Environ. Sci. Hokkaido	6 (1)	43~66	June 1983

A Study on Analytical Methods for Land Use Control in Flood Estimated Areas

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洪水氾濫想定地域における土地利用管理分析手法に関する研究

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1. Introduction

In Japan, it is not uncommon for the people to suffer from natural disasters, in particular, inundations due to conditions of geographical and meteorological features. In addition approximately 50% of the population and 70% of properties are known to have been concentrated in the flood estimated areas, which comprise 10% of the whole country [1]. The flood estimated area is considered as the range of the flood periphery assumed in the maximum flooding based on historical data or probable flooding estimated in the future. In spite of the great amount of endeavor towards flood control, serious losses are suffered each year. This is especially so in recent years when flood damages have increased in urban areas with the advance of urbanization and development of watersheds. Therefore, it has become a very important task for not only government agencies but also the inhabitants in an inundated area to defend their lives, to protect their porperties and to maintain normal routine life. In a view of these points, the problem of land use planning in flood estimated areas becomes one of the most important issues for regional planning.

The recent trends in land use have taken a greater interest in the efficient enhancement of urban functions. This results in a rapid increase in demands for residential or for industrial sites, and the flood-plains are utilized intensively. Consequently, the reduction of flood damages is not so remarkable, in fact, damage has even increased in several potential areas, though river work has advanced steadily. Thus the characteristics of river basins have increased in diversity.

Received 21 Feb. 1983
1983年2月21日受理

The first purpose of this paper is to examine the structure and function of the land use activities in flood estimated areas, and this is interrelated to factors of water resources, in particular, the characteristics of regional potential floods.

The second purpose is to establish the procedure for investigating the dynamic system of land use control related to regional potential damages of flooding.

In order to achieve these purposes, certain types of systems analysis have been utilized in the investigation of interaction of land use and watershed management. Systems analysis is an alternative method for optimizing the response to the regional flood problem. Systems analysis also helps to overcome one of the main defects of conventional cost-benefit analyses, namely that the latter emphasises a static view of the project, whereas in an actual case objectives change both with the passage of time and as more data are collected ; in effect, there is often a dynamic interaction between policy making and project design. The systems analysis approach can be applied to widely deffering levels of complexity [2].

2. Structural Characteristics of Land Use Management of Flood Estimated Areas

Land use problems exist in a field where earth science with planning are integrated and the control problem of land use can be regarded as one of the most important issues in environmental problems. Generally, a land environment may be said to be composed of natural environment and social environment. Fig. 2. 1 shows the land use system from a viewpoint of structure of flood damage [3]. The flood damage may be influenced by causes of natural environment and social environment. Namely, in this case, the determinants of land use can be also established as determinants of interactions between the natural environment and social environment [4].

The flood intensity is determined by meteorological factors, which include rainfall or rainstorm, snowmelt, etc., as well as the geographical and geological factors.

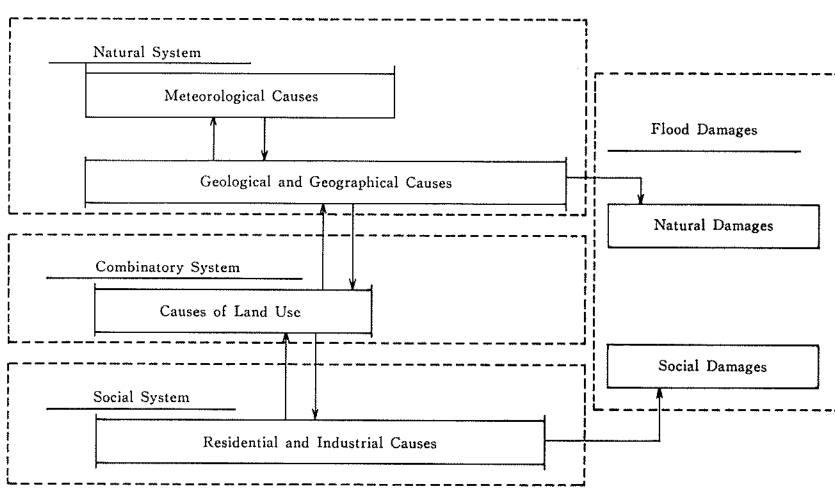

Fig. 2. 1. Structure of Flood Damage.

These factors are taken as a subsystem of natural environment. The damage scale is decided by regional residential or industrial activities. The special features of land use exert an influence on damage generation. It also acts as a feed back of influences from social environment to the natural environment. Therefore, the subsystem of land use can be regarded as a system that combines both subsystems.

Several measures for flood control contribute to land use the run-off coefficient. Thus, the structure of flood damage is composed of various factors in fixed and sequential patterns so that land use can be considered as a significant viewpoint.

Further the subsystem composed of land use is broadly classified into five items : ① agricultural use, ② residential use, ③ river way, ④ road lots and ⑤ forest and waste land.

Fig. 2. 2 shows the relation between spaces of flooded area and the flood damage category corresponding to time.

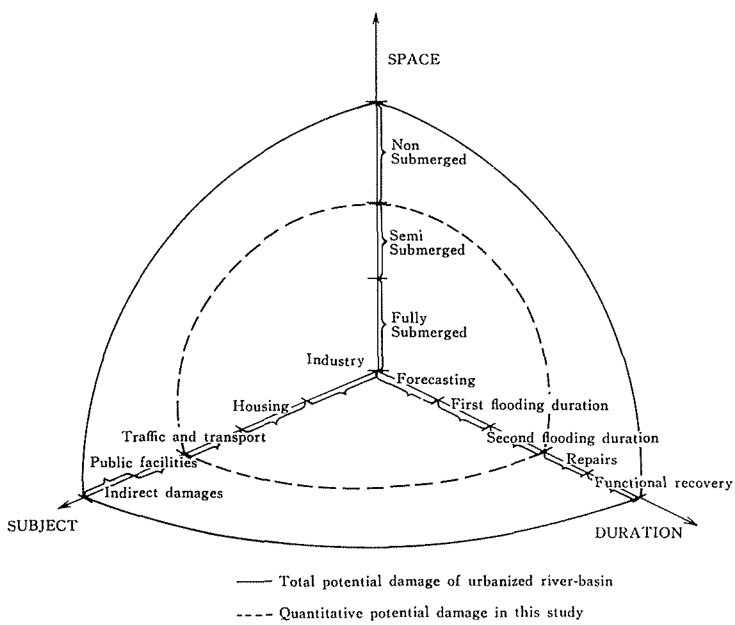

Fig. 2. 2. Spatial concepts of potential flood damages.

1) Space axis of flooded area······Here space is defined as the area influenced by inundations and is offered for land usage. The space is divided into three categorical areas according to the degree of flood intensity.

a) Fully submerged area······When the area is fully submerged, in other words, houses are inundated above the floor level of agricultural products are completely flooded.

b) Semi-submerged area······When the area is partly submerged, namely, when houses are inundated below the floor level or agricultural products are only partly flooded.

c) Non-submerged area but influenced area······This area is neither submerged nor deluged by rainwater. This area is closely related to the submerged area in that, for example, it is influenced by the traffic and transportation conditions.

The axes of damaged subjects and damage duration is indicated in correspondence to the axis of space: To explain the concepts of these axes briefly,

2) The axis of subjects……The subjects are introduced as arrangement of the sectors which are likely to suffer damage from inundation. These are arranged in an order which takes on descending values of directness of influence. These subjects in the order of directness of influence. These subjects in the order of directness of flood damages are:

a) Damages to industry……These indicate the damages of products or consumer goods stored in agriculture, facilities, industry and commerce, including the equipment of the facilities.

b) Damages to housing……These are the damages of residential utilities, such as houses, furniture and cooperative utilities.

c) Damages to traffic and transporatation……These are the damages of facilities and functions of highway, railway, port and airport, including postal facilities.

d) Damages to the other public facilities……These are the damages of public buildings, such as city offices, community centers, schools and public facilities, such as parks and recreational facilities, garbage dumps or sewage disposal and facilities for energy or water supply.

e) Indirect damages to society……These are the loss of beautiful landscape, cultural inheritances, natural monuments and therefore, includes the social stress involved.

3) The axis of time duration……The axis of duration is established from the time of flood forecasting till the time of recovery of function. These periods are divided as follows:

a) Periods of forecasting floodings……These are the announced hours when the occurrence of inundation is forecasted and reorganized for flood prevention.

b) Periods of the first flooding duration……These are the duration when the discharge continues to increase to the peak and the period with the direct damages increase.

c) Periods of the secondary flooding duration……These are the durations when the direct flood damages stop occurring and mainly functional or indirect damages continue.

d) Periods under repairs……These are when floods terminate and restoration works of facilities and its functions are carried out.

e) Periods of functional recovery……These refer to the time until the repairs are completed, and social and economic activities how returned to their respective normal routine. Potential damage is indicated in this space. The characteristics of the watershed decide the scale of axes, for example, in an urbanized watershed, the submerged area is small but the non-submerged and influenced areas are relatively large.

3. Methods and Procedures of Analysis for Land Use Control of Flood Estimated Areas

(1) Procedures of Systems Analysis

Systems analysis is defined as the systematic methods which are designed for decision makers to support the selection of best alternatives by means of defining the objectives of problematic and evaluating alternatives in a comparative manner.

The general procedure of systems analysis is shown in Fig. 3. 1. 'problem definition' is to recognize and to clarify the solved problem. 'Screening objectives' is to decide on the objectives of the system, to relate one to the other and to establish the criteria for evaluation and presupposed conditions. 'Systems observation' consists of collection related data, grasping the relations of causal factors and enumerating the alternatives. 'Systems analysis' is to comprehend the system quantitatively and to analyse the system's alternatives in planning and design. 'Interpretation and evaluation' is to check the non-quantitative or abridged determinants, to ascertain the uncertainties, to verify the system and to form a conclusion. 'Decision making' is to select the optimal system of all the alternatives by scientific facts or subjective inferences.

In the procedure of solving problems, the objective systems and the problems

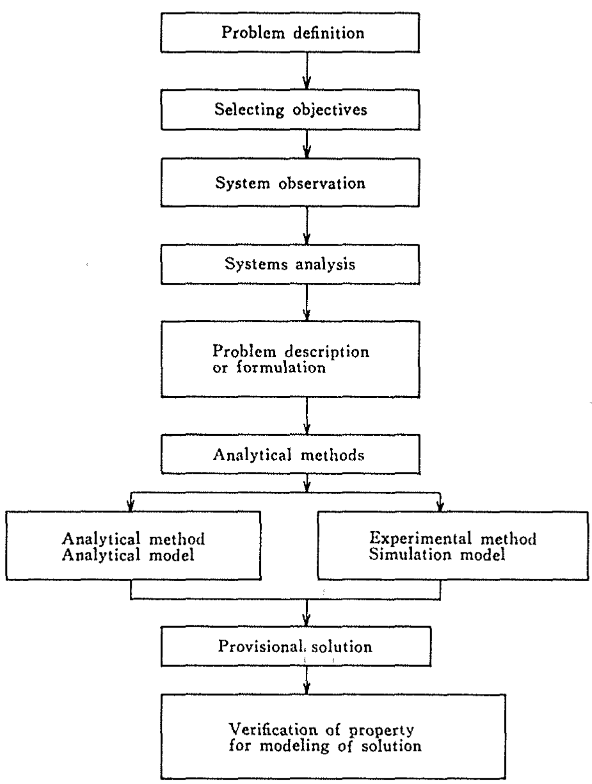

Fig. 3. 1. General Procedure of Systems Analysis.

Table 3.1. Procedure of Modeling Technique in This Study.

Procedure	Aim	Technique	Collection of Information
Problem definition ↓ Systems observation ↓	· Decision of systems area · Collection of basic data		
Descriptive modeling ↓	· Selection of determinants and factors	· Brain-storming · KJ-Method · NGT-Method	· Broad and diverse offerer
Structural modeling ↓	· Arrangement and Hierarchy of determinants and factors · Division or integration of problems	· ISM-Method · DEMATEL-Method · FSM-Method	· Planner · A pair comparison
Quantitative modeling	· Screening · Composition of factors · Establishment of evaluating criteria · simulation analysis · scenario analysis	· Multi-objective planning · Optimal control theory · System Dynamics	· Analyst and decision maker

to be solved are recognized accurately. 'Model building' are comprised of descriptive modelings, structural modelings and quantitative modelings. The descriptive models are mental models which are expressed by sentences or words. Structural models are to investigate the composing factors, parameters, variables and relationships of large-scale systems. Quantitative models are mathematical models, the system of which is represented by the variables, parameters and relationships mathematically and logically [5].

(2) Dynamic Expected Potential Damage

Potential damage has been used as a method for assuming regional damage. It is defined as the damage which may occur in the present maximum flooded areas. Namely, it can mean the maximum damage likely to occur due to inundations in a river basin. The potential damage method accounts for an economic investigation of flood control, an establishment of assumed area of inundation and a decision of a priority of work for flood control. This also includes static damage occurred during a maximum flood [6].

In this study, the dynamic expected potential damage is defined. That is, an improvement is made on the potential damage in order to follow the dynamic changes and to evaluate the potential damage for each scale of flooding.

The dynamic expected potential damage is characterized as follows:

1) To assess the relative potential damage of several flooded areas by con-

sidering the occurrence of flooding in each region.

2) To indicate the reduced effects of damage resulting from the structural achievement of flood control.

3) To follow dynamic changes of land use and regional economics.

4) To investigate the scale of potential damage compared with the real damage in case of regional flooding data.

5) To be widely flexible in comprehending the indirect damage exerted on other areas, for example, damages of traffic and transportation, as well as non-monetary damages. As controversial points, an examination must be made on the occurrence probability of run-off and the geographical information on the flooded areas, and the contours of submerged beds.

The dynamic expected potential damage is formulated in a mathematical method :

$$
\begin{aligned}
&D(t) = \sum_i d_i(t) + \sum_j d_j(t) \qquad (i \neq j) \\
&d_i(t) = A_E(t) \cdot P_i(t) \cdot R_i(t) \\
&d_j(t) = F\big(Q(t)\big) \qquad\qquad (2.1) \\
&A_E(t) = A\big(Q(t)\big) \\
&Q(t) = Q(f, r, A_r, t)
\end{aligned}
$$

where f; the coefficient of run-off, r; the probable rainfall (mm/hr), t; simulated year, d_i; potential damage in a flooded area (million yen), d_j; indirect potential damage in unflooded areas (million yen), A_E; expected flooded area (m^2), P_i; property of item i per area (million yen/m^2), R_i; rate of damage and $Q(t)$; probable discharge (m^3/sec) [7].

(3) Technique for Model Building

The probabilities of adapting systems analysis exist in land use control of flood estimated areas as that mentioned above. In this paragraph, several model building for land use control of flood estimated areas are explained as concepts of methodology and concrete models. These descriptions of technique for model building are shown in Table 3. 1. As for the technique and procedure, three modelings are introduced and they are applied to the problems of land use management escalatedly. That is, the informations and the factors related with these problems collected from broad and various fields. These are screened by the modeling methods in succession. These procedures are based on the idea of 'the problem-oriented'.

a) Descriptive model

As one of the descriptive models, the Nominal Group Technique (NGT) is adopted in selecting the causal factors of the regional system for interrelation of land use and water resources. The NGT was developed by A. L. Delbecq and Andrew H. Van de Ven in 1968 [8]. It was derived from social-psychological studies of decision conferences, management science studied of aggregating group judgements and social-work studies of problems surrounding citizen participation in program planning. Since that time, the NGT has gained extensive recognition and has been widely applied in health, social service, education, industry and government organizations. The process of decision making in the NGT is as follows:

1) Silent generation of ideas in writing.

2) Round-robin feedback from group menbers to record each ideal in a terse phrase on a flip chart.

3) Discussion of each recorded idea for clarification and evaluation.

4) Individual voting on priority ideas with the group decision being mathematically derived through rank-ordering or rating.

This method can be considered as a combination of a kind of brain-storming where as many opinions as possible are presented, and a kind of voting system, the Delphi method. The procedure of this method is shown in Fig. 3. 2.

b) Structural model

In studying complex problems of a social system, methods of structure of these problems have recently been proposed. These are ISM, DEMATEL and so on. Most of these methods are developed on the basis of the graph theory. It is particularly popular as ISM is effective in obtaining the consenting structure of a problem [9]. A matrix in this method representing a subordination matrix and the elements are filled with a binary relation. However, it will not be always reasonable to use the binary relation among elements. DEMATEL method displays the strength of connection among factors with several degrees and several

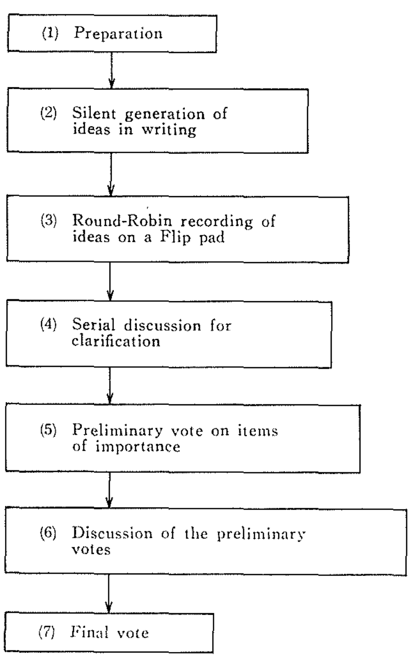

Fig. 3. 2. Procedure of Nominal Group Technique.

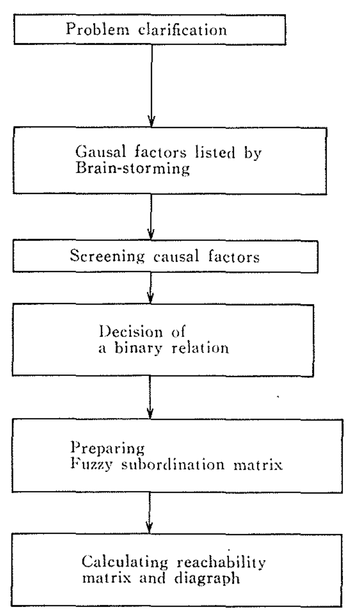

Fig. 3. 3. Procedure of Fuzzy Structural Method.

points on a two dimesional plate. E. Tazaki and M. Amagasa proposed a method for structuring hierarchy for several social problems on the basis of fuzzy sets theory. The method is Fuzzy Structural Modeling (FSM). A fuzzy reachability matrix is the form by which the necessary data is acquired and organized into a form by which a structural model can be developed [10]. In this study FSM were adopted. These procedures are shown in Fig. 3. 3 and described roughly.

In the first step the problem is verified and causal factors are selected. The brain-storming or NGT is used in the method of the selection of factors. The results are arranged so that the binary relations can be grasped. In the second step a questionnaire by means of a Pairwise Comparative Method is enforced to some answers in order or difine the binary relations. For example, these questions may ask "Which is important, either A or B?". At the third step the results which are acquired in these investigations are aggregated and all of binary relations are arranged with the matrix model. In FSM the binary relationships are considered as the fuzzy binary relationships. The fuzzy matrix models are composed of and defined as fuzzy subordination matrix for a given object (a causal factor). The structural modelings are formed into multilayer diagraph on the basis of these fuzzy subordinate matrices. The rules for structural modeling and algorithm are generalized as follows: Let a system object be $S=\{S_1, S_2, \cdots, S_n\}$. A fuzzy subordination matrix A which represents a fuzzy subordination relation among the elements of S on the basis of a certain contextual relation:

$$A=[a_{ij}], \qquad i,j=1,2,\cdots,n \tag{2}$$

where A is a square $n \times n$ matrix and element a_{ij} of A is given by the fuzzy binary relation f_R as follows:

$$a_{ij}=f_R(S_i, S_j), \quad 0 \leqq a_{ij} \leqq 1, \qquad i,j=1,2,\cdots,n \tag{3}$$

This variable set shows the grade in which the subject is subordinate to S_j. In order to show the grade in which the subject is subordination is greater than a given certain grade, a parameter is introduced as a threshold. The ρ can be given on the semi-open interval $[0<\rho\leqq 1]$.

As for the properties of these binary ralations, the following are some definiions:

1) When $a_{ij}<\rho$ for $\forall(S_i, S_j)\in S\times S$, the relation is called a fuzzy irreflexive.

2) When either $a_{ij}<\rho$ or $a_{ij}>\rho$ for $\forall S_i, S_j \in S$ $(i \neq j)$, the relation is called fuzzy asymmetric.

3) Let $M=\max\{\min(a_{ij}, a_{jk})\}\geqq\rho$ for $\forall(S_i, S_j), (S_j, S_k)\in S\times S$ $(i\neq j\neq k)$, when $a_{ij}\geq M$ for any (S_i, S_k).

The relation is called a fuzzy semi-transitive relation. Besides this, the level sets of the factors of S which give the connective relation among the layers are determined as follows:

4) A top level set $L_t(S)$, an intermediate level set $L_i(S)$, a bottom level set $L_b(S)$ and an isolation level set $L_{is}(S)$ are respectively defined as follows:

$$L_t(S)=\left[S_k \mid \max_{l\leq j\leq n}\{a_{kj}\}<p<\max_{l\leq l\leq n}\{a_{lk}\}\right], \qquad (4)$$

$$L_i(S)=\left[S_k \mid p<\max_{l\leq l\leq n}\{a_{lk}\},\ p<\max_{l\leq j\leq n}\{a_{kj}\}\right], \qquad (5)$$

$$L_b(S)=\left[S_k \mid \max_{l\leq l\leq n}\{a_{lk}\}<p<\max_{l\leq j\leq n}\{a_{kj}\}\right], \qquad (6)$$

$$L_{iS}(S)=\left[S_k \mid \max_{l\leq l\leq n}\{a_{lk}\}<p,\ \max_{l\leq j\leq n}\{a_{kj}\}<p\right], \qquad (7)$$

Next, the procedure of structural modeling algorithm is given by the following steps. STEP 1···Give a fuzzy subordination matrix $A=[a_{ij}]$ and construct the fuzzy semi-reachability matrix A' satisfying the fuzzy semi-reachability law form A. STEP 2··· Identify the level sets $L_t(S)$, $L_i(S)$, $L_b(S)$ and $L_{iS}(S)$ on the basis of A'. Further, determine the subordination relation sets $B(S_i)$ between $L_t(S)$ and $L_b(S)$ ($S_i \in L_b(S)$) and the block sets $\{Q_j\}$. STEP 3···Eliminate all of the columns including elements belonging to $L_b(S)$ and the rows and columns including elements belonging to $L_{iS}(S)$. The fuzzy subordination matrix consisting of the remaining rows and columns is reconstructed as A'. STEP 4···From A' obtained in Step 3, construct

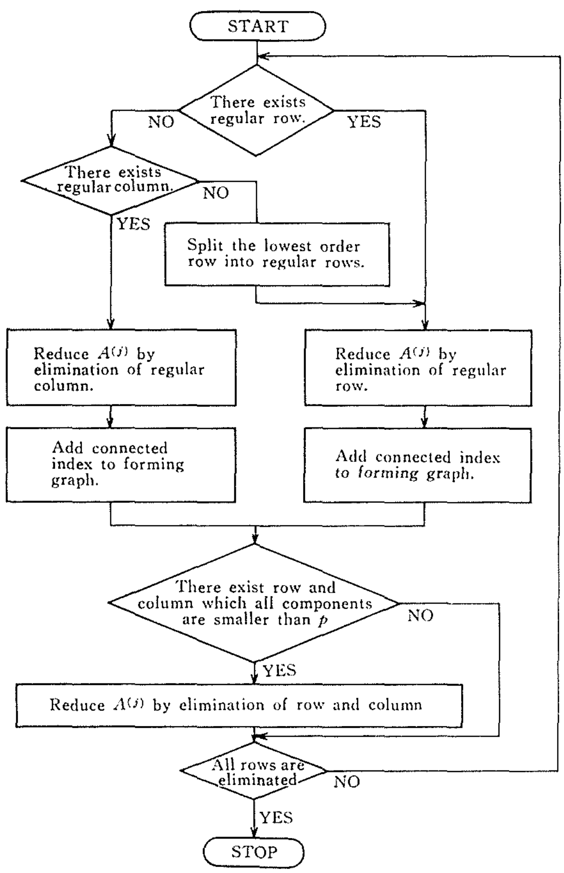

Fig. 3.4. Flowchart for Graphic Construction of System.

the single hierarchy matrix $A^{(1)}$ corresponding to each block set Q_j. STEP 5…Set up a fuzzy structure parameter and identify the graphic structure regarding each single hierarchy matrix $A^{(i)}$ according to the flowchart given by Fig. 3. 4. Here, assume that the regular rows corresponding to S_j are a_{ik}, $k=1, 2, \cdots, m$ $(m<n)$. Such regular rows are eliminated by substituting the following values.

$$[a_{.j}{*}] = [a_{.j}] \wedge \overline{[a_{.i}]} \wedge \overline{[a_{.i}]} \cdots \wedge \overline{[a_{ik}]} \tag{8}$$

provided that

$$\overline{[a_{.i}]} = \left(1-[a_{.i}]\right) \Big/ \left(1+\lambda [a_{.i}]\right) \tag{9}$$

The subordinate relation among the subjects corresponds to the node and branch of graph theory. The FSM method is adopted for synthetic evaluation of watershed management in the next paragraph.

c) Quantitative model

In quantitative modeling, the analytical method and the simulation method is proposed. Up to the present, the analytical method has been used, for example, several methods in OR. However when these methods are used, a great number of hypotheses must be established and the determinants must be screened for mathematical modeling. Thus, the modeling for a large scale system requires an operational technique when introduced and it causes a gap to occur between the model and the actual-system. Therefore, several simualtion models have been developed in order to express as the direct system in the complex real world. In this paragraph, three modelings are proposed: One is the multiobjective evaluated method, the Min-Max modeling and the second is the optimal control modeling and the last is the System Dynamics modeling. The former two modelings are analysed with mathematical programming and the latter by simulation modeling.

1) Min-Max model for multiobjective planning [11]

For about twenty years, many multiobjective optimization theories have been developed in the realm of systems analysis.

This is because the use of a uni-dimensional decision criterion does not always reflect adequately the individual and collective preferences. The multiobjective optimization theory or vector optimization theory has been an increasingly important element of modern decision making, planning and design. Usually, a unidimensioned programming problem can in general terms be described as the maximization of an objective function, subject to a set of constraints. The general formalization of such a problem is

$$\max \omega(x_1, \cdots, x_I), \tag{10}$$

subject to:

$$g_1(x_1, \cdots, x_I) \leq \bar{g}_1$$
$$\vdots$$
$$g_k(x_1, \cdots, x_I) \leq \bar{g}_k,$$

where $x_i (i=1, \cdots, I)$ represent a decision variable to be established in such way that the objective function ω reaches its maximum. This maximization should take into account the side-conditions $g_k(k=1, \cdots, k)$ with regard to the decision variables. In case of a multiobjective optimization approach, the following model may be assumed:

$$\begin{aligned} &\max \omega_1(x_1, \cdots, x_I) \\ &\quad\vdots \\ &\max \omega_j(x_1, \cdots, x_I) \end{aligned} \tag{11}$$

subject to:

$$\begin{aligned} g_1(x_1, \cdots, x_I) &\leq \bar{g}_1 \\ \vdots \qquad & \quad \vdots \\ g_k(x_1, \cdots, x_I) &\leq \bar{g}_k \end{aligned}$$

in which $\omega_j(j=1, \cdots, J)$ represents the jth objective function.

Various types of the multiobjective optimization approach are proposed such as utility maximization, penalty models, goal-programming models, constraint models, hierarchical optimization models, Pareto optimization models etc.. In this case, the Min-Max model is introduced as the method of multiobjective optimization model. The Min-Max models are based on the formal resemblance between optimization conflects in the case of multiple objective functions and oligopolistic conflicts in the case of game-theoretic strategies. Therefore, the notion of a pay-off matrix plays and important role in Min-Max multi-objective models [12].

The first step of a Min-Max optimization procedure is a separate optimization of all individual objective functions:

$$\max \omega_j(x_1, \cdots, x_I), \ \forall j, \tag{12}$$

Subject to:

$$g_k(x_1, \cdots, x_I) \leq \bar{g}_k, \ \forall k,$$

The optimal value of each jth objective function resulting from (11) will be denoted by $\omega_j^0(x_1{}^j, \cdots, x_I{}^j)$, where the decision variables associated with each individual optimum $\omega_j^0(x^j)$ are denoted by $x_1{}^j, \cdots, x_I{}^j$. It is clear that a substitution of $x_1{}^j, \cdots, x_I{}^j$ into a different objective function $\omega_{j}^0(j'=1, \cdots, J;\ j=j)$ will lead to a value $\omega'_j(x_1{}^j, \cdots, x_I{}^{j'})$ which is lower than the maximum value $\omega_j^{0'}(x_1{}^j, \cdots, x_I{}^{j'})$. On the basis of such a set of mutual substitutions the pay-off matrix P for multiobjective programming can be constructed:

$$P = \begin{array}{c|ccc} & \omega_1 & \omega_2 \cdots\cdots & \omega_J \\ \hline x_1^1, \cdots\cdots\cdots, x_I^1 & \omega_1^0(x^1) & \omega_2(x^1) & \\ x_1^2, \cdots\cdots\cdots, x_I^2 & \omega_2(x^2) & \omega_2^0(x^2) & \\ \vdots & & \ddots & \\ x_1^J, \cdots\cdots\cdots, x_I^J & & & \omega_J^0(x^J) \end{array} \tag{13}$$

The characteristics of this method are explained as follows :

1) It is possible to calculate the vector optimization by means of scalarization using the weights if relative importance for each objective to balance the pay-off functions.

2) It is possible for the decision maker to make calculations to permit changes for the worse of the objective functions successively by means of an interactive procedure.

3) The optimal solution by means of Min-Max model is the necessary to assume the convexity of the objective functions or the constraints.

The successive steps of the interactive procedure for Min-Max models are :

① Calculate the pay-off matrix P auch as (12)

② Calculate the weights λ_j

An equilibrium solution with respect to the pay-off matrix P can be calculated on the basis of the following set of relationships :

$$P\lambda = c\,e$$
$$e^T\lambda = 1 \qquad (14)$$

and c are calculated as follows :

$$\lambda = P^{-1}e(e^T P^{-1} e)^{-1}$$
$$C = (E^T P^{-1} e)^{-1} \qquad (15)$$

C is the equilibrium value in the case of balancing the priority of strategy.

③ Calculate the solution of the related parametric model.

$$\max x_j\,\omega_j(x_1, \cdots, x_I)$$
$$g_k(x_1, \cdots, x_I) < \bar{g}_k \forall k$$
$$\omega_j^{\min}(x_1, \cdots, x_I) < \omega_j < \omega_j^{\max}(x_1, \cdots, x_I),\ \forall j \qquad (16)$$

The optimal goal achievements $\omega_1(x), \cdots, \omega_I(x)$ are given by (15).

④ Propose $\omega_1(x), \cdots, \omega_j(x)$ as a provisional solution to the decision maker.

⑤ Let the decision maker express his relative preference with regard to the provisional solution by specifying achievement standards $\omega_1, \cdots, \omega_j$ according to the following rules :

$$\tilde{\omega}_j \leq \hat{\omega}_j(\hat{x}),\ \forall j, \qquad (17)$$

and :

$$\tilde{\omega}_j = \hat{\omega}_j(\hat{x}),\ \text{for at least one } j, \qquad (18)$$

⑥ Calculate the following multiobjective programming model :

$$\max \omega_j(x),\ \forall j,$$

subject to :

$$g_k(x_1, \cdots, x_I) \leq \bar{g}_k,\ \forall k,$$
$$\omega_j(x) \geq \omega_j,\ \forall j. \qquad (19)$$

⑦ Calculate the new pay-off matrix associated with (17).
⑧ Calculate the adjusted weights λ_j.
⑨ Solve the corresponding parametric program :

$$\left.\begin{array}{l} \max \psi = \sum_{j=1}^{J} \lambda_j \omega_j(x), \\ \text{subject to:} \\ g_k(x_1, \cdots, x_I) \leq \bar{g}_k,\ \forall k, \\ \omega_j(x) \geq \bar{\omega}_j,\ j. \end{array}\right\} \quad (20)$$

⑩ Repeat steps ④ and ⑤.
⑪ Terminate the interactive procedure when the difference between two successive solutions is smaller than apriori specified ε-limit.

Such methods are introduced in order to allocate investments and new water supply in certain regions.

2) System Dynamics as simulation modeling [13]

The social system belongs to the complex, nonlinear feedback system. The characteristics of these systems are listed as follows :

① These systems do not adapt themselves to human intuition.
② Most of the systems parameters change non-sensitively.
③ The systems are strongly resistant to policy changes.
④ The structure of systems possess loops of cause and effect relations.
⑤ The component factors have complex interdependent relationships.
⑥ The activities of systems are nonlinear.
⑦ The phenomenon of system is a single occurrence.
⑧ The effects are not lasting if the causes are not eliminated.
⑨ Human intuitions or experiences accustomed to simplified systems.

The method of System Dyamics is very effective in analysis dynamically such a complex and intangible system as the present society. As mentioned above, the interrelation between land use and flood control can be considered as a complex and dynamic system. It is necessary to select an analytical method ; a problem-oriented method in which is contained the interrelation between natural and social environment. Namely, it is more desirable to formulate a system that establishes system barriers and extracts causal factors than to built a model by means of some mathematical tools. The System Dynamics is favorable for such ideas : This method is also effective in building models through group discussions and in improving on or in developing the model efficiently.

4. Objectives and Measures for Watershed Management

(1) Descriptive Model for Watershed Management

The causal factors for objectives and measures were selected by the method of the NGT. In this section, these factors were arranged and oriented towards human living environment. The descriptive relations of objective and measures for watershed management are shown in Fig. 4. 1. 1–4. 1. 2.

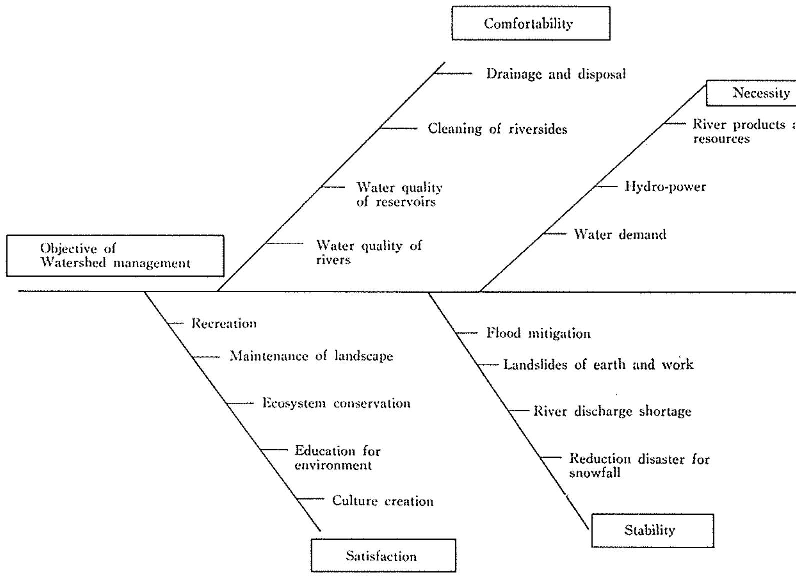

Fig. 4.1.1. Cause and Effect Diagram for Objectives of Watershed Management.

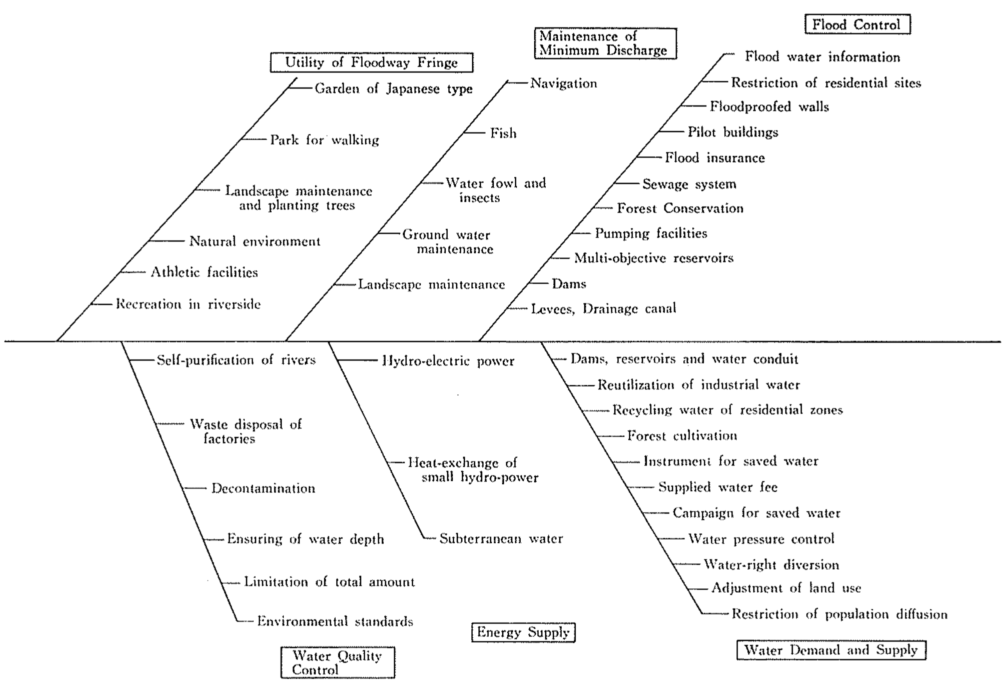

Fig. 4.1.2. Measures for River basin Management.

(2) Structural Model

The objectives and measures of watershed management has been multivarious as mentioned above. In particular, it has become important to institute comprehensive measures in the near future. In this clause, the structural models of objectives

Table 4. 1. The Objectives and Measures for Water Resources Management.

1. Necessity
  - 1.1 Management of water demand and supply
    - 1.1.1 Saving water independently
    - 1.1.2 Saving water by administrative guidance
    - 1.1.3 Regional recycling system
    - 1.1.4 Independent recycling system
    - 1.1.5 New water resources development
    - 1.1.6 Renewal of water resources development
    - 1.1.7 New law and policy for water management
    - 1.1.8 Policies of population and industry
  - 1.2 Management of hydroelectric power
    - 1.2.1 New hydroelectric power development
    - 1.2.2 Developing small and medium scale hydroelectric power
2. Stability
  - 2.1 Flood control
    - 2.1.1 Flood control by national or municipal projects
    - 2.1.2 Indirect flood control by public agencies
    - 2.1.3 Independent flood control
    - 2.1.4 Agricultural and forestry abatement
    - 2.1.5 Flood insurance
    - 2.1.6 Flood protection of housings and facilities
    - 2.1.7 Restriction of land use
  - 2.2 Maintenance of minimum discharge
    - 2.2.1 Anadromous or migrating fish (ex. salmon)
    - 2.2.2 Fish, waterfowls and insects control
    - 2.2.3 Landscape maintenance
    - 2.2.4 Groundwater maintenance
    - 2.2.5 Navigation
3. Comfortability
  - 3.1 Water quality control
    - 3.1.1 Management of self-purification
    - 3.1.2 Independent wastewater prevention
    - 3.1.3 Administrative guidance for wastewater
    - 3.1.4 Diffusion of sewage and disposal facilities
    - 3.1.5 Restriction of urban area developments
4. Satisfaction
  - 4.1 Utility of floodway fringe
    - 4.1.1 Recreation on floodway
    - 4.1.2 Nature and wildlife conservation
    - 4.1.3 Athletic facilities
    - 4.1.4 Park for walking

and measures through comparison of mutual importance were built in a watershed. As for regional information, a questionnaire for a pairwise comparison was enforced for 66 persons working in the project sections, which were the sections of water resource, urban planning, economic, industrial, agricultural planning and synthetic planning. This example refers to the case of several municipalities in the Chitose River Basin, Hokkaido.

The FSM method was introduced in this analysis as structural modeling. The objectives and measures utilized in this analysis were arranged in Fig. 4. 1. 1–4. 1. 2. referring to the above mentioned items. The items in Table 4. 1 were rearranged to correspond to the region. The results for the analysis of managemental objectives are presented in Table 4. 2 briefly. According to these results, while the measure of water quality control was ranked at the upper level in R-1, R-3 and R-5, the other regions dealt with at the medium level. While the utility of floodway fringes were ranked at the medium level, regions in lower stream, in the upper or middle stream at the lower level. General speaking, both objectives of management of water demand and supply and flood control were ranked at the upper level in all regions while the objectives of maintenance of minimum discharge and utility of floodway fringes were ranked at the lower level. Fig. 4. 2. 1–4. 2. 6 shows the analysis of the whole watershed with directional graphs. According to the structure of the objectives, three objectives namely the management of water demand and supply, flood control and water quality control were most important and two objectives, namely, the management of hydro-electric power and maintenance of minimum discharge were at the medium level. Moreover, the objective of utility of floodway fringe was ranked at the lower level. From the viewpoint of the importance for measure, in total, it was confirmed that the structural measure of public work, which were the main measure from post purses higher dependency. However, it appears to evaluate the measure highly, the measures of administrative guidance, for example, utility expenses, flood insurance etc. are not ranked at too high a level. Thus, structural modeling is effective in clarifying the complex problem using the task opinion for the specialist or planner in the study area.

Table 4. 2. Results of Analysis of Structural Modeling.

	R-1	R-2	R-3	R-4	R-5	R-6
Level-T	1-1, 2-1 3-1	3-1	3-1	2-1	1-1, 3-1 1-2	1-1, 2-1
Level-I	2-2, 4-1	1-1, 2-1 1-2, 4-1	1-1, 2-1 1-2	1-1, 3-1 1-2	2-1, 2-2	1-2, 3-1
Level-B	1-2	2-2	2-2, 4-1	2-2, 4-1	4-1	2-2, 4-1

(T; Top, I; Intermediate, B; Bottom)

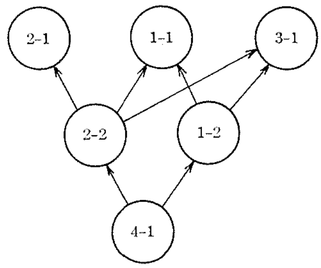

Fig. 4. 2. 1. Structure of Objectives.

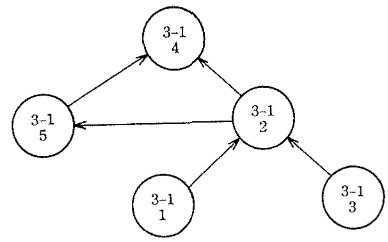

Fig. 4. 2. 4. Measures of Water Quality Control.

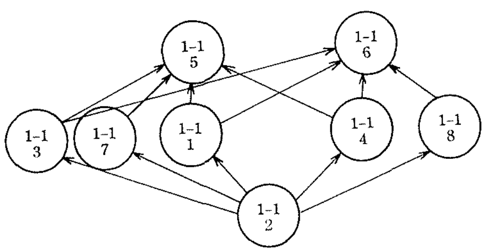

Fig. 4. 2. 2. Measures of Water Use.

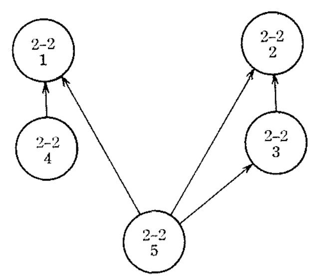

Fig. 4. 2. 5. Measures of Maintenance of Minimum Discharge.

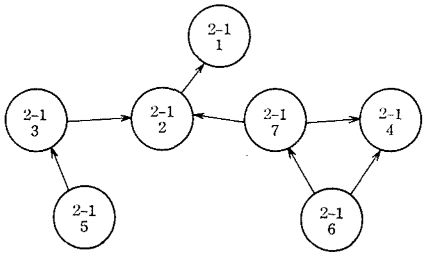

Fig. 4. 2. 3. Measures of Flood Control.

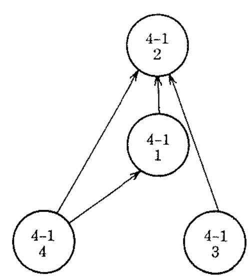

Fig. 4. 2. 6. Measures of Utility of Floodway Fringe.

5. Quantitative Model for Interaction between Land Use and Flood Control

(1) Construction of a model for interaction between land use and flood control (MILUF)

The System Dynamics model-MILUF is built to evaluate the stability of land use development in flood estimated areas quantitatively. This model is composed of four subsystems, which are land use, socio-economic, flood damage and flood control within the system boundaries. The system of land use is composed of factors in residential and industrial sites, agricultural farms and waste land. The socio-economic system is mainly represented by factors for population and industry. The system of flood damage is made up of the factors of the damages to industrial and residential properties. In addition, as indirect damages, the damages of traffic and transportation are indicated. The flood control system is classified into the type of the flood path inundation and the type of the landside submergence. The former type is composed of the factors for the height of levees, the reduced discharge and the embankment volume. The latter is composed of factors for pumping facilities, the reduced volume of submergence and the maintenance and management.

(2) System flow diagrams of the MILUF model

i) The subsystem of land use……This system flow can follow the change of agricultural zones or residential zones. In this system, two alternatives are established: One is the method for forecasting the change of land use in the past and the forecasting in each region was investigated. The other is the method for grasping the possibility for enhancement of the land use by flood control.

ii) The socio-economic subsystem……The forecasting of regional population can be calculated for every generation. The population is divided into five generation.

The industrial sector is classified into agriculture, manufacturing and commerce. Each industrial development in the future is followed according to the change of each land use. In other words, the allocated rate of each industrial employee is decided by the future state of land use. Flood damages or flooded areas in each industrial zone are influenced by the land use in the future.

According to agricultural products, for instance, rice and farm products, such as potatoes or beans, are introduced. The properties of manufacturing and commerce are divided by the repayment and the stock.

iii) The subsystem of flood damages……In the subsystem of flood damages, a system-flow is composed of industrial damages, housing damages and traffic damages. Industrial damages are considered as agricultural, manufactural and commercial damages. Agricultural damages includes damage of rice and farm products. Manufactural and commercial damages are divided by repayment and stock. General housing damages are classified with housing and articles of domestic use. Traffic damages include the reduced products by stopping of traffic and time cost by the delay of through traffic in the flood estimated area.

iv) The subsystem of flood control……The subsystem of flood control of floodways and landside water control generally. The method of flood control for floodway is assumed to fill the embankment, while the method for landside water control presupposed the building of pumping facilities. Moreover, in the subsystem of flood control for floodways, the maintenance of embankments are also introduced in this model. These include three methods, which are the adjustment of levee settlement, the sodding and its management and the displacement of soil for the stability of levee.

Fig. 5. 1 shows the flowdiagram of the total system of the MILUF model. [14]

(2) Regional characteristics of dynamic potential flood damages

The System Dynamics Model-MILUF was applied to observe each characteristic of the dynamic potential flood damages of the lower reached and midstream sections of the watershed of the Ishikari River, which is about 125 km in length

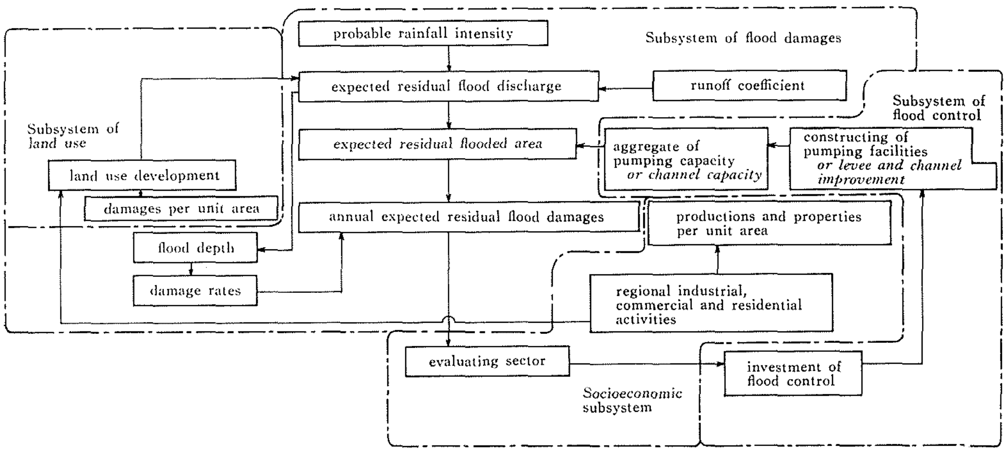

Fig. 5. 1 Flowdiagram of the total system of the MILUF model.

Table 5. 1. Municipalities Belonging to Each Reach.

Reach	Municipalities
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

running from Fukagawa City to the estuary. The study areas were divided into ten reaches. Each municipality belongs to each reach as shown in Table. 5. 1. [15]

a) Verification of the model

The assumed values of the simulation model was verified by comparing the actual values which were indicated during the flooding of August in 1975.

Table 5. 2 compares the assumed flood damages with the actual damages on Reach-F. The errors were less than 10%-30% approximately. The other reaches were similar to this reach. The agricultural damages fitted the actual values accurately, but the number of damaged offices and houses did not correspond so well. This is because the boundary line of flooding was across the center of residential and business zones and a slight difference of the line amplified these errors.

Table 5. 2. The Verification of the Model by the Flooding of August in 1975.

		Assumed Value (AS)	Actual Value (AC)	Ratio of (AS)/(AC)
Paddy	Area (Ha)	6,200	6,602	1.06
Field	Damage ($\times 10^8$ Yen)	28.8	28.1	1.02
Farm	Area (Ha)	800	1,012	0.79
	Damage ($\times 10^8$ Yen)	5.3	4.7	0.89
Number of Houses		2,640	2,052	1.28
	Damage ($\times 10^8$ Yen)	5.2	4.3	1.27

Table 5. 3. Rate of Each Item of Potential Damage (%).

Planning Year		0	10	20	Planning Year		0	10	20	Planning Year		0	10	20
Reach A	1	70	36	19	Reach E	1	75	69	63	Reach I	1	32	28	20
	2	17	13	8		2	16	14	12		2	8	6	5
	3	9	36	49		3	5	8	10		3	40	41	44
	4	2	10	15		4	3	7	11		4	14	18	21
	5	1	3	10		5	1	2	4		5	6	8	9
Reach B	1	15	8	5	Reach F	1	68	56	52	Reach J	1	53	53	38
	2	17	24	14		2	15	11	13		2	9	7	5
	3	23	23	22		3	15	30	33		3	23	22	31
	4	38	36	49		4	1	2	1		4	9	11	17
	5	7	10	14		5	1	2	1		5	6	8	10
Reach C	1	38	25	16	Reach G	1	64	50	43					
	2	34	20	13		2	15	8	5					
	3	9	15	16		3	13	22	24					
	4	9	21	29		4	4	9	12					
	5	10	19	27		5	4	11	16					
Reach D	1	75	65	59	Reach H	1	54	46	39					
	2	6	5	5		2	16	12	9					
	3	16	23	26		3	18	25	24					
	4	2	5	7		4	6	10	14					
	5	1	2	3		5	6	8	15					

1; paddy field, 2; farm, 3; housing, 4; commerce, 5; industry

b) Simulation of regional characteristics of potential flood damages

The simulations were administered with the MILUF model for ten separate reaches. The estimated results in the case to follow the current trend are described to evaluate the dynamic potential flood damages corresponding to the regional developments of these reaches in the future. Table 5. 3 shows the rate of each item of potential flood damage. Land use characteristics are better clarified. Namely, in Reach-D, E, F and G the damage of rice crops is about 70% and the rate will not change to a great extent in the future. But the rate of the agricultural damage in Reach-A and Reach-C has decreased rapidly while damages of housing properties have increased greatly. In particular, the pattern of Reach-C became similar to that of Reach-B. Therefore, a comprehensive management of land development is gradually becoming necessary.

6. Conclusion

The results in this paper can be summarized as follows:

1) The problems of land use control in flood estimated areas consist of, directly, the attainment of stability of regional land use and, indirectly, the adjustment of potential flood damages. These damages are decided by causes of natural environment and social environment.

On basis of these concepts, the dynamic expected potential damage, which is represented as the indirect variation of regional land use, is defined by combining hydrologic factors, socioeconomic factors and flood control measures.

2) These proposed problems are generally complex systems called as the problematics. Therefore, in order to clarify the problems, various causal factors must be devised by investigating the relation of causes and effects and those combinations. The relative changes causal factors must be also examined and quantified. In this method, it is possible to make clear the problems by introducing a stageous method of three modelings, which are the descriptive, the structural and quantitative modelings.

3) The objectives and measures of regional water resources interrelated with land use control were clarified by the former two modelings. In particular, these objectives were selected and arranged by a view of attributes of human living environment and these measures were classified into structural and nonstructural measures.

4) The regional dynamic potential flood damages were estimated by using the System Dynamics Model-MILUF model. It can be effective to clarify the regional characteristics of potential flood damages, for example, the trend of the potential, the each item of damages and etc..

It has become essential to assess to synthesize and systematize the interrelation between land use and flood control in the flood estimated areas, in particular, in rapid urbanized areas. It can become furitfull for the intangible and complex systems of land use control to utilize these techniques and concepts.

The concrete applied examples of the real river basins will be described in the next papers.

Acknowledgement

The author gratefully appreciates the constant guidance and advice of professor Estuo Yamamura, professor Minoru Ohta, Professor Isao Yamaoka and Professor Hideo Igarashi of Hokkaido University to accomplish his study.

Computations in this paper were done using the FACOM 230-75 and HITAC M-200 at the Hokkaido University Computer Center, as well as the PANAFACOM U-1500 at the School of Environmental Science.

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Summary

The first purpose of this paper is to examine the structure and function of the land use activities in flood estimated areas and this is interrelated to factors of water resources, in particular, the cahracteristics of regional potential floods.

The second purpose is to establish the procedure for investigating the dynamic system of land use control related to regional potential damages of flooding.

In order to achieve these purposes, certain types of systems analysis have been utilized in the investigation of interaction of land use and watershed management. The results are summarized as follows:

1) In order to solve the problems of land use control in flood estimated areas, the dynamic potential flood damages were defined as the index of regional stability. Moreover, a stepwise

modeling system composed of the descriptive, structural and quantitative modelings was proposed to evaluate the activities and controls of land use in flood estimated areas.

2) The interrelation of land use and flood control is a complex system. It is effective to apply these modelings to clarifying of such a complex system.

3) The objectives and measures of regional water resources interrelated with land use control are clarified by the descriptive, the structural models.

4) The regional dynamic potential flood damages are estimated by using the System Dynamics Model-MILUF model as continuous changes.