Synthesized Technical and Socio-Economic Efficient Evaluation of Water Quality Improving Devices and Technologies : An Example of the Lake Kasumigaura Basin

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1. Introduction

The quality of water in Lake Kasumigaura has been deteriorating since the 1970's by the pollution discharged from socio-economic activities of the catchment area. As a result of construction of a sewage system, and enaction of an ordinance to prevent the environment by the government, water quality of Lake Kasumigaura has improved to some extent, but the process of deteriorating is still continuing. Recently, many engineering groups are working to develop technologies in order to solve the problem.

In this study, we analyze a dynamic optimal policy and evaluate technologies to improve the water quality of the lake, considering both - the total ecological system in and around the lake and the situational changes over a certain period of time.

We specify three sub-models (the ecosystem model, the socio-economic model and the water balance model) and one objective function (Regional GDP; GRP) in order to analyze the optimal policy to improve the water quality of Lake Kasumigaura. The ecosystem model describes how the amount of generation and flow of pollutants are changed and the extent to which it is abated by removal equipments in the lake and the rivers flowing into the lake. The socio-economic model describes the social and economic activities in the catchment area and the relationship between the activities and the emission of pollutants. And the water balance model describes the incoming water and outgoing water which is considered as dependent on the generation of the water in nature and the water demand by social economy activity. The optimal policies are derived so as to maximize the objective function (GRP) subject to the structural equations, which describe both the ecosystem and the socio-economic system.

We also try to estimate residents' evaluation of the water quality of Lake Kasumigaura in Ibaraki prefecture by using the contingent valuation method (CVM).

The pollutants measured in this study are nitrogen, phosphorus and COD.

2. Framework of the model

In this study, we constructed a model referring to Hirose and Higano (2000), Aramaki and Matsuo (1998) ([2]) and Aramaki and Matsuo (1998)([3]). The number of areas in this study was 31 (See

Table 1) and the running period was from 1995 to 2004. The ecosystem model includes, in addition to the lake, the catchment rivers, and the socio-economic model represents not only production, household wastewater, cultivating fishery but also land use (See Table 3,4 and 5) . And we use the data of 1995. We set three simulation cases (Case 1, 2 and 3), so that the water quality of Kasumigaura might be improved greatly by the year 2004 as compared to actual water quality shown in the data of 1995. The restricted water quality in each simulation case is shown in the Table 6.

The pollution load curtailment policies we are concerned with in this research are described below.

<Measures against household wastewater generation source: policy for promotion of advanced disposing system>

1. Subsidy provision for the promotion of installment of sewage systems and rural community sewage systems in the catchment area.
2. Subsidy provision for the promotion of installation of combined treatment septic tanks in the catchment area.
3. Subsidy provision for the promotion of installation of a new type of septic tank in the catchment area.

< Measures against land use generation source: policy on fallow land (capital reduction)>

4. Curtailment of the area of cultivated land by a provision of subsidy to farm workers (conversion to a fallow land).

<Measures against the industry generation source: capital reduction policy.>

5. Production control by reducing capital for the subsidy provision provided to each industry.

< Water pollutants direct removal: water pollutants removal equipment installation policy>

6. Installation of water pollutant removal equipment in Lake Kasumigaura and sewage disposal plants.

Table1. Classification of Rivers and Catchment Area

River index	**River's name**	**Catchment area**	**Area index**
1	Shin-Tone Riv.	Ryugasaki City etc.	1-5
2	Ono Riv.	Ushiku City etc.	6-8
3	Seimei Riv.	Ami Town etc.	9,10
4	Sakura Riv.	Tsuchiura City etc.	11-17
5	Koise Riv.	Ishioka City etc.	18-21
6	Ichinose Riv.	Kasumigaura Town	22

7	Sonobe Riv.	Tamari Village	23
8	Tomoe Riv.	Minori Town etc.	24-26
9	Kajinashi Riv.	Tamatsukuri Town	27
10	Jyoka Riv.	Asou Town	28
11	Yogoshi Riv.	Ushibori Town	29
12	Maekawa Riv.	Itako Town	30
13	Yamada Riv.	Kitaura Town	31

Table 2. Pollutant Index

Index	Pollutants
1	Nitrogen (Total-Nitrogen)
2	Phosphorus (Total- Phosphorus)
3	COD

Table 3. Classification of Household Wastewater Disposal System.

Index	Facility
1	Sewage System
2	Rural Community Sewage System
3	Combined Treatment Septic Tank
4	Treatment Septic Tank
5	Night Soil Septic Tank
6	Untreated Waste Water
7	New Technology A

Table 4. Classification of Land Use

Index	Land Use
1	Paddy Field
2	Rice Field
3	Mountain Forest
4	City Area
5	Other Land Use

Table 5. Classification of Industry

Index	Industry
1	Agriculture
2	Stock Rising
3	Fisheries
4	Manufacturing Industry
5	Other Industries

Table 6. Simulation Case

		Case 1.	Case 2.	Case 3.
Water Quality Target	Total-Nitrogen [mg/l]	0.29	0.61	1.12
	Total –Phosphorus [mg/l]	0.02	0.04	0.08
	COD [mg/l]	1.89	3.46	6.22

3 About the new technology to improve the water quality

Recently, research on developing water pollutant removal equipment and inventing discharge control technology to improve the water quality are being carried out.

In this research we deal with two different types of new technology (A and B). The new technology A is a small-scale type equipment to install at each home. And new technology B is a large-scale type equipment to install along the lakeside or in sewage disposal plants.

We estimated digital data of each technology by the technical data which was released by The Science and Technology Promotion Foundation of Ibaraki.

3.1. New technology A and B

The new technology A is the technology, which we can use as a substitute for a septic tank. The digital data that defines this technology has been shown in Table 7. According to this estimated data, there is almost no water pollutant contained in the processed water, and a very advanced drainage processing is made possible by it. However, it is estimated that installation cost will be 2 to 3 times higher than a usual septic tank. Since this technology is considered as a new type of septic tank, in this simulation, it is presupposed that the number of persons who use this technology is determined by the subsidy provided only by prefectural government and municipal governments. The reason behind our assumption is that the national government would never pay for the subsidy for installing of this new type of technology as that technology still does not have an a concrete result and, even when actually introduced, we cannot expect the payment of subsidy from national government, at least for the time being. Here, we set up the rate of subsidy from Ibaraki prefectural government (60%) based on the subsidy rate data of usual household wastewater disposal system.

The new technology B is a type, which is to be installed along the sides of Lake Kasumigaura and each sewage disposal plant, and performs direct removal of water pollutants. As for this new technology, a prefecture shall perform installation, management, and administration directly. The digital data about this technology is shown in Table 8.

Table 7. Estimated Data of the New Technology A

Name of Data	**Data**
Construction Cost (5 person tub)	2 million yen
Emission Coefficient (Nitrogen)	0.18 (kg / person – year)
Emission Coefficient (Phosphorus)	0.00 (kg / person – year)
Emission Coefficient (COD)	0.00 (kg / person – year)
The rate of the subsidy for installation (from Ibaraki Pref.)	60%

Table 8. Estimated Data of the New Technology B

Name of Data	**Data**
Construction Cost	50 (million yen / set)
Maintenance Cost	1.2 (million yen / year)
Abatement Coefficient (Nitrogen)	0.567 (kg / million yen – year)
Abatement Coefficient (Phosphorus)	0.101 (kg / million yen – year)
Abatement Coefficient (COD)	0.946 (kg / million yen – year)

4. Residents’ evaluation to improve the water quality of Lake Kasumigaura.

We try to estimate residents’ evaluation of the water quality of Lake Kasumigaura in Ibaraki prefecture. We investigated on the payment intention of the residents for the improvement of water quality by a questionnaire survey for residents in Ibaraki prefecture using the contingent valuation method (CVM). Residents’ willingness to pay (WTP) is estimated by a random utility model using the double-bounded dichotomous choice elicitation method. The present water quality (COD) of Lake Kasumigaura is 7.7 mg/l in 1999. We set the water quality targets and estimated the median annual WTP for each target. The results are shown in Table 9

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Table 9. Residents’ WTP for Each Water Quality Target

5. The specified model

5.1. Model

5.1.1 Water pollutants flow into lake Kasumigaura

[Amount of pollutants flowing into the lake]

$$Q\ (t) = \sum_j a_j(t) + Q^F(t) + \sum_k Q_k^S(t) + Q^r(t) - Q_L^a(t) \tag{1}$$

$Q(t)$: Amount of pollutants flowing into lake Kasumigaura ;

$a_j(t)$: Amount of pollutants flowing from riversw

$Q^F(t)$: Amount of pollutants emitted by fishery;

$Q_k^S(t)$: Amount of pollutants flowing from sewage disposal plants;

$Q^r(t)$: Amount of pollutants by rainfall into lake Kasumigaura;

$Q_L^a(t)$: Amount of pollutants, abated by mew technology B in lake

: fishery : sewage disposal plants : rainfall a : abatement machines

: river index : Kinds of sewage disposal plants L; Lake Kasumigaura

[River flowing pollutants]

$$a_j(t) = \quad _j r_j(t) \tag{2}$$

where,

$r_j(t)$: Amount of pollutants flowing into rivers emitted by the socioeconomic activities,

$_j$: Rate of remainder pollutants (after purifying) that fall into lake Kasumigaura

[Pollutants emitted by the socioeconomic activities]

$$r_j(t) = (\mathbf{E}\hat{\mathbf{z}}_j(t) - Q_{jE}^a(t)) \cdot l + \mathbf{G}\hat{\mathbf{L}}_j(t) \cdot l + \mathbf{P}\hat{\mathbf{x}}_j(t) \cdot l \tag{3}$$

$\mathbf{E}$: Coefficient of pollutants from household waste water disposal system

$\hat{\mathbf{z}}_j(t)$: Population using each household waste water disposal system

$\mathbf{G}$: Coefficient of pollutants from land use, $\hat{\mathbf{L}}_j(t)$; Area of each land use

$\mathbf{P}$: Coefficient of pollutants from industries, $\hat{\mathbf{x}}_j(t)$; Production amount

$Q^a_{jE}(t)$: Amount of pollutants, abated by new technology A

l : Vector of aggregation

[Pollutants emitted by Fishery]

$$Q^F(t) = P^3 x^3(t) \tag{4.}$$

P^3 : Coefficient of pollutants from fishery, x^3 : Production amount (Fishery)

[Amount of water pollutants emitted from sewage disposal plants]

$$Q^S_k(t) = E^1_k \sum z^1_i(t) - Q^a_{E^1_k}(t) \tag{5}$$

1: Sewage disposal plants

: Kinds of household waste water disposal system

$Q^a_{E^1_k}(t)$: Amount of pollutants, abated by new technology B in sewage disposal plants

[Pollutants by rainfall]

$$Q^r(t) = \quad L_l \tag{6}$$

;Coefficient of pollutants from rainfall, L_l : Surface area of lake Kasumigaura

l: Lake Kasumigaura

[Amount of pollutants abated by new technology B]

$$Q^a_L(t) = D_L \cdot k^a_L \tag{7}$$

$$Q^a_{E^1_k}(t) = D_{E^1_k} \cdot k^a_{E^1_k} \tag{8}$$

D : Abatement coefficient of new technology B

k^a : Number of abatement machines

: Lake Kasumigaura   E: Sewage disposal plant

5.1.2 The number of person using each household waste water disposal system

[Population of catchment area]

$$Z_i(t+1) = Z_i(t) + \quad Z_i \tag{9}$$

z_i : Change of population

: catchment area index

[Finance of catchment area]

$$R_i(t) = \quad {}_i Z_i(t) \tag{10}$$

$R_i(t)$: Scale of finance, $_i$: individual scale of finance

[User population of each household wastewater disposal system]

$$Z_i(t) = \sum_h Z_i^h \tag{11}$$

$$Z_i^h(t+1) = Z_i^h(t) + \quad Z_i^h(t) \tag{12}$$

: Style of sewage disposal   1: Sewage system,   2: Rural community sewage System,   3: Combined treatment septic tank,   4.: Treatment septic tank , 5: Night soil septic tank, h=7: New technology A

[User population of sewage system and rural community Sewage System]

$$Z_i^h(t) \leq \Gamma_i^h \cdot i_i^h(t) \tag{13}$$

$i_i^h(t)$: Constructional investments of catchment area, ^h_i ;Parameter,

h 1: Sewage system, h=2: Rural community sewage System

[Constructional investments]

$$i_i^h(t) = \left(\frac{1}{1-M_i^h}\right) cc_i^h(t) \tag{14}$$

M_i^h : Construction subsidy rate by government, $cc_i^h(t)$: Construction share cost of catchment area

[Construction share cost of catchment area]

$$cc_i^h(t) = db_i^h(t) + b_i^h(t) \tag{15}$$

$db_i^h(t)$; Local bond, $b_i^h(t)$; General account budget

[Maintenance cost of each household wastewater disposal system]

$$mc_i^h(t) = {}_i^h z_i^h(t) = N_i^h z_i^h(t) + g_i^h(t) \tag{16}$$

$mc_i^h(t)$: Maintenance cost, ${}_i^h$; Maintenance cost per an user

N_i^h: Charge for a user, $g_i^h(t)$;General account budget

[Issue of bonds]

$$db_i^h(t) \leq {}_i^h R_i(t) \tag{17}$$

${}_i^h$: Rate of Issue bonds

[Financial supports for combined treatment septic tank]

$$3 \quad z_i^3(t) = \left(\frac{1}{1 - M^3} \right) b_i^3(t) \tag{18}$$

^{3};Setting cost for combined treatment septic tank per person, M^3;Governmental financial support rate (subsidy rate) $b_i^3(t)$;Setting financial supports from municipality
3;Combined treatment septic tank

[Financial supports for new technology A]

7 $$z_i^7(t) = \left(\frac{1}{1-M^7}\right) b_i^7(t) \qquad (19)$$

7 Setting cost for new technology A per person

M^7 Governmental financial support rate (rate of subsidy from Ibaraki prefectural government)

$b_i^7(t)$ Setting financial supports from municipality

7; New technology A

[Constraint budget]

$$b_i^1(t) + b_i^2(t) + b_i^3(t) + g_i^1(t) + g_i^2(t) \leq R_i(t) + s_i^1(t) \qquad (20)$$

$s_i^1(t)$: subsidy for using abatement facility

5.1.3 Subsidy for lands

[Land use]

$$\overline{L} = \sum_{k=1}^{5} L_j^k(t) \qquad (21)$$

$\overline{L}$: catchment area , $L_j^k(t)$: Using area, k of catchment area j

[Change of land use]

$$L_j^k(t+1) = L_j^k(t) + L_j^k(t) \qquad (22)$$

$$L_j^k(t) = \sum_{k \neq l} L_j^{lk}(t) - \sum_{l \neq k} L_j^{kl}(t) \qquad (23)$$

p : Coefficient of land needs

$L_j^{lk}(t)$: Change of land use from to

$L_j^{kl}(t)$: Change of land use from to

$L_j^k(t)$: Land (k) use change impact in area

[Subsidy of land use change]

$$L_j^{k5}(t) \geq {}^{k} s_j^{m}(t) \qquad 24$$

[Area of town]

$$L_j^{54}(t) \geq z_j(t) + {}^{4} i_j^{4P}(t) + {}^{5} i_j^{5P}(t) \qquad (25)$$

: Coefficient of housing area needs, ^{4,5} : Coefficient of industrial area needs

$i_j^{4P,5P}(t)$: Investment for production

5.1.4 Provision for Industry

[Subsidy of production]

$$x_j^{n}(t) \leq {}^{n}\{k_j^{nP}(t) - s_j^{m}(t)\} \qquad (26)$$

^{n} : a proportion coefficient of production to capital stock

[Capital accumulation]

$$k_j^{nP}(t+1) = k_j^{nP}(t) + i_j^{nP}(t) - d^{n} k_j^{nP}(t) \qquad (27)$$

$k_j^{nP}(t)$: Capital accumulation of industrial production $i_j^{nP}(t)$;investment

d^{n} : Depreciation rate

5.1.5 The budget for new technology B

[Budget of abatement machines]

$$s_w^{a}(t) \geq i_w^{a}(t) + mc_w^{a}(t) \qquad (28)$$

$i_w^{a}(t)$: Installing investment for new technology B

$s_w^{a}(t)$: Prefecture budget of new technology B

[Cost for maintenance of new technology B]

$$mc_w^{a}(t) = M_w^{a} \cdot q(t) \qquad (29)$$

$mc_w^a(t)$: Cost for maintenance of new technology B

M_w^a: Coefficient of main technology cost (maintenance cost / 1 million yen of new technology B)

$q_w(t)$: Amount of abated pollutants by abatement machines

[Capital accumulation of new technology B]

$$k^a(t+1) = k^a(t) + i_w^a(t) - d_w^a q_w(t) \qquad (30)$$

d_w^a : Abatement machines depreciation rate

5.1.6 Measure cost for lake Kasumigaura water problem

[Measure cost]

$$y(t) = \sum_i s_i^1(t) + \sum_j \sum_m s_j^m(t) + \sum_w s_w^a(t) \qquad (31)$$

$y(t)$: Measure cost expensed by Ibaraki prefectual government to improve water quality of Kasumigarura

5.1.7 Economical index

[Flow conditions of production market]

$$\mathbf{x}(t) \geq \mathbf{A}\,\mathbf{x}(t) + \mathbf{C}(t) + \mathbf{i}^P(t) + \mathbf{B}^S(i^1(t) + i^2(t)) + \mathbf{B}^C(Z^3(t)) + \mathbf{B}^A(Z^7(t)) + \mathbf{B}^a i^a(t) + \mathbf{e}(t) \qquad (32)$$

$\mathbf{x}(t) = \sum_j \mathbf{x}_j(t)$;total industrial production vector,

$\mathbf{i}^P(t) = \sum_j \mathbf{i}_j^P(t)$: total production investment vector

$i^h(t) = \sum_i i_i^h(t)$: Investments for setting of sewage system and rural community sewage system, $z^3(t) = \sum_i z_i^3(t)$: combined swage system setting cost

$\mathbf{A}$: Input Coefficient matrix, $\mathbf{C}(t)$: consumption,

$\mathbf{B}^s, \mathbf{B}^c, \mathbf{B}^a$: Capital formation matrix,

$\mathbf{e}(t)$: export, $s_j^m(t)$: subsidy for industries m=3.,5,6,7,8 , f^n : parameter

5.2. The water balance in the basin.

The water balance model of the basin was made especially referring to two studies done by Aramaki and Matsuo (Aramaki and Matsuo (1998) ([2]) and Aramaki and Matsuo (1998)([3])) .

The composition element of water balance are the water of lake Kasumigaura, rivers flowing into the lake, ground water, spontaneous generation flux, water supply enterprises and sewage disposal plants. There are three kinds of water use: such as for household, for industry and for agriculture activity.

When there are heavy river flow and spontaneous generation flow, the water balance in each component is calculated as the following:

5.2.1 Total amount of water collected by water supply enterprises.

Total amount of water collected by water supply enterprises are calculated according to the following equation.

$$W_j^g(t) = WL_j(t) + \sum_i WS_{ij}(t) + \sum_i WG_{ij}(t) - \sum_m WW_{jm}(t) + \sum_m WW_{mj}(t) \qquad 33$$

$W_j^g(t)$: the total amount of water collected by the water supply enterprise j

$WL_j(t)$: the amount of water collected from Lake Kasumigaura.

$WS_{ij}(t)$: the amount of water collected by the water supply enterprise j from spontaneous generation flow in the basin municipality i

$WG_{ij}(t)$: the amount of water collected by the water supply enterprise j from ground water in the basin municipality i

$WW_{jm}(t)$: the amount of water supply from the water supply enterprise j to other water supply enterprise m

$WW_{mj}(t)$: the amount of water supply from the water supply enterprise m to other water supply enterprise j .

5.2.2 The amount of total water supply from each water supply enterprise

$$W_j^s(t) = \sum_i UDW_{ji}(t) + \sum_i UIW_{ji}(t) \tag{34}$$

$W_j^s(t)$: the total amount of water supply from the water supply enterprise j.

$UDW_{ji}(t)$: the total amount of water supply from water supply enterprise j to the municipality i for household activities

$UIW_{ji}(t)$: the total amount of water supply from water supply enterprise j to the municipality i for industrial activity

5.2.3 The balance between water collection and water supply of each water supply enterprise

The each water supply enterprise is supposed to carry out water collection more than the amount of available water supply.

$$W_j^g(t) \geq W_j^s(t) \tag{35}$$

5.2.4 The amount of water supply for the household activity in each basin municipality

$$UD_i^s(t) = \sum_j UDW_{ji}(t) + UDS_i(t) + UDG_i(t) + \sum_k UDSP_{ki}(t) \tag{36}$$

$UD_i^s(t)$: the amount of water supply for the household activity in the basin municipality i

$UDS_i(t)$: the amount of water collected from spontaneous generation flow in basin munic ipality i

$UDG_i(t)$: the amount of water collected from ground water in basin municipality i.

$UDSP_{ki}(t)$: the amount of water supply from the sewage disposal plant k , for reuse for the household activities of basin municipality i.

The water demand of household activity in the basin municipality is given by the following equation.

$$UD_i^d(t) = Z_i^1(t)LWD^1 + Z_i^2(t)LWD^2 + Z_i^3(t)LWD^3 + Z_i^4(t)LWD^4 + Z_i^5(t)LWD^5 + Z_i^7(t)LWD^7 \quad 37$$

$UD_i^d(t)$: the amount of water demand of the household activity in the basin municipality i

LWD^h : the water demand coefficient of each wastewater disposal system

upper subscript

h the classification of wastewater disposal system

h=1: Sewage System h=2: Rural Community Sewage System h=3: Combined Treatment Septic Tank h=4: Treatment Septic Tank h=5: Night Soil Septic Tank h=7: New TechnologyA

The amount of water collected for household activity in basin municipality, which is presupposed to be more than the demand for water.

$$UD_i^s(t) \geq UD_i^d(t) \quad 38$$

5.2.5 The amount of water supply for the industrial activity of basin municipalities

$$UI_i^s(t) = \sum_j UIW_{ji}(t) + UIL_i(t) + UIS_i(t) + UIG_i(t) \quad (39)$$

$UI_i^s(t)$: the amount of water supply for the industrial activity of basin municipality i

$UIL_i(t)$: the amount of water collected from the lake Kasumigaura for the industrial activity of basin municipality i

$UIS_i(t)$: the amount of water collected from spontaneous generation flow in the basin municipality i for industrial activity

$UIG_i(t)$: the amount of water collect from ground water in the basin municipality i for industrial activity

The water demand of industrial activity in the basin municipality is given by the following equation

$$UI_i^d(t) = X_i^4(t)IWD^4 + X_i^5(t)IWD^5 \quad 40$$

$UI_i^d(t)$: the amount of water demand for industrial activity in the basin municipality i.

IWD^n : the water demand coefficient for each industry. (manufacturing industry and other industry).

upper subscript n=4: the manufacturing industry n=5 the other industry.

The amount of water collected for industrial activity in basin municipality, which is presupposed to be more than the demand for water.

$$UI_i^s(t) \geq UI_i^d(t) \qquad 41$$

5.2.6 The amount of water supply for the agricultural activity in basin municipalities

$$UA_i^s(t) = UAL_i(t) + UAS_i(t) + UAG_i(t) \qquad (42)$$

$UA_i^s(t)$: the amount of water supply for the agricultural activity in the basin municipality i

$UAL_i(t)$: the amount of water collected from Lake Kasumigaura for the agricultural activity in the basin municipality i

$UAS_i(t)$: the amount of water, drawn from spontaneous generation flow in the basin municipality i for agricultural activity

$UAG_i(t)$: the amount of water collected from ground water in the basin municipality i for agricultural activity

The water demand for agricultural activity in the basin municipality is given by the following equation

$$UA_i^d(t) = X_i^{11}(t)AWD^{11} + X_i^{12}(t)AWD^{12} + X_i^2(t)AWD^2 \qquad 43$$

$UI_i^d(t)$: the amount of water demand for agricultural activity in the basin municipality i.

IWD^n : the water demand coefficient of each industry. (agriculture and livestock industry).

upper subscript n=11: the farming agriculture. n=12 the rice cultivation agriculture. n=2 stock raising industry.

The amount of water collected for agricultural activity in basin municipality, which is presupposed to be more than the demand for water..

$$UA_i^s(t) \geq UA_i^d(t) \qquad 44$$

5.2.7 The amount of sewer processing water in the sewage disposal plant.

$$SP_k(t) = \boldsymbol{b}_k \left[\sum_i SPUD_{ik}(t) + \sum_i SPUI_{ik}(t) \right] \qquad 45$$

$SP_k(t)$: The amount of sewer processing water in the sewage disposal plant k.

$\boldsymbol{b}_k$: Extra rate of the sewer processing water considering the underground infiltration to the sewerage system.

$SPUD_{ik}(t)$: The amount of water displaced to the sewerage system which runs to the sewage disposal plant k from household activity in the basin municipality i

$SPUI_{ik}(t)$: The amount of water displaced to the sewerage system which runs to the sewage disposal plant k from industrial activity in the basin municipality i

5.2.8 The water balance of the ground water

In this study, we consider the groundwater is something like the buffer of infinite size and the water balance is affected only by water collection and artificial recharge. So, we assumed that even if the amount of water recharge and water collection change, the amount of groundwater is not affected.

$$\begin{aligned} G_i(t) = &\sum_j WG_{ij}(t) + UDG_i(t) + UIG_i(t) + UAG_i(t) \\ &- LUD_i \cdot UD_i^s(t) - LUI_i \cdot UI_i^s(t) - LUA_i \cdot UA_i^s(t) \qquad (46) \\ &+ \left\{ \frac{[SP_k(t)\boldsymbol{b}_k - 1]}{\boldsymbol{b}_k} \right\} - \sum_j NGW_{ji} \{ W_j^g(t)[1 - \boldsymbol{a}_j] \} \end{aligned}$$

LUD_i : The loss rate when the water used for household activity in basin municipality i.

LUI_i : The loss rate when the water used for industrial activity in basin municipality i.

LUA_i : The loss rate when the water used for agricultural activity in basin municipality i.

NGW_{ji} : The coefficient which shows whether it cultivates the invalid water supply of water supply enter prise j to the groundwater in basin municipality i. (the case in which it is cultivated=1 the case in which it is not cultivated=0)

$\boldsymbol{a}_j$: The rate of effective water supply by the water supply enterprise j.

5.2.9 The river flow in the basin municipality.

$$\begin{aligned} R_i(t) = R_{i-1}(t) &+ \left[SF_i(t) - WS_{ij}(t) - UDS_{ii}(t) - UIS_{ii}(t) - UAS_{ii}(t)\right] \\ &+ \left[UD_i^s(t) - LUD_i \cdot UD_i^s(t) - SPUD_{ik}(t)\right] \\ &+ \left[UI_i^s(t) - LUI_i \cdot UI_i^s(t) - SPUI_{ik}(t)\right] \\ &+ (1 - LUA_i)UA_i^s(t) \end{aligned} \tag{47}$$

R_i : The river flow in basin municipality i.

SF_i :The amount of spontaneous generation flow rate in basin municipality i.

5.2.10 The balance of the amount of spontaneous generation flow of water

$$SF_i(t) \geq \sum_j WS_{ij}(t) + UDS_i(t) + UIS_i(t) + UAS_i(t) \tag{48}$$

5.2.11 The total amount of water collection from Lake Kasumigaura.

$$KW^g(t) = \sum_j WL_j(t) + \sum_i UIL_i(t) + \sum_i UAL_i(t) \tag{49}$$

$KW^g(t)$:The amount of water collected from Lake Kasumigaura

5.2.12 The total amount of water which flow into Lake Kasumigaura from each river.

$$KW^r(t) = \sum_i R_i^E(t) + \sum_i \sum_k \left[SP_k(t) - UDSP_{ki}(t)\right] \tag{50}$$

$KW^r(t)$: The total amount of water which flow into Lake Kasumigaura from each river.

$R_i^E(t)$: The river flow in basin municipality i near the mouth of the river.

5.2.13 The restriction in the water quality of inflow water.

In this study, we analyze the influence of the policy by applying restrictions to the water quality of the water which flows into Kasumigaura.

$$\overline{WQ}(t) \geq WQ(t) \tag{51}$$

where

$$WQ(t) = \frac{Q(t)}{KW^r(t)} \tag{52}$$

$\overline{WQ}(t)$:The water quality restrictions imposed on the water which flows into Lake

Kasumigaura

$WQ(t)$: The water quality of the water which flows into Lake Kasumigaura.

5.2.14 Objective function

$$\max \sum_{t=1} \frac{1}{(1+r)^{(t-1)}} GRP(t) \qquad (53)$$

s.t. (1)-(52)

6. The simulation

We ran this simulation with 'LINGO' which is the computer software for operations research released by LINDO SYSTEMS.

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