Study on Efficient Arrangement of Anti-Inundation Facilities

Etude de la disposition efficiente des installations de lutte contre les inondations

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RÉSUMÉ

Eu égard aux récents épisodes de pluies torrentielles, il est aujourd'hui devenu nécessaire au Japon, de réduire de façon efficiente les dégâts liés aux inondations et ainsi de minimiser les dégâts d'inondations en zones urbaines. La présente étude des mesures efficientes contre les dégâts des inondations est indiquée à titre d'exemple, en tant qu'étude de cas menée sur la manière efficiente de disposer des installations telles que bassins de retenue, conduites de retenue et ouvrages d'infiltration dans une zone où la capacité d'écoulement du cours d'eau est insuffisante par rapport aux précipitations de calcul.
Nous avons effectué, pour quelques cas, des simulations d'analyse de débordement en modifiant les types et les emplacements des installations dans la zone objet de l'étude pour calculer le montant des dégâts des inondations à partir de la superficie des dégâts des inondations, estimée avant et après la mise en place des installations de lutte contre les inondations, et avons comparé ensuite les rapports coût-bénéfice. Or, le résultat de cette analyse indique que la mesure la plus efficace dans cette étude de cas est l'aménagement de dispositifs d'infiltration. Par ailleurs, ce résultat indique également que, dans le cas d'aménagement de bassins de retenue, il est plus efficace de disposer plusieurs bassins en les répartissant à plusieurs endroits que de prévoir un bassin à un seul endroit.

ABSTRACT

In Japan, following recent cases of torrential rains, it is required to mitigate inundation damage in an efficient manner and minimize inundation damage in urban areas. We have conducted a case study on efficient arrangement of reservoirs, storage pipes and infiltration facilities in an area where river flowability is insufficient for design rainfall, as a case example of efficient anti-inundation measures.
We conducted flood simulation of several cases with different types and arrangements of facilities in the target area, calculated the amount of inundation damage from the areas of inundation before and after the establishment of anti-inundation facilities, and compared cost-effectiveness. The result shows that the establishment of infiltration facilities will be most effective. We have also found that dispersed arrangement of reservoirs is more effective than having a reservoir in a single location.

KEYWORDS

Cost-effectiveness, Flood simulation, Infiltration facilities, Sewerage and rivers, Simulation model

1 INTRODUCTION

In Japan, sewage systems have been almost completed in Tokyo and other major cities and the stormwater drainage facilities are at the level that can deals with 3-5 year probable rainfalls (50-70 mm/hour). However, in recent years, inundation has frequently occurred due to advancement of urbanization and increase of torrential rains in urban areas that seem to have been caused by global warming. Moreover, concentration of assets in urban areas and advancement of urban functions have increased the scale of inundation damage.

Therefore, it is required to respond to recent torrential rains, mitigate inundation damage in an efficient manner and minimize inundation damage in urban areas.

We have conducted a case study on efficient arrangement of reservoirs, storage pipes and infiltration facilities in an area where river flowability is insufficient for design rainfall (3-year probable rainfall, 50 mm/hour), as a case example of efficient anti-inundation measures.

2 STUDY METHOD

The purpose is, in an area where river flowability is insufficient for design rainfall (3-year probable rainfall of 50 mm/hour), to maximize cost-effectiveness in consideration of rainfall exceeding planned intensity through effective arrangement of anti-inundation facilities necessary to achieve the development level that can deal with design rainfall.

The effect of the establishment of anti-inundation facilities should be checked through flood simulation. Cost-effectiveness should be estimated by calculating inundation damage amount from the areas of inundation before and after measure determined through simulation and comparing the amount with the construction cost.

The Figure 1 shows the study flow.

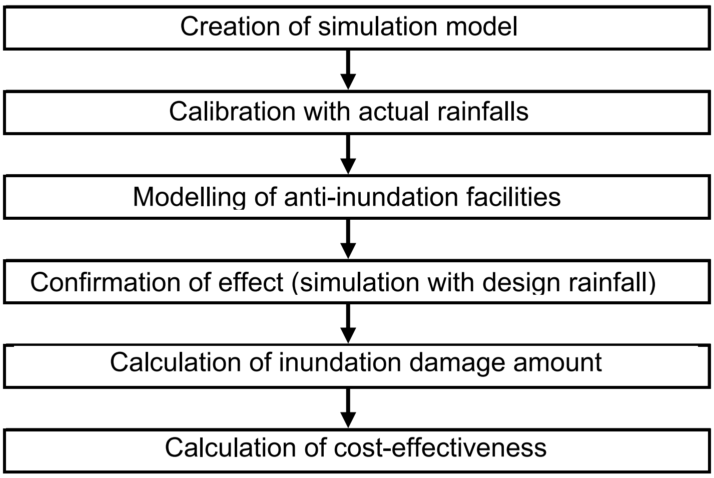

Figure 1 Study Flow

The Figure 2 shows the target area for the study.

As simulation is conducted with combined river courses in this study, the simulation model needs to cover a vast area of 2,900 ha, of which, we selected the area where insufficient river capacity frequently causes inundation (about 300 ha) as the target area for the study.

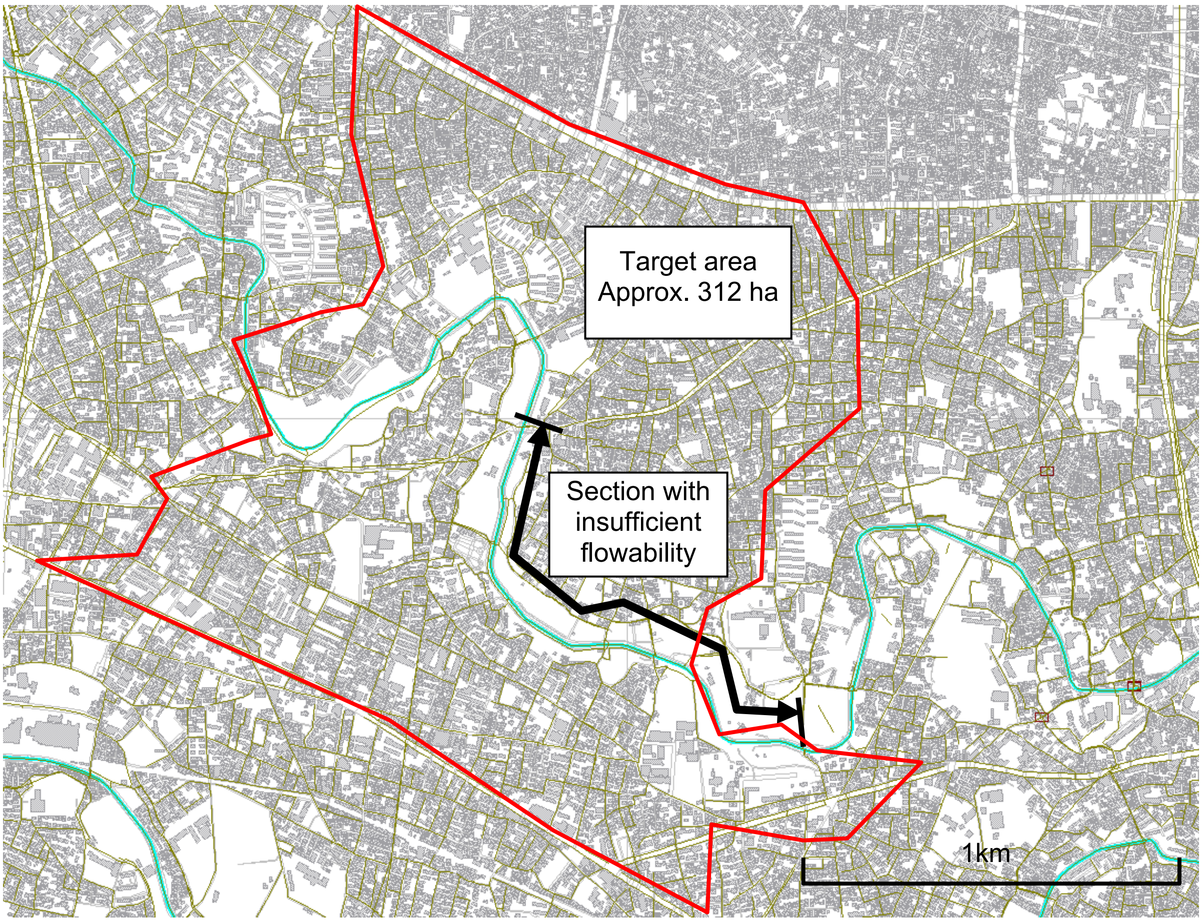

Figure 2 Target Area for the Study

3 CREATION OF SIMULATION MODEL AND CALIBRATION

3.1 Local Conditions

The target area for the study is an urban residential area. As river channel improvement is difficult in this densely-housed area and there has not been much progress in river improvement, rainfall around the level of design rainfall can cause river flooding in the area.

3.2 Method to Establish Analysis Model

We used InfoWorksCS as software for flood simulation. We decided to conduct simulation after modelling the river channel and combining the river and the sewer system. We conducted modelling in the following method.

- Created a sewage model using a digitally-mapped sewage system ledger.
- Included in the model small-bore branch sewers as well as major sewers.
- Created a river channel model using design drawings.

3.3 Calibration

In order to verify that the created simulation model properly show inundation damage caused by rainfall, we conduct simulation using the data of actual rainfalls that caused inundation and correct the model if necessary. This process is called calibration and we conducted simulation under the following conditions.

- Use the data of the rainfall that caused inundation on September 4, 2005.
- Use the data collected at 11 rain-gauge stations and adjust bias by Thiessen Method.
- The boundary condition for the river for discharge is the river level at the downstream end of the modelled river section.

The Figure 3 shows the overview of the analysis model used for the study. The Table 1 contains the observation values of September 4, 2005, obtained at each rain-gauge station used for the calibration.

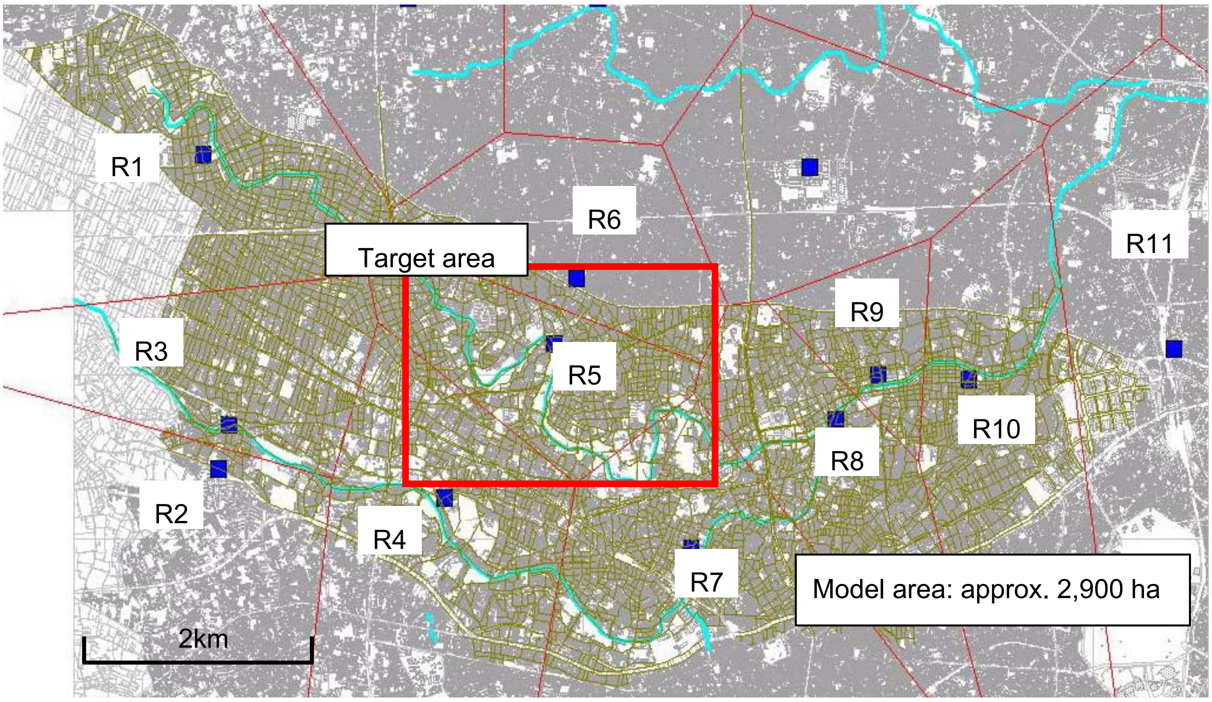

Figure 3 Overview of Analysis Model

Table 1 Observation Values of Each Rain-Gauge Station (09/04/2005)

Rain-gauge station	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
Total amount of rainfall (mm)	206	240	238	190	196	203	119	91	91	79	58
Maximum rainfall per hour (mm/hr)	79	97	97	80	82	90	80	59	54	51	39

The Figure 4 shows both the actual inundation areas and the possible inundation areas identified through simulation. When we compare the result of the simulation conducted with the actual rainfall data (before modification) with the actual inundation record, we see the inundation area identified through the simulation is larger than the actual area. When we checked the actual site, we found that there is low ground connecting to an embankment and water overflowing banks can flood the low ground and flow down. We thought the flowability of the river was underestimated in the simulation model. Therefore we modified the simulation model, considering the low ground as a compound double-cross -section of the river channel.

Comparing the inundation areas before and after the modification, we see the inundation area after modification is closer to the actual area than before modification.

The Figure 5 shows conceptual diagram of modification of river channel model.

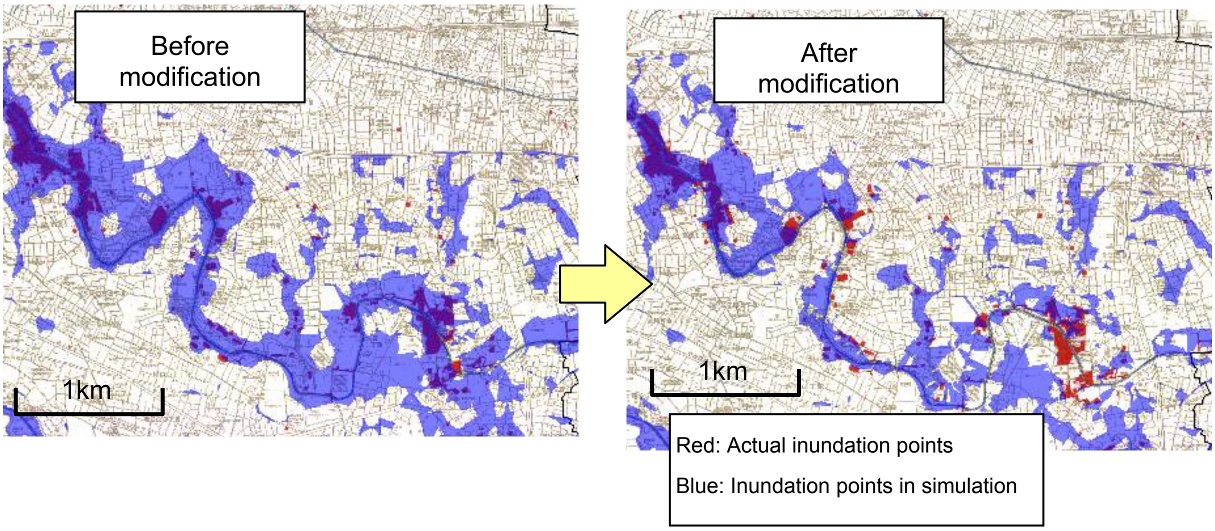

Figure 4 Comparison between Actual Inundation Points and Simulation Result

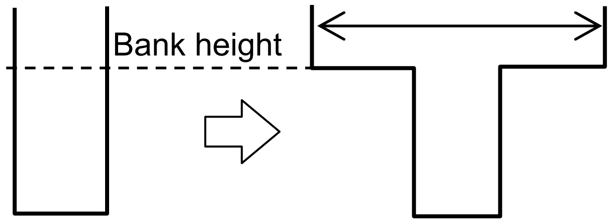

Figure 5 Conceptual Diagram of Modification of River Channel Model

4 SETTING OF COUNTERMEASURE CASES

We considered installation of three types of facilities; reservoirs that take water from a river, storage pipes that take water from sewer culverts, and porous measures installed in houses. Such facilities will be installed near the section where the flowability of the river is the least sufficient so that the facilities will be improved and able to deal with design rainfall.

For reservoirs that take water from the river, we have set multiple cases to see difference in effect among different installation locations and also between the case of a reservoir in a single location and the case of dispersed arrangement in multiple locations.

As for the capacity of reservoirs and storage pipes, the simulation result shows that the storage capacity required to improve the facility level in the section with insufficient flowability is 50,000 m^3. Therefore, the total storage capacity should be 50,000 m^3 for all the cases.

For infiltration facilities, we calculated how long it will take to collect 50,000m^3 in the event of design rainfall and decided 50,000 m^3 of water should infiltrate within the time period. The time required for water collection was calculated to be 30 minutes and the required infiltration capacity to be 100,000 m^3. The required infiltration capacity is equivalent to about 9 mm/hour on average in the inflow area of the target section of the river. The Figure 6 shows method of ascertaining collection time.

The Table 2 shows summary of countermeasure cases. The Figuer 7 shows Locations of Anti-Inundation Facilities.

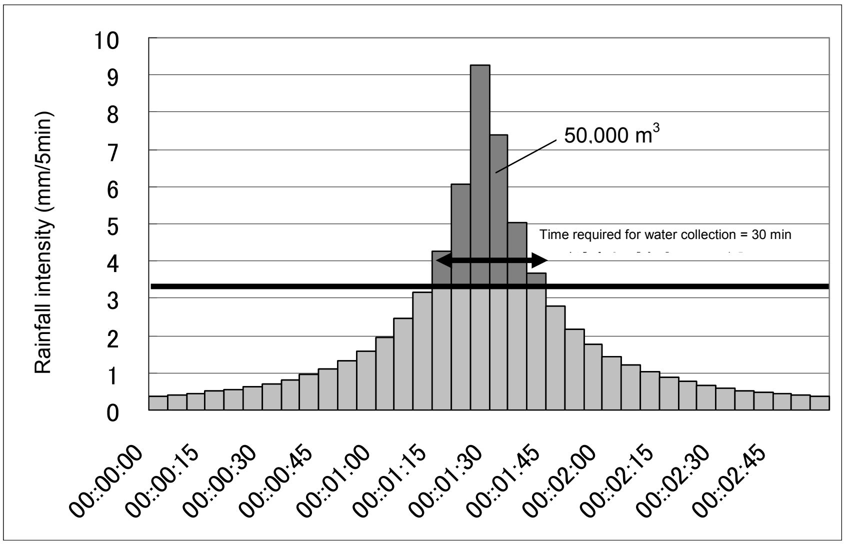

Figure 6 Method of Ascertaining Collection Time

Table 2 Summary of Countermeasure Cases

	Case1	Case 2	Case 3	Case 4	Case 5
Type of facilities	Balancing reservoir with water from river	Balancing reservoir with water from river	Balancing reservoir with water from river	Storage pipe with water from sewage	Porous measures installed in house
Installation site	A	B	A+B+C		
	Direct upper part of the section with insufficient flowability	Middle part of the section with insufficient flowability	Upper and middle parts of the section with insufficient flowability	Sewer culverts that go into the section with insufficient flowability	Dispersed arrangement in houses in a 312-hectare area that discharge water into the section with insufficient flowability
No. of units installed	1	1	3	12	
Capacity	50,000 m^3	50,000 m^3	Total reserve volume 50,000 m^3	Total reserve volume 50,000 m^3	Equivalent to 50,000 m^3 at 9 mm/hr

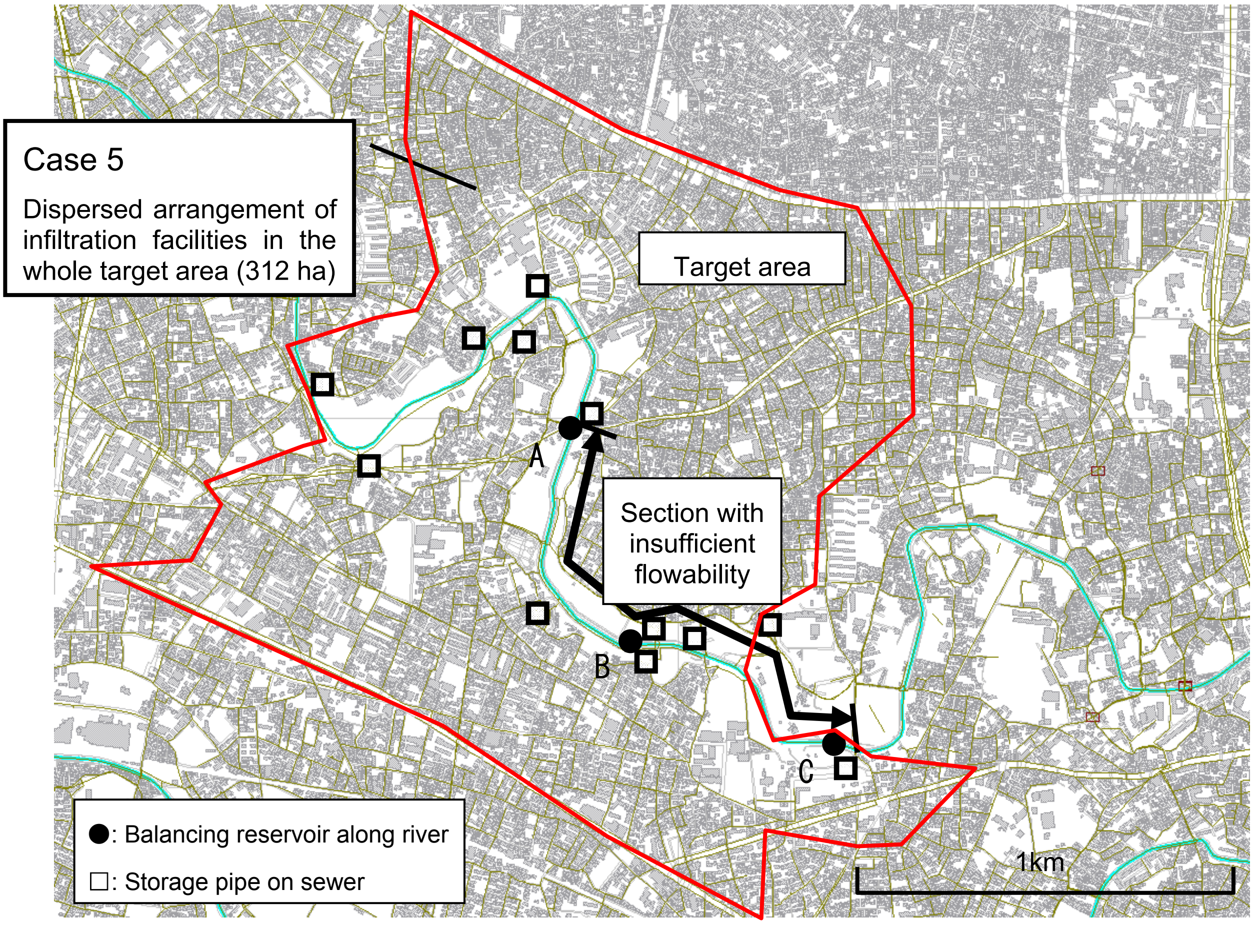

Figure 7 Locations of Anti-Inundation Facilities

5 EFFECT OF INSTALLATION OF ANTI-INUNDATION FACILITIES

We conducted simulation based on design rainfall for each case we had set, and calculate the area where inundation damage would occur. We used five design rainfalls for the calculation; 3-year probable rainfall (50 mm/hr), 15-year probable rainfall (75 mm/hr), 30-year probable rainfall (90 mm/hr), 50-year probable rainfall (95 mm/hr) and 100-year probable rainfall (110 mm/hr).

The Figure 8 shows the inundation damage identified as a result of the simulation of 15-year probable rainfall (75 mm/hr). As the improvement is to be made to the level that can deal with 3-year probably rainfall, we see inundation damage in all the cases with 15-year probable rainfalls. However, we can see the area has become smaller than before measure.

The Table 3 shows the inundation area of each case of probable rainfall obtained as a result of simulation conducted with the selected probable rainfalls. Like the Figure 5, this table also shows that the damage area after measure will be smaller than before measure.

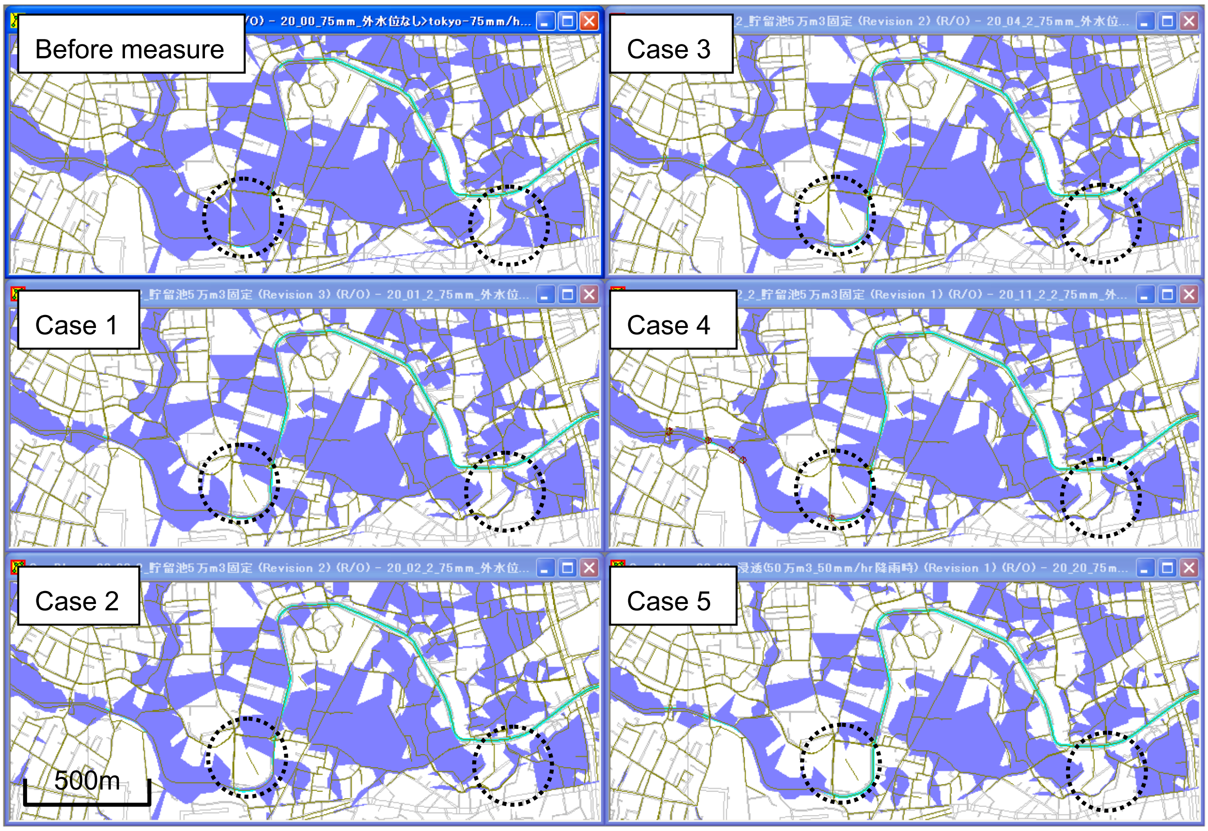

Figure 8 Simulation Result of Each Case (15-year probable rainfall (75 mm/hr))

Table 3 Inundation Area Shown in the Result of Simulation of Each Case (Unit: ha)

		Inundation below floor level						Inundation above floor level					
		Before measure	Case 1	Case 2	Case 3	Case 4	Case 5	Before measure	Case 1	Case 2	Case 3	Case 4	Case 5
3-year return period	50mm/hr	20.64	17.69	17.69	16.94	16.61	13.91	0.45	0.00	0.00	0.00	0.00	0.00
15-year return period	75mm/hr	334.83	336.26	332.11	332.88	327.83	269.69	48.04	42.01	41.58	41.55	41.13	32.87
30-year return period	90mm/hr	460.63	470.02	467.84	467.42	471.02	425.14	111.23	94.89	98.02	95.68	93.57	73.21
50-year return period	95mm/hr	509.27	516.68	515.90	516.79	515.99	475.32	132.10	119.61	120.69	119.38	121.18	97.31
100-year return period	110mm/hr	598.80	604.62	601.13	603.56	605.58	581.67	192.64	183.72	185.49	184.24	183.99	166.34

6 CALCULATION OF COST-EFFECTIVENESS

We calculated cost-effectiveness by calculating the amount of damage from the inundation area based on the simulation result of each case and comparing it with the construction cost. We adopted “Present Value Comparison Method”, which is effective in understanding investment cost and onset of effect in chronological order, and set the measurement period to be 50 years after the installation of the facilities.

6.1 Calculation of Damage Amount

We calculated average damage amount per unit area by calculating total amount of damage caused by flooding below/above floor level based on the statistical data of asset value in the target area and dividing it by unit area of the target area. For damage calculation, we considered both direct inundation damage (houses and properties, cars and other household articles, office assets, and public civil engineering facilities) and indirect inundation damage (loss from interruption of business, cost for emergency measures and psychological damage).

- Average amount of damage caused by flooding below floor level: 82.2 million yen/ha
- Average amount of damage caused by flooding above floor level: 448.3 million yen/ha

Damage amount of each case of probable rainfall can be calculated by multiplying the above values by the area of inundation damage. The Table 4 shows the calculation result.

Table 4 Damage Amount of Each Case (Unit: Million yen)

		Inundation below floor level						Inundation above floor level					
		Before measure	Case 1	Case 2	Case 3	Case 4	Case 5	Before measure	Case 1	Case 2	Case 3	Case 4	Case 5
3-year return period	50mm/hr	1,696	1,454	1,454	1,392	1,365	1,143	202	0	0	0	0	0
15-year return period	75mm/hr	27,521	27,638	27,297	27,360	26,945	22,167	21,535	18,832	18,639	18,625	18,437	14,735
30-year return period	90mm/hr	37,861	38,633	38,454	38,419	38,715	34,944	49,861	42,536	43,939	42,890	41,944	32,818
50-year return period	95mm/hr	41,859	42,468	42,404	42,477	42,411	39,068	59,216	53,617	54,101	53,514	54,321	43,621
100-year return period	110mm/hr	49,218	49,696	49,409	49,609	49,775	47,810	86,354	82,356	83,149	82,589	82,477	74,565

		Total					
		Before measure	Case 1	Case 2	Case 3	Case 4	Case 5
3-year return period	50mm/hr	1,898	1,454	1,454	1,392	1,365	1,143
15-year return period	75mm/hr	49,056	46,470	45,936	45,985	45,382	36,902
30-year return period	90mm/hr	87,722	81,169	82,393	81,309	80,659	67,762
50-year return period	95mm/hr	101,075	96,085	96,505	95,991	96,732	82,689
100-year return period	110mm/hr	135,572	132,052	132,558	132,198	132,252	122,375

6.2 Calculation of Damage Reduction

We calculated damage reduction made by the installation of anti-inundation facilities by subtracting the damage amount after measure from that before measure, and then calculated annual average damage reduction by multiplying the amount of damage reduction by the probability of inundation.

The Table 5 shows the calculation result of annual average damage reduction.

Table 5 Calculation Result of Annual Average Damage Reduction (Unit: Million yen)

	Annual average exceeding probability	Damage ruduction					Average damage ruduction in the section				
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 4	Case 5
3-year return period	0.3333	444	444	506	533	755					
15-year return period	0.0667	2,586	3,120	3,071	3,674	12,154	1,515	1,782	1,789	2,104	6,455
30-year return period	0.0333	6,553	5,329	6,413	7,063	19,960	4,570	4,225	4,742	5,369	16,057
50-year return period	0.0200	4,990	4,570	5,084	4,343	18,386	5,772	4,950	5,749	5,703	19,173
100-year return period	0.0100	3,520	3,014	3,374	3,320	13,197	4,255	3,792	4,229	3,832	15,792

	Section probability	Annual average damage reduction				
		Case 1	Case 2	Case 3	Case 4	Case 5
3-year return period						
15-year return period	0.2667	404	475	477	561	1,721
30-year return period	0.0333	152	141	158	179	535
50-year return period	0.0133	77	66	77	76	256
100-year return period	0.0100	43	38	42	38	158
Total		676	720	754	854	2,670

6.3 Calculation of Cost-Effectiveness

We calculated the amount of damage reduction made by the installation of anti-inundation facilities by subtracting the damage amount after measure from that before measure, and then calculated annual average damage reduction by multiplying the amount of damage reduction by the probability of inundation.

For the calculation of construction cost, we set a standard price for each of the facilities and set the durable years to be 50 years.

- Construction unit cost of Balancing reservoir: 200000 yen/m3 (2500 USD/m3)
- (land acquisition cost not included)
- Construction unit cost of Storage pipe:2.2 million yen/m (φ 3000 mm)= 311000 yen/m3 (3900 USD)
- Construction unit cost of Porous measures:150000 yen/unit = 231000 yen/m3/hr (2900 USD/m3/hr)

The Table 6 shows the cost-effectiveness of each case calculated with capitalized annual average damage reduction and construction cost.

As a whole, cost-effectiveness is the highest in case a porous measure is installed in each house in the river basin. It is because infiltration facilities can exercise a certain level of infiltration ability for excess rainfall, although it depends on ground and groundwater conditions, and therefore is expected to have a certain level of effect on excess rainfall, while water retention facilities do not have further inundation mitigation effect when they are filled to capacity and therefore much effect cannot be expected with excess rainfall.

The result shows that water retention facilities have a greater inundation mitigation effect if they are arranged dispersedly than when installed in one location. Compared with balancing reservoirs that takes water from the river, storage pipes that takes water from sewage is more effective in reducing inundation damage but less cost-effective as the construction cost per unit of retention volume is 1.5 times higher. As the unit cost of reservoirs used in the calculation does not include land acquisition cost, they need to be built in public land.

Table 6 Cost-Effectiveness of Each Case (Unit: million yen)

	Case 1	Case 2	Case 3	Case 4	Case 5
Annual average damage reduction	676	720	754	854	2,670
Construction cost	10,000	10,000	10,000	18,300	23,100
Present value(50years of evaluation period)					
Benefit					
Damage reduction	12,413	13,221	13,846	15,682	49,029
Remaining value	115	115	115	211	201
Total	12,528	13,336	13,960	15,893	49,231
Cost					
Development cost	9,260	9,260	9,260	14,584	21,390
B/C	1.35	1.44	1.51	1.09	2.30

7 CONCLUSION

- The result of this case study shows that dispersed arrangement (Case 3) is most cost-effective among the different cases of development of reservoirs that take water from the river (Case 1 to Case 3). The reason might be that the pieces of land that can be easily flooded are scattered.
- Case 4 (development of storage pipes that take water from sewage) has turned out to be less cost-effective than Case 1 to Case 3 because the development cost is high although it is more effective in reducing inundation damage than Case 1 to Case 3.
- Case 5 (installation of porous measures in houses) is found to be most effective among all. Although it could be a very effective measure if they could actually be installed, it is impossible for the government to force installation as they are to be installed in houses and other private properties. Therefore, voluntary installation by the residents needs to be promoted through guidance and subsidies.

LIST OF REFERENCES

Japan Sewage Works Association (2006). Manual for Cost-Effectiveness Analysis of Sewage Works. 205-254