cases by the 20-, 30- and 70-year rainfalls, we can recognize the importance to protect dikes. In the simulation, the overtopping/dike-break did not happen in the Hinogawa river. As the Hinogawa river has some records that the dike was broken, the dike-break condition will continuously be considered.

6 CONCLUDING REMARKS AND FUTURE ASPECTS

This paper shows the results of the rainfall-runoff simulation with the Hinogawa dam operational rule; and flood and inland-water inundation simulation focusing on Ryuou Town toward the community-based flood management in the region. The effect of the dam, the influences by the dike-break and the inland-water are comprehensively investigated. As the result, we identified that:

- although the Hinogawa dam is one of the smallest scale dams in Shiga, it has a certain effect in the flood defence,
- it is very important to protect dikes. The dike-break brings a few times larger inundation area according to the simulations this time,
- the inundation area becomes severalfold larger if the inland-water is considered.

We also considered the importance of clearly notifying the simulation condition when the simulation results are used in e.g. hazard maps. As the future work, the possibility of the real-time delivery of the simulation results is sought and the inquiry survey based on the results is scheduled. How to realize the community-based flood management is continuously considered.

ACKNOWLEDGMENTS

The rainfall, water-stage and discharge data are provided by the department in charge of Shiga Prefecture. The first author received supports from Emeritus Professor Kazuya Inoue of Kyoto University, Dr. Kenji Kawaike and Dr. Takahiro Sayama from the Disaster Prevention Research Institute, Kyoto University. The authors would like to thank all of them.

REFERENCES

Ichikawa, Y., Murakami, M., Tachikawa, Y. and Shiiba, M. (2001), Development of a basin runoff simulation system based on a new digital topographic model, *Journal of Hydraulic, Coastal and Environmental Engineering,* No. 691/II-57, pp. 43-52 (in Japanese).

Ichikawa, Y., Hirano, K., Shiiba, M., Tachikawa, Y. and Takara, K. (1999), 構造的モデル化法によるダム要素モデルの構築, *Proceedings of the 54th annual conference of the Japan society of civil engineers, 2* , pp. 592-593 (in Japanese).

Inoue, K., Toda, K. and Maeda, O. (2000), Inundation model in the region of river network system and its application to Mekong delta, *Annual Journal of Hydraulic Engineering*, JCSE, vol. 44, pp. 485-490 (in Japanese).

Japan Institute of Construction Engineering (2008), 水文統計ユーティリティー, http://www.kasen-keikaku.jp/suimon (in Japanese).

Japan Society of Civil Engineers (2001) , 水理公式集例題プログラム集平成 13 年度版 (in Japanese).

Japan Society of Civil Engineers (1985) , 水理公式集例題昭和 60 年版, pp. 287-288 (in Japanese).

Kawaike, K., Inoue, K., Toda, K. And Noguchi, M.(2003), Inundation flow analysis due to heavy rainfall in low-lying urbanized river basin, *Journal of Hydraulic, Coastal and Environmental Engineering,* No. 751/II-67, pp. 57-68 (in Japanese).

Kobayashi, K., Takara, K. and Tachikawa, Y. (2004), Parameter estimation of a distributed rainfall-runoff model by a Levenberg-Marquardt optimization algorithm, *Annual Journal of Hydraulic Engineering*, JCSE, vol. 51, pp. 409-414 (in Japanese).

Sayama, K., Tachikawa, Y. and Takara, K. (2004), Development of a distributed rainfall-runoff prediction system considering dams' flow regime control, *Annuals of Disas. Prev. Res. Inst.*, Kyoto Univ., No.47 B, pp. 1-16 (in Japanese).

Tachikawa. Y., Nagatani, G. and Takara, K. (2004), Development of stage-discharge relationship equation incorporating saturated-unsaturatedflow mechanism, *Annual Journal of Hydraulic Engineering*, JSCE, vol. 48, pp. 7-12 (in Japanese).