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Operational Control Modeling for Land Use Development of Flood Estimated Areas in Small Scale Basins

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Abstract

In recent years, the inundations in urbanized areas have been increasing. From this viewpoint the concepts of comprehensive flood control system has been proposed. It is the first purpose of this study to discuss a few points about the synthetic land use management in consideration of flood prevention in urbanized flood-prone areas. The second purpose is how to evaluate the feasible area in several watersheds by using dynamic quantitative models. As such techniques, two modelings are proposed, which are the System Dynamics Modeling (SD-Modeling) for an adaptive type and the Optimal Control Modeling for an optimal type. Both models have the purpose of deciding the scale of allowable development of urbanized areas and flood control investment. As the results, the regional safety level of flood control and the necessity of flood control measures can be evaluated by the SD model and the scale of land development and that of flood control measures can be decided on the basis of regional economic efficiency simultaneously by the Optimal Control Model.

Key Words: Systems analysis, structural or nonstructural measures for flood control, floodproofing ratio, land use treatment, System Dynamics, Optimal Control Modeling, landside inundation, flood control for urbanized area.

1. Introduction

The scale of flooding which occurred in recent years may be determined not only by hydrologic factors, which means flooding height, flooding velocity and duration, but also by human activities including residential, social and economic developments of the flooded plain. This situation is often changed with advanced urbanization and concentration of population and properties on the flooded-prone areas. From this viewpoint the concepts of comprehensive flood control system has been proposed by the Ministry of Construction. [1] In several basins some of these methods have been enforced to manage the land use, to offer information on the probability of flooding to the inhabitants, to establish an evacuation system and to increase floodproofing. Thus a comprehensive flood control proposed is also to protect the flood-prone area and to prevent floodings with various emergency measures. [2] In particular, non-structural measures, which are floodproofing measures and land use treatments should be included in the flood prevention of the urbanized areas. [3]

The flood plain management has previously been considered as a problem of allocating land uses for a given pattern of flooding or as a problem of routing flood water for a given land use pattern. [4], [5] These decision problems have also beeen attempted as treatments of only the restriction of land use or the flood damage. [6], [7] As an empirical example to relate land use to flood control, a dynamic programming model has been proposed for land use allocation in flood plains in such a way as to maximize the total economic rent to land. [8] Meanwhile, as a investigation on attitude of inhabitants for flooded areas, a concept of dealing with human and social system of a recreational planning of flooded areas has been described. [9]

Recently a research has been presented regarding the building of a comprehensive model in urbanized watershed and examining the cost-effective analysis of flood control measures and methods of investment of flood control. [10]

It is the first purpose of this study to discuss a few points about the synthetic land use management in urbanized flood-prone areas. The second is how to evaluate the feasible area in several watersheds.

As a concrete method, two modelings are proposed in this study, which are the System Dynamics Modeling (SD-modeling) for an adaptive type and the Optimal Control Modeling for an optimal type. Both models have the purpose of deciding the scale of the allowable development of urbanized areas and flood control investment. The SD Model is to grasp these quantities by simulation methods. And then, the Optimal Control Model is to find these quantities analytically. [11], [12], [13].

2. Outline of Study Areas

The empirical study areas are two river basin in northerneast part of Sapporo City, which are the Hassamu River Basin and the Fushiko River Basin. Both river basins have large land use enhancements and small scale inundations in the landside have been occurring for several years.

In this paper, the Hassamu river Basin is expressed as Basin-A and the Fushiko River Basin as Basin-B.

The current population, the land use and industrial or commercial indicators are shown in Table 1 and the change of land use pattern in the two river basins is presented in Fig. 1.

The residential areas in both river basins are increasing at an average rate from 1.0 to 1.5%. The expected flood damage in Basin-B is higher than that in Basin-A because of the difference of land conditions. Each safety height level of the flood-proofing measure is 1.5 m in height in Basin-A and 3.2 m in height in Basin-B.

Table 1. Statistical Vales of the Empirical Study Areas

Watershed	Hassamu River Basin-A		Fushiko River Basin-B	
	1975	1980	1975	1980
Housing area	717	1,240	1,456	1,920
Paddy field	0	0	190	125
Farm land	1,628	1,031	1,915	1,530
Others (ha)	306	280	124	110
Population ($\times 10^3$)	75	100	94	114
Number of Household ($\times 10^3$)	24	32	30	36
Offices of Enterprise	1,644	2,122	2,306	3,745
Employees ($\times 10^3$)	10	13	18	43

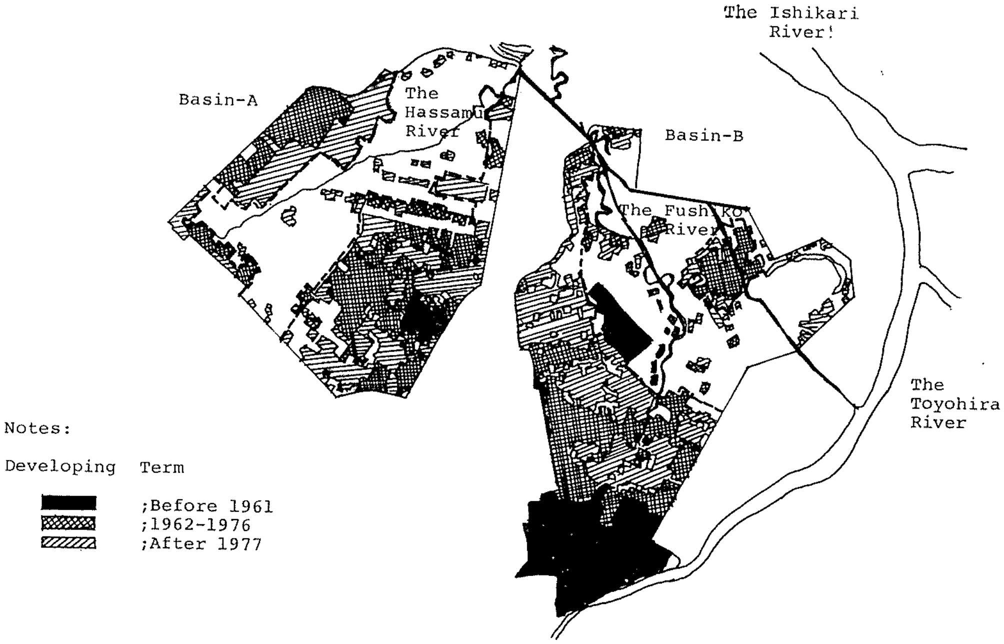


Fig. 1. Land use enhancement of empirical study areas.

3. Analysis of Land Use Control Corresponding to Drainage of Landside Basins

This section deals with the problem of the interaction between land use and flood control in urbanized flooded areas.

The models used in this section are generalized as follows :

(1) SD Model of Adaptive Type (MODEL-I)

An adaptive control system is usually characterized by two devices, one which automatically measures the dynamics of the controlled system and the other which automatically adjusts to the controller based on a comparison of the measurements with some optimal figure of merits. In this model, we can control some of flood control measures, which involves land use development, to reduce the annual flood damage. For the model of adaptive type the method of the System Dynamics was proposed to estimate the regional flood damage potential.

This model is composed of three subsystems, which are the flood control system, the flood damage system and the socioeconomic system.

The modeling conditions are based on the following assumptions:

a) The assumed flooding is the urban flooded region in small river watersheds.

b) The probable rainfall is determined on the basis of the historical data of regional rainfall.

c) The rainfall which has a longer duration than the flood onset time is incorporated in this model.

d) The rainfall intensity is selected as two days strength of the probable rainfall intensity-duration curve.

e) The analysis of runoff is used as the rational equation.

f) The coefficient of runoff is based on the values proposed previously.

g) All of the runoff in a watershed is presumed to be drained by pumping. These concepts lead to the following equation:

$$S_p = (1/3.6) \cdot f \cdot r \cdot A - Q_p , \qquad (1)$$

where S_p; a peak runoff in a watershed (m^3/sec), f; the coefficient of runoff, r; the probable rainfall in 48 hours (mm), A; watershed area (km^2), Q_p; pumping abilities (m^3/sec).

h) The flooding area is decided by regional geological, hydrological data and flood control level. The damage extent is based on the flooded depth and the regional properties or productions. The flooded depth is lead forth by the discharge and geological data as the flooded depth. The composition of flood damage which are the regional properties and production is decided by the regional tendency of social and economic factors and the trend of land use.

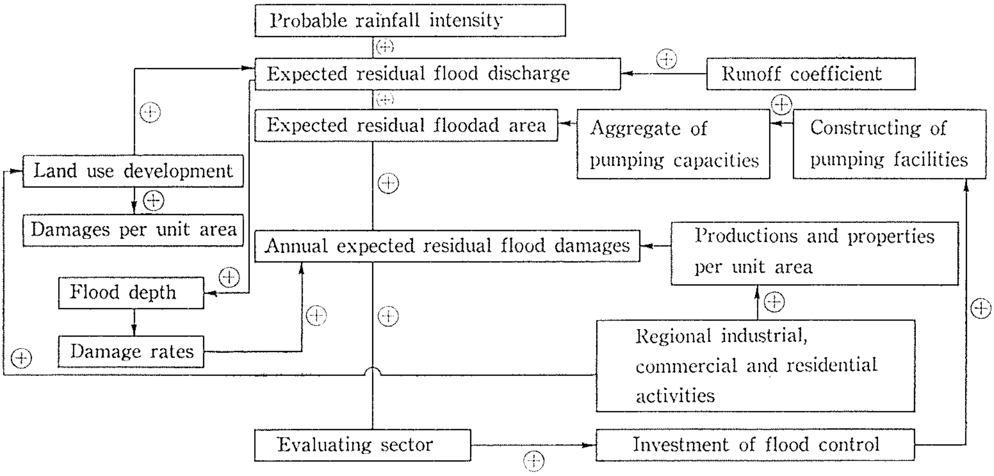


Fig. 2. Flowdiagram of MODEL-I.

i) The coefficient of runoff depends on the regional land use treatment. Therefore the runoff can change with the trend of land use. On the basis of these suppositions, the System Dynamics Model with adaptive control would be as shown in Fig. 2.

(2) Control Model of Optimal Type (MODEL-II)

The above-mentioned model is built with a substantial flood control or an attained level which is dusturbed only by the regional development or the planning of an upper decision level.

Some of problems are left as follows:

a) As this system is an input oriented system, it can adopt its environment but usually the control problem is the second best problem to the other best state variables.

b) In most regional plans which exist in the social system, the object areas are considered as a flooding zone by the assessment for disaster protection.

c) While in these areas the control is expected to be carried out by national or municipal project, private prevention of self-protection measures are desired to be taken into the comprehensive measures.

The concrete model is built by adhering to the following conditions.

a) The state variables which are treated by this method refer to multiregional land use enhancement and such investments for flood control. The land enhancement refers to regional developments. Such investments express the scale of flood control projects.

b) To express this concertely, they are used in relation to each increased/decreased land use area, each increased/decreased flood control and rations of each floodproofing. The rations of floodproofing are given as parameters and the other variables are the input as control variables in the optimal control.

c) Several objective functions are prepared with the information from public agencies carrying out flood control or private persons or companies on flooded plains.

d) The residential area and the industrial area are the possible extent of urbanization.

e) The pumping facilities making use of public investments, one of many flood control measures, can be increased continuously. By using these conditions the following model is formulated. Six objective functions are as follows:

$$J_1 = \int_{t_0}^{t_f} e^{-rt} \Big\{ C_f(t) + C_p(t) \Big\}\, dt\,, \tag{2}$$

$$J_2 = \int_{t_0}^{t_f} e^{-rt} \Big\{ C_f(t) + C_{fp}(t) - U(t) \Big\}\, dt\,, \tag{3}$$

$$J_3 = \int_{t_0}^{t_f} e^{-rt} \Big\{ C_f(t) + C_{fp}(t) + C_p(t) - U(t) \Big\}\, dt\,, \tag{4}$$

$$J_4 = \int_{t_0}^{t_f} e^{-rt} \Big\{ C_f(t) + C_p(t) - C_g(t) \Big\}^2 dt\,, \tag{5}$$

$$J_5 = \int_{t_0}^{t_f} \Big\{ e^{-rt} \Big\{ C_f(t) + C_{fp}(t) - U(t) - C_g(t) \Big\}^2 dt\,, \tag{6}$$

And then

$$J_6 = \int_{t_0}^{t_f} e^{-rt} \left\{ C_f(t) + C_{fp}(t) + C_p(t) - U(t) - C_g(t) \right\}^2 dt \,. \tag{7}$$

The objective function J_1 is composed of damage cost $C_f(t)$ and the cost of structural measures $C_p(t)$. It is the function to maximize the benefit of public agencies, that is, to perform the objectives of flood control. The objective function J_2 is the function which takes the increase of properties $U(t)$ from the 'damage cost $C_f(t)$. It is carried out to maximize the benefit of the private areas which are gained by flood control projects. The function J_3 is a hybrid function composed of objectives for these two groups. The function J_4 is a disutility function which has two objectives, one is to minimize the quadratic difference between estimated total cost and admissible cost and the other is to minimize the disparity of flood damage cost in each region. Similarly J_5 is the objective function to minimize the quadratic difference of two costs for the private sector. Furthermore, the function J_6 is equation which has an objective to minimize the quadratic difference for these costs in each region.

The equation $C_f(t)$ is the annual expected damage due to inundation.

$$C_f(t) = \sum_i \sum_j \left[P_i(t) \cdot G_{ij}\left\{q_j(t)\right\} \cdot R_i\left\{q_j(t)\right\} \cdot B_{ij}(t) \left\{1 - e_j(t)\right\} \right], \tag{8}$$

$$C_p(t) = \sum_j u_{pj}(t) \,, \tag{9}$$

$$C_{fp}(t) = \sum_i \sum_j u_{ij}(t) \cdot h_j \cdot e_j(t) \cdot P_{pj}(t) \,, \tag{10}$$

$$U(t) = \sum_i \sum_j u_{ij}(t) \cdot P_i(t) \,, \tag{11}$$

$$B_{ij}(t) = l_{ij}(t) / L_j \,, \tag{12}$$

and then

$$q_j(t) = \sum_i R_{si} \cdot f_i \cdot l_{ij}(t) - q_{uj}(t) \,. \tag{13}$$

The state variables are expressed as

$$\dot{l}_{ij}(t) = u_{ij}(t) \,, \tag{14}$$

and

$$\dot{q}_{uj}(t) = u_{pj}(t) \cdot E_a \,. \tag{15}$$

The equation (14) is the state variables of land use i in a region j. The equation (15) is the state of flood control in a region j.

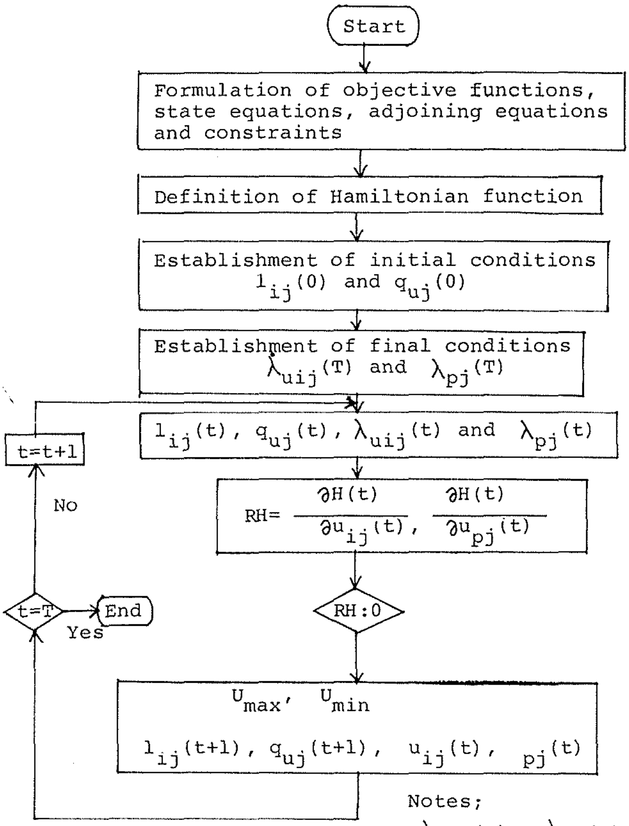
Some constraints are

$$u_{ij}(t) = \sum_k u_{kj}(t) \quad \text{and} \quad k \neq j \,, \tag{16}$$

$$\sum_i l_{ij}(t) = L_j \,, \tag{17}$$

$$u_{ij}(t),\ u_{kj}(t),\ u_{pj}(t) > 0 \,. \tag{18}$$

These defined problems are solved by using the Pontryagin's maximum principle. The procedure is explained as in Fig. 3.



Notes;
$\lambda_{uij}(t)$, $\lambda_{pj}(t)$; adjoint variables

Fig. 3. Algorithm for analysing optimal control.

The objective function J_1 was already shown in Equation (2). As a result of analysis the damage potential $C_f(t)$ increased when the enhanced land use $U(t)$ increased. Moreover, when the control investment $u_p(t)$ increased, $C_f(t)$ became larger.

In other words, we can express these relations with the following inequalities:

$$\partial C_f(t)/\partial u_{ij}(t) > 0 \quad \text{and} \quad \partial C_f(t)/\partial u_{pj}(t) < 0 \tag{19}$$

In particular, Equation (2) become a concave function with respect to $u_{pj}(t)$. We can aquire a point of $u_{pj}(t)$ which minimizes the objective function J_1 with respect to $u_{ij}(t)$. Also considered are the land use change which minimizes J_1 and is given linearly, Thus the Equation $u_{pj}(t)=\text{const.}=u^m_{pj}(t_0 \leqq t \leqq t_f)$ is provided. The less the variable $u_{ij}(t)$ acts in its range, the less the variables $u_{pj}(t)$ became.

In conclusion, the scale of the investment is decided independently in the separation of land use enhancement by using the objective function J_1.

In the cases of Equation (3) and Equation (4), the Hamiltonian functions become primary functions with respect to $u_{ij}(t)$ and $u_{pj}(t)$. Therefore the solution of these control problems are the bang-bang control. These are represented as follows:

In the case of Equation (4),

$$u_{ij}(t)=\begin{cases}U_{ij\,\mathrm{Max}} & \text{if} \quad \lambda_{ij}(t)+h_j\cdot p_{pi}(t)\cdot e_j(t)-p_i(t)>0\\ u_{ij\,\mathrm{Min}} & \text{if} \quad \lambda_{ij}(t)+h_j\cdot p_{pi}(t)\cdot e_j(t)-P_i(t)<0\,,\end{cases} \tag{20}$$

$$u_{pj}(t)=\begin{cases}u_{pj\,\mathrm{Max}} & \text{if} \quad \lambda_{pj}(t)+1>0\\ u_{pj\,\mathrm{Min}} & \text{if} \quad \lambda_{pj}(t)+1<0\,,\end{cases} \tag{21}$$

In the case of Equation (3), the solution is acquired to replace $\lambda_{pj}+1$ and in the case of Equation (4) with λ_{pj}, where the control is undetermined if the quality holds.

The Equation (5) is the quadratic disutility function which is expressed by the total cost composed of the annual expected damage and the cost of the structure measures.

The Equation (6) is displayed by the quadratic distility function which consists of the total cost. Moreover Equation (7) decides the costs in the watersheds.

The optimal solution of Equation (5) is analyzed as follows: In this case, the Hamiltonian function is defined by

$$H_4(t)=\left\{C_f(t)+C_p(t)\right\}^2+\lambda_{ij}(t)\,u_{ij}(t)+\lambda_{pj}(t)\,u_{pj}(t)\,, \tag{22}$$

where $i=1, 3$ and $j=1, 2$.

The necessary conditions correspond to the possible combinations of state and control variables. The conditions become

$$\frac{\partial H_4(t)}{u_{ij}(t)}=\lambda_{ij}(t)=0\,, \tag{23}$$

$$\frac{\partial H_4(t)}{u_{pj}(t)}=2\left\{C_f(t)+C_p(t)\right\}+\lambda_{pj}(t)=0\,. \tag{24}$$

The Equation (24) is transformed to

$$\lambda_{pj}(t)=-2\left\{C_f(t)+C_p(t)\right\}=0\,. \tag{25}$$

Moreover, the adjoint equations become

$$\dot{\lambda}_{ij}(t)=-\frac{\partial H_4(t)}{\partial l_{ij}(t)}=-2\left\{C_f(t)+C_p(t)\right\}\frac{\partial C_f}{\partial l_{ij}(t)}\,, \tag{26}$$

provided that

$$\frac{\partial C_f(t)}{\partial l_{ij}(t)}=A(t)\left[\frac{\partial G\{q_j(t)\}}{\partial l_{ij}(t)}R\left\{q_j(t)\right\}+G\left\{q_j(t)\right\}\frac{\partial R\{q_j(t)\}}{\partial l_{ij}(t)}\right], \tag{27}$$

$$\dot{\lambda}_{pj}(t)=-\frac{\partial H_4(t)}{\partial q_{uj}(t)}=2\left\{C_f(t)+C_p(t)\right\}\frac{\partial C_f(t)}{\partial q_{uj}(t)}\,. \tag{28}$$

provided that

$$\frac{\partial C_f(t)}{\partial q_{uj}(t)}=A(t)\frac{\partial G\{q_j(t)\}}{\partial q_{uj}(t)}\left[R\left\{q_j(t)\right\}+G\left\{q_j(t)\right\}\frac{\partial R\{q_j(t)\}}{\partial q_{uj}(t)}\right],$$

$$A(t)=p_i(t)\,B_{ij}(t)\left\{1-e_j(t)\right\}, \tag{29}$$

The optimal control trajectories are solved with the Equation (6) and Equation (7) with the similar methods to the case of Equation (5).

The solution with the Equation (6) becomes

$$H_5(t)=\left\{C_f(t)+C_{fp}(t)-U(t)\right\}^2+\lambda_{ij}(t)\cdot u_{ij}(t)+\lambda_{pj}(t)\cdot u_{pj}(t)\cdot E_a\,. \tag{30}$$

$$\frac{\partial H_5(t)}{\partial u_{ij}(t)}=2\left\{h_j\cdot e_j(t)\cdot P_{pj}(t)C_f(t)+C_{fp}(t)-U(t)-P(t)\right\}+\lambda_{ij}(t)=0\,, \tag{31}$$

$$\dot{\lambda}_{ij}(t)=-\frac{\partial H_5(t)}{\partial l_{ij}(t)}=-2\left\{C_f(t)+C_{fp}(t)-U(t)\right\}\frac{\partial C_f(t)}{\partial l_{ij}(t)}\,. \tag{32}$$

In the same way as for Equation (7), the Hamiltonian function

$$H_6(t)=\left\{C_f(t)+C_{fp}(t)+C_p(t)-U(t)\right\}^2+\lambda_{ij}(t)\cdot u_{ij}(t)+\lambda_{pj}(t)\cdot u_{pj}(t)\,. \tag{33}$$

The necessary conditions are

$$\frac{\partial H_6(t)}{\partial u_{ij}(t)}=2\left\{C_f(t)+C_{fp}(t)+C_p(t)-U(t)\right\}A(t)+\lambda_{ij}(t)=0\,, \tag{34}$$

$$\frac{\partial H_6(t)}{\partial u_{pj}(t)}=2\left\{C_f(t)+C_{fp}(t)+C_p(t)-U(t)\right\}+\lambda_{pj}(t)=0\,. \tag{35}$$

The adjoint equations are formulated with

$$\frac{\partial H_6(t)}{\partial l_{ij}(t)}=2\left\{C_f(t)+C_{fp}(t)+C_p(t)-U(t)\right\}\frac{\partial C_f(t)}{\partial l_{ij}(t)}=-\dot{\lambda}_{ij}\,, \tag{36}$$

$$\frac{\partial H_6(t)}{\partial q_{uj}(t)}\doteq 2\left\{C_f(t)+C_{fp}(t)+C_p(t)-U(t)\right\}\frac{\partial C_f(t)}{\partial q_{uj}(t)}=-\dot{\lambda}_{pj}\,. \tag{37}$$

These solutions are treated as the two point boundary value problem. That is, the necessary conditions for minimizing each objective function is given by (34) and (35), for example. But in general, it is very difficult to solve the two point boundary value problem. In this case, we established a method of numerical analysis. The algorithm of calculation is shown in Fig. 3.

(3) Verification of the models

It is difficult to verify these models because empirical flooding records are limited. In the first part, we attempted verification by comparing the estimated value of these models to the average flood damages in the record of the 1975 flooding were compared with the results of the same simulation year. The results of these conparison are shown in Table 2. It is evident from the Table 2 that the regional flood damage potential can almost be regarded as the annual expected flood damage, although some damages have some differences between the estimated value and the actual measured value. Moreover, it was shown positively that the expected flood damage almost was equalled to actual data.

(4) Results of analysis of MODEL-I

To simulate the MODEL-I, five scenarios according to land use politics predicted on the future and three scenarios in some measures of flood control investment were established.

The results of the simulation anlysis with respect to each alternative were expressed as follows:

Table 2. Comparison between estimated and actual values of the 1975 Flood

	Basin-A		Basin-B	
	Autual measurement	Estimate	Actual measurement	Estimate
Precipitation of 24 hours (mm)	133	180	120	100
Discharge of inundation ($\times 10^4 m^3$)	375	375	205	205
Inundated area (ha)	520	518	340	353
Inundated area of paddy field (ha)	87	92	130	175
Inundated area of other fields (ha)	355	259	50	35
Number of inundated housing (house)	167	194	370	230
Damage of paddy field ($\times 10^8$ yen)	0.15		0.28	
Damage of other field ($\times 10^8$ yen)	3.87		3.21	
Damage of housing ($\times 10^8$ yen)	0.44		0.40	
Total Damage ($\times 10^8$ yen)	0.46		4.30	

Table 3. Results using the alternatives of investment

Evaluated value	Allocation rate of investment (Basin-B=1.0)	Taget year (years)		Total damage cost ($\times 10^8$ yen)	Total investment ($\times 10^8$ yen)	Damage cost per household ($\times 10^4$ yen)	
		A	B			A	B
Minimizing damage cost	0.72	26	15	34.42	50.29	4.13	5.76
	0.72	17	12	29.73	57.49	3.33	5.57
	0.54	19	15	14.82	43.12	1.76	3.07
Minimizing investment	0.62	21	16	35.76	46.55	3.71	5.06
	0.54	14	13	33.43	53.41	3.10	4.61
	0.62	24	14	14.83	42.21	1.98	2.56
Balancing damage per household	0.88	33	14	38.68	48.41	5.15	5.06
	0.94	25	10	33.36	53.02	4.70	4.61
	0.70	30	13	16.34	44.59	2.56	2.56
Balancing target year	0.47	19	19	40.37	48.42	3.52	8.16
	0.48	14	14	35.39	59.19	3.07	8.16
	0.46	17	17	15.50	45.11	1.60	3.46

Notes: 1) Upper line; Case-B.1, Middle line; Case-B.2, Lower line; Case-C

2) A; Basin-A, B; Basin-B

3) Case-B. 1; Annual rate of investment increase is 10%, Case-B.2; Annual rate of investment increase is 20%. Case-C; in the case of benefit-cost ratio 1.0

a) The results using the different measures of investment can be computed in Table 3.

b) The methods of investment were introduced as Ⓐ a case of no investment (Case-A), Ⓑ a case of a constant ratio of increased investment (Case-B), Ⓒ a case of benefit-cost ratio of increased investment (Case-C). As a result, it was found that case-C was more efficient than the Case-B.

c) It is suggested that the achievement of the comprehensive objectives which are to minimize regional investment, to minimize the total expected damage and to

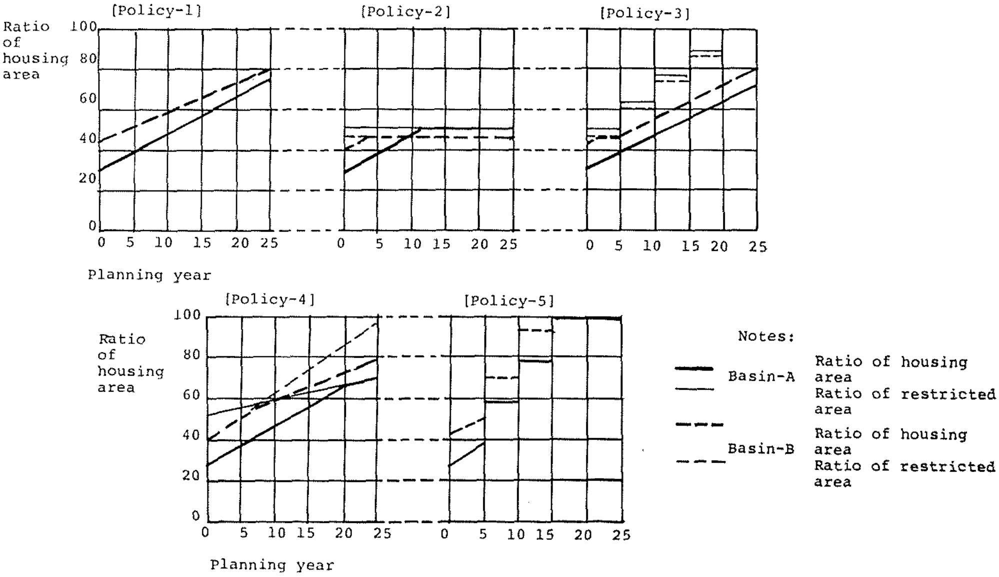


Fig. 4. Alternatives of land use policy in the study areas.

Table 4. Results using the alternatives of land use

Basin	Evaluated Value	Planning of land use				
		P-1	P-2	P-3	P-4	P-5
A	Total damage cost	1.00 1.13	1.00 1.00	1.00 1.07	1.00 1.19	1.46 1.82
	Total damage cost per household	1.00 1.23	1.00 1.00	1.00 1.19	1.00 1.25	1.37 2.05
B	Total damage cost	1.12 1.35	1.00 1.00	1.00 1.26	1.06 1.22	1.36 1.80
	Total damage cost per household	1.17 1.41	1.00 1.00	1.14 1.32	1.07 1.25	1.45 1.91

Notes: 1) Upper line; Accumulated for ten years, Lower line; Accumulated for twenty years.

2) P-1, P-2, ···, P-5; Policy-1, Policy-2, ···, Policy-5, respectively.

balance the attained term are satisfied simultaneously. But it is difficlut to satisfy the objective of balancing the expected damage per capita or per household at the same time because of incresasing disparity investment as well as the objective years of the basins.

d) As for the different land use policies, these assumed transitions are presented in Fig. 4. The expected damage potential can also be calculated in some cases of changed land use patterns. The results are presented in Fig. 5. On the basis of the results in Policy-1, which is the case of the trend of the present condition, each evaluation value with respect to each policy can be expressed relatively in

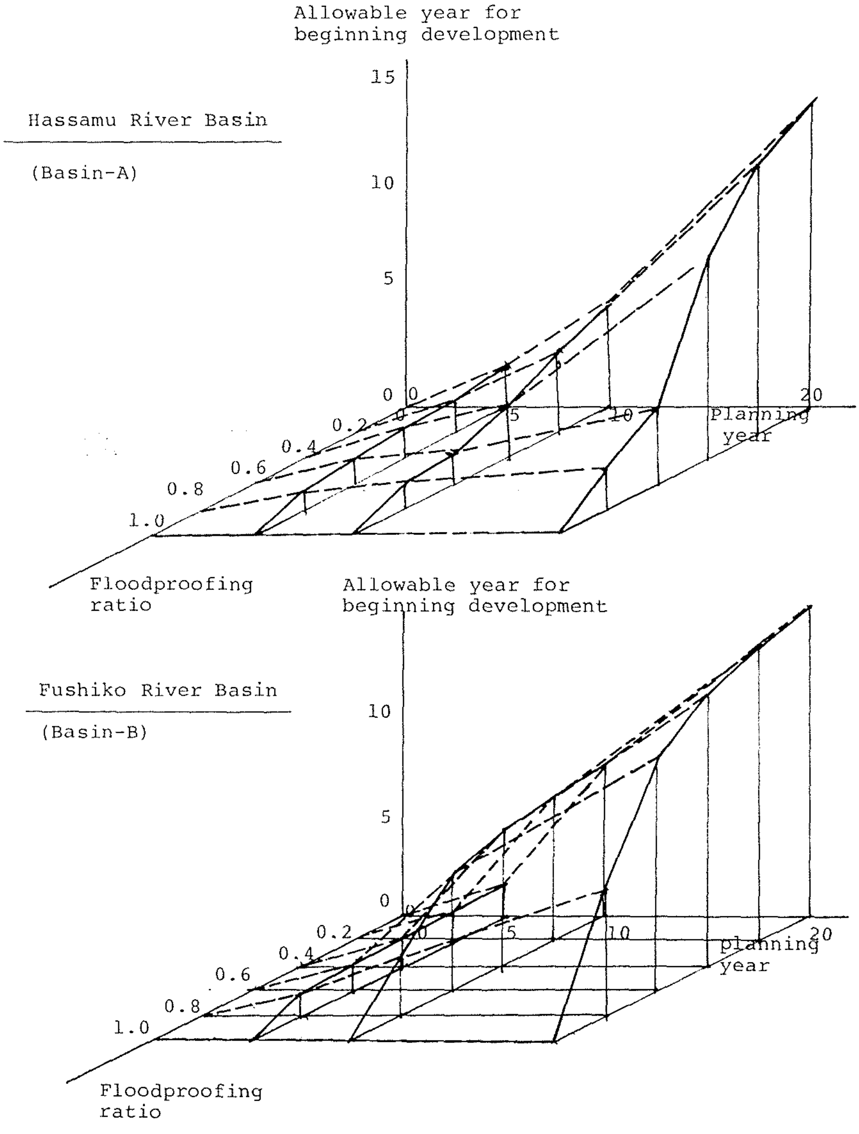


Fig. 5. Changes year from land restriction to land development (by Equation 4).

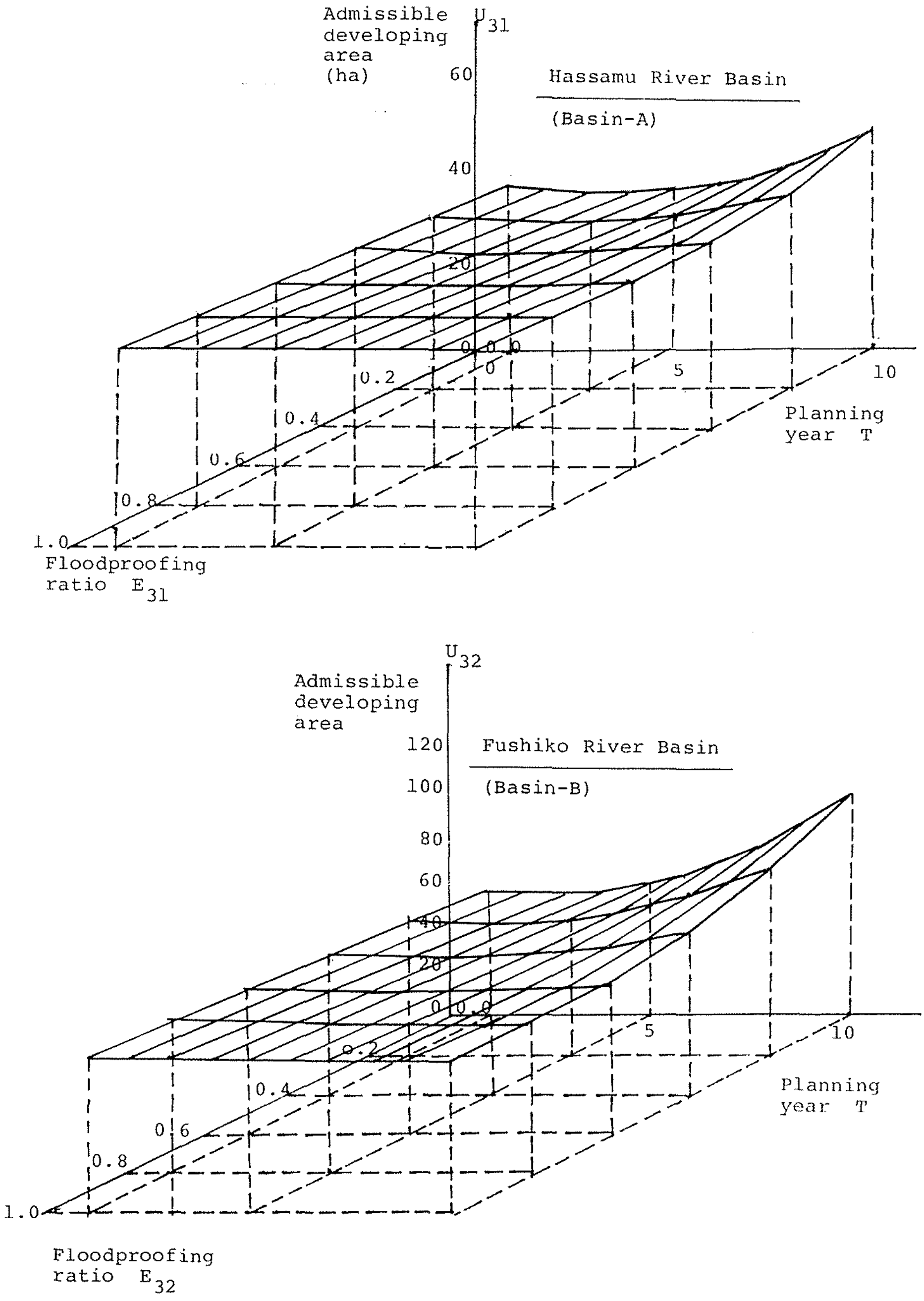


Fig. 6. 1. Scale of allowable development of urbanized areas by the Optimal Control Model (in the case of equation 7).

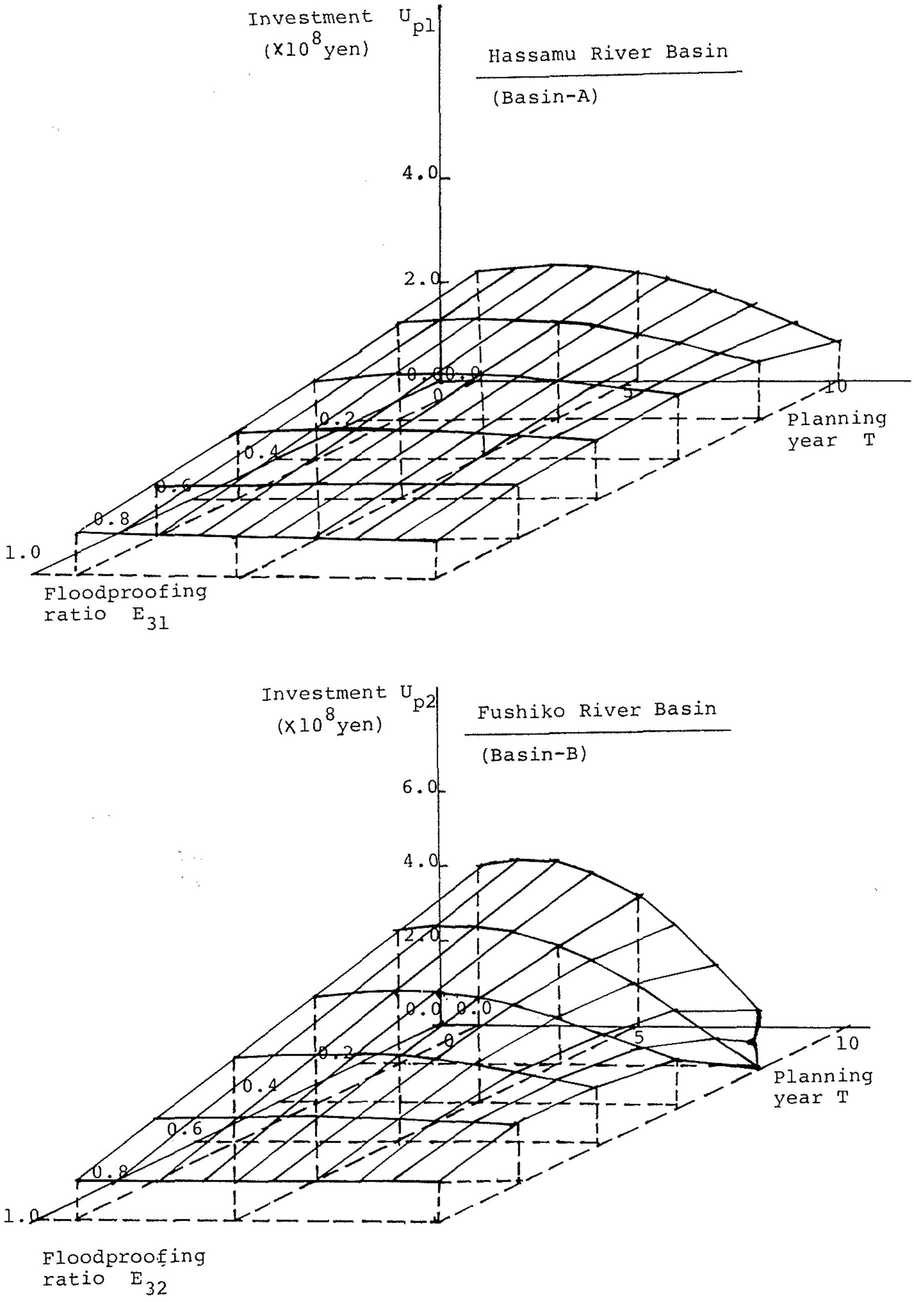


Fig. 6. 2. Scale of investment of pumping facilities by the Otpimal Control Model (in the case of Equation 7).

Table 4. The total accumulated flood damage can be increased 13% in 1985 and 23% in 1990. Moreover the accumulated flood damage per capita can be increased 35% in 1985 and 1990. Inversely, if the land use change is restricted the annual expected flood damage can be reduced by only these rates.

(5) The Results of Analysis of MODEL-II

As typical cases of these proposed policies with MODEL-II, the numerical solutions calculated by Equation (4) and Equation (7) were presented in Fig. 5 and Fig. 6.1-6.2.

a) The policy of land use on conditions of Equation (4) was expressed in Fig. 5. As the ratio of floodproofing is increased, the change year, namely, when the policy is increasingly modefied from a restriction form of land use to an nonrestriction form, is considerably speeded up.

b) Meanwhile Fig. 6.1-6.2 show the results of evaluation of each optimal trajectories in the case of Equation (7). For the beginning several years of this simulation, the admissible area of the land development is almost constant and after the years

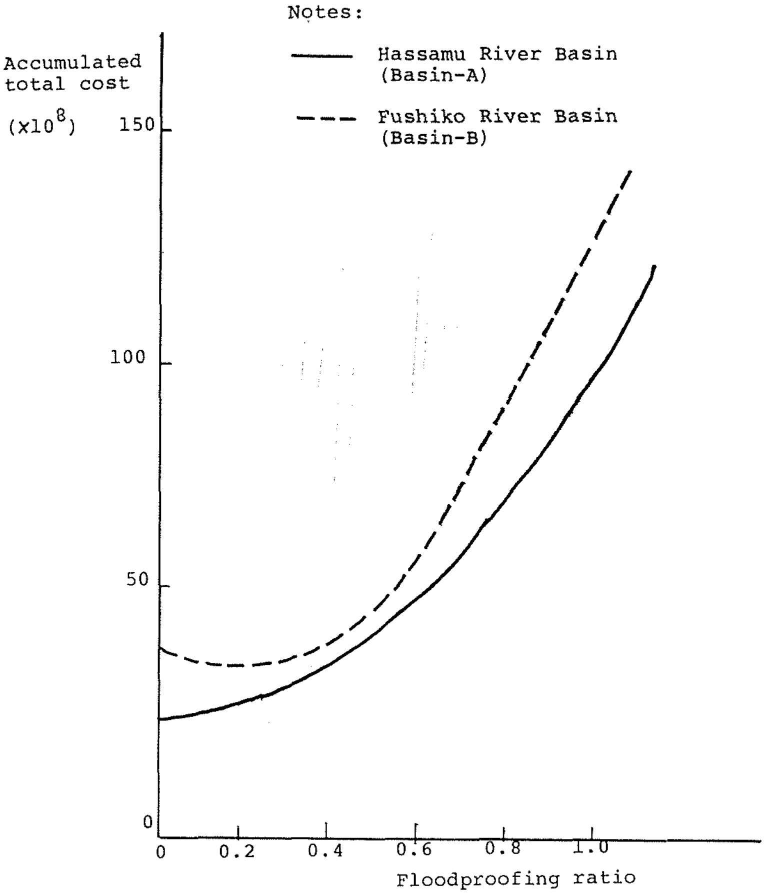


Fig. 7. Relation between accumulated total cost and floodproofing.

elapse, it increases slightly. This is because of the raise of the flood control level.
c) For each watershed the sensitivity of the control level on Basin-B is higher than that of Basin-A. This is because of the effect of the investment in a more dangerous watershed.
d) Fig. 7 shows the relation between the accumulated total cost and floodproofing ratio. According to this, in Basin-A on the condition of no floodproofing the lowest total cost was calculated, while in Basin-B the range from 0.2 to 0.4 indicated the lowest total cost. This is because of the differences of land conditions between two watersheds. It means that the measures of the watershed which has the worse conditions of land should adopt the combined methods of the structural and nonstructural measures.

4. Conclusion

The following contents were clarified by this research:
a) For the examination of the adequacy of enhancement to apply two dynamic models, which are the adaptive type and the optimal type. That is, it clarifies that the regional safety level of flood control and the necessity of flood control measures can be evaluated by the adaptive type model (SD model). In addition, the scale of land development and that of flood control measures can be decided by the optimal type model on the basis of regional economic efficiency simultaneously.
b) The other characteristic of the models can indicate structural measures and nonstructural measures at the same time. Considering the economic efficiency, it is more effective to promote the structural measures. Nonstructural measures can be effective for the social understanding of disasters and the avoidance of risk of flooding with the acception of economic effectiveness. Therefore, both measures can be promoted in the future.
c) It becomes necessary to work on the recognition of social measures (nonstructural measures) and the participation of flood preventive training for the inhabitants in the flooded areas. Moreover, it is also necessary to adhere to the comprehensive method of risk elevation by analysing several numerical methods.

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