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Corroborations of Analytical Methods for Interrelation between Land Use and Water Resources

—In the Case of Large and Medium River Basins—

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Abstract

In this study a new analytical method of regional land management corresponding to riparian planning is proposed in order to evaluate the achievement of regional planning aims, especially, as for land use and the related flood control. These techniques are expressed as a phased method of modeling, which includes descriptive medels, structural models and quantitative models. These models were applied to the large and medium-scale river basins which were the Isihkari River Basin and the Chitose River Basin in Hokkaido. The objectives of the study for a large-scale river basin are to assess the dynamic potential damage (annual potential damage) and to evaluate the appropriate investment of flood control. In order to accomplish the objectives, two models were constructed. One is the interrelational model of flood mitigation and regional activities by System Dynamics. (MILUF model) The other is the model for allocating investment of flood control by multiobjective optimization. In these analyses, it is important to measure each land use pattern, because the type of potential flood damage can be determined by the pattern of land use.

The more effective method of investmnet to reduce the residual potential flood damages is to be adaptive to the land use movement, that is, the net benefit of regional flood control. The analytical objectives for a medium-scale river basin are to develop the regional extensive watershed model and to evaluate the multi-regional levels of several achievements of water policies interacted with land use development.

As the results, the more desirable measures can be searched on basis of the combined measures which are selected into structural and nonstructural measures of interrelation with land use and water resources.

Key words: Systems analysis, water resources planning, land use management, maltiobjective optimization, System Dynamics, Min-Max optimization, annual potential flood damage, flood control, joint occurrence probability, large and medium-scale river basin.

1. Introduction

It is referred by E. P. Odum that a watershed can be considered as one of the minimum econological system. This means that such a space is effective not only to solve water resources problems but also to settle all regional problems[1].

In general, a watershed is composed of several municipalities from viewpoints of the socio-economic aspect. And then it is important in watershed management to assess natural factors and social factors. Land use management is one of significant problems in a watershed. Because it is influenced with water resources problems, i. e. flood control, water use and water quality. As the recent years, the development of land use is ill-conditional land, which has a steep hill or a soft peat layer. Flood hazard issues are often caused by land use enhancement in such a land. Recent trends show that various properties are accumulated and large-scale population and industry are concentrated rapidly around such flooded areas. On the other hand, urban planning, which plays one of the important roles in land management, is not being promoted with regards to safety against flood and flood control level. The objectives of urban planning are to guide urban development according to intentions to schematize the safety of human life and the efficient activities of urban functions, and also to design urban facilities. However, it is not clear how to relate the arrangement of river functions with urban plan in order to attain these objectives.

Consequently, there are several areas of urbanization which have not considered the flood damage potential. For example, housing has been made possible through deforestation of mountains, conversion of paddy fields and by reclamation of small rivers. These cause the reduction of storage abilities of land and a low protection against flooding in urban areas. Accordingly, taking appropritate measures are necessary for reducing urban flood damages to restoring the storage ability of land and the discharge flow of rivers. In other words, the riparian measures today should be adapted to the state of watershed developments. As a concrete method, a new concept which unities two programs should be realized. In some urban areas, it is more effective to restrict the landuse rather than to raise the embankment.

The riparian planning was mainly conformed to "line management". However, it will be necessary to accelerate the concept in which land management is combined with riparian management as "spatial management" in the near future.

The former studies of interaction between land use and flood mitigation within a watershed come under three categories, which are the assessments of flood damages, Cost-Benefit analysis of flood control and alternative methods of optimizing response to the flooding through systems analysis from economic aspects.

One of the assessments of flood damages has been classified according to the categories of land use affected which cause different types of damage, for example, physical damage to buildings and their contents, bridges, roads, railways etc., agricultural crop losses, loss of income due to interruption of business and cost of flood fighting, evacuation, care and rehabilitation of flood victims[2,3].

The other is to calculate the potential damage and damage reduction by a detailed computer model[4].

Such studies of the assessment of regional flood damage, there have been a number of studies using Cost-Benefit analysis of floof control as government-funded schemes in many countries. Cost-Benefit analysis is a technique for evaluating and comparing the benefits and costs and is based on the assumption that the best solution is represented either by the lowest-cost alternative or by the scheme which maximizes the desired objective. And then, the systems analysis approach can be applied at widely differing levels of complexity, for instance, nonstructural methods of flood damage reduction and multi-reservoir flood control systems[5~13].

Moreover, there has been a number of studies for comprehensive water resources system. As for the multiobjective decision system or multi-regional planning system, there have been a study on the Rio-Colorado River by D. C. Major and R. L. Lenton[14], the Maumee River Basin Study analysed with the SWT method by Y. Y. Haimes and W. Hall[15], the Tisza River Basin Model with MUF method by R. L. Keeney and etc.[16], the Yodo River Basin Model by F. Seo and etc.[17] and application of nonlinear goal programming by K. Yoshikawa and N. Okada[18]. On the other hand, there have been the Ohio River Basin Study by A. D. Little[19], the Lehigh River Basin Study by A. Maass[20], the Susquchanna River Basin Study by H. R. Hamilton and etc.[21] and analysis of water supply-demand structure in Kinki District[22] from the viewpoint of interlation between regional planning and water resources projects.

The objectives of this study are to build a new analytical method of regional land management corresponding to riparian planning and to establish the process for evaluating the achievement of regional planning aims, especially, as for land use and the related flood control. Concretely speaking, these techniques are expressed as a phased method of modeling, which includes descriptive models, structural models and quantitative models. The detail of its modeling was described in the previous paper.[23]

Furthermore, in this paper, a extensive model which is improved including the other subsystems for water resouces and the interaction between land use control and flood control or other water resources management can be proposed by using that model.[24,24,26]

2. Illustrative Examples

2.1 Division of River Basin

As mentioned above, objective river basins are divided into three class, which are large, medium and small scales. The large-scale river basin is generally considered as a main stream. In this study the river basin which has more than a hundred km of river length and more than 5,000 km^2 of watershed area. This basin is relevant to the comprehensive development of watershed, the national land planning and regional comprehensive equipmental planning, that is, the level of national planning. The medium-scale river basin is mainly a tributary. Its scale is defined as the range about from 50 to 100 km length and from 100 km^2 to 2,000 km^2 of watershed area. This watershed is relevant to the planning for an extensive sphere of life, the plan for combined urban regions and the planning of watershed water service, etc.. In other words, this area corresponds to the regional planning of prefectural level. The small-scale river basin is the area which is determined by a small tributary. This has less than 50 km of river length and less than 100 km^2 of watershed area. This area corresponds to the scale of the urban planning, the district planning, etc..

2. 2 Objective River Basin

In this study, two river basins are introduced from the scales of watershed mentioned above. One is a large-scale river basin and the other is a medium-river basin.

(1) Large-scale river basin

The example of large-scale river basin is applied to the downstream and mid-stream reaches of the watershed of the Ishikari River, which is about 125 km in length running from Fukagawa City to the estuary town. The areas are divided into ten reaches. Each municipality belongs to each district as shown in Fig. 2. 1 and Table 2. 1. The regional characteristics of such reaches is explained briefly.

1) Reach-A···This reach is an estuary zone including most of Ishikari Cho, which is a neighboring town of Sapporo City, and where a new port has recently been constructed with continuously related industrial zones. Residential developments,

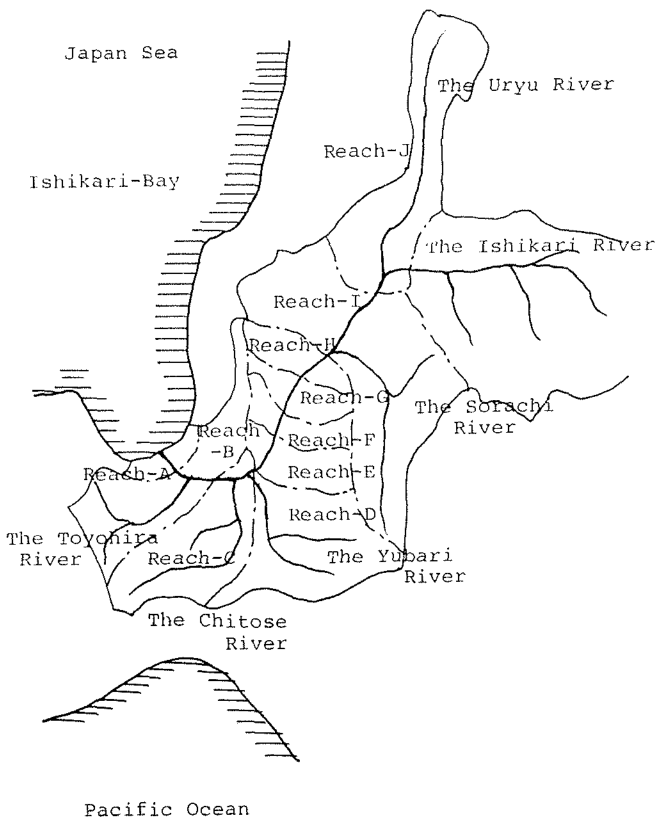


Fig. 2. 1 Location of large-scale river basin The Ishikari River Basin).

Table 2. 1 Municipalities belonging to each reach

Reach	Municiparities
A	Ishikari-Cho
B	Sapporo City, Tobetsu-Cho
C	Ebetsu City, Tobetsu-Cho
D	Shinshinotsu-Mura, Iwamizawa City, Kita-Mura, Ebetsu City
E	Shinshinotsu-Mura, Iwamizawa City, Kita-Mura
F	Bibai City, Kita-Mura, Tsukigata-Cho, Iwamizawa City
G	Urausu-Cho, Bibai City, Naie-Cho
H	Sunagawa City, Shintotsukawa-Cho
I	Takikawa City, Shintotsukawa-Cho, Uryu-Cho
J	Moseushi-Cho, Fukagawa City

such as the Bannaguro housing area and the Shin-Sapporo housing area.

2) Reach-B···This reach includes the northern, eastern and western part of Sapporo City and a part of Tobetsu Cho. It has the highest development level and the most rapid land enhancement of all reaches. Huge damages will be incurred through interactive properties concentration even if a small inundation strikes in this reach.

3) Reach-C···Ebetsu City and the rest of tobetsu Cho are included in this reach. Floodings are frequent because of the junction of two rivers, that is the Ishikari River and the Chitose River. This reach is a important zone for traffic and transport and has been influenced by the extent of the urban periphery of Sapporo City.

4) Reach-D···This reach includes Shinshinotsu-Mura, Iwamizawa City, Kita-Mura and a part of Ebetsu City. This reach has many small branches and a paddy fields zone occupies more than half of this large inundations across embankments are frequent.

5) Reach-E···Iwamizawa City, a part of Kita-Mura and the north area of Shinshinotsu-Mura are included in this reach. This reach is one of the largest granary zone in the Plains of Ishikari. There are residential zone in Iwamizawa City and inner industrial area of Shinshinotsu-Mura are included in this reach. There are residential zone in Iwamizawa City and inner industrial zones are allocated.

6) Reach-F···This area is composed of Tsukigata Cho, Bibai City and the other part of Kita-Mura and Iwamizawa City. The main industry of this reach is agriculture, particularly rice cultivation. In this area, the soft foundation of peat soil is widely distributed. Therefore, the engineering works of levees are difficult.

7) Reach-G···This reach is composed of Urausu Cho, Naie Cho and a part of Bibai City. The population in this reach has decreased gradually. Because of prevention of population decrease, an inner industrial zone has been planned. Agriculture is the chief industry at present.

8) Reach-H…This reach includes Sunagawa City and a part of Shintotsukawa Cho. This area produces rice and some vegetables. The chemical industry is also an important feature.
9) Reach-I…This is composed of Takikawa City, the rest of Shintotsukawa Cho and a part of Uryu Cho. A commercial zone has been allocated and the concentration of property is higher than any other reach in the midstream.
10) Reach-J…This reach is composed of Fukagawa City and Moseushi Cho. The cheif industry is agriculture, particularly some kinds of productions in the fields.
(2) Medium-scale river basin

The watershed area is the Chitose River Basin which is one of the tributaries of the Ishikari River.

The reason why it was selected as a study area are as follows :
1) This river has a slow slope of river bed, of which sources origins from Shikotsu Lake as shown in Fig. 2. 2. Several agricultural zones, mainly paddy land, spread on the rightside of the river and the urban areas extend at hills on the leftside of it. In downstreams there are much soft land with low level and peat soil. The area around Shikotsu Lake is a part of the national Park, the Shikotsu and Toya.
2) It is forecasted that regional population can be increased largely in the future and the land use of the agricultural area can be changed to the industrial zone near urban areas. Therefore the problems of water resources, for instance, as for urban or rural floodings, the supply and demand of regional water system or rationalization of water rights will be anticipated.

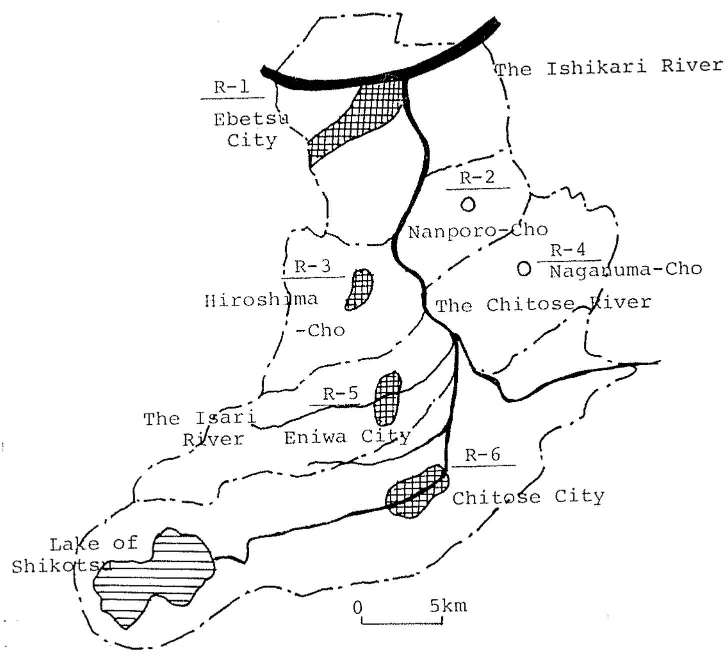


Fig. 2. 2 Outline of medium-scale river basin (The Chitose River Basin).

3) This watershed is adjacent to Sapporo City which has more than 1.5 milions population and include in many other bed-towns and to Tomakomai-Tobu Industrial Park. The water resources in this watershed are influenced with the impacts of both movements. Six municipalities, which are three cities and three towns, exist in this watershed. These municipalities are regard as the object reaches in this study. These reaches are also shown in Fig. 2. 2. The regional economic indexes are represented in Table 2. 2.

Table 2. 2 Regional economic index (1975=initial planning year)

	Ebetsu Reach-1	Nanporo Reach-2	Hiroshima Reach-3	Naganuma Reach-4	Eniwa Reach-5	Chitose Reach-6
Population	77,623	5,651	22,263	13,263	39,883	61,031
Rate of population increase	1.22	0.87	2.23	0.93	1.16	1.09
Land use (km^2)						
Paddy field	52.80	56.03	10.83	94.40	34.09	11.58
Farm	38.34	5.00	16.44	16.01	20.07	56.52
Residential area	9.61	1.73	6.47	4.30	8.30	10.73
Forest	18.26	0.00	44.26	9.96	139.65	332.72
Others	69.62	16.45	48.03	46.03	92.60	261.64
Total area	188.83	73.21	121.05	170.07	294.71	594.36
Agricultural workers	3,007	2,034	1,307	4,359	2,255	1,621
Factorial employees	17,283	830	6,928	2,435	14,249	26,878
Commercial employees	3,892	244	1,109	801	2,651	4,902
Industrial products (10^4 yen)	46,850	411	18,260	1,106	26,899	45,886
Commercial selling (10^4 yen)	45,399	3,559	11,461	12,137	27,322	54,211
Water supply (m^3/day)	39,600	2,000	17,321	4,000	11,945	35,700

3. Analytical Methods and Applications

3.1 Regional Analysis of Characteristics of Potential Flood Damage in a Large River Basin

The main objectives of the study for a large river basin are to assess the dynamic potential damage in each reach and to evaluate the appropriate investment of flood control. In order to accomplish the objectives, two models were constructed. One is the interrelational model of flood mitigation and regional activities by System Dynamics (SD modeling). The other is the model for allocating investment of control by multiobjective programming. The former model was already detailed and clarified in the previous paper[23]. In this paper, the advanced ideas are represented, for example, the evaluation of dynamic achievemental degree of flood control, the influences of indirect damage potential, etc..

(1) Regional characteristics of potential flood damage

Several results of simulation with the model for interaction between land use and flood control (MILUF model) were analysed in the ten reaches. The results are described to evaluate the potential flood damages corresponding to the regional developments of these reaches in the future. The potential flood damage of each reach using the Benefit-Cost Ratio as a method of investment is shown in Fig. 3. 1. By the way, the Benefit-Cost Ratio (B/C) equals 1.0 in the case of this figure.

These trends are classified by three patterns :

1) The first is the type of the highly urbanized reach like Reach-B. That is, the marginal benefit of investment is very high in this pattern and in the initial term of simulation, residual potential flood damage decrease rapidly. But after the objective level is accomplished and the investment is stopped, the residual potential flood damage may return to the former state and continue after that. In other words, the sensitivity to investment is large and the potential damage is varied with a method of investment like a sponge. It is important to determine the level of flood control like in this pattern of land use by the complement of both structural and nonstructural measures.

2) The second pattern is that of slightly increasing residual potential flood damage like Reach-A, Reach-C, Reach-H and Reach-J. Future land development will be expected in these reaches and do not followed the scale of considered

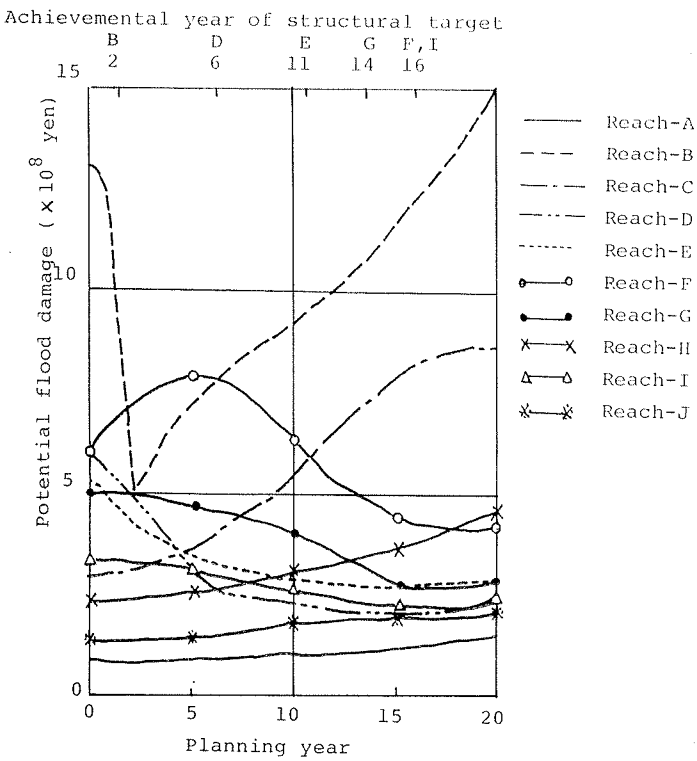


Fig. 3. 1 Potential damage in each reach using Method-I.

method of investment. It is necessary to increase the rate of investment when the level of control is higher than the present one. In other words, the level of flood control should be established in consideration of the land development and land enhancement in each reach.

3) The last pattern is that of decreasing a residual flood damage potential corresponded to flood control investment like Reach-D, Reach-E, Reach-F, Reach-G and Reach-I. In other words, the effect of flood control investment is stabilized. This is because of the agricultural pattern of land use.

(2) Investment allocation problem of flood control

In this paragraph, several methods of the investment of flood control are discussed. The investment is divided broadly into two kinds of costs. These are the cost of construction and the cost of maintenance. The cost of construction involves the construction of levees in this case, and the cost of maintenance involves reinforcement of subsidences of levees, turfing and trimming of turfs. The methods introduced in this study are three and they are described as follows:

1) Method using the Benefit-Cost Ratio (Method-I)

This method assumes that a benefit is an annually reduced potential flood damage and a cost is an annual investment. By using these two values and multiplying the ratio by a constant, the following annual investment is determined:

$$IR_{i+1} = (RCPD_i/IR_i)\cdot M_c\,, \qquad (3.1)$$

where IR_{i+1}; the investment of $(i+1)$ th year, $RCPD_i$; the reduced potential flood damage of i-th year, IR_i; the investment of i-th year, M_c; the constant (in general, $M_c=1$).

2) Method using the net-Benefit (Method-II)

The net-Benefit is the difference between benefit and cost. These two values are the same as values of the former method. The investment of the following year is defined as:

$$ID_{i+1} = MB_i\cdot M_d\,, \qquad (3.2)$$

where ID_{i+1}; the investment of $(i+1)$th year, NB_i; the net-Benefit of i-th year, M_d; the constant (in general, $M_d=1$).

3) Method solving the multiobjective problem (Method-III)

In this method the problem which minimums two objectives, that is the total cost and the disparity of the total cost with each reach.

The problem is formulated with:

$$C_i(t) = C_{0i}(t) + C_{mi}(t) + D_i(t)\,, \qquad (3.3)$$

$$C = \sum_{t=1}^{T}\sum_{i=1}^{N} C_i(t) \longrightarrow \min.\,, \qquad (3.4)$$

$$C_{mi}(t) = R_m\left\{C_{0i}(t)\right\}, \qquad (3.5)$$

$$D_i(t) = \sum_{j=1}^{J} P_j(t)\cdot G_{ij}\left\{q_i(t)\right\}\cdot RD_j\left\{q_i(t)\right\}, \qquad (3.6)$$

$$W_{di}(t) = \left| C_i(t) - C_{av}(t) \right| , \tag{3.7}$$

$$C_{av}(t) = (1/n) \sum_{i=1}^{N} C_i(t) , \tag{3.8}$$

$$W = \sum_{t=1}^{T} \sum_{i=1}^{N} W_{di}(t) \longrightarrow \text{min.} , \tag{3.9}$$

subject to

$$q_i(t) = Q_i \left\{ C_{0i}(t) \right\} , \tag{3.10}$$

$$\sum_{i=1}^{N} C_{0i}(t) \leq C_{0\,\max} , \tag{3.11}$$

$$\sum_{i=1}^{N} C_{mi}(t) \leq C_{m\,\max} , \tag{3.12}$$

$$C_{0i}(t) \geq 0 \quad \forall i , \tag{3.13}$$

where $C_i(t)$; the total cost of t-th year, $C_{0i}(t)$; the construction cost of structural measures, $C_{mi}(t)$; the cost of maintenance, $D_i(t)$; the annual potential damage, $W_{di}(t)$; the disparity of total cost in reach i, $C_{av}(t)$; the average value of total cost in the whole watershed, $P_j(t)$; the property of the production per unit area, $G_{ij}\left\{q_i(t)\right\}$; the function inundated area, $RD_j\left\{q_i(t)\right\}$; the function of rate of damages (the function of damage density) and $q_i(t)$; the saved discharge.

Figure 3. 2 compares with the costs of two reaches by the difference between

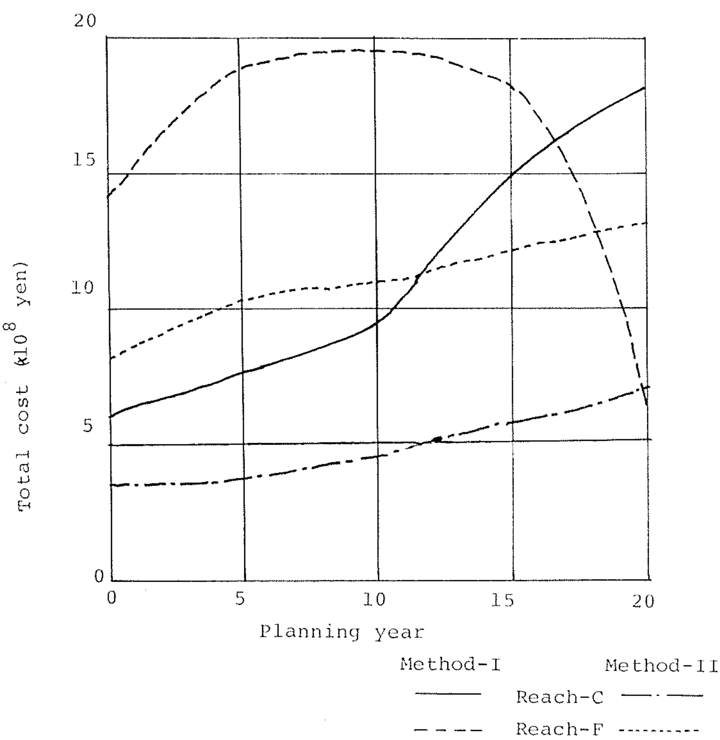


Fig. 3. 2 Total cost compared Method-I with Method-II.

Method-I and Method-II.

The accumulated total cost for twenty years by Method-II were less than that of Method-I in both reaches, i. e. Reach-C and Reach-F. In the case of Method-I, the total cost in Reach-C which included a core city of the local area, was less than that of Reach-F, which was in an agricultural area. This is because of the difference of flood control level, that is, the level of Reach-C was higher than that of Reach-F.

Moreover, the reduction of potential damage is not so substantial, while the cost of construction is large.

After all, Method-II may be more effective than another methods under the condition that there is an outstanding economic efficiency and adaptability for land management.

Table 3. 1 provides the allocated rates of investment in each reach given by three methods.

Method-I requires more investment and allocates higher rates to the reaches which have large potential damages in the initial term. In case of Method-II, the investment responded to the change of land use more susceptibly. The rate of investment was especially higher in the reach where land development was prospected. This is similar to the results of Method-III which is at the target year. In other words, Method-I can be more dependant on the initial potential damage and Method-II can be more adaptive to the future regional development.

(3) Scenarios analysis for land use-flood control interaction

(i) The impact of potential damage of traffic

The damage of traffic is taken as the reduction of a total production for the whole of Hokkaido caused by the inundation on each reach. The scale of traffic damage is shown in Fig. 3. 3.

The damage of Reach-B reached a much larger value when compared with that of the other reaches, on account of the extensive impact over the entire region.

Table 3. 1 Allocated rate of investment in each reach

Reach	Method-I	Method-II	Method-III
A	0.025	0.025	0.028
B	0.212	0.082	0.105
C	0.009	0.072	0.070
D	0.242	0.094	0.150
E	0.211	0.194	0.173
F	0.084	0.200	0.169
G	0.082	0.169	0.128
H	0.019	0.055	0.052
I	0.102	0.105	0.098
J	0.014	0.004	0.027

(Each total equals 1.0).

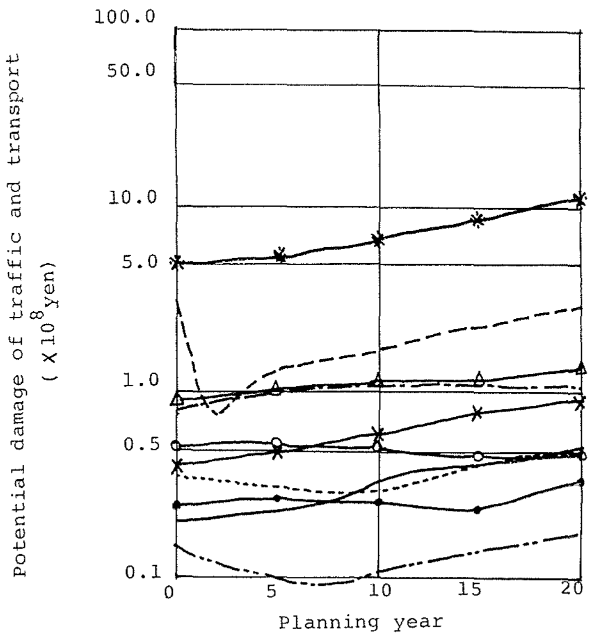


Fig. 3. 3 Potential of traffic and transport damage (Symbols are same as Figure 3.1).

Table 3. 2 Increases of potential damage by investment of agricultural developments ($\times 10^4$ yen)

Planning year	0	5	10	15	20
Reach-A	0	15	178	207	216
Reach-B	0	551	1,177	1,881	2,650
Reach-C	0	353	665	864	872
Reach-D	0	8	100	164	239
Reach-E	0	23	24	68	99
Reach-F	0	664	569	84	148
Reach-G	0	214	111	286	423
Reach-H	0	741	1,305	2,482	1,910
Reach-I	0	267	319	266	378
Reach-J	0	86	179	280	386

Reach-J had also the largest damage of all reaches. This is because the inundating duration. The influences of past traffic volume was computed in only Reach-D and Reach-F. It happens that the heights of roads (national highways) are above the inundated heights in other reaches. The expected losses by delay of detour of past traffic were 4 millions yen in Reach-D and 30 thousands yen in Reach-F.

(ii) The impact on damages by agricultural investment

Table 3. 2 provides increase of potential damage by the investment of agricultural developments. The increases of Reach-B and Reach-H were remarkably

similar. These damages can be increased in scale when accumulated for planning term, though the damage in each year is very small.

3.2 Land Use Management Interacted with Flood Control and Regional Water Supply in Medium Scale Basins

In general, a medium scale basin is defined as a watershed of a branch of a large scale river and including several municipalities. The extensive administrative areas which are combined by some cities, towns and villages have often appeared in a medium scale basin. For example, the extensive sewerage system for watershed or extensive allocative system of water supply has been planned in these areas.

There are several specific characteristics in a medium scale basin as follows:

1) It has a multiplicity of land use and the planning of land use in each municipality is independant.

2) The comprehensive problems between land use management and water resources planning, which are water use management, flood control and water quality control can be investigated more easily.

3) The extensive planning in a watershed can be needed more strongly.

(1) The evaluation for joint occurrence probability of flooding influenced by upper reaches

The watershed system is supposed as Fig. 3.4. The upper reach is Reach-A and the lower reach is Reach-B. Both reaches are protected with levees. The flow Q_A and Q_B is the peak flow of Reach-A and Reach-B, when levees in either district are not destroyed.

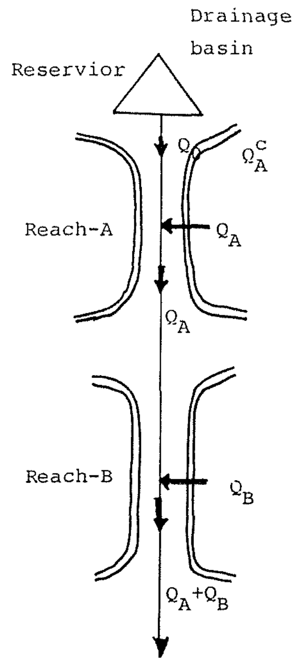


Fig. 3.4 Model of interrelation of two reaches in a watershed.

In this case, the following events may be assumed:

① Levees in either reach are not destroyed.
② Levees in Reach-B are destroyed.
③ Levees in both reaches are destroyed.
④ Levees in Reach-A are destroyed.

Each condition of occurrence of four events is indicated in Equations (3.14)-(3.17)[27].

$$\text{Condition 1);}\quad Q_A \leq Q_A^c \text{ and } Q_A + Q_B \leq Q_B^c, \tag{3.14}$$

$$\text{Condition 2);}\quad Q_A \leq Q_A^c \text{ and } Q_A + Q_B > Q_B^c, \tag{3.15}$$

$$\text{Condition 3);}\quad Q_A > Q_A^c \text{ and } Q_A + Q_B > Q_B^c, \tag{3.16}$$

$$\text{Condition 4);}\quad Q_A > Q_A^c \text{ and } Q_A + Q_B \leq Q_B^c, \tag{3.17}$$

where Q_A^c and Q_B^c are the capacities of flowing in those reaches. Each probability of occurrence in each reach is described in Equations (3. 18) and (3. 19).

$$P_A = \iint_{C_3+C_4} P(Q_A, Q_B)\, dQ_A dQ_B\,, \tag{3. 18}$$

$$P_B = \iint_{C_2+C_3} P(Q_A, Q_B)\, dQ_A dQ_B\,, \tag{3. 19}$$

Therefore, annual potential damage (annual expected flood damage) in each reach is calculated by Equations (3. 20) and (3. 21).

$$\begin{aligned} APD_A(t) = &\iint_{C_3} G\left(Q_A(t) - Q_A^c(t)\right) \cdot P\left(Q_A(t), Q_B(t)\right) dQ_A(t)\, dQ_B(t) \\ &+ \iint_{C_4} G\left(Q_A(t) - Q_A^c(t)\right) \cdot P\left(Q_A(t), Q_B(t)\right) dQ_A(t)\, dQ_B(t) \end{aligned} \tag{3. 20}$$

$$\begin{aligned} APD_B(t) = &\iint_{C_2} G\left(Q_A(t) - Q_A^c(t)\right) \cdot P\left(Q_A(t), Q_B(t)\right) dQ_A(t)\, dQ_B(t) \\ &+ \iint_{C_3} G\left(Q_A(t) - Q_B^c(t)\right) \cdot P\left(Q_A(t), Q_B(\mathrm{t})\right) \mathrm{d}Q_A(t)\, dQ_B(t) \end{aligned} \tag{3. 21}$$

Where $APD_A(t)$ is the annual potential damage in Reach-A and $APD_B(t)$ is that is that in Reach-B. Each variable is considered as the annual data by introducing the t-th year.

Figure 3. 5 shows the degree of achievement of flood control level in each region when the conditions of upper reach are not considered. Fig. 3. 6 shows the same index when such conditions are considered.

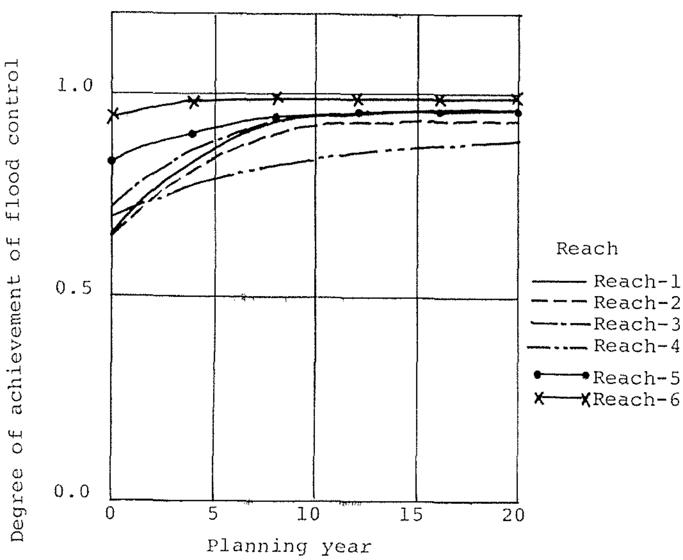


Fig. 3. 5 Degree of achievement of flood control level (In case of no consideration of upper reaches).

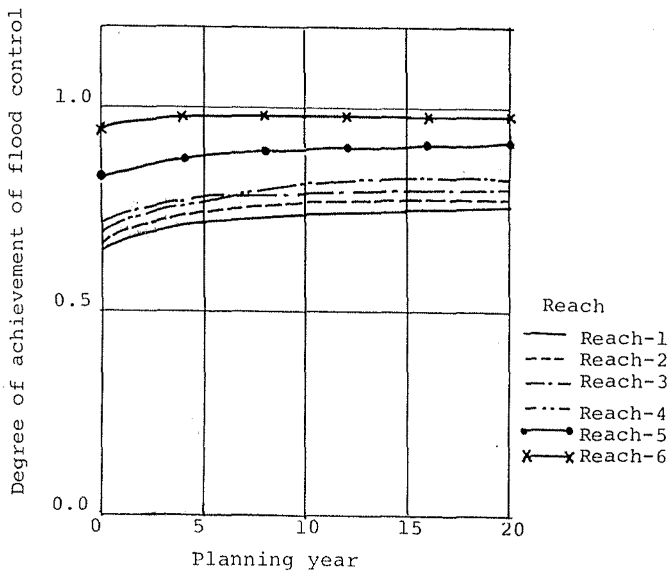


Fig. 3. 6 Degree of achievement of flood control level (In case of consideration of upper reaches).

In this analysis, several results are described as follows :

1) In the case of potential damage in present years, the regions which have larger potential are Reach-1, Reach-4 and Reach-5. The potential damage of Reach-1 is the highest in all regions because it includes the potential damage of the Ishikari River. Reach-4 has the highest potential of only the Chitose River.

2) In the ratio of components of damage, the reaches which have a high ratio of agricultural damage in present years are Reach-6 and Reach-3. This is because most of the residential zones of these areas are located on higher land. Therefore, the safety of residential zones have similar height of land to the agricultural zones.

3) As for the model considering, influences of upper reaches, the probabilities of occurrence in lower reaches are heigher and goal attainments are delayed. For example, Reach-1 where is in the lowest reach drops in 78% of the independant type.

(2) Analysis by the model of allocating water resource in a watershed

The controllable variables in management problem for utilization of water are ① allocation of new water supply, ② restriction of land use or urbanized area and ③ arrangement of facilities for water resource management and so on.

It is very difficult to determine allocated volume of water in each reach because of decision of water right in the future. Generally, in the case of large-scale, the allocation of a new water, development to each region is considered as the problem of decisionmaking for national government or a public corporation of water resources.

In this case, the allocation problem to several reaches is treated considering various causal factors in regional conditions. The problem is formulated on basis of the following conditions.

1) The land use of each reach is given as a parameter and the total water from reservoir is also given as a parameter.
2) The controllable variable is allocation of water in each reach.
3) Two objective functions are proposed: One is the degree of achievement for water supply, the other is the degree of achievement for environmental standards.
4) The new water resource is allocatable to all reaches without structural constraints.
5) The cost for allocated water in each reach can be charged completely by each reach.
6) Water supply in each reach is considered as the volume added the present demand to new allocated water. And water demand of each reach in the target year is forecasted by means of the regional index in the future.
7) Each reach has on facility of sewerage.

On basis of these conditions the following equations are formulated.

When new water supply form reservior Q_d is derived, Q_d forms a trade-off with controlled discharge for flood of dam Q_{fd}. That is, the relation of these variables is implied as follows:

$$Q_d = Q_t - Q_{fd}\,, \tag{3. 22}$$

where Q_t is the total controllable volume of the reservoir. Meanwhile the change of land use has influenced on the water demand in each region. Q_{di} is the water demand of i- reach in the target year. Water demand depends on the regional activities, for example, population migration and location of factories. Therefore, it is derived with the following relation:

$$Q_{di} = G(l_{ij})\,. \tag{3. 23}$$

In this case, these variables Q_{fd} and l_{ij} are given. q_{xi} represents the allocated water in i reach newly.

The achievemantal degree of water use W_{i1} and environmental standard W_{i2} in i-reach can be formalized each other:

$$W_{i1} = (Q_{si} + q_{xi})/Q_{di}\,, \qquad \forall i\,, \tag{3. 24}$$

$$W_{i2} = B_{si}/B_{ri}\,, \qquad \forall i\,, \tag{3. 25}$$

$$B_{ri} = b_i(q_{si} + qx_i) + B_{ri-1}\beta_{i-1}\,, \qquad \forall i\,, \tag{3. 26}$$

where;

Q_{si}; water supply in a target year without new development of water (m^3/day), B_{si}; limited value of environmental standard (ppm), B_{ri}; load of environmental sewage (ppm), b_{ri}; load of environmental sewage per unit discharge (ppm/m^3), β_{i-1}; rate to reach the flowing sewage.

In the case of the Equation (3. 26), Q_{si} is selected to the smaller one of $Q_{si}+q_{xi}$ and Q_{di} actually.

By using the Equations of (3. 24) and (3! 25), the following planning problems are formulated:

$$W_1=\sum_{i=1}^{N} W_{i1} \longrightarrow \text{max.}, \tag{3. 27}$$

$$W_2=\sum_{i=1}^{N} |W_{i1}-W_{i1}^A| \longrightarrow \text{min.}, \tag{3. 28}$$

$$W_{i1}^A=\frac{1}{N}\sum_{i=1}^{N} W_{i1}, \tag{3. 29}$$

$$W_3=\sum_{i=1}^{N} W_{i2} \longrightarrow \text{max.}, \tag{3. 30}$$

$$W_4=\sum_{i=1}^{N} |W_{i2}-W_{i2}^A| \longrightarrow \text{min.}, \tag{3. 31}$$

$$W_{i2}^A=\frac{1}{N}\sum_{i=1}^{N} W_{i2}. \tag{3. 32}$$

The following constraints are also represented :

$$\sum_{i=1}^{N} q_{xi} \leq Q_d \qquad \forall i, \tag{3. 33}$$

$$0 \leq q_{xi} \leq q_{xi}^{\max} \qquad \forall i, \tag{3. 34}$$

where W_1 ; the objective of achievement of water use, W_2 ; the objective of disparity among each achievement of water use, W_{i1}^A ; the average of each achievement in a whole watershed, W_3 ; the objective of achievement of environmental standard, W_4 ; the objective of each achievement in a whole watershed.

Table 3. 3 implies the ratio of allocated water to each reach. In this case, the target year is supposed as 1995. The new developmental water is supposed as the present projected value. In the case of A-1, the objectives of water use, i. e. Equations of (3. 27) and (3. 28) are introduced and in the case of A-2, the objectives of water use and water quality are considered as Equations of (3. 27) (3. 38), (3. 30) and (3. 31).

As the result of case A-1, while the achievement of water use can be balanced

Table 3. 3 Result of water allocation and degree of achievement in 1995 (in case of Q_d)

	A-1		A-2	
	Rate of allocation	Degree of achievement	Rate of allocation	Degree of aceievement
Reach-1	0.21	0.86 0.72	0.07	0.70 0.92
Reach-2	0.09	0.86 3.60	0.19	1.48 1.82
Reach-3	0.20	0.86 3.20	0.24	0.94 1.12
Reach-4	0.09	0.86 1.22	0.20	1.70 1.64
Reach-5	0.20	0.86 1.22	0.23	0.92 0.92
Reach-6	0.20	0.86 0.72	0.07	0.70 0.92

Note ; Degree of achievement upper line- water use, lower line- environmental standard.

Table 3.4 Result of water allocation and degree of achievement in 1995 (in case of 0.5 Q_d)

	A-1		A-2	
	Rate of allocation	Degree of achievement	Rate of allocation	Degree of achievement
Reach-1	0.24	0.82 0.80	0.08	0.68 0.98
Reach-2	0.06	0.80 3.70	0.18	1.43 1.92
Reach-3	0.19	0.80 1.30	0.24	0.91 1.23
Reach-4	0.07	0.79 3.34	0.20	1.65 1.75
Reach-5	0.22	0.81 1.33	0.23	0.90 0.99
Reach-6	0.22	0.80 0.80	0.07	0.68 0.95

Notes; Degree of achievement upper line- water use, lower line- environmental standard.

in each reach, the achievements of environmental standard is unbalanced in each reach remarkably. In case of A-2, both achievements are unbalanced in each reach, but the disparity of achievement of environmental standard can be decreased.

Table 3.4 implies the allocation of the new developmental water in each reach when the water supply decreases half of the present projected water by influences of flood control. As a result, the rates of allocation are influenced by the conditions of the reaches more strongly. And the degree of achievement in each reach is about 6-7% lower than that of the former case generally.

(4) Evaluation of importance of land use by restriction of water resource in watershed management

(i) The regional watershed management model (RWM model)

The model used in this paragraph is for middle scale basins, in particular, for those prossessing varying characteristics on each region. This system model aims for an interaction between attainment of flood control and the other achievement of water resources. That is, the process for the selection of alternatives of water resources management is formed by the dynamic model.

The condition for the model construction are as follows:

1) Each objective to change dynamically and the degree of each goal attainment defined previously can be evaluated by the related factors of natural environment and social environment.

2) The interrelation of each objective for water resources system and the concrete alternatives can be formed into the related factors of natural environment and social environment.

3) The establishment of scenerios and alternatives for the simulation model can be treated considering the priority of measures by structural modeling.

4) The model can analyse the alternatives corresponding to the regional changes in the future not only for structural measures but also for nonstructural measures.

5) Comprehensive measures for water resources can be evaluated by simulation

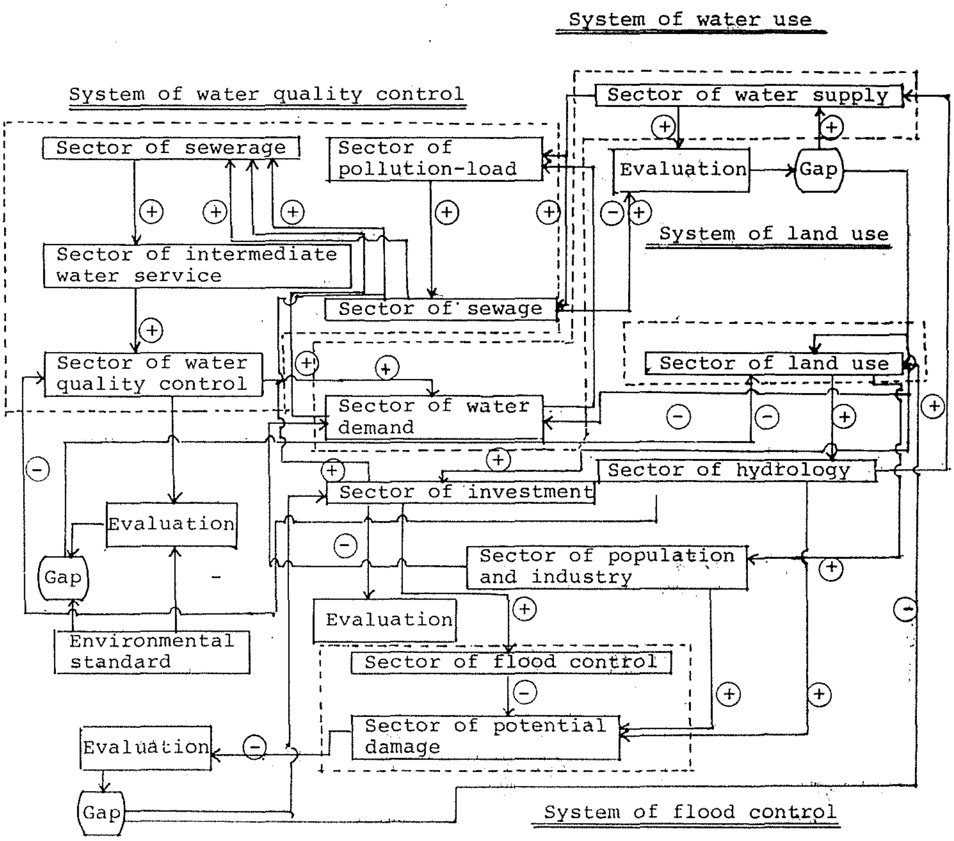


Fig. 3. 7 System structure of regional watershed management model (RWM-model).

analysis. The extensive linkage model between flood control and land use showed in Fig. 3. 7 includes managements of other comprehensive water resources.

By means of the basic structure of the RWM model, the combination of subsystem is explained. The sector of water supply is composed of the water system from river and the recycle water system. The sector of water demand from the sector of population and industry. Finally the level of water use is defined by water supply and water demand. The sector of population and industry is included in the forecasting of region, land use adjustment and the restriction of industrial site. In the sector of pollution-load, pollutant load is calclulated and cost of facilities. The sector of water quality takes the value of water quality from the sector of disposal and sector of intermediate water service.

The objectives of water resource management are evaluated by means of the following indexes:

a) The degree of achievement for living use···This index is acquired by dividing supply by demand. It is also considered as level of satisfaction for housing or business.

b) The degree of achievement for industrial use···This index is similar to

the index of living use. That is satisfaction of industry is implied.
c) The degree of achievement for environmental standard···This index is given by dividing environmental standard by water quality of each reach. It represents level of satisfaction for comfortability.
d) The degree of achievement for flood control···This index is represented as dividing annual expected reduced flood damage by annual expected flood damage. It implies the level of satisfaction for the safety.
e) Level of total cost···This index is represented as dividing the total cost by the planning scale of budget for water resources in each region.

The indices mentioned above are formulated as follows:

$$D_w^k = W_s^k / W_{ind}^k \tag{3.32}$$

$$D_{win}^k = W_{ins}^k / W_{ind}^k \tag{3.33}$$

$$D_q^k = B_s^k / B_r^k \tag{3.34}$$

$$D_f^k = D_r^k / (D_e^k + D_r^k) \tag{3.35}$$

$$D_c^k = C_i^k / C_p^k \tag{3.36}$$

where;
D_w^k; degree of achievement for industrial use, D_{win}^k; degree of achievement for industrial use, D_q^k; degree of achievement for environmental standard, D_f^k; degree of achievement for flood control, D_c^k; level of total cost, W_d^k; demand of living use (m^3/day), W_{ins}^k; supply for industrial use (m^3/day), W_{ind}^k; demand of industrial use, B_s^k; restricted environmental standard, B_r^k; load of sewage (Both loads—g/day), D_e^k; annual expected damage (10^4yen), D_r^k; annual expected reduced flood damage (10^4yen), C_i^k; total cost, C_p^k; projected allowable cost.
(ii) The results of the analysis of regional watershed management model (RWM model)

The goal attainments of watershed planning were analysed by the RWM model dynamically. In these simulation analyses, the condition of scenarios of 19 cases were used as shown in Table 3. 5. Then, alternatives were described in Table 3. 6. In case of transition that depends on present trend the results are presented in Table 3. 7.

Except for the flood control level, all other levels were assumed to go down. In particular, the level of water supply dropped remarkably. In case of Reach-6 (Chitose City), conditions for level of water supply was severe.

The results are represented in Fig. 3. 8. According to these results, the level of residential water use was improved by structural measures. However the level of industrial water use was improved only by structural measures to combine nonstructural measures. The level of river quality was also maintained by nonstructural measures. The influences on the level of flood control was small in case of structural measures. But the influence was large in case of the restriction of nonstructural measures. That is, land development reduced regional flood damage. However to achieve the level of flood control in these reaches, it is sufficient to imply only structural measures.

Table 3.5 Alternatives and their conditions

Alternatives	Conditions
1. Arrangement of sewerage system	a. The case of the present project. b. The case of twice scale of present project.
2. Rationalization of industrial use	Reutliization rate of the water for cooling or adjustment of temperature a. till 1990. b. till 2005.
3. Reutilization of third disposal water	20% of whole volume will be used as industrial and the other use in 1990. And then the usage will be increased by a constant value.
4. Save of living use	The instruments of saved water begin to use from 1980 and rate of saved water will be 25% in 1995.
5. Rationalization of agricultural use	Residual water right is divided by decrease of agricultural land.
6. Flood control	a. Levee. b. Flood-proofing.
7. Restriction of industry	Restriction new industrial site by evaluation of a gap.
8. Restriction of developmental housing area	Stopping new establishment of urbanized area by evaluation of a gap.

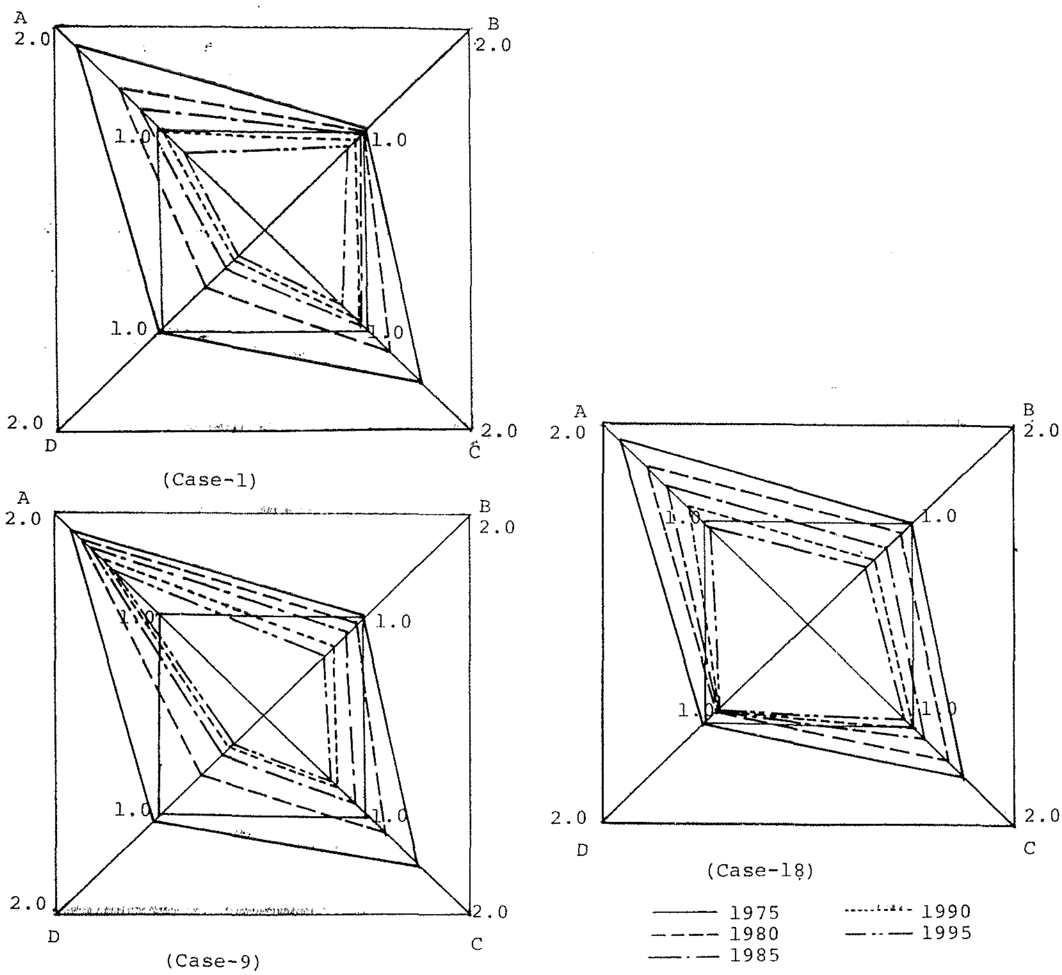
Table 3.6 Scenarios applied to the simulation

Type	Case	Sewerage system	Industrial use	Third disposal	Save water	Rationalization of agricultural water	Flood control	Restriction of industry	Restriction of housing
I	1	a	a				s		
	2	a	a				n		
	3	b	a						
II	4	a	b	×	×				
	5			○	×				
	6			○	×				
	7			×	○				
	8			○	×				
	9			○	○				
III	10			×	×	○		×	×
	11			×	×	×		○	×
	12			×	×	×		×	○
	13			×	×	○		×	×
	14			×	×	×		○	×
	15			×	×	×		×	○
	16			×	×	×		○	○
	17			×	×	○		○	○
	18			○	○	×		○	○
	19			○	○	○		○	○

Notes; ○; adoption, ×; no adoption, a; trend of the present, b; advanced s; structural measures, n; nonstructural measures.

Table 3.7 Results of the analysis of RWM model (Type of I and Case of 1)

Degree of achievement \ Reach	Year	Reach-1	Reach-2	Reach-3	Reach-4	Reach-5	Reach-6
Living use	1975 1985	1.14 0.96	0.82 0.79	1.96 1.63	1.89 1.79	0.93 0.98	1.56 1.13
Industrial use	1975 1985	0.58 0.51	— —	1.03 0.91	2.50 1.11	0.38 0.38	0.78 0.54
Environmental standard	1975 1985	2.00 1.44	2.00 1.44	1.52 1.41	1.77 1.67	1.41 2.40	1.04 1.16
Flood control	1975 1985	0.65 0.95	0.65 0.93	0.72 0.95	0.70 0.84	0.83 0.95	0.95 0.98



A ; Degree of achievement for living use
B ; Degree of achievement for industrial use
C ; Degree of achievement for environmental standard
D ; Level of total cost

Fig. 3.8 Results of simulation analysis (In case of Reach-6)

4. Conclusion

The results in this paper can be summarized as follows:

(1) Analytical results in the case of large-scale river basin

1) The simulation model which has the interactional functions between land use and flood control-MILUF can be generally applied to the large-scale river basin, e. g. the Ishikari River Basin. The characteristics of potential damage in several areas within a watershed can be interrelated with land use activities by using the model. Namely, many factors included in several subsystems, that is, the land use, the social and economic, the flood damage and the flood control subsystems, are connected on the same stage and the same time. The regional safety of land development can be evaluated by means of the comprehensive system.

2) In these analyses, it is important to measure each land use pattern, because the type of potential flood damage can determined by the pattern of land use.

3) The more effective method of investment to reduce the residual potential flood damages is to be adaptive to the land use movement. That is, the adaptive method is to evaluate the interaction between benefit and cost in each year, particularly, the annual net benefit. On the basis of the net benefit or the benefit-cost ratio, the regional cost should be allocated to each region (each reach).

4) This model can be extended to the comprehensive planning of regional land use to the extent of indirect potential damage, for example, impacts of stoppage and the interruption of business.

(2) Analytical results in the case of medium-scale river basin

1) These modeling techniques proposed can be applied to the comprehensive system of land use management in a medium-scale of river basin. That is, the problems of the complex water resources management can be solved by means of investigation of this sequential and phased modeling techniques.

2) The more desirable measures can be searched on basis of the combined measures which are selected into structural or nonstructural measures of interrelation with land use and water resources.

3) The simulation of large scale SD model can be analysed by a few scenarios on basis of several support systems.

4) In case of the area for which it is difficult to develop the new water resources, even if the water supply is increased by the present project of water development, the level of water use, in particular, in the urbanized area may be reduced gradually. Because of the prevention of these trends, nonstructural measures should be promoted strongly, for example, a saved water measure and restriction of land use.

5) The level of flood control will be advanced because the absolute potential damage in each reach is not large so much. However in a view of comparison with whole reaches each other, the disparity of achievement for flood control in these reaches is large significantly. Therefore, it will be important to consider the priority of each reach to the project.

After all, the System Dynamics Model- MILUF was introduced to analyse the regional land use patterns interrelated with the regional potential flood damage in the large-scale river basin. The extensive watershed model-RMW was also el-laborated in order to measure the objectives of water resources planning interacted with regional socio-economic activities in the medium-scale river basin. Both models were made sure to be effective in order to present the complex systematical behaviors of those watershed.

Furthermore, a kind of the adaptive control technique, the Cost-Benefit analysis and a technique of multiobjective optimization-Min-Max optimization were much valuable for deciding water resources policies among several reaches. The most important approach for researches of interrelation between water resources and land use is to combine and to apply these methods of systems analysis orderly and systematically.

As for the future studies, it is necessary for the researches of flooded areas to investigate the geographical, geological and socio-economic factors and to collect the regional information data including the structure of consciousness of inhabitants more accurately. In particular, the structure of consciousness of inhabitants has been investigated by a questionnaire after an inundation. Moreover, it is also necessary for mesh-data or specific data in flooded areas to be arranged for future land use.

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