International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Evaluations for Industrial Land-Use Program Related to Water Quality Management

Seo, F. and Sakawa, M.

IIASA Working Paper

WP-80-049

April 1980

Working Paper

EVALUATIONS FOR INDUSTRIAL LAND-USE PROGRAM RELATED TO WATER QUALITY MANAGEMENT

Fumiko Seo
Masatoshi Sakawa

April 1980
WP-80-49

International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

NOT FOR QUOTATION
WITHOUT PERMISSION
OF THE AUTHOR

EVALUATIONS FOR INDUSTRIAL LAND-USE PROGRAM RELATED TO WATER QUALITY MANAGEMENT

Fumiko Seo
Masatoshi Sakawa

April 1980
WP-80-49

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

PREFACE

Since the early period of IIASA activity, researchers on multicriteria decision-making have been forming a core with which IIASA has been contributing to the academic world, and at present it is on a new line. The main characteristics of the complex problems facing humans today are multidimensional and multiple objective. They include noncommensurate and conflicting elements. In order to cope with these, multidisciplinary implementation must be performed. Systems analysis is an integrated approach to meet this request. Particularly in order to solve complex problems with conflicting objectives, an improvement in decision-making processes will be urgently expected.

In the System and Decision Sciences Area of IIASA, Decision Processes and Hierarchical Structure is one of the main projects in Task 1 Decision and Planning Theory. In this project, the emphasis is placed on making mathematical descriptions of hierarchical decision making processes and balancing conflicting objectives. Multiobjective mathematical optimization processes shall be combined with judgemental or coordinating processes. This paper is a part of the modest works which contribute to this direction. The numerical results have been obtained in cooperation with the Systems Engineering Department of Kobe University in Japan, from where Dr. Masatoshi Sakawa came to

IIASA and cooperated with Fumiko Seo. The authors are indebted to Mr. Kozo Tazumi of Kobe University for his excellent contributions to computational works.

ABSTRACT

For analyzing a regional land-use program based on water pollution control, a hierarchical modeling of multilevel systems is presented. The overall, large scale objectives complex is decomposed into functional as well as regional subsystems. The device for coordinating and evaluating the sub-system is based on multiattribute utility analysis combined directly with dual variables obtained from mathematical programming. Shadow prices are used to derive the component criterion ("utility") functions which is a device for commensurating noncommensurate attributes. In the upper layer of the decision making system, uncertainty based on judgemental probability distributions is explicitly taken into consideration. This procedure is provided as a modified dynamic version of the nested Lagrangian multiplier method and is applied to the northern Senshu area in the Osaka prefecture of Japan.

1. INTRODUCTION

In this paper we are concerned with a regional land-use program combined with water quality management. The purpose of this paper is to present a methodology for planning, management and evaluation of the land-use program based on an industrial reallocation plan, in which economic growth and environmental management are compatible with each other. An illustration is also provided for a suburban area of southern Osaka, the northern Senshu area.

The objective area is the Otsu river basin in the Osaka prefecture. The Otsu river has three tributaries: the Makio (15,134m), the Matsuo (12,331m) and the Ushitaki (17,534m) rivers. These rivers have their origin in the Izumi mountains in the south-eastern border of the Osaka prefecture. The Makio and the Matso rivers flow through Izumi city and the Ushitaki river flows through the agricultural area of Kishiwada city. The Otsu river gathers water from these tributaries, passes through the border between Izumi otsu city and Tadaoka cho and finally flows into Osaka Bay (Figure 1). In Izumiotsu and Tadaoka cho, the southern part of the Sakai-Senboku (northern Senshu) coastal industrial complex is located. In Izumi city, residential, agricultural and forest lands cover a large area.

Among them some industrial plants are located. Thus, the region is a typical example of a *regional complex problematique,* which is interpreted as an objectives complex.

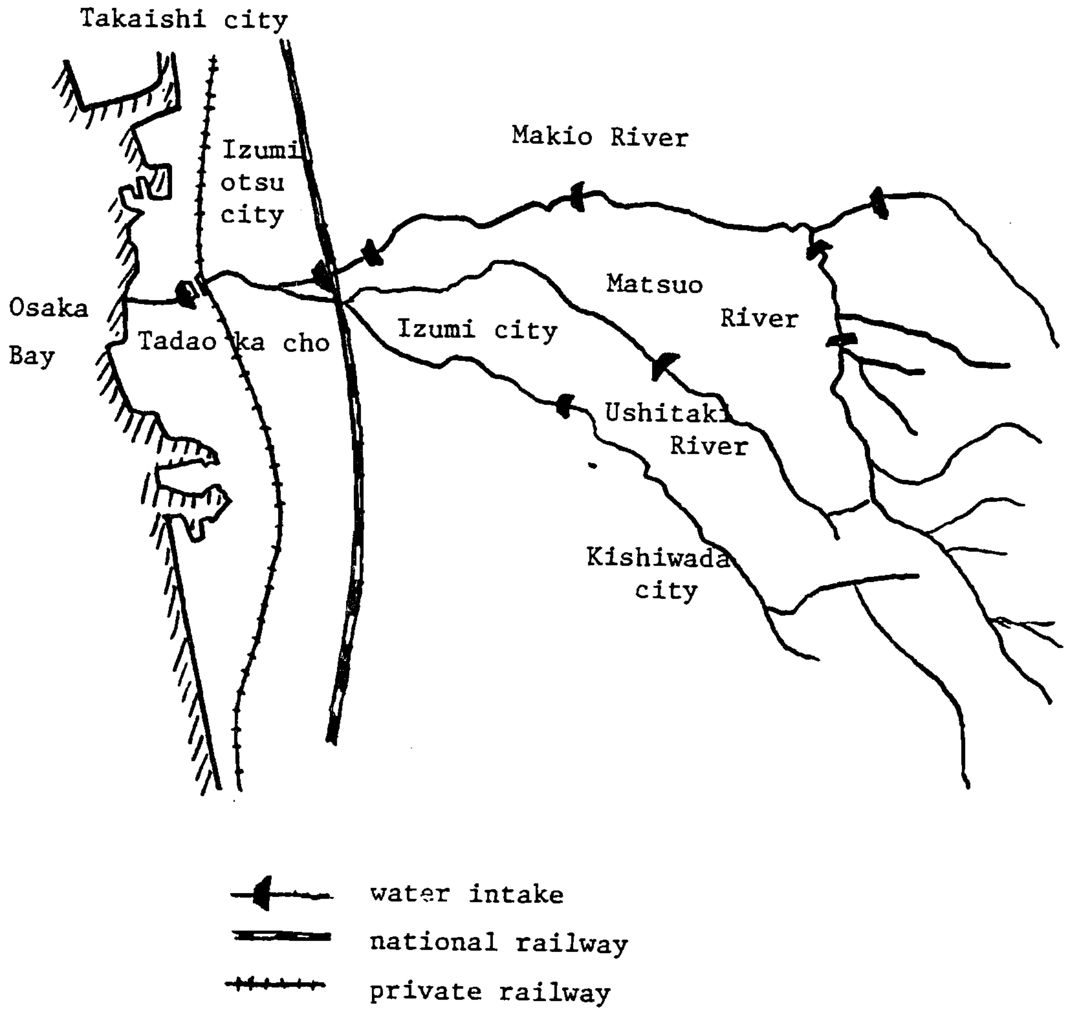


Figure 1. Map of the Otsu River Basin.

The object to be analyzed is large-scale because it includes many objectives and variables (instruments, i.e. the lowest-level objectives) which correspond to various kinds of multidisciplinary aspects. The object also has a complexity because the objectives and variables (instruments) are usually noncommensurate and in conflict with each other. This means that, generally, an overall supreme solution among Pareto-optimal solutions does not exist, which is a major characteristic of multidimensional criteria problems. A methodology for coping with these difficulties has to be developed based on a multi-objective systems analysis.

In this paper, the nested Lagrangian multiplier method which has been developed by the authors (1977, 1979a, 1979b) is applied in a probabilistic and dynamic version. The main procedure of this method is based on a hierarchical configuration and decomposition of the large-scale complex problematique in multilevel systems. Based on the decomposed subsystems, water quality simulation processes are independently introduced and combined with a main program unit for industrial land-use program. Mathematical programming is applied to the main program unit in the linkage with the simulation unit. A dynamic loop for iterative evaluation and calculation of optimal solutions is used sequentially during each subperiod of the planning time horizon. The final result of the systems evaluation is presented in terms of the multiattributable utility functions. In the process of deriving the multiattribute functions, component utility functions (or utile index) are treated as uncertain quantities. Thus assessments of judgemental probability distributions for component utility functions are executed. Using the expected values of the utility functions, the numerical values of the multiattribute utility functions are derived and calculated.

2. HIERARCHICAL MODELING

The regional complex related to water resources in the objective area, the Otsu river basin, is primarily shown in a model diagram (Figure 2). This diagram almost corresponds to the graphical location order.

For structuring the complex programatique, an overall regional system is decomposed into "independent" subsystems in multilevel. A hierarchical configuration is depicted in Figure 3. There is one main program unit and two subsidiary units: water quality simulation unit and agricultural planning unit. The hierarchical modeling of multilevel systems is composed of two strata. The first stratum is concerned with the analytical

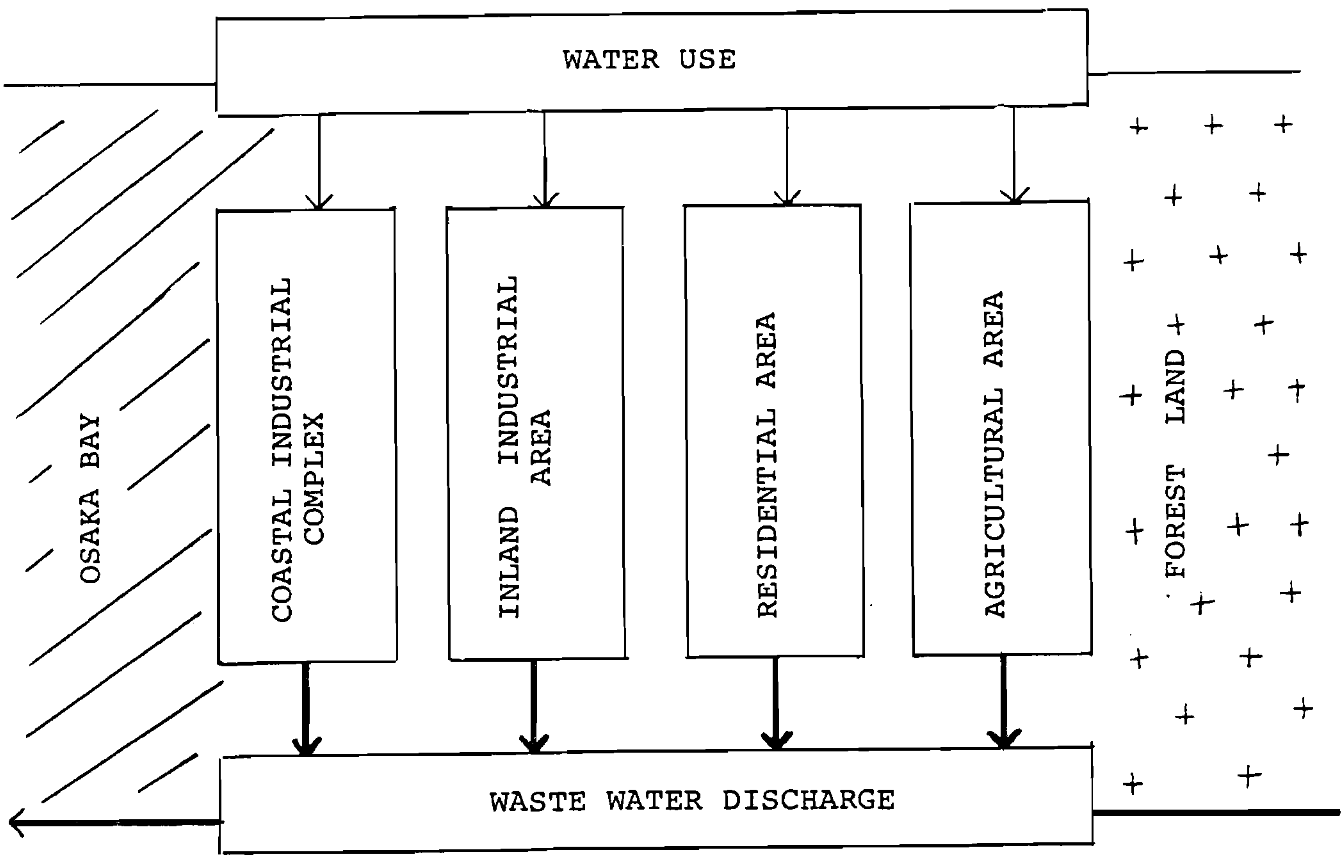


Figure 2. Model Diagram of the Otsu river basin.

aspect of the system's behavioral description - *optimization*. The second stratum has a more ambiguous aspect - *coordination*, for which a subjective evaluation must be made. The analytical aspect is composed of the main program unit (two infimal levels in which regional and time decomposition are executed) and the subsidiary units. The coordination aspect is composed of three levels. The supremal coordination unit in the highest level is the (hypothetical) Otsu river basin regional authority. Infimal coordination units are composed of the two-level industrial reallocation planning in the main program unit and are in the same interface as the two subsidiary units. They correspond to a functional decomposition.

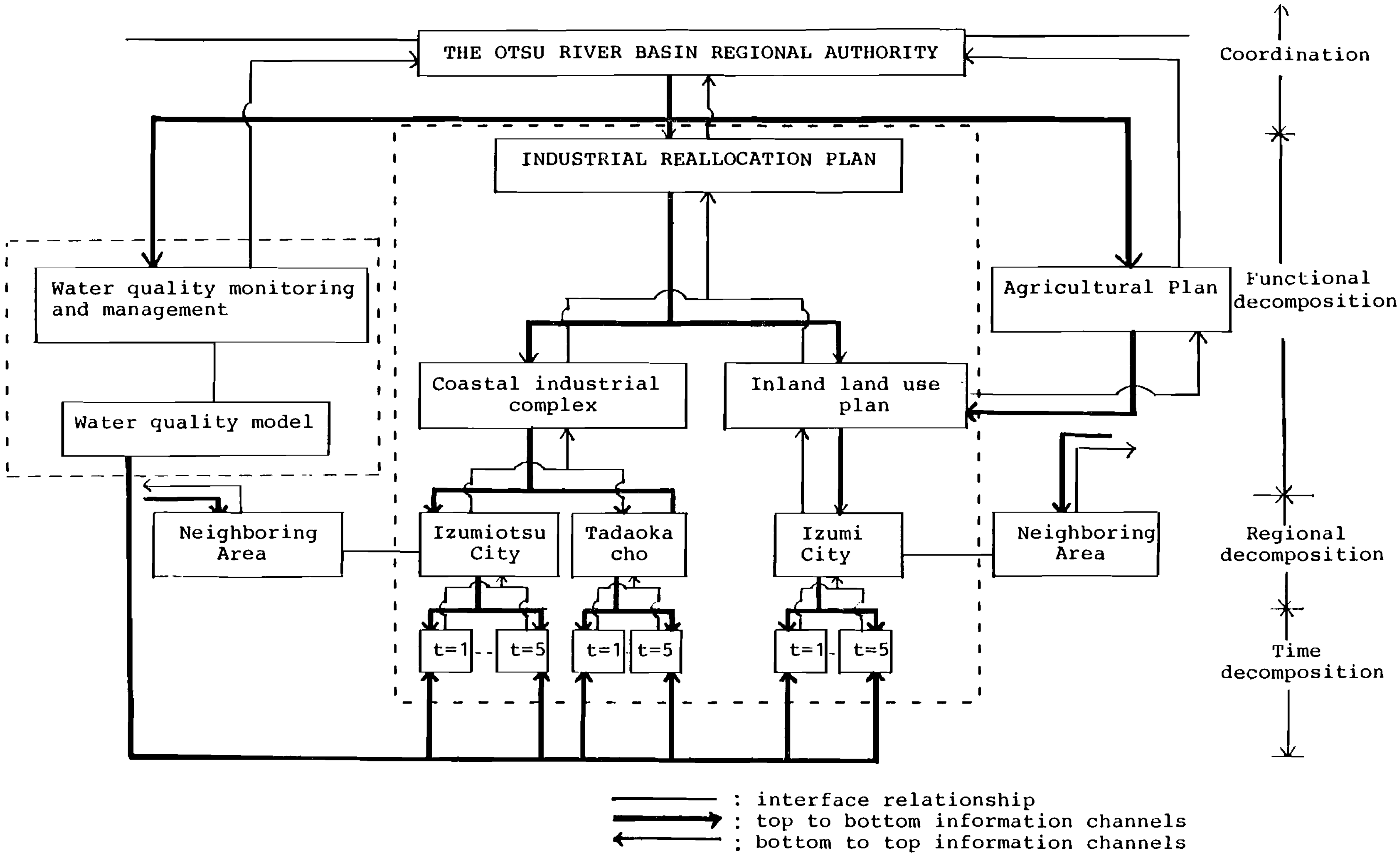
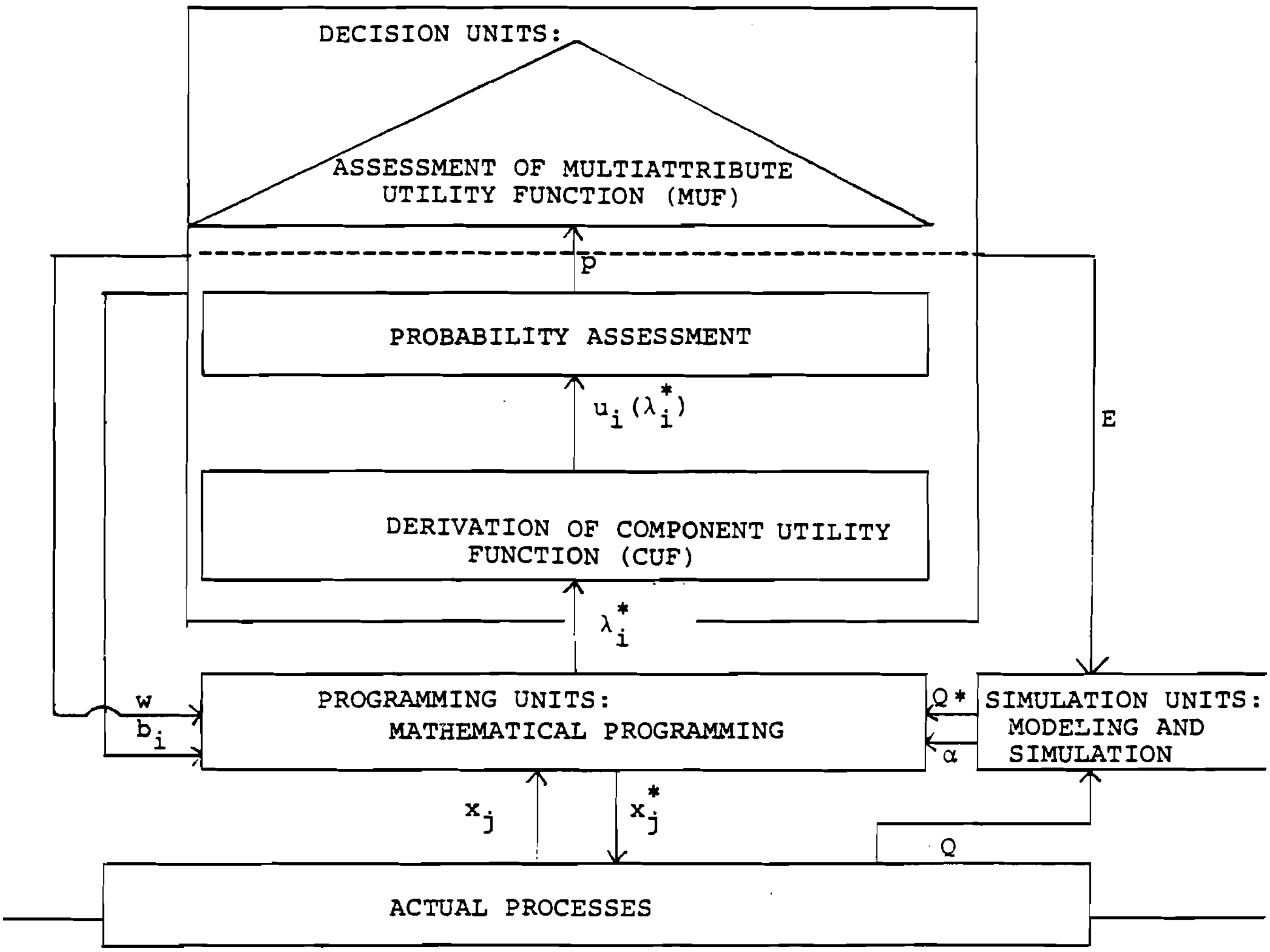


Figure 3: Systems decomposition and hierarchical modeling in multilevel for the Otsu river basin.

In the main program unit, land-use programs connected with an industrial reallocation plan for each sub-region are formalized and evaluated. The main concern of the decision maker is to find a compatible way for environmental (water pollution) control and regional economic growth. The subsidiary units provide complementary information for modeling and evaluation of the land-use program. Main information channels have their counterflow in each level. Thus, iterative evaluation and calculation for obtaining optimal solutions are interactively executed through learning and adaption processes. This process forms a closed loop of the information channels via data input-output relationship.

Corresponding to the multilevel structurization of the problems, decision making processes are also depicted in multilevel systems (Figure 4). They are composed of two layers - *operational* and *judgemental*. At the first layer, the programming unit is concerned with mathematical programming for finding optimal solutions for resource allocations and related evaluations. The simulation unit is concerned with the modeling and simulation of water quality. At the second layer, decision units execute decision analysis in three levels. Assessment and evaluation of the degree of satisfaction for water quality management and economic growth in each region are performed in terms of the multiattribute utility function in which component utility values are treated as uncertainty quantities. Namely, the decision maker at the upper level takes account of the uncertainty with which the systems will be faced in all courses of the planning.



NOTATIONS:

- Q - observed data set
- α - parameter set (for hard constraints)
- Q^* - refined data set
- x_j^* - primal optimal solution
- λ_i^* - dual optimal solution
- u_i - component utility function
- b_i - constraint constants
- w - parameter set (for soft constraints)
- x_j - observed variables
- U - multiattribute utility function
- p - probability set
- E - adjustment parameter set

Figure 4. Structure of multilevel decision making.

3. INTERACTIVE MATHEMATICAL PROGRAMMING

Mathematical programming for the major program unit is formulated in each sub-region: Izumi-otsu and Izumi cities and Tadaoka cho.

Maximize:

$$\sum_j H_j = \int_{to}^{t_1} \sum_{j=1}^{n} A_{jto}\, e^{\mu_j t}\, K_j(t)^{\alpha_j}\, L_j(t)^{\beta_j}\, D_j(t)^{1-\alpha_j-\beta_j} dt \qquad (1)$$

Subject to:

$$\sum_{j=1}^{n} \left(k_j / d_{jto} e^{-\psi t}\right) D_j(t) \leq K(t) \qquad (t=1,...,5) \qquad (2)$$

$$\sum_{j=1}^{n} \left(\omega_{jto} e^{-\rho t} / k_j\right) K_j(t) \leq W(t) \qquad (t=1,...,5) \qquad (3)$$

$$\sum_{j=1}^{n} L_j(t) \leq L_{to} e^{\eta t} \qquad (t=1,...,5) \qquad (4)$$

$$\sum_{j=1}^{n} D_j(t) \leq D^U \qquad (t=1,...,5) \qquad (5)$$

$$\left(K/L\right)_j^L \leq K_j(t)/L_j(t) \leq \left(K/L\right)_j^U \qquad (j=1,...,n;\ t=1,...,5) \qquad (6)$$

$$K_{jto} e^{-\pi t} \leq K_j(t) \leq K_{jo}\, e^{\pi' t} \qquad (j=1,...,n;\ t=1,...,5) \qquad (7)$$

$$L_{jto} e^{-\pi t} \leq L_j(t) \leq L_{jto} e^{\pi' t} \qquad (j=1,...,n;\ t=1,...,5) \qquad (8)$$

where j is an industry and t is a planning subperiod. The objective function (1) is the sum of a local Cobb-Douglas-type production function for each industry. Hicks-neutral technological progress is included in each function. Capital value K_j, labour force L_j, and land D_j are decision variables.

In constraint (2), the variable $D_j(t)$ is related to a growth policy for total capital $K(t) = K_{to}e^{\eta' t}$. k_j is a capital coefficient and d_j is a land coefficient in each industry. In constraint (3), the variable $K_j(t)$ is related to a pollution control policy, W(t), which shows a target level of COD effluent discharge. ω_j is a unit load of COD per industrial shipment. ω_j and d_j are changed in each subperiod by a gradual reduction policy. These right-hand side constraint constants and indicative parameters are imposed by the second layer decisionmaker.

Constraint (4) shows that all the labour requirements do not exceed the predicted total labour supply. Constraint (5) shows upper bounds of total availability of land for industrial use. Constraint (6) is a technical constraint and shows upper and lower bounds of capital-labour ratio in each industry. Constraints (7) and (8) are frictional constraints and are set for avoiding radical changes of industrial structure. It is admissable for local decisionamkers to assign these constraint constants as their own policy. Actually indicative parameters are set as shown in Table 1.

Table 1. Indicative Parameters in Mathematical Programming

		Percentage change for time period (10 years)	
ρ	0.032	(-)	15%
π	0.071	(-)	30%
π'	0.139	(+)	100%
ψ	0.022	(-)	10%

In this problem, the constraints (2) and (3) are especially important because they are the main subjects of decisionmaking for the integrated regional planning. Thus, the problem is to find an optimal policy for resource allocation (capital, labour and land) for maximizing local industrial outputs under the conditions performing a prescribed economic growth policy and water quality control, considering the total supply of available labour forces and land resources. In the process of solving nonlinear mathematical programming, an evaluation for local economic growth and environmental management policy is provided with the dual optimal solutions which are combined with constraints (2) and (3). Thus, mathematical programming simultaneously provides the optimal resource allocation policy and its evaluation. In fact, the problem (1)-(8) has been solved iteratively in the time decomposition form. For solving nonlinear mathematical programming, Generalized Reduced Gradient Algorithm developed by Lasdon et al. (1974, 1975) is used.

In addition, iterative learning and adaption processes in a dynamic loop are also embedded in the optimization processes. Namely, the main program unit is combined with the simulation unit by receiving information on the pollutant discharge as an input and by sending information on the industrial shipments as output. In the simulation unit, an ecological water quality model is used for assessing interrelationships among ecological constituents based on self-purification mechanisms in the river. The river quality model, based on a chemical reaction between dissolved oxygen (DO) concentration and biochemical oxygen demand (BOD) concentration, is well-known as the Streeter-Phelps model. In ecological models which have recently been developed (Beck, 1978), more detailed information on ecological activities such as sunlight effects, water temperatures and photosynthetic activity of plant and algae is included. Beck has presented various types of the ecological model describing the ecological interrelationships and has provided some empirical results of simulation in the River Cam (1978,1978b). According to his experiment, it is known that to include the algal population does not greatly improve the model fitting of the observed system. Thus, for simulating self-purification mechanism of the freshwater river, the following model, based on the continuously stirred tank reactor (CSTR) idealization, is utilized on a day-by-day basis. (Beck and Young, 1975,1976).

$$\dot{X}_1 = -(\kappa_1 + Q(\tau)/V)\, X_1(\tau) - \kappa_2 X_2(\tau) +$$

$$+ (Q(\tau)/V)\, U_1(\tau) + \kappa_1 C(\tau) + \kappa_4 (h(\tau) - \bar{h}) + S \qquad (9)$$

$$\dot{X}_2 = -(\kappa_2 + \kappa_3 + Q(\tau)/V)\, X_2(\tau) +$$

$$+ (Q(\tau)/V)\, U_2(\tau) + \kappa_5 (h(\tau) - \bar{h}) + R \qquad (10)$$

where

$$h(\tau_k) = h(\tau_{k-1}) + 1/T[v(\tau_k) \left\{ \frac{\theta(\tau_k) - \bar{\theta}}{\bar{\theta}} \right\} -$$

$$- h(\;_{k-1})] \;, \qquad (11)$$

$$(h(\tau_k) - \bar{h}) = 0 \text{ for } h(\tau_K) < \bar{h} \;, \qquad (12)$$

$$h(\tau_0) = 0.0 \;, \qquad (13)$$

and

$$C(\tau) = 14.5412 - 0.3928\, \theta(\tau) - 0.0073[\theta(\tau)]^2 -$$

$$- 0.000066[\theta(\tau)]^3 \qquad (14)$$

$$\tau_0 \leq \tau_k \leq \tau_{365} \;, \quad \tau_k - \tau_{k-1} = 1 \text{(day)} \qquad (15)$$

In this model, it is assumed that there is no transportation delay. Measurement errors are also neglected.

Variables and parameters are explained in Table 2. Values of the parameters are almost similar to the River Cam's data because geographical conditions are not so different from each other. However, some corrections have been made for empirical data in the Otsu river during the whole year. Special consideration is given to the hot and humid weather conditions in Japan in the summer season. A time-series data for the sunlight hours $V(\tau_k)$ are shown in Appendix A.

The simulation output $X_2^*(\tau)$ of this model is used at the input data to the main program along with $Q(\tau)$ in summation. The input variables $U_1(\tau)$ and $U_2(\tau)$ are obtained from optimal values of the industrial shipment $H_j^*(t)$ which is the value of the production function, multiplied by the pollutant-load parameter $\omega_j(t)$. These values are iteratively revised in each planning subperiod (t=1,...5).

On the other hand, the main program unit also obtains information on available land resources for the industrial use from the agricultural planning unit. Especially for Izumi city, which includes a large area of agricultural land, constraint constants in the equation (5) are treated as time-variants $D^U(t)$, t-1,...,5, based on a revised industrialization plan which intends to slow down the conversion speed of agricultural land to industrial uses to less than in the past few years. Here again, iterative learning and adaption processes are also assumed. These interactive processes among the main program unit and two subsidiary units are depicted in Figure 5.

4. EVALUATION PROCEDURE

According to the nested Lagrangian multiplier (NLM) method (Seo 1977,1979), the dual optimal variables obtained in each subsystem are utilized as the basic factor of the system's evaluation. Utilization of Lagrangian multipliers (shadow prices) as a base of the system's evaluation has been developed by Haimes and Hall (1974), Haimes, Hall and Friedman (1975)

Table 2. Variables and Parameters.

VARIABLES and PARAMETERS	DEFINITION	VALUE
$U_1(\tau)$	influent DO concentration	input variable (gm^{-3})
$U_2(\tau)$	influent BOD concentration	input variable (gm^{-3})
$X_1(\tau)$	effluent DO concentration	output variable (gm^{-3})
$X_2(\tau)$	effluent BOD concentration	output variable (gm^{-3})
$Q(\tau)$	volumetric flow-rate	121391 ($m^3 day^{-1}$). 39611 for τ_1, τ_2, τ_3 and afterwards for two days after every five days.
V	mean volumetric hold-up in the reach	121824 ($m^3 day^{-1}$)
κ_1	reaeration rate for DO	0.17(day^{-1})
κ_2	BOD decay rate	0.32 (day^{-1})
κ_3	BOD sedimentation rate	0.001 (day^{-1})
κ_4	coefficient for sustained sunlight effect in DO equation	0.31 ($gm^{-3}\ day^{-1}$)
κ_5	Coefficient for sustained sunlight effect in BOD equation	0.32 ($gm^{-3}\ day^{-1}$)
$h(\tau)$	sustained sunlight effect at day τ_k	equation(11) (hr. day^{-1})
$\bar{h}$	threshhold level for sustained sunlight effect	6.0 (hr.)
C	saturation concentration of DO	equation (14) (gm^{-3})
S	additional rate of DO by decomposition of bottom mud deposits	0.0 for $\tau_1 < \tau_k < \tau_{90}$ and $\tau_{335} < \tau_k < \tau_{365}$, -0.5 for $\tau_{91} < \tau_k < \tau_{151}$ and $\tau_{274} < \tau_k < \tau_{334}$ -2.0 for $\tau_{152} < \tau_k < \tau_{181}$ and $\tau_{244} < \tau_k < \tau_{273}$ -4.5 for $\tau_{182} < \tau_k < \tau_{243}$
v	hrs. of sunlight incident at day τ_k	time-series data (hr)
R	additional rate of BOD by local surface runoff	0.001 ($gm^{-3} day^{-1}$)
$\theta(\tau)$	stream water temperature	time-series data (°C)
$\bar{\theta}$	mean river water temperature	8.0 (°C)
T	time constant for discrete-time low-pass filter	4
$X_1(\tau_0)$	initital condition for effluent DO concentration	9.0 (gm^{-3})
$X_2(\tau_0)$	initital condition for effluent BOD concentration	4.9 (gm^{-3})

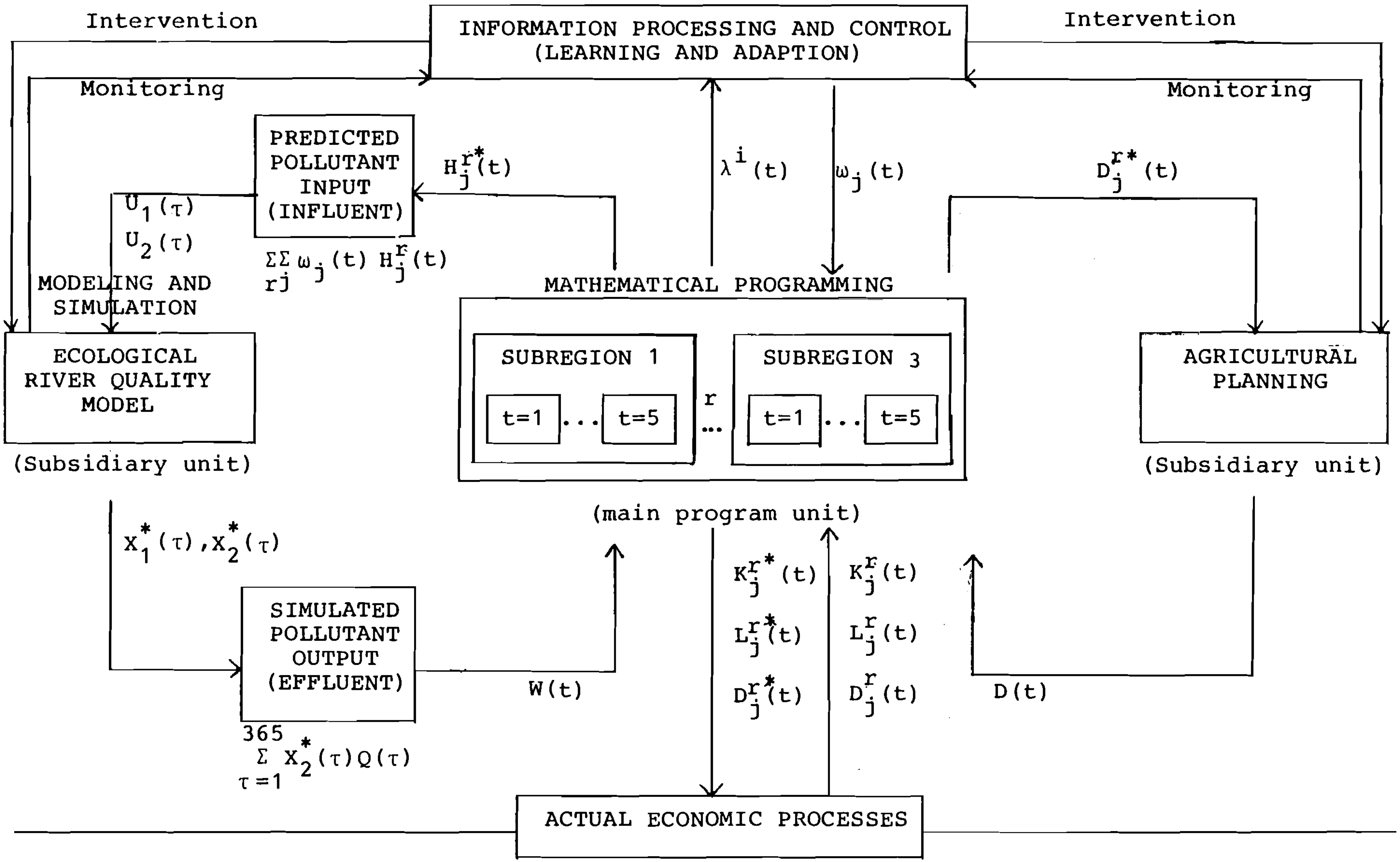


Figure 5. An interactive loop of regional planning.

In their method the shadow prices are mediately used via the trade-off rate functions. Worth functions are assessed simply with subjective judgement in ordinal scale.

In our method, it is asserted that numerical ordering of the shadow prices corresponds to preference ordering for local decisionmaking. This is because numerical values of the Lagrangian multiplier in optimal are regarded as an expression of the degree of marginal sacrifice of local objective functions in terms of constraint constants, which are imposed by the upper-level decisionmaker. Thus, the shadow prices are considered as a *difficulty index* for local decisionmakers in methematical terms, and used directly as inverse images of the utility functions (utile index). For numerically evaluating the difficulty index on a cardinal scale, the Lagrangian multipliers are positive-linearly transformed into normalized values from 0 to 1. With this device, noncommensurate attributes are measured in commensurate terms. We call the normalized values the component utility function.

Then trade-offs between each pair of numerical values of the component utility functions are examined. Based on the trade-off experiments and 50-50 chance lottery techniques, scaling constants are calculated. Multiattribute utility functions are derived using the component utility functions and the scaling constants. Raiffa (1968) and Keeney (1974), Keeney and Raiffa (1976) have greatly contributed to this aspect. However, in our method, the trade-off experiments are performed in terms of the normalized utility values, differing from the original device in which the experiments are in terms of the attributes.

Thus, in our method, the subjective or judgemental phase for the coordination processes of decisionmaking is immediately based on results from the mathematical phase for the programming processes. The basic evaluation factor is the shadow-prices as difficulty index for the management system, which is regarded as opportunity costs for interorganizational decisionmaking at multilevel. This device intends to minimize ambiguity which will be introduced into primal evaluation processes at lower levels of multi-layer systems.

Thus, in the original NLM method, values of the component utility functions which have been transformed from Lagrangian multipliers are treated as deterministic values.

However, decisionmaking for the coordination processes at upper levels of the multi-layer systems is much more complex, and uncertain or fuzzy elements must be included. As one device for such an inclusion, the values of the component utility functions are treated as uncertain quantities. Namely, expected values of the component utility functions with judgemental or hypothetical probability distributions are assessed and used for deriving the multiattribute utility functions at upper levels. Thus, hazardous factors in decisionmaking processes are introduced into systems evaluation.

The multiattribute utility functions are derived at multilevel. According to Fishburn-Keeney's representation theorems, the multiattribute utility functions are assessed in additive or multiplicative forms under the preferencial and utility independence conditions:

Additive form:

$$U\{\lambda(x)\} = \Sigma_i k_i \tilde{u}_i \{\lambda_i(x)\} \tag{16}$$

where

$$\Sigma_i k_i = 1, \qquad 0 \leq U, \tilde{u}_i \leq 1$$

Multiplicative form:

$$U\{\lambda(x)\} = 1/K[\Pi_i\{K\ k_i \tilde{u}_i\{\lambda_i(x)\} + 1\} - 1] \tag{17}$$

where

$$\Sigma_i k_i \neq 1,\ 0 < k_i < 1,\ 0 \leq U,\ \tilde{u}_i \leq 1,\ K > -1$$

λ is a vector of Lagrangian multipliers in optimal and λ_i is an element in it. x is a vector of attributes. $\tilde{u}_i$ is an expected value of the component utility function and U is a multiattribute utility function. k_i and K are scaling constants and obtained by the trade-off experiments and 50-50 chance lottery technique among the utlity values. With nesting procedures, the multiattribute utility functions are derived one after another in the hierarchical systems. Actually the value u_i^s for the cumulative distribution function

$$F_i^s(u_i^s \leq \bar{u}_i)$$

is assessed for several fractiles of distribution. Schlaifer (1969,1970) has contributed to derive judgemental distribution functions and to computerize them. Expected values of the component utility functions with probability distribution function $f_i^s(u_i^s)$

$$\tilde{u}_i = Eu_i = \sum_s f_i^s(u_i^s)\ u_i^s \quad ,$$

are used for calculating the multiattribute utility functions. Alternative experiments which take account of probalistic factors in any level of the utility functions are efficiently performed with ICOPSS/1 computer package which has been newly developed by the authors (Sakawa and Seo 1980a,1980b).

Using these numerical values, spots where the difficulties for executing the integrated regional program exist are searched in the whole system. The results are utilized for better understanding of implications of the current management plan and for decision-aid for framing and evaluating more desirable alternative plans.

5. SOME NUMERICAL RESULTS

For obtaining numerical results, major industries in each sub-region have been chosen. The number of industries is nine in Izumiotsu, seven in Izumi and three in Tadaoka. Details are shown in Table 3.

Alternative plans for the integrated regional management-land use program are formed and evaluated over five planning periods (t=1,...,5). Active constraint constants for all the

Table 3. Selected industries in each subregion.

Code	Industry	Izumiotsu	Tadaoka	Izumi
18-19	Foods			o
20	Textile Mill products	o	o	o
21	Apparel products	o		o
22	Lumber & related products		o	
24	Pulp & Paper products	o		o
26	Chemicals & related products	o		o
30	Clay & Stone products	o		
31	Iron and Steel	o		
33	Fabricated Metal products	o	o	o
34	Machinery	o		o
36	Transportation Equipment	o		
	Total	9	3	7

alternatives are shown in Appendix B . The selection of measurement units is crucial and assumed to be reasonable and practically meaningful.

Alternative I.

First, as one of the alternative land-use plans, a radical industrial reallocation program between coastal and inland areas is examined. The total capital formation at the end of the planning period will reduce about 18% in the coastal area (Izumiotsu and Tadaoka), but will increase about 26% in the inland area (Izumi). Connected with the industrial reallocation program in the coastal area, industrial land areas are reduced about 45 and 51% at the end of the planning period. In the inland area (Izumi city), the industrial land is decreased about 20%. The total volume of COD, which will be discharged into Osaka Bay, is reduced about 28%. The reduction rate ψ for land coefficient is 0.022 for industry code no. 21, 22, 24, 34 and 36 (-10% for five periods), and is 0.08616 for no. 18-19, 20, 26, 30, 31 and 33 (-35% for five periods). Other data are the same as in Table 1.

Results:

(1) Among industries in Izumiotsu city, capital formation in machinery is increased and there are some aspects for increasing capitals in Fabricated Metal products as well as in Clay and Stone. Pulp and Paper and Iron and Steel industries are constantly decreased. In Tadaoka cho, capitals in Textile, Lumber and Fabricated Metal industries are constantly decreased. In Izumi city, capitals in Fabricated Metal and Machinery are increased. Because the production functions include Hicks-neutral technological progress, the total amount of industrial shipment will increase about 17% in Izumiotsu, 80% in Tadaoka and 45% in Izumi.

(2) The results of water pollution control are shown in Table 4. As you see, the capacity of natural purification is rather large. Under the given conditions on the COD unit load ($\rho=0.032$), the waste water treatment rate for COD discharge is increased. However, required rates of treatment are less than 50% and the current capacity of sewage treatment plants will meet these requirements. Actually, water quality constraint constant W(t) has been changed in accordance with an adjustment parameter EPSI which is a reduction rate from the predicted value of COD discharge $\sum_r \sum_j \omega_j(t) H_j^{r*}(t)$ in order to secure prescribed values of U_2 in each planning period and the control parameter EPSI is set as follows:

$$\frac{\mathrm{EPSI}\cdot\sum_r \sum_j \omega_j^r(t) H_j^r(t)}{365\cdot Q(\tau)} = U_2(\tau)$$

With revised (gradually reduced) values of $U_2(\tau)$ a simulation result:

$$\sum_{\tau=1}^{365} X_2^*(\tau) Q(\tau)$$

is calculated and assigned as constraint constant $W^r(t)$ for each subregion in the main programming unit. (Subscript r shows each subregion). A similar procedure is followed in other alternatives.

Table 4. Results of water pollution control (Alternative I).

Period	U_1	U_2	X_1	X_2	reduction rate via natural purification (BOD) $\dfrac{\sum_{\tau=1}^{365} X_2(\tau)Q(\tau)}{\sum_{\tau=1}^{365} U_2(\tau)Q(\tau)}$	reduction rate via control policy (COD) $\dfrac{\sum_r \sum w^r(t)}{\sum_r \sum_j \omega_j H_j^{r*}(t)}$	(COD) $\dfrac{w(t)}{w(0)}$
0 → I	12.0	6.4	9.0	4.9	23%	7%	6.3%
I → II	11.1	5.9	8.5	4.6	23	22	13.5
II → III	10.4	5.5	7.9	4.3	22	27	17.1
III → IV	9.6	5.1	7.4	4.0	22	39	22.9
IV → V	8.9	4.8	6.9	3.8	21	47	27.8

Note:

$$U_1 = \sum_{\tau=1}^{365} Q(\tau)U_1(\tau) \Big/ \sum_{\tau=1}^{365} Q(\tau)$$

$$X_1 = \sum_{\tau=1}^{365} Q(\tau)X_1(\tau) \Big/ \sum_{\tau=1}^{365} Q(\tau)$$

$$U_2 = \sum_{=1}^{365} Q(\tau)U_2(\tau) \Big/ \sum_{=1}^{365} Q(\tau)$$

$$X_2 = \sum_{=1}^{365} Q(\tau)X_2(\tau) \Big/ \sum_{=1}^{365} Q(\tau)$$

(3) Total labor force consistent with this plan will decrease about 16% in Izumiotsu, 1% in Tadaoka, and increase about 18% in Izumi. Thus, a labor force transfer from the coastal area to the inland area is predicted.

(4) The evaluation for this policy is shown in Table 5. Policy constraints on K(t) show much more difficulty in terms of the local objective functions than on W(t). Degrees of difficulty for the capital reallocation policy which is combined with a land-use policy are lowest in Izumiotsu at t=1,2, and in Tadaoka at t=3,4,5. This means that the guided capital reformation policy must be rearranged or some complementary means for performing it are required.

The difficulty of the land-use policy is at its worst in Izumi after t=2. This is a matter of course as, in Izumi, a growth policy for capital formation has been introduced. The capital growth policy has some effect on labor availability in Izumi; namely, although the difficulty in labor availability is fairly moderate until t=4, it is at its worst at t=5.

(5) Multiattribute utility functions and their numerical values at t=1,3 and 5 are evaluated in deterministic terms.

t=1

Izumiotsu: $U_{IO}(u_W, u_K, u_D, u_L) = 0.786$

$$U_{IO} = \frac{1}{K}[(1+0.83K\ u_W)\ (1+0.2905K\ u_K)$$

$$(1+0.249K\ u_D)\ (1+0.166K\ u_L)-1]$$

$$K = -0.8516$$

Tadaoka: $U_{TA}(u_W, u_K, u_D, u_L) = 0.895$

$$U_{TA} = \frac{1}{K}[(1+0.9K\ u_W)\ (1+0.315K\ U_K)$$

$$(1+0.36K\ u_D)\ (1+0.225K\ u_L)-1]$$

$$K = -0.9453$$

TABLE 5. POLICY EVALUATION (ALTERNATIVE I)

In terms of	t=1		t=2		t=3		t=4		t=5	
	λ	u	λ	u	λ	u	λ	u	λ	u
IZUMI OTSU										
K(t)	0.3315	9.37×10^{-5}	0.0674	9.15×10^{-6}	0.370	0.0055	0.7349	0.0039	0.705	0.0029
W(t)	1326.26	0.9468	1767.40	0.9296	29.410	0.9485	34.170	0.9759	35.560	0.9604
L(t)	1.1730	6.95×10^{-4}	1.206	6.08×10^{-4}	1.969	0.0574	1.499	0.0261	2.259	0.0456
D(t)	2.5953	1.71×10^{-3}	2.046	0.0011	1.400	0.0390	0.960	0.0105	1.4033	0.0221
TADAOKA										
K(t)	1.095	0.0063	1.478	0.0049	0.970	0.0033	1.0247	0.0020	1.660	0.0020
W(t)	31.432	0.9816	36.844	0.9686	50.590	0.9724	63.730	0.9801	79.790	0.9849
L(t)	1.8324	0.0300	2.329	0.0280	2.193	0.0272	2.594	0.0264	3.135	0.0206
D(t)	6.1695	0.1694	8.139	0.1864	6.031	0.1022	6.488	0.0872	9.633	0.1023
IZUMI										
K(t)	1.176	0.0229	1.720	0.0335	1.490	0.0186	1.160	0.0132	1.220	0.0043
W(t)	29.220	0.9736	32.590	0.9578	36.850	0.9690	42.030	0.9770	50.733	0.9753
L(t)	1.670	0.0397	2.390	0.0536	11.288	0.2819	2.236	0.0386	1.4878	0.0096
D(t)	0.695	0.0066	0.749	0.0045	0.8739	0.0020	0.678	0.0018	1.230	0.0045

Izumi: $U_{IZ}(u_w, u_K, u_D, u_L) = 0.737$

$$U_{IZ} = \frac{1}{K}[(1+0.75K\ u_w)\ (1+0.225K\ u_K)\ (1+0.2625K\ u_D)\ (1+0.1875K\ u_L)-1]$$

$K = -0.7461$

Region: $U_R(U_{IO}, U_{TA}, U_{IZ}) = 0.908$

$$U_R = \frac{1}{K}[(1+0.18K\ U_{IO})\ (1+0.9K\ U_{TA})\ (1+0.27K\ U_{IZ})-1]$$

$K = 0.8398$

<u>t=3</u>

Izumiotsu: $U_{IO}(u_w, u_K, u_D, u_L) = 0.830$

$$U_{IO} = \frac{1}{K}[(1+0.87K\ u_w)\ (1+0.2871K\ u_K)\ (1+0.2175K\ u_D)\ (1+0.1305K\ u_L)-1]$$

$K = -0.8672$

Tadaoka: $U_{TA}(u_w, u_K, u_D, u_L) = 0.901$

$$U_{TA} = \frac{1}{K}[(1+0.92K\ u\ )\ (1+0.276K\ u_K)\ (1+0.3496K\ u_D)\ (1+0.184K\ u_L)-1]$$

$K = -0.9492$

Izumi: $U_{IZ}(u_w, u_K, u_D, u_L) = 0.777$

$$U_{IZ} = \frac{1}{K}[(1+0.78K\ u_w)\ (1+0.2184Ku_K)$$

$$(1+0.2574K\ u_D)\ (1+0.156K\ u_L)-1]$$

$K = -0.7578$

Region: $U_R(U_{IO}, U_{TA}, U_{IZ}) = 0.851$

$$U_R = \frac{1}{K}[(1+0.2975K\ U_{IO})\ (1+0.2125K\ U_{TA})\ (1+0.85K\ U_{IZ})-1]$$

$K = -0.7929$

<u>t=5</u>:

Izumiotsu: $U_{IO}(u_w, u_K, u_D, u_L) = 0.867$

$$U_{IO} = \frac{1}{K}[(1+0.9K\ u_w)\ (1+0.27K\ u_K)$$

$$(1+0.18K\ u_D)\ (1+0.09K\ u_L)-1]$$

$K = -0.875$

Tadaoka: $U_{TA}(u_w, u_K, u_D, u_L) = 0.939$

$$U_{TA} = \frac{1}{K}[(1+0.95K\ u_w)\ (1+0.2375K\ u_K)$$

$$(1+0.3325K\ u_D)\ (1+0.1425K\ u^L)-1]$$

$K = -0.9609$

Izumi: $U_{IZ}(u_w, u_K, u_D, u_L) = 0.782$

$$U_{IZ} = \frac{1}{K}[(1+0.8K\ u_w)\ (1=0.16K\ u_K)$$

$$(1+0.24K\ u_D)\ (1+0.12K\ u_L)-1]$$

$$K = -0.7109$$

Region: $U_R(U_{IO}, U_{TA}, U_{IZ}) = 0.907$

$$U_R = \frac{1}{K}[(1+0.8K\ U_{IO})\ (1+0.32K\ U_{TA})\ (1+0.24K\ U_{IZ})-1]$$

$$K = -0.7524$$

Therefore, during the planning period, utility values are highest in Tadaoka and lowest in Izumi. This is mainly due to the fact that degrees of satisfaction for land constraints are highest in Tadaoka and lowest in Izumi[1/]. Generally, utility values of each subregion are increasing, corresponding to the increase of scaling constants for u_w, and to the decrease of scaling constants for u_K, u_D, and u_L.

1/ In the case where activeness of land constraints is neglected, the degree of satisfaction for the same policy is highest in Izumi and lowest in Izumiotsu (Seo and Sakawa 1980).

Alternative II.

In the second alternative plan, the industrial allocation policy between coastal and inland areas nearly follows current trends. Thus, in the coastal area (Izumiotsu and Tadaoka), the total capital formation increases about 22% and 28%. In the inland area (Izumi), the capital formation increases about 17%.

However, more radical land-use and water quality management policies are pursued. Namely, reduction rate ψ of the land coefficients is revised to 0.08618 for industry code no.24, 30 and 31 (i.e. -35% for five periods), to 0.1386 for no.18,19,20,26 and 30 (i.e. -50% for five periods), and to 0.022 for no.21,22, 34 and 36 (i.e. -10% for five periods). Reduction rate ρ for the COD unit load is increased to 0.05754 for all the industries (-25% for five periods).

Thus, industrial land areas are reduced about 29% in Izumiotsu, 20% in Tadaoka and 38% in Izumi. The total volume of COD, which will be discharged into Osaka Bay, is reduced about 30%.

Results:

(1) Among industries in Izumiotsu, Alternative II allows an increase of capital formation in the Clay and Stone industry. The increase in Fabricated Metal is much more than Alternative I. The increase in Chemicals as well as the decrease in Iron and Steel is less than Alternative I. In Tadaoka, the capital formation in Lumber and Fabricated Metal industries increases. In Izumi, on the contrary to Alternative I, an increase in Chemicals is permitted. However, decreases in Textile and Apparel industries are more than Alternative I. The total amount of industrial shipment will increase about 45% in Izumiotsu, 133% in Tadaoka, and 15% in Izumi, until the end of the planning period.

(2) The results of water pollution control are shown in Table 6. The capacity of natural purification for Alternative II is as effective as Alternative I. As a result of an overall capital growth policy, reduction rates for COD discharge are slightly increased to 54%.

Table 6. Results of water pollution control (Alternative II)

Period	U_1	U_2	X_1	X_2	Reduction rates: via natural purification (BOD) $\dfrac{\sum_{\tau=1}^{365} X_2(\tau)Q(\tau)}{\sum_{\tau=1}^{365} U_2(\tau)Q(\tau)}$	via control policy (COD) $\dfrac{\sum_r W^r(t)}{\sum_r \sum_j \omega_j H_j^{r*}(t)}$	(COD) $\dfrac{W(t)}{W(0)}$
0 → I	12.0	6.4	9.1	4.9	23%	4%	4.0%
I → II	11.3	6.0	8.5	4.6	23	25	10.9
II → III	10.4	5.5	7.9	4.3	22	38	17.2
III → IV	9.8	5.2	7.5	4.1	22	45	21.9
IV → V	9.1	4.8	7.0	3.8	21	54	29.6

(3) Total labor force for Alternative II increases about 23% in Izumiotsu and 9% in Tadaoka and decreases 30% in Izumi. Thus, a labor force transfer from the inland area to the coastal area will still continue. Moreover, capital intensive technological changes in Izumi will be especially induced.

(4) The utility evaluations for this policy is shown in Table 7. Degrees of satisfaction for the regional planning are generally lowest for land resource constraints, differing from Alternative I. This is natural from the viewpoint of the radical reduction policy for land coefficients. In particular, the land resource policy has most difficulty in Tadaoka. This phenomena is combined with the highest rate of capital formation in Tadaoka.

(5) Multiattribute utility functions and their numerical values at t=1,3 and 5 are evaluated in deterministic terms. For the evaluation, trade-off ratios or scaling constants for the component utility fuctions are the same as for Alternative I. Thus, forms and parameters of the multiattribute utility functions are the same as those in Alternative I.

TABLE 7. POLICY EVALUATION (ALTERNATIVE II)

In terms of	t=1 λ	t=1 u	t=2 λ	t=2 u	t=3 λ	t=3 u	t=4 λ	t=4 u	t=5 λ	t=5 u
IZUMIOTSU										
K(t)	0.4515	0.0901	0.5845	0.0185	0.634	0.0153	0.790	0.0107	0.9665	0.0202
W(t)	3.760	0.9384	30.459	0.9826	34.067	0.9732	36.515	0.9867	42.024	0.9772
L(t)	2.780	0.6872	1.4117	0.0452	1.587	0.0426	1.780	0.0377	2.00	0.0443
D(t)	0.224	0.0318	0.0148	0.0002	0.209	0.0031	0.531	0.0036	0.178	0.0018
TADAOKA										
K(t)	0.626	0.0084	0.788	0.0157	0.8615	0.0139	0.9193	0.0123	0.997	0.0107
W(t)	38.133	0.9776	49.20	0.9840	60.690	0.9771	74.265	0.9899	91.88	0.9877
L(t)	2.351	0.0530	2.492	0.0498	3.035	0.0489	3.80	0.0507	4.466	0.0480
D(t)	0.420	0.0031	0.002	2.0×10^{-5}	1.58×10^{-3}	9.3×10^{-6}	9.9×10^{-5}	2.5×10^{-7}	1.68×10^{-4}	7.3×10^{-7}
IZUMI										
K(t)	0.8705	0.0486	0.8343	0.0216	1.066	0.0248	0.9031	0.0375	1.057	0.1238
W(t)	13.287	0.9483	15.135	0.9440	39.625	0.9664	19.1613	0.9577	4.643	0.9205
L(t)	1.818	0.1172	1.977	0.0953	1.97	0.0469	1.388	0.0619	2.10	0.3555
D(t)	0.3465	0.0106	0.644	0.0093	0.0765	0.0006	0.1825	0.0011	0.73	0.0511

t=1

Izumiotsu: $U_{IO}(u_w,u_K,u_D,u_L) = 0.828$

Tadaoka: $U_{TA}(u_w,u_K,u_D,u_L) = 0.883$

Izumi: $U_{IZ}(u_w,u_K,u_D,u_L) = 0.728$

Region: $U_R(U_{IO},U_{TA},U_{IZ}) = 0.901$

t=3

Izumiotsu: $U_{IO}(u_w,u_K,u_D,u_L) = 0.850$

Tadaoka: $U_{TA}(u_w,u_K,u_D,u_L) = 0.903$

Izumi: $U_{IZ}(u_w,u_K,u_D,u_L) = 0.759$

Region: $U_R(U_{IO},U_{TA},U_{IZ}) = 0.844$

t=5

Izumiotsu: $U_{IO}(u_w,u_K,u_D,u_L) = 0.882$

Tadaoka: $U_{TA}(u_w,u_K,u_D,u_L) = 0.939$

Izumi: $U_{IZ}(u_w,u_K,u_D,u_L) = 0.771$

Region: $U_R(U_{IO},U_{TA},U_{IZ}) = 0.915$

General characteristics of utility values are almost similar to Alternative I. However, the degrees of satsifaction for Izumiotsu in Alternative II are higher than in Alternative I, and those for Izumi are lower. This is mainly due to the difference of the degree of satsifaction for the capital formation policies which has been described above. (See Tables 5 and 7).

Alternative III.

In the third alternative plan, an overall capital growth policy is followed. It is worth noting that the growth rate increases to 29% in Izumi. Connected with this policy, industrial land area increases 6% in Izumi. Details of this plan are shown in Table 8 and compared with other alternatives. On the other hand, reduction rates of land coefficients are mitigated; namely the reduction rate ψ is 0.0220 for the industry code no.21,22, 34 and 36 (i.e. -10% for five periods) and 0.0446 for no.18-19, 20,24,26,30,31 and 33 (i.e. -20% for five periods). Reduction rate ρ for the COD unit load is the same as Alternative II.

Table 8. Alternative policies for the integrated regional management (ratios of constraint constants for t=5 to those for t=0)

	Alternative I			Alternative II			Alternative III		
	IO	TA	IZ	IO	TA	IZ	IO	TA	IZ
	%	%	%	%	%	%	%	%	%
K(t)	-18.3	-18.6	+25.8	+22.1	+27.8	+17.1	+21.9	+28.4	+29.4
W(t)	-27.8	-27.8	-27.8	-26.8	-26.8	-33.4	-36.7	-27.1	-27.1
L(t)	-16.3	- 1.3	+17.5	+23.0	+ 8.8	-29.4	-21.6	+ 3.0	+ 5.0
$D^u(t)$	-50.8	-43.3	-20.3	-29.0	-19.8	-38.5	-31.8	+ 2.4	+ 6.2

IO = Izumiotsu TA = Tadaoka IZ = Izumi

Thus, industrial lands will increase about 2% in Tadaoka and 6% in Izumi, but decrease about 32% in Izumiotsu. The total volume of COD which will be discharged into Osaka Bay is reduced about 31%.

Results:

(1) Among industries in Izumiotsu, capital formation in Iron and Steel, as well as Fabricated Metal industries, is decreased as much as in Alternative I. The increase in Chemicals

is also the same as in Alternative I and the decrease in Textile industry is as in Alternative II. The capital formation in Machinery increases less than in Alternative I and II. In Apparel, Pulp and Paper, and Clay and Stone industries, capital formation constantly decreases. In Tadaoka, predicted results are almost the same as in Alternative II. In Izumi, the decrease in Pulp and Paper, and Chemicals, is the same as in Alternative I, and the decrease in Apparel, and Fabricated Metal is the same as in Alternative II. However, in Izumi, an increase in Textile is permitted. The total amount of industrial shipment increases about 16% in Izumiotsu, 142% in Tadaoka and 58% in Izumi.

(2) The results of water pollution control are shown in Table 9 . An overall capital growth policy which is the most generous among the three alternatives has an effect on reduction policy for COD discharge. Thus reduction rates of COD discharge to Osaka Bay amount to 56% at the final stage of the planning period.

Table 9. Results of water pollution control (Alternative III).

Period	U_1	U_2	X_1	X_2	Reduction rates: via natural purification (BOD) $\frac{\sum_{\tau=1}^{365} X_2(\tau)Q(\tau)}{\sum_{\tau=1}^{365} U_2(\tau)Q(\tau)}$	via control policy (COD) $\frac{\sum_r W^r(t)}{\sum_{rj} \omega_j H_j^{*r}}$	(COD) $\frac{W(t)}{W(0)}$
					%	%	%
0 → I		6.9		4.9	23	5	4.9
I → II		5.9		4.6	23	29	15.7
II → III		5.5		4.3	22	33	17.4
III → IV		5.1		4.0	22	46	23.3
IV → V		4.8		3.8	21	56	31.4

(3) Total labor force for Alternative III increases about 9% in Tadaoka, 5% in Izumi and decreases about 22% in Izumiotsu. This means that, in Izumiotsu, the capital intensive technological change in particular will be greatly induced.

(4) The utility evaluation for Alternative III is depicted in Table 10. Degrees of satisfaction for this plan are the lowest for capital formation policy in Tadaoka and for land resource in Izumi. Difficulty in labour availability is at its worst in Izumi and this is combined with the highest rate of capital growth. This situation is almost the same for land resource policy.

(5) First, multiattribute utility functions with the same scaling constants as other alternatives and their numerical values are evaluated in the deterministic terms at t=1,3 and 5.

t=1

Izumiotsu: $U_{IO}(u_w, u_K, u_D, u_L) = 0.833$

Tadaoka: $U_{TA}(u_w, u_K, u_D, u_L) = 0.854$

Izumi: $U_{IZ}(u_w, u_K, u_D, u_L) = 0.743$

Region: $U_R(U_{IO}, U_{TA}, U_{IZ}) = 0.884$

t=3

Izumiotsu: $U_{IO}(u_w, u_K, u_D, u_L) = 0.839$

Tadaoka: $U_{TA}(u_w, u_K, u_D, u_L) = 0.912$

Izumi: $U_{IZ}(u_w, u_K, u_D, u_L) = 0.766$

Region: $U_R(U_{IO}, U_{TA}, U_{IZ}) = 0.847$

TABLE 10. POLICY EVALUATION (ALTERNATIVE III)

In terms of:	t=1		t=2		t=3		t=4		t=5	
	λ	u	λ	u	λ	u	λ	u	λ	u
IZUMIOTSU										
K(t)	0.503	0.1033	0.4879	0.0003	0.337	0.0068	0.455	0.0089	0.288	0.0040
W(t)	3.837	0.9582	1461.44	0.9976	33.58	0.9592	37.90	0.9488	21.47	0.9763
L(t)	2.059	0.5023	2.065	0.0013	2.16	0.0590	2.65	0.0640	19.95	0.9065
D(t)	0.1915	0.0235	0.178	5.5×10^{-5}	0.8631	0.0219	0.1427	0.0011	2.511	0.1061
TADAOKA										
K(t)	0.265	0.0016	0.291	0.0018	0.218	2.87×10^{-4}	0.1231	0.0003	0.04	0.0002
W(t)	37.80	0.9438	49.40	0.9889	61.27	0.9881	76.0	0.9715	93.30	0.9794
L(t)	2.33	0.0535	2.469	0.0456	3.0617	0.0463	3.83	0.0477	4.97	0.0520
D(t)	1.34	0.0286	1.343	0.0230	1.816	0.0261	2.40	0.0294	3.29	0.0343
IZUMI										
K(t)	0.769	0.0385	0.944	0.0191	0.7569	0.0157	0.888	0.0259	1.30	0.0134
W(t)	14.584	0.9724	33.79	0.9947	40.94	0.9761	21.893	0.9522	58.14	0.9684
L(t)	1.7836	0.1071	1.55	0.0371	1.811	0.0409	1.56	0.0556	2.125	0.0273
D(t)	0.307	0.0072	0.4179	0.0035	0.118	0.0004	0.36	0.0027	0.796	0.0050

t=5

Izumiotsu: $U_{IO}(u_W,u_K,u_D,u_L) = 0.902$

Tadaoka: $U_{TA}(u_W,u_K,u_D,u_L) = 0.932$

Izumi: $U_{IZ}(u_W,u_K,u_D,u_L) = 0.778$

Region: $U_R(U_{IO},U_{TA},U_{IZ}) = 0.925$

Compared to the other alternative plans, Alternative III is generally most acceptable. Namely, the degree of satisfaction of Alternative III for each sub-region is the best, or very close to the best among alternative plans, especially at the end of the planning period. For many cases in the other planning period, Alternative III is preferable, or almost preferable, to the other alternatives. The degrees of satisfaction for the overall region increase during the whole of the planning period.

Alternative I is least preferable for Izumiotsu and Alternative II is least preferable for Izumi.(Table 11).

Table 11. Ranking for degree of satisfaction of each alternative (AI,AII,AIII) among sub-regions).

	Izumiotsu			Tadaoka			Izumi			Region		
t	A1	AII	AIII	AI	AII	AIII	AI	AII	AIII	AI	AII	AIII
1	3	2*	1*	1	2	3	2*	3	1*	1	2	3
3	3	1	2	3*	2*	1	1*	3	2*	1*	3	2*
5	3	2	1	1*	1*	2	1*	3	2*	3	2	1

Note: * means almost the same as other alternatives for each sub-region.

(6) Now we will introduce probabilistic elements to the utility evaluation, namely the component utility values for Alternative III are treated as uncertainty quantities. Thus,

judgemental probability distribution for the prescribed values of the component utility functions are assessed at t=1,3 and 5. It is assumed that uncertainty is the largest in the beginning of the planning period and decreases up to the end of the period. Assessment of the judgemental probability distribution functions is performed in terms of cumulative functions,and their evaluations are effectively executed with CDISPRI computer program of MANECON collection (Schlaifer 1971). Characteristics of the probability distribution functions are listed in Appendix C and D.

Using these probability distribution functions, the expected values of the component utility functions are calculated. Numerical values of multiattribute utility functions (MUF) based on the same scaling constants as the previous ones are also derived. The calculations can be more effectively executed with ICOPSS/I which is a new integrated computer package for subjective systems. Numerical results are listed in Table 12.

Compared with the deterministic cases, dispersement of the utility values for resource constraints is reduced. Consequently, MUF values for each sub-region are generally decreased. This is due to large weights on the water quality constraints which have high utility values but, in a probabilistic case, whose numerical values are reduced. In many cases, the utility values for land resource constraints increase and those for capital formation decrease. This is because uncertainty of capital formation is supposed to be larger than that of land constraints.

6. CONCLUDING REMARKS

Decision processes usually face uncertain or fuzzy elements. In this paper, the uncertaintry which is included in the industrial land-use program combined with water quality management has been treated in terms of probability distribution of the utility values for environmental constraint constants.

The nested Lagrangian multiplier method, which has been developed by the authors since 1977, is applied for evaluating the land-use prgram with some revision. Systems configuration has been constructed in two layers: operational and judgemental. In the first layer, a simulation unit is combined with a programming

Table 12.

```
COMMAND:
= [redacted]
INPUT ALT NAME:
= PERIOD-5
INPUT UTIL NAME (OR ALL):
= ALL
EVALUTION OF PERIOD-5
  NAME      : UTIL VALUE
 R          :      0.8369
 IO         :      0.7910
*
 TA         :      0.7935
 IZ         :      0.6932
 IOW        :      0.8442
 IOD        :      0.0765
 IOK        :      0.0464
 IOL        :      0.7602
 TAW        :      0.8255
 TAD        :      0.0562
 TAK        :      0.0416
 TAL        :      0.0653
 IZW        :      0.8509
 IZD        :      0.0448
 IZK        :      0.0456
 IZL        :      0.0527
```

```
COMMAND:
*
= EVAL
INPUT ALT NAME:
= PERIOD-1
INPUT UTIL NAME (OR ALL):
= ALL
EVALUTION OF PERIOD-1
  NAME      : UTIL VALUE
 R          :      0.7305
 IO         :      0.6999
 TA         :      0.6671
 IZ         :      0.5651
 IOW        :      0.7915
 IOD        :      0.2550
 IOK        :      0.0954
 IOL        :      0.0509
 TAW        :      0.7212
 TAD        :      0.0530
 TAK        :      0.0424
 TAL        :      0.0660
 IZW        :      0.7157
 IZD        :      0.0437
 IZK        :      0.0597
 IZL        :      0.1222
```

```
COMMAND:
= EVAL
INPUT ALT NAME:
= PERIOD-3
INPUT UTIL NAME (OR ALL):
= ALL
EVALUTION OF PERIOD-3
  NAME      : UTIL VALUE
 R          :      0.7204
 IO         :      0.7128
 TA         :      0.7606
 IZ         :      0.6065
 IOW        :      0.8049
 IOD        :      0.0475
 IOK        :      0.0464
*
 IOL        :      0.0653
 TAW        :      0.8140
 TAD        :      0.0509
 TAK        :      0.0417
 TAL        :      0.0632
 IZW        :      0.7553
 IZD        :      0.0418
 IZK        :      0.0498
 IZL        :      0.0640
```

unit. A closed loop via input-output relationship is composed with intervention inputs of adjustment parameters from the decision maker in the second layer. With the intervention inputs, the programming unit can revise the data for water quality management based on simulation output from ecological modeling. Thus, learning and adaption processes are embedded in the decision making processes in the first layer. For further research, more prompt adaptation processes such as real-time control can be included in water quality management.

In the second layer, expected values of the multiattribute utility function can also be constructed. For this purpose, the way to assess probability functions must be further developed.

The nested Lagrangian multiplier method is one device for multiobjective systems evaluation. With this device, satisfaction degrees for prescribed policy plans are numerically compared among periods and alternatives as well as sub-regions and also the spots which have major troubles or difficulty are sought through all the systems. The information is utilized as a reference for better understanding of a prescribed policy and for installing some complementary or alternative means for improving the current situation.

APPENDIX A.

EFFECTIVE SUNLIGHT HOURS (1978); $V(\tau_k)$

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Hours											
1	3.7	3.9	5.8	11.2	2.9	10.1	-	11.6	11.5	10.8	10.0	9.3
2	4.4	4.9	10.5	-	10.5	5.4	-	4.6	8.5	10.7	4.4	1.4
3	1.8	7.4	9.8	3.5	6.9	2.6	0.5	0.5	4.0	10.7	6.9	9.0
4	5.4	7.3	-	10.7	3.7	-	0.9	10.9	7.0	10.5	8.4	2.3
5	5.9	6.7	4.9	11.0	9.4	8.8	0.4	11.5	5.6	-	9.0	6.6
6	4.4	2.2	10.2	3.8	-	5.5	2.3	11.8	10.7	9.2	8.7	7.1
7	6.1	8.9	8.8	8.8	0.1	10.0	-	7.2	11.8	5.7	0.7	9.0
8	1.6	7.8	8.7	11.5	2.3	8.3	-	6.9	X	7.4	7.8	8.3
9	1.9	0.3	5.4	10.6	4.2	4.9	-	9.7	10.0	6.6	7.8	6.6
10	3.3	0.8	3.4	9.7	-	3.0	-	12.6	6.7	6.8	8.5	4.8
11	4.6	2.5	8.4	1.3	0.1	-	1.7	12.7	6.4	8.3	2.1	3.8
12	7.6	0.1	6.7	4.5	11.2	0.7	-	12.1	0.4	9.7	0.3	8.9
13	-	3.9	6.6	2.6	7.0	4.2	2.1	8.3	9.3	3.3	0.1	7.3
14	7.1	5.2	8.6	11.4	9.6	5.6	3.3	12.1	2.9	7.9	8.7	4.5
15	8.3	3.8	5.9	9.6	6.2	2.8	3.7	11.1	7.1	-	5.6	0.5
16	5.4	9.9	9.3	1.4	4.5	-	1.7	7.6	3.9	8.7	6.4	9.0
17	1.6	8.3	10.6	2.4	0.1	2.7	6.4	9.8	10.3	9.5	0.6	6.2
18	3.0	6.3	7.2	-	1.2	4.3	3.2	10.5	11.7	6.0	8.6	8.7
19	8.4	7.4	6.9	10.9	1.3	1.2	0.5	8.3	11.2	6.7	6.0	1.7
20	5.8	9.3	10.8	7.9	7.7	1.5	1.8	7.6	4.4	9.5	6.2	4.8
21	3.3	5.3	-	4.9	7.2	1.4	4.8	12.5	5.6	4.2	9.4	6.3
22	5.4	6.6	1.5	10.2	1.9	-	4.7	8.9	4.8	8.5	9.1	3.8
23	6.9	6.4	7.4	4.2	9.2	-	6.5	11.4	3.5	10.0	7.1	-
24	-	9.1	11.1	0.7	9.6	-	3.8	9.5	6.4	6.4	8.0	7.3
25	8.5	0.3	9.8	6.0	4.0	0.1	X	11.8	8.4	8.7	9.0	9.0
26	5.4	9.1	10.2	12.0	9.6	1.4	11.2	11.4	7.5	1.4	0.2	8.8
27	8.5	8.3	1.3	11.2	7.7	-	12.7	11.4	0.5	1.2	2.1	3.1
28	0.5	1.9	-	5.3	1.0	1.6	11.2	11.0	1.4	-	2.2	-
29	7.0		10.8	0.1	0.1	1.5	6.1	11.1	-	0.2	2.9	3.6
30	6.3		9.0	8.6	0.4	-	12.1	8.8	7.8	8.4	6.1	6.9
31	7.7		9.9		3.9		12.7	9.7		9.9		7.2
Total	149.7	153.9	219.5	196.0	143.5	87.6	114.3	304.9	189.3	206.9	172.9	175.8

APPENDIX B: ACTIVE VALUES OF CONSTRAINT CONSTANTS

Alternative I

Izumiotsu

t	0	1	2	3	4	5
K(t)	25773.	23841.	22361.	20829.	21000.	21060.
W(t)	3178.8	2960.9	2670.8	2633.8	2450.1	2295.9
L(t)	10409.	11857.	11473.	9411.	11990.	8758.5
$D^u(t)$	17450.	10100.	10100.	10000.	10100.	8592.1
$\sum_j H_j^*(t)$	121114.	115500.	117335.	133058.	146830.	141817.

Tadaoka

t	0	1	2	3	4	5
K(t)	13414.	12495.	11638.	10841.	10864.	10921.
W(t)	908.9	849.79	803.58	753.08	700.55	656.47
L(t)	3737.	3948.0	3260.8	3948.0	3847.7	3689.7
$D^u(t)$	5466.	3500.0	3100.	3100.	3100.	3100.
$\sum_j H_j^*(t)$	45540.	54670.	55912.	65641.	73146.	82333.

Izumi

t	0	1	2	3	4	5
K(t)	15617.	14548.	13550.	15500.	17021.	19648.
W(t)	3004.8	2837.9	2656.8	2489.8	2316.2	2170.4
L(t)	8840.	9981.	7548.	7101.	6652.	10386.
$D^u(t)$	13704.	11065.7	9539.6	10250.	10562.	10925.
$\sum_j H_j^*(t)$	98163.	100603.	103479	111760	116556	141907

Alternative II

Izumiotsu

	t = 1	2	3	4	5
K(t)	27388.	27920.	29059.	30245.	31475.
W(t)	2950.4	2832.3	2631.9	2482.0	2327.1
L(t)	9778.8	12654.	12729.	12805.	12881.
$D^u(t)$	15821.1	146559.	14137.5	12732.	12399.
$\sum_j H_j^*(t)$	110881.	143376.	153554.	164493.	176137.

Tadaoka

	t = 1	2	3	4	5
K(t)	14102.	14825.	15585.	16384	17148
W(t)	1018.2	809.84	752.53	709.68	665.38
L(t)	3971.	3995.	4019.	4042.	4066
$D^u(t)$	5600.	5317.8	4976.4	4668.2	4381.3
$\sum_j H_j^*(t)$	69519.	72417.	81986.	93460.	106328.

Izumi

	t = 1	2	3	4	5
K(t)	16093.	16583.	17088.	17608.	18291.
W(t)	2837.9	2677.5	2488.0	2346.4	2000.1
L(t)	8407.	8194.	8070.6	7995.9	6240.
$D^u(t)$	11470.1	10410.4	9259.1	8306.8	8433.7
$\sum_j H_j^*(t)$	98141.	103933.	118992.	115538.	112707.

Alternative III

	Izumiotsu t=1	2	3	4	5	Tadaoka t=1	2	3	4	5
K(t)	26825.	27920.	29058.	30245.	31478.	14102.	14825.	15585.	16384.	17224.
W(t)	2887.1	2539.6	2626.4	2426.	2011.6	1018.2	799.4	750.9	700.0	662.9
L(t)	9825.	9235.	9328.	8148.	8165.3	3791.	3995.	4019.	4042.	4066.
$D^u(t)$	15644.2	15646.3	16327.5	17999.	11902.5	5600.	5600.	5600.	5600.	5600.
$\sum_j H_j^*(t)$	111811.	112835.	149406.	142534.	139925.	69884.	73029.	83931.	95871.	110087.

	Izumi t=1	2	3	4	5
K(t)	16470.	17087.	17874.	19799.	20215.
W(t)	2837.9	2642.9	2482.7	2313.4	2191.6
L(t)	8197.	7756.	9102.	7037.9	9282.
$D^u(t)$	12875.	12741.	12137.	13568.	14553.
$\sum_j H_j^*(t)$	99538.	112089.	127867.	120995.	155120.

Note: K(t) = million yen/year
W(t) = ton/year
L(t) = person
$D^u(t) = 100m^2$
$H_j^*(t)$ = million yen/year

APPENDIX C. Characteristics of the probability distributions for component utility values

t=1: Izumiotsu : u_w

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .73 .85 .90 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1

MEAN      =     0.791
*
STD DEV   =     0.165
VARIANCE  =     0.273E-01
FRACTILES
 .001   .01   .1    .25   .5    .75   .9    .99   .999
  589  1862  5890  7300  8500  9000  9368  9800  9937
    UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumiotsu: u_k

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .01 .035 .11 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
*
= 1

MEAN      =     0.096
STD DEV   =     0.153
VARIANCE  =     0.233E-01
FRACTILES
 .001   .01   .1    .25   .5    .75   .9    .99   .999
    0     4    40   100   350  1100  2409  7600  9241
    UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumiotsu: u_L

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .001 .005 .02 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
*
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =     0.051
STD DEV   =     0.140
VARIANCE  =     0.196E-01
FRACTILES
 .001   .01   .1    .25   .5    .75   .9    .99   .999
    0     0     4    10    50   200  1303  7250  9130
    UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumiotsu: u_D

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .07 .175 .4 1
*
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =     0.255
STD DEV   =     0.227
VARIANCE  =     0.514E-01
FRACTILES
 .001    .01    .1     .25    .5     .75    .9     .99    .999
   3      28    280    700   1750   4000   6053   8744   9603
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_w

```
VALUES OF UQ IN ASCENDING ORDER
*
= 0 .58 .78 .90 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =     0.721
STD DEV   =     0.220
VARIANCE  =     0.483E-01
FRACTILES
 .001    .01    .1     .25    .5     .75    .9     .99    .999
  397   1255   3933   5800   7800   9000   9600   9960   9998
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_k

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .0005 .001 .0015 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =     0.043
STD DEV   =     0.138
VARIANCE  =     0.191E-01
*
FRACTILES
 .001    .01    .1     .25    .5     .75    .9     .99    .999
   0      0      2      5     10     15    1071   7177   9107
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E--
```

Tadaoka: u_L

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .005 .015 .05 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =      0.066
STD DEV   =      0.143
VARIANCE =      0.204E-01
FRACTILES
 .001    .01    .1    .25    .5    .75    .9    .99    .999
*
   0      2     20     50    150    500   1667   7365   9167
      UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_D

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .001 .005 .025 1
*
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =      0.053
STD DEV   =      0.141
VARIANCE =      0.198E-01
FRACTILES
 .001    .01    .1    .25    .5    .75    .9    .99    .999
   0      0      4     10     50    250   1371   7271   9137
      UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_W

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .60 .75 .87 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =      0.716
STD DEV   =      0.197
*
VARIANCE =      0.388E-01
FRACTILES
 .001    .01    .1    .25    .5    .75    .9    .99    .999
 451   1426   4478   6000   7500   8700   9437   9898   9968
      UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_k

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .005 .015 .035 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =      0.060
STD DEV   =      0.140
VARIANCE =       0.197E-01
FRACTILES
 .001     .01     .1      .25     .5      .75     .9      .99     .999
    0       2     20       50    150      350   1461     7300     9146
*
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_L

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .03 .065 .15 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =      0.122
STD DEV   =      0.156
VARIANCE =       0.242E-01
*
FRACTILES
 .001     .01     .1      .25     .5      .75     .9      .99     .999
    1      12    120      300    650     1500   2823     7731     9282
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_D

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .001 .002 .004 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =      0.044
STD DEV   =      0.138
VARIANCE =       0.191E-01
*
FRACTILES
 .001     .01     .1      .25     .5      .75     .9      .99     .999
    0       0      4       10     20       40   1100     7186     9110
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

t=3: Izumiotsu: u_w

VALUES OF UQ IN ASCENDING ORDER
= 0 .75 .86 .91 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1

MEAN = 0.805
*
STD DEV = 0.162
VARIANCE = 0.263E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
613	1939	6131	7500	8600	9100	9456	9830	9946

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumiotsu: u_k

VALUES OF UQ IN ASCENDING ORDER
= 0 .001 .003 .01 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
*
= 1

MEAN = 0.047
STD DEV = 0.139
VARIANCE = 0.193E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
0	0	4	10	30	100	1177	7210	9118

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumiotsu: u_L

VALUES OF UQ IN ASCENDING ORDER
= 0 .005 .01 .05 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN = 0.065
STD DEV = 0.144
VARIANCE = 0.206E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
0	2	20	50	100	500	1691	7373	9169

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumiotsu: u_D

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .003 .006 .01 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

*
MEAN       =      0.048
STD DEV    =      0.138
VARIANCE   =      0.191E-01
FRACTILES
 .001     .01     .1     .25     .5     .75     .9     .99     .999
   0       1      12      50     60     100    1163   7206    9116
       UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_W

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .75 .87 .93 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN       =      0.814
STD DEV    =      0.170
VARIANCE   =      0.289E-01
FRACTILES
 .001     .01     .1     .25     .5     .75     .9     .99     .999
  607    1920   6071    7500   8700   9300   9677    9925    9976
       UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_k

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .00010 .00018 .00035 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN       =      0.042
STD DEV    =      0.138
VARIANCE   =      0.191E-01
FRACTILES
 .001     .01     .1     .25     .5     .75     .9     .99     .999
   0       0       0      1      2       3    1060    7173    9106
       UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_L

VALUES OF UQ IN ASCENDING ORDER
= 0 .005 .01 .045 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN = 0.063
STD DEV = 0.143
VARIANCE = 0.204E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
0	2	20	50	100	450	1622	7351	9162

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Tadaoka: u_D

VALUES OF UQ IN ASCENDING ORDER
= 0 .001 .005 .02 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN = 0.051
STD DEV = 0.140
VARIANCE = 0.196E-01
FRACTILES
*

.001	.01	.1	.25	.5	.75	.9	.99	.999
0	0	4	10	50	200	1303	7250	9130

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumi: u_W

VALUES OF UQ IN ASCENDING ORDER
= 0 .65 .82 .90 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN = 0.755
STD DEV = 0.194
VARIANCE = 0.378E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
483	1528	4795	6500	8200	9000	9513	9874	9960

*
UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumi: u_k

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .003 .008 .015 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN     =      0.050
STD DEV  =      0.139
VARIANCE =      0.193E-01
FRACTILES
 .001     .01     .1     .25     .5     .75     .9     .99     .999
   0       1      12      30     80     150   1221    7224    9122
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_L

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .01 .02 .04 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN     =      0.064
STD DEV  =      0.140
VARIANCE =      0.195E-01
FRACTILES
 .001     .01     .1     .25     .5     .75     .9     .99     .999
   0       4      40     100    200     400   1505    7314    9151
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_D

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .00017 .00035 .00055 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN     =      0.042
STD DEV  =      0.138
VARIANCE =      0.191E-01
FRACTILES
 .001     .01     .1     .25     .5     .75     .9     .99     .999
   0       0       1       2      3       5   1062    7173    9106
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

t=5: Izumiotsu: u_w

VALUES OF UQ IN ASCENDING ORDER
= 0 .82 .88 .93 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1

MEAN = 0.844
*
STD DEV = 0.147
VARIANCE = 0.217E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
704	2227	7042	8200	8800	9300	9631	9894	9967

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumiotsu: u_k

VALUES OF UQ IN ASCENDING ORDER
= 0 .001 .003 .01 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
*
= 1

MEAN = 0.047
STD DEV = 0.139
VARIANCE = 0.193E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
0	0	4	10	30	100	1177	7210	9118

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumiotsu: u_L

VALUES OF UQ IN ASCENDING ORDER
= 0 .65 .83 .91 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

*
MEAN = 0.760
STD DEV = 0.199
VARIANCE = 0.397E-01
FRACTILES

.001	.01	.1	.25	.5	.75	.9	.99	.999
476	1507	4722	6500	8300	9100	9597	9915	9973

UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4

Izumiotsu: u_D

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .01 .02 .07 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN      =       0.077
*
STD DEV   =       0.145
VARIANCE  =       0.211E-01
FRACTILES
 .001    .01     .1     .25     .5     .75     .9     .99    .999
    0      4     40     100    200     700   1920    7445    9192
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_w

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .75 .90 .95 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75
*
= 1
OPTION?
= 1

MEAN      =       0.816
STD DEV   =       0.144
VARIANCE  =       0.209E-01
FRACTILES
 .001    .01     .1     .25     .5     .75     .9     .99    .999
  588   1861   5874    7500   9000    9500   9800    9980    9998
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_k

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .00005 .00012 .0002 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= .0 .25 .5 .75 1
OPTION?
= 1

*
MEAN      =       0.042
STD DEV   =       0.138
VARIANCE  =       0.191E-01
FRACTILES
 .001    .01     .1     .25     .5     .75     .9     .99    .999
    0      0      0       1      1       2   1056    7172    9106
     UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_L

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .005 .01 .05 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN        =      0.065
STD DEV     =      0.144
*
VARIANCE =         0.206E-01
FRACTILES
 .001    .01     .1     .25     .5     .75     .9     .99    .999
   0       2     20      50    100     500   1691    7373    9169
      UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Tadaoka: u_D

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .003 .009 .03 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1
*

MEAN        =      0.056
STD DEV     =      0.141
VARIANCE =         0.197E-01
FRACTILES
 .001    .01     .1     .25     .5     .75     .9     .99    .999
   0       1     12      30     90     300   1420    7287    9142
      UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_W

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .83 .91 .93 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
*
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN        =      0.851
STD DEV     =      0.148
VARIANCE =         0.219E-01
FRACTILES
 .001    .01     .1     .25     .5     .75     .9     .99    .999
  702   2221   7024    8300   9100    9300   9474    9833    9947
      UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_k

```
VALUES OF UQ IN ASCENDING ORDER
*
= 0 .003 .005 .006 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN       =      0.046
STD DEV    =      0.138
VARIANCE   =      0.190E-01
FRACTILES
 .001     .01     .1      .25     .5      .75     .9      .99     .999
    1       4     15       30     50       60   1114     7190     9111
        UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_L

```
VALUES OF UQ IN ASCENDING ORDER
= 0 .005 .01 .02 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
*
= 0 .25 .5 .75 1
OPTION?
= 1

MEAN       =      0.053
STD DEV    =      0.139
VARIANCE   =      0.193E-01
FRACTILES
 .001     .01     .1      .25     .5      .75     .9      .99     .999
    0       2     20       50    100      200   1280     7242     9128
        UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

Izumi: u_D

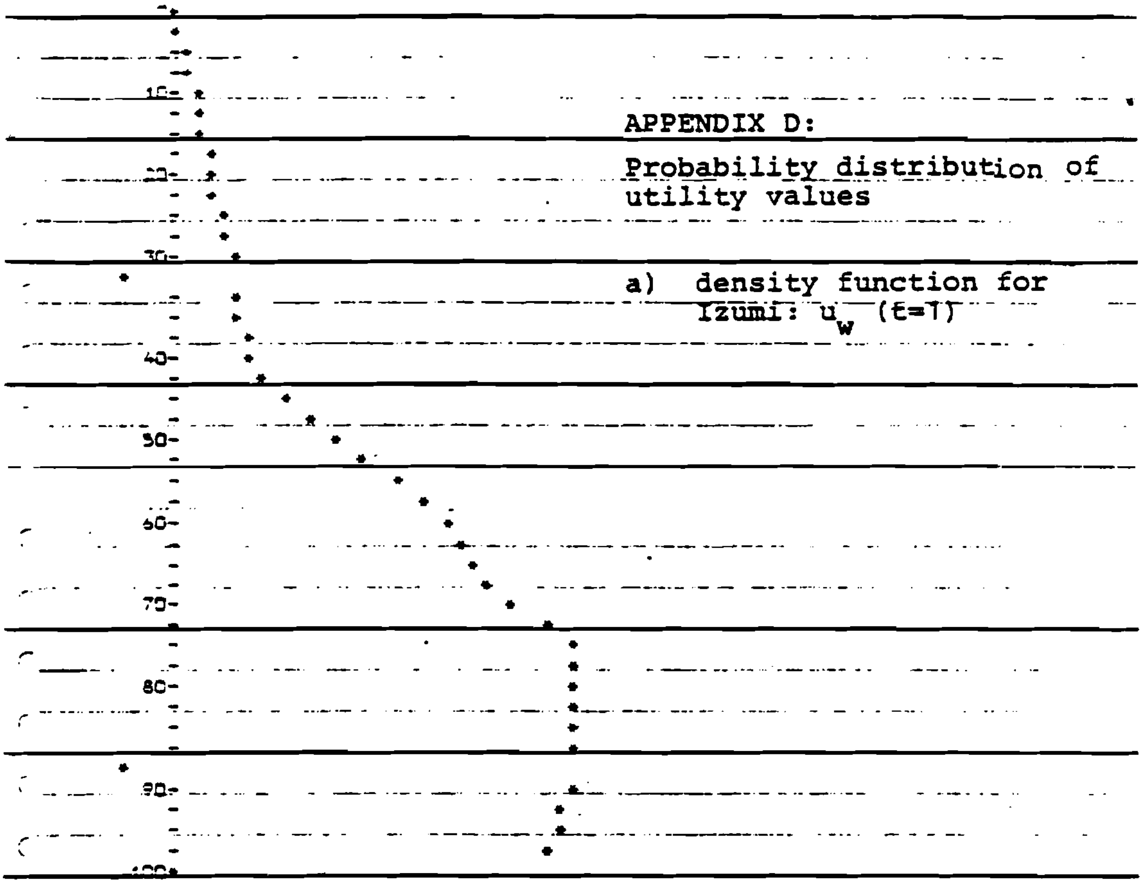
```
VALUES OF UQ IN ASCENDING ORDER
= 0 .0017 .0035 .0055 1
CUMULATIVE PROBABILITIES IN ASCENDING ORDER
= 0 .25 .5 .75 1
*
OPTION?
= 1

MEAN       =      0.045
STD DEV    =      0.138
VARIANCE   =      0.191E-01
FRACTILES
 .001     .01     .1      .25     .5      .75     .9      .99     .999
    0       1      7       17     35       55   1114     7190     9111
        UQ VALUES JUST ABOVE ARE TO BE MULTIPLIED BY 10E-4
```

APPENDIX D:

Probability distribution of utility values

OPTION?
= 4

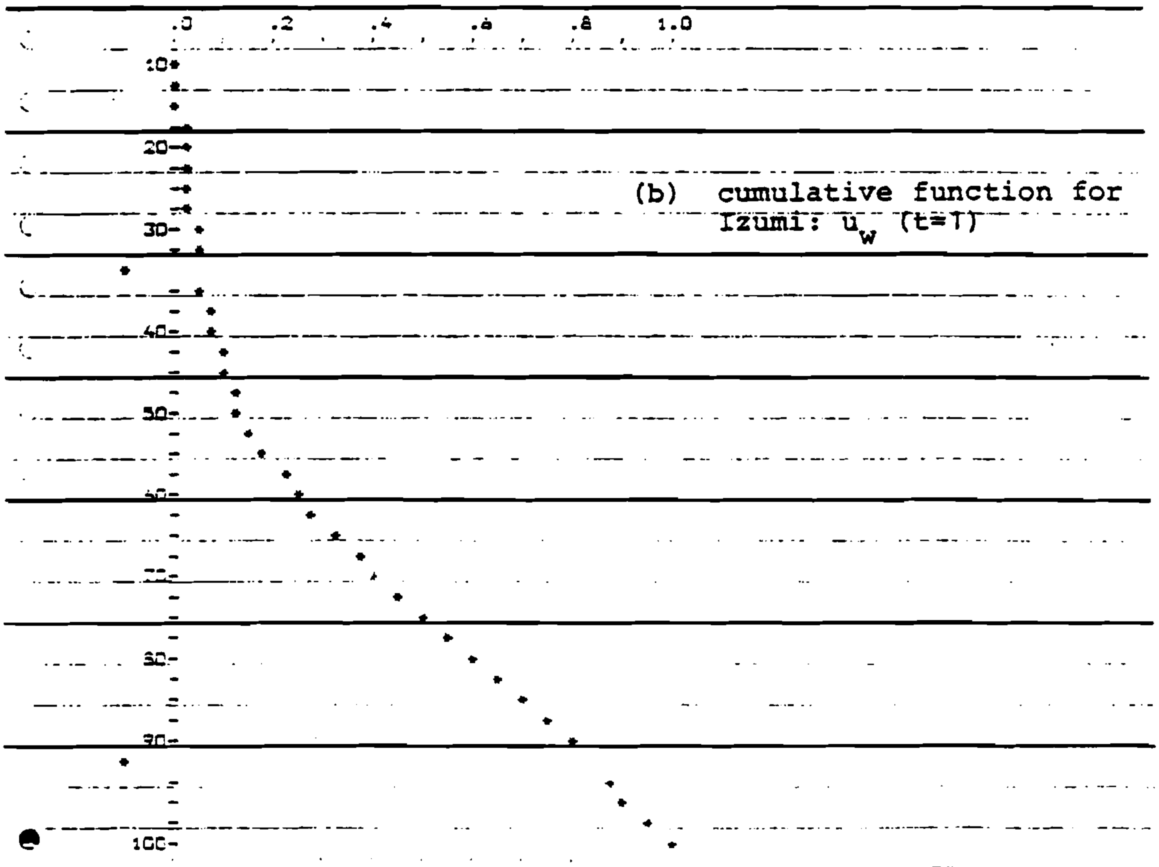
VALUES ON UQ AXIS ARE TO BE MULTIPLIED BY 10E-2



a) density function for Izumi: u_w (t=1)

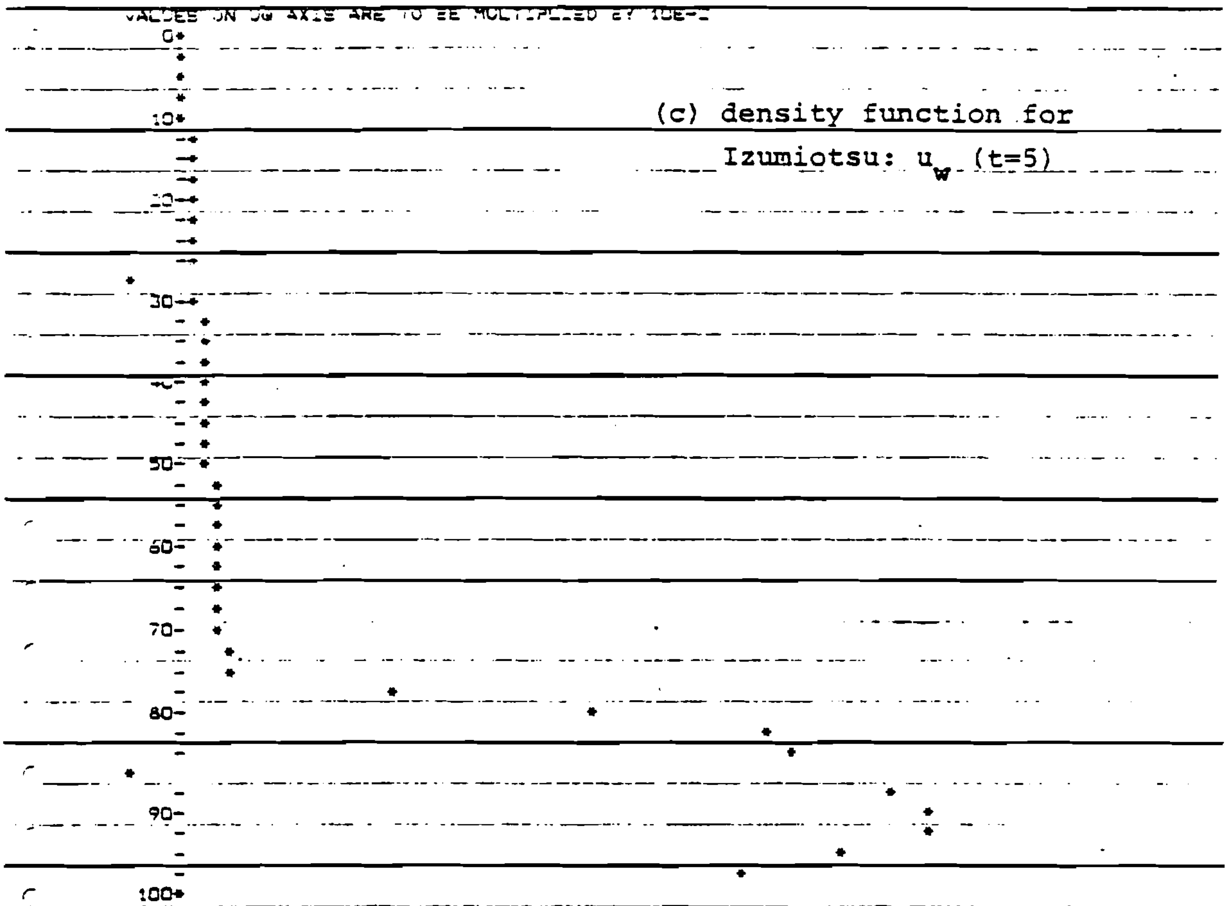
OPTION?
= 5

VALUES ON UQ AXIS ARE TO BE MULTIPLIED BY 10E-2



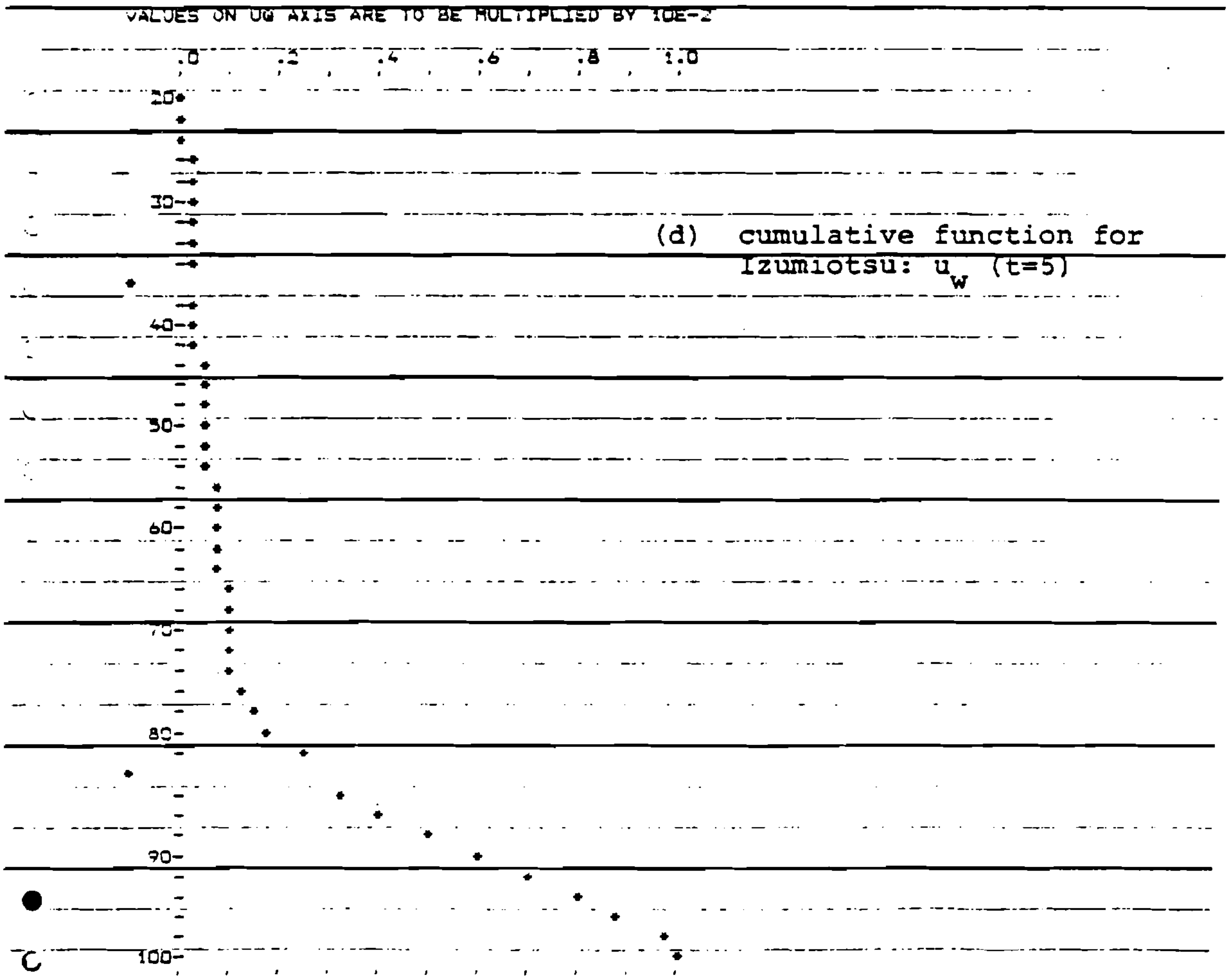
(b) cumulative function for Izumi: u_w (t=1)

OPTION?
= 4



(c) density function for Izumiotsu: u_w (t=5)

OPTION?
= 5



(d) cumulative function for Izumiotsu: u_w (t=5)

APPENDIX E. PARAMETERS OF PRODUCTION FUNCTIONS (α_j, β_j)

Industry code	Izumiotsu			Tadaoka			Izumi		
	α_j	β_j	$1-\alpha_j-\beta_j$	α_j	β_j	$1-\alpha_j-\beta_j$	α_j	β_j	$1-\alpha_j-\beta_j$
18-19	-	-	-	-	-	-	0.7349	0.0754	0.1879
20	0.7143	0.1386	0.1471	0.7280	0.1220	0.1500	0.7284	0.1217	0.1499
21	0.6423	0.2046	0.1531	-	-	-	0.6045	0.2479	0.1476
22	-	-	-	0.6776	0.1320	0.1904	-	-	-
24	0.6375	0.1897	0.1728	-	-	-	0.6775	0.1387	0.1838
26	0.7552	0.1146	0.1302	-	-	-	0.7842	0.0807	0.1351
30	0.7700	0.0717	0.1583	-	-	-	-	-	-
31	0.7439	0.0886	0.1675	-	-	-	-	-	-
33	0.6041	0.1152	0.2807	0.5561	0.1849	0.2590	0.5627	0.1757	0.2616
34	0.6588	0.1839	0.1573	-	-	-	0.6540	0.1902	0.1558
36	0.5556	0.2017	0.2427	-	-	-	-	-	-

APPENDIX F. PARAMETER OF PRODUCTION FUNCTIONS (μ_j) AND CONSTRAINT CONSTANTS

	μ_j			ω_{jto}	d_{jto}	k_j		
	Izumiotsu	Tadaoka	Izumi			Izumiotsu	Tadaoka	Izumi
18-19	-	-	0.07842	0.08488	0.0692	-	-	0.1604
20	0.06411	0,16577	0.10387	0,03353	0.1516	0.1507	0.2861	0.1718
21	0.0	-	0.11157	0.03353	0.1068	0.1229	-	0.2099
22	-	0.0	-	0.00153	0.0608	-	0.2546	-
24	0.0	-	0.02091	0.23368	0.0765	0.1479	-	0.1121
26	0.14946	-	0.08551	0.07689	0.1952	0.4876	-	0.1199
30	0.0	-	-	0.00213	0.3107	0.18805	-	-
31	0.0	-	-	0.00633	0.1086	0.4318	-	-
33	0.08893	0.0	0.0	0.00125	0.1442	0.4738	0.1093	0.2731
34	0.10825	-	0.04711	0.00089	0.0966	0.3179	-	0.2421
36	0.0	-	-	0.00079	0.0681	0.1516	-	-

REFERENCES

Beck, M.B. 1978. Modelling of dissolved oxygen in a non-tidal stream. Mathematical Models in Water Pollution Control. John Wiley & Sons, New York.

Beck, M.B. 1978b. A Comparative Case Study of Dynamic Models for DO-BOD-Algae Interaction on a Freshwater River. RR-78-19, IIASA, Laxenburg.

Beck, B. and P.C. Young.1976. Systematic Identification of DO-BOD Model Structure. J. Environmental Eng. Div. 102, EE5:907-927.

Beck, B. and P.C. Young. 1975. A Dynamic Model for DO-BOD relationship in a non-tidal stream. Water Research 9: 769-776.

Haimes, Y.Y. and W.A. Hall. 1974. Multiobjectives in water resource systems analysis: The Surrogate Worth Trade-off method. Water Resources Research 10:615-624.

Haimes, Y.Y., W.A. Hall and H.T. Friedman. 1975. Multiobjective Optimization in Water Resource Systems: The Surrogate Worth Trade-off Method. Elsevier, New York.

Input-Output Table for Industrial Pollution Analysis in the Kinki area in 1973. Division of Trade and Industry, Osaka Prefecture, Osaka, (in Japanese).

Japan River Association (ed.) 1975. Yearbook on Japanese River Quality. Division of Rivers, Ministry of Construction, Tokyo, (in Japanese).

Keeney, R.L. 1974. Multiplicative utility functions. Operative Research, 22:22-34.

Keeney, R.L. and H. Raiffa. 1976. Decision with Multiple Objectives: Preferences and Values Trade-offs. John Wiley & Sons, New York.

Lasdon, L.S., R.L. Fox and M.W. Ranter. 1974. Nonlinear optimization using the generalized reduced gradient method. Revue Francaise d'Automatique, Informatique et Recherch Operationnelle. 3.

Lasdon, L.S., R.D. Warren, A. Jain and M.W. Ranter. 1975. Design and testing of a generalized reduced gradient code for nonlinear optimization. Technical Memorandum 353. Case Western Reserve University.

Raiffa, H. 1968. Decision Analysis. Addison-Wesley, Reading. Mass.

Rinaldi, S., R. Soncini-Sessa, H. Stehfest and H. Tamura. 1979. Modeling and Control of River Quality. McGraw-Hill, London.

Research and Statistics Department, Ministry of International Trade and Industry. 1976,1978,1979. Census of Manufacturers, Report on Industrial Land and Water. Tokyo. (in Japanese).

Schlaifer, R.O. 1969. Analysis of Decisions under uncertainty. McGraw-Hill, New York.

Schlaifer, R.O. 1971. Computer Programs for Elementary Decision Analysis. Division of Research, Graduate School of Business Administration, Harvard University, Cambridge. Mass.

Seo. F. 1977. Evaluation and control of regional environmental systems in the Yodo River Basin: Socio-economic aspects. Proc. IFAC Symposium on Environmental Systems Planning, Design and Control. Pergamon Press, Oxford.

Seo. F. 1979. An integrated approach for improving decision-making processes, WP-79-54, IIASA, Laxenburg, Austria.

Seo. F. and M. Sakawa. 1979a. An evaluation method for environmental system planning: an alternative utility approach. Environmental and planning, A, 11(2):149-168.

Seo. F. and M. Sakawa. 1979b. A methodology for Environmental Systems Management: Dynamic Application of the Nested Lagrangian Multiplier Method. IEEE Transactions on Systems, Man and Cybernetics. SMC.9(12):794-805.

Sakawa, M. and F. Seo. 1980a. Integrated methodology for computer-aided decision analysis. Proceedings of Fifth European Meeting on Cybernetics and Systems Research, Vienna.

Sakawa, M. and F. Seo. 1980b. An interactive computer program for subjective systems and its application. WP. IIASA, Laxenburg. (Forthcoming).

Sicherman, A. 1975. An interactive computer program for assessing and using multiattribute utility functions. Technical Report 11, Operation Research Centre, M.I.T. Cambridge, Mass.

The Statistical Office of Osaka Prefecture. 1976. Industrial Statistics Survey Results Table in 1973. Osaka Prefecture. Osaka, (in Japanese).

The Statistical Office of Osaka Prefecture. 1978. Industrial Statistics Survey Results Table in 1975. Osaka Prefecture, Osaka, (in Japanese).

Stehfest, H. 1973. Mathematical modelling of self-purification of rivers. Report KFK 1654 UF, Kernforschungszentrum, Karlsruhe, (in German). English translation as PP-77-11, IIASA, Laxenburg, Asutria.

Stehfest, H. 1978. On the monetary value of an ecological river quality model. RR-78-1. IIASA, Laxenburg, Austria.

White Paper on pollution in Osaka Prefecture in 1977. Life and Environmental Division,Osaka Prefecture, Osaka (in Japanese).