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The classification of water shortage degree of irrigated plot area in command area by LP technique, Hiikawa-karyu irrigation project, Japan

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Two optimization models are formulated based on different objectives for assisting the irrigation planner in making decision on agricultural planning during drought year. The sensitive degree of water shortage area in the irrigation project are classified by those models. They are solved by simplex method. Firstly, the Two-phase method is applied to analyze the artificial variables in the formulated model. Then, the formulated model is modified after getting rid of the artificial variables to obtain the feasible solution. The agricultural planning is planned by considering the classified area with social equity and economic improvement. Crop diversification is introduced to conduct in the very sensitive water shortage area and intermittent irrigation system is introduced to operate in the moderately sensitive water shortage area. The integrated farming system, the separation of land owner and cultivator and the disposition of substitute lots system are also suggested to conduct in this study project.
Key words: agricultural planning, Two-phase method, integrated farming, sensitive water shortage, disposition of substitute lots system.

1. INTRODUCTION

As demand of water(i.e. domestic use, industrial purpose and agricultural purpose) is increasing continually and/or drought condition is facing, the utilization of conventional sources of supply is becoming excessive. Under these circumstances the efficient technique in water resources management for optimal utilization of available water is being required. Many researchers have introduced some approaches to solve this problem by considering different criteria. DeBoer,1983; Crook, 1985 and Gideon, et al., 1987 have introduced some measures to satisfy those demands by calling for a comprehensive investigation of potential alternative water resources such as saline water, waste water and runoff water and alternative operation and management such as intermittent irrigation and rainwater harvest. In Broadview Water District, California, the district cooperated with the farmers to improve water management during drought. The district provided accurate water use data to farmers during that period, increased the flexibility allowed in scheduling water deliveries and managed water transfer and purchases when water was available. The farmers implemented new irrigation practices and increased the efficiency of water application(Dennis, et. al, 1992).

As the agriculture in Japan, the water demand is generally increasing since consolidated

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land because of the separation of irrigation system and drainage system. Moreover nowadays new larger plot system which requires more water is being introduced. Some approaches have been applied to settle the water user conflict during drought in Japan by increasing the low flow discharge of resource -rivers during dry spells by construction of reservoirs, or by the diversion of water from other rivers, by the unification of the existing diversion dam or unification of the water user association and change of water delivery system (Satoh et. al, 1990). However, the optimal water utilization under limited available water in command area is a necessary method. In this study, the linear programming technique is applied to classify the water shortage degree of irrigated plot in the command area for using in making decision on an agricultural planning. Hiikawa-karyu irrigation project is selected to be a case study.

2. THE PROJECT OUTLINES

Hiikawa-karyu irrigation project is in Hiikawa plain in lower reaches of the Hii river. It is located in the eastern part of the Shimane Prefecture and called the granary of the Shimane. Its irrigated area is 3210 ha with 2990 ha of paddy rice and 220 ha of field crop. Its simplified lay out of the project is shown in Fig. I . The irrigation water in this area depends mainly on the Hii river with annual average rainfall of 1845 mm. The riverbed deposited by fine sand is high. It causes to be water shortage during drought period especially in the downstream area. The sample of drought condition in 1978 is shown in Fig. II . The agriculture activities suffer from a constant shortage of irrigation water. Irrigation water in the lowland of this area is supplied by about 110 points of installed pumping stations and about 200 sites of irrigation ponds. Most of the facilities mentioned above become obsolete. These obsolete irrigation facilities are aimed to rehabilitate, such as the main canals which have been constructed more than 30years ago. The supplemental water supply is taken from Lake Shinji(desalinization of water), by means of the Nakaumi Reclamation Project, when the irrigation water from the Hii river and the existing irrigation ponds is not sufficient. Moreover, the drainage water from drainage canal in this project is reused for agricultural purpose by pumping and pipe line system. This project is expected to promote the rationalization and stabilization of farming management by improving the present situation of agricultural infrastructure of this region.

3. THE OPTIMIZATION MODEL

Two optimization models are formulated by combining a water river allocation model, reused water allocation of drainage canal model with a land allocation cropping pattern model. The objectives of models are to minimize the intake water from river and to minimize the operation of pump. They are well suited to be solved by linear programming techniques, because the objective functions and constraints can be expressed as linear functions.

3.1 The minimized intake water from river.

This objective is concerned to improve rational use of water resource.

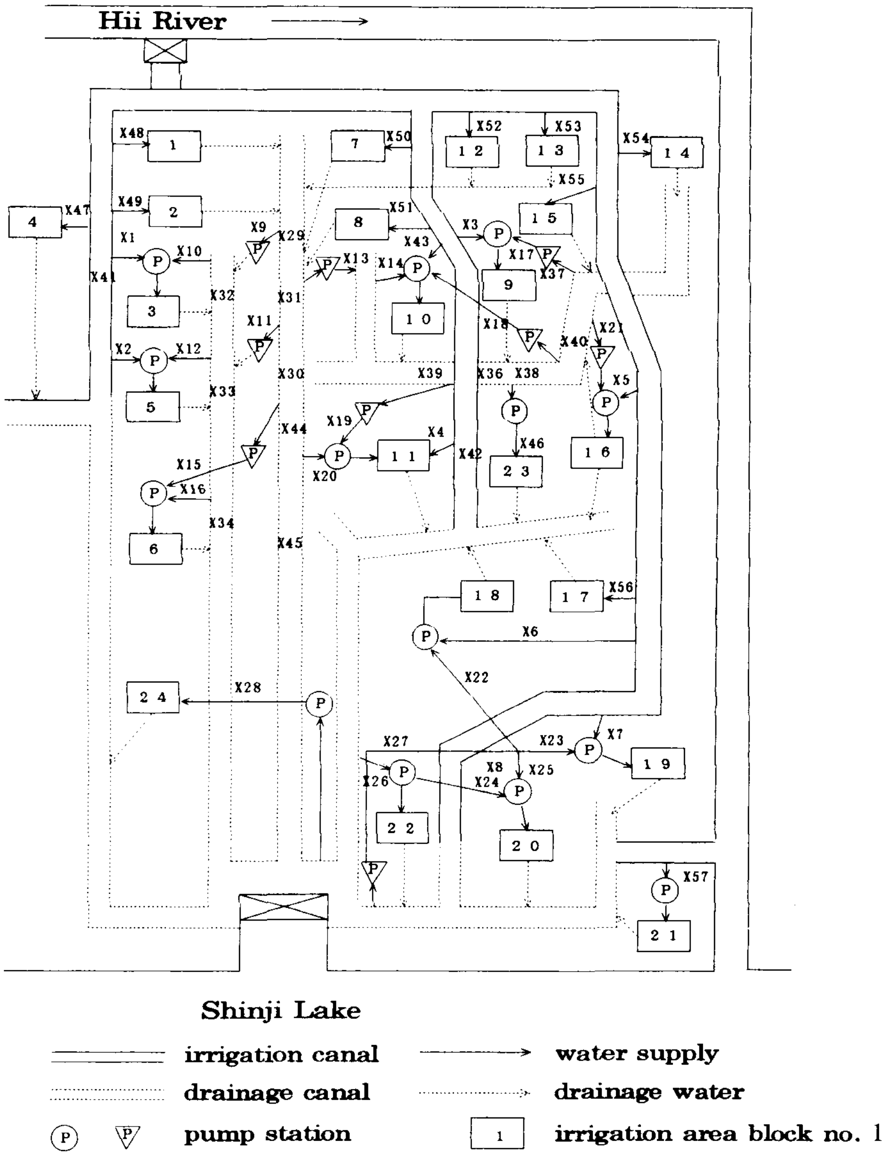

Fig. I Simplified lay out of the project

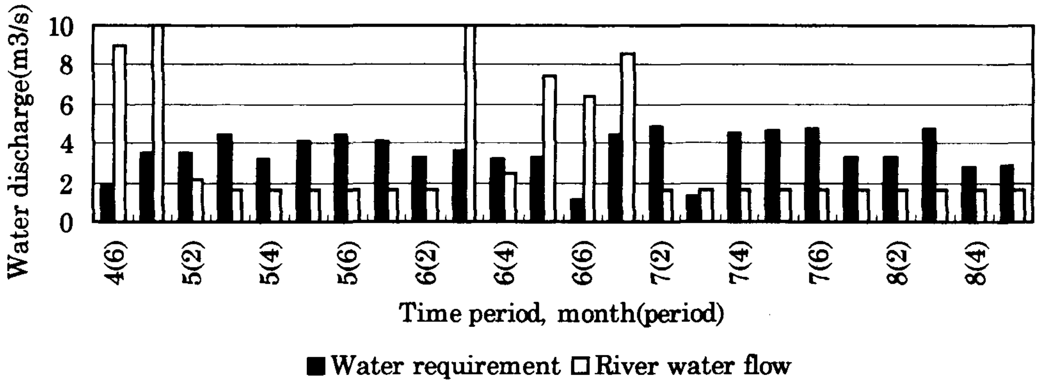

Fig. II The comparison of available river discharge and water requirement

$$\text{Minimize } Z_1 = \sum_{i=1}^{n} Ir_{it} \qquad \forall t \qquad (1)$$

where Z_1 = the total water consumption from river, m^3/s,

Ir_{it} = the irrigation water supplied to the i^{th} area in period t, m^3/s.

and subject to the following constraints:

River water availability

$$\sum_{i=1}^{n} Ir_{it} \leqq RW_t \qquad \forall t \qquad (2)$$

where RW_t = available water river in period t, m^3/s

Crop water requirement

$$\sum_{i=1}^{n} Ir_{it} + Re_{it} \geqq A_i H_{it} \qquad \forall i, t \qquad (3)$$

where Re_{it} = water reuse supplied to the i^{th} area in period t, m^3/s,

A_i = crop area of the i^{th} area, m^2,

H_{it} = the net water requirement in depth per second of the i^{th} area in period t, m/s.

Upstream flow & downstream flow

$$Re_{it} + Red_{it} = Dr_{(i-1)t} + Reu_{it} \qquad \forall i, t \qquad (4)$$

where Red_{it} = downstream flow in drainage canal of the i^{th} area in period t, m^3/s,

$Dr_{(i-1)t}$ = drainage discharge of the $(i-1)^{th}$ area in period t, m^3/s,

Reu_{it} = upstream flow in drainage canal of the i^{th} area in period t, m^3/s.

Pump capacity

$$Re_{it} \leqq C_i \qquad \forall i, t \qquad (5)$$

where C_i = the i^{th} pump capacity, m^3/s.

and nonnegativity

$$Ir_{it}, Re_{it}, Red_{it} \text{ and } Reu_{it} \geqq 0 \qquad (6)$$

3.2 The minimized operation of pump.

This objective is concerned to maximize the benefit for the farmer.

$$\text{Minimize } Z_2 = \sum_{i=1}^{n} Rep_{it} \qquad \forall t \qquad (7)$$

where Z_2 = the total reused water supplied by pump, m^3/s,

Rep_{it} = reused water supplied by the i^{th} pump in period t, m^3/s.

and subject to the following constraints:

River water availability

$$\sum_{i=1}^{n} Ir_{it} \leqq RW_t \qquad \forall t \qquad (8)$$

Crop water requirement

$$\sum_{i=1}^{n} Ir_{it} + Re_{it} \geqq A_i H_{it} \qquad \forall i, t \qquad (9)$$

Upstream flow & downstream flow

$$Re_{it}+Red_{it} = Dr_{(i-1)t}+Reu_{it} \qquad \forall i, t \qquad (10)$$

Pump capacity

$$Re_{it} \leqq C_i \qquad \forall i, t \qquad (11)$$

and nonnegativity

$$Ir_{it}, Re_{it}, Red_{it} \text{ and } Reu_{it} \geqq 0 \qquad (12)$$

3.3 Model analysis

The objective function of both LP models subject to functional inequality constraints and equality constraints. Thus the slack variables, surplus variables and artificial variables are necessary to be introduced in the model before being solved by the simplex method. According to the assumption of simplex method, the feasible solution can be obtained when the introduced artificial variables are zero. Therefore, Two-phase method is firstly applied to determine the artificial variables in this study.

3.4 Initial Analysis

In the first phase of the analysis, it was found that the shadow price (i.e. the coefficients of the slack and surplus variables in the objective function equation when the solution is the optimal solution) of water river availability constraint, crop water requirement constraints and upstream and downstream constraints were not zero, while the shadow price of pump capacity constraints were zero. Furthermore, the artificial variables of upstream and downstream constraints were zero, while the artificial variables of the crop water requirement constraints were not zero. Therefore, the solution for both LP models formulated as given were not feasible solutions because some artificial variables were not zero. The artificial variables and shadow prices of the crop water requirement constraints are shown in Table1.

3.5 Modified Formulation

The sum of artificial variables in Table 1 is the sum of infeasibilities(i.e. the optimal solution of phase 1). It means that the optimal solution from the phase 1 must be reduced by the sum of infeasibilities to make the feasible solution in the original model. As the shadow price of a constraint is the rate at which the objective function value will improve as the right-

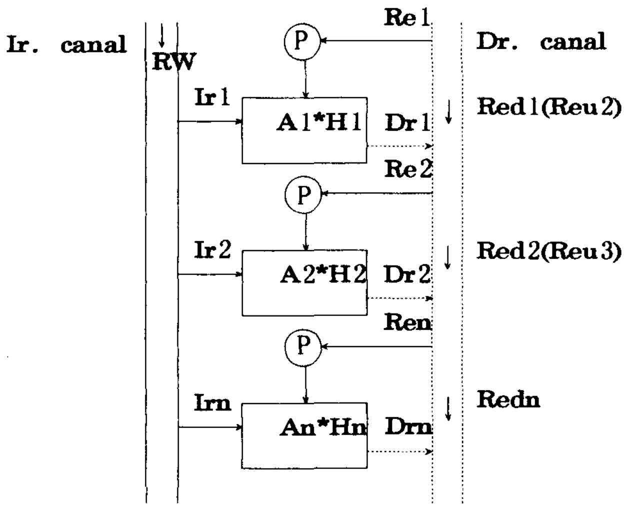

Fig. Ⅲ The irrigation and drainage system for the LP model

Table 1 The results from phase1of water requirement constraint

Block No.	Net WR (m^3/s)	The first model: Artificial variable	The first model: Shadow price	The second model: Artificial variable	The second model: Shadow price
1	0.351	0.000	-1	0.000	-1
2	0.168	0.000	-1	0.168	-1
3	0.123	0.000	-1	0.000	-1
4	0.240	0.000	-1	0.000	-1
5	0.189	0.000	-1	0.000	-1
6	0.291	0.000	-1	0.000	-1
7	0.154	0.000	-1	0.000	-1
8	0.085	0.000	-1	0.085	-1
9	0.164	0.000	-1	0.000	-1
10	0.179	0.000	-1	0.000	-1
11	0.179	0.000	-1	0.000	-1
12	0.132	0.132	-1	0.000	-1
13	0.132	0.000	-1	0.132	-1
14	0.396	0.396	-1	0.000	-1
15	0.255	0.255	-1	0.255	-1
16	0.203	0.038	-1	0.000	-1
17	0.198	0.000	-1	0.000	-1
18	0.128	0.000	-1	0.064	-1
19	0.198	0.000	-1	0.000	-1
20	0.291	0.000	-1	0.000	-1
21	0.190	0.190	-1	0.190	-1
22	0.498	0.000	-1	0.000	-1
23	0.117	0.000	-1	0.117	-1
24	0.529	0.000	-1	0.000	-1

hand-side of the constraint is changed. Therefore, the change of right-hand-side of the river water availability constraints, crop water requirement constraints and upstream and downstream constraints can effect the optimal solution(i.e. sum of artificial variables in the phase 1). But due to the artificial variables of the river water availability constraints and downstream and upstream constraints were zero, the downstream and upstream constraints are affected by the crop water requirement constraints in term of drainage and the available river water is limited. Therefore, the constraint on water requirement of block no. 12, 14, 15, 16 and 21 in the first model and block no. 2, 8, 13, 15, 18, 21 and 23 in the second model were found to be violated because their artificial variables and shadow prices were not zero. It means that the right-hand-side of block no. 12, 14, 15, 16 and 21 in the first model should be reduced by 0.132, 0.396, 0.255,0.038 and 0.190 respectively and by 0.168, 0.085, 0.132, 0.255, 0.064, 0.190 and 0.117 for block no. 2, 8, 13, 15, 18, 21 and 23 in the second model to get rid of the artificial variables. However, after reducing the net crop water requirement in the original model, some artificial variables still were not zero because the drainage in the upstream and downstream constraints in the original model were reduced also after reducing the net water requirement. Thus, the procedure of the phase 1 was revised until all artificial variables were zero. The procedure of model analysis is shown in Fig.Ⅳ.

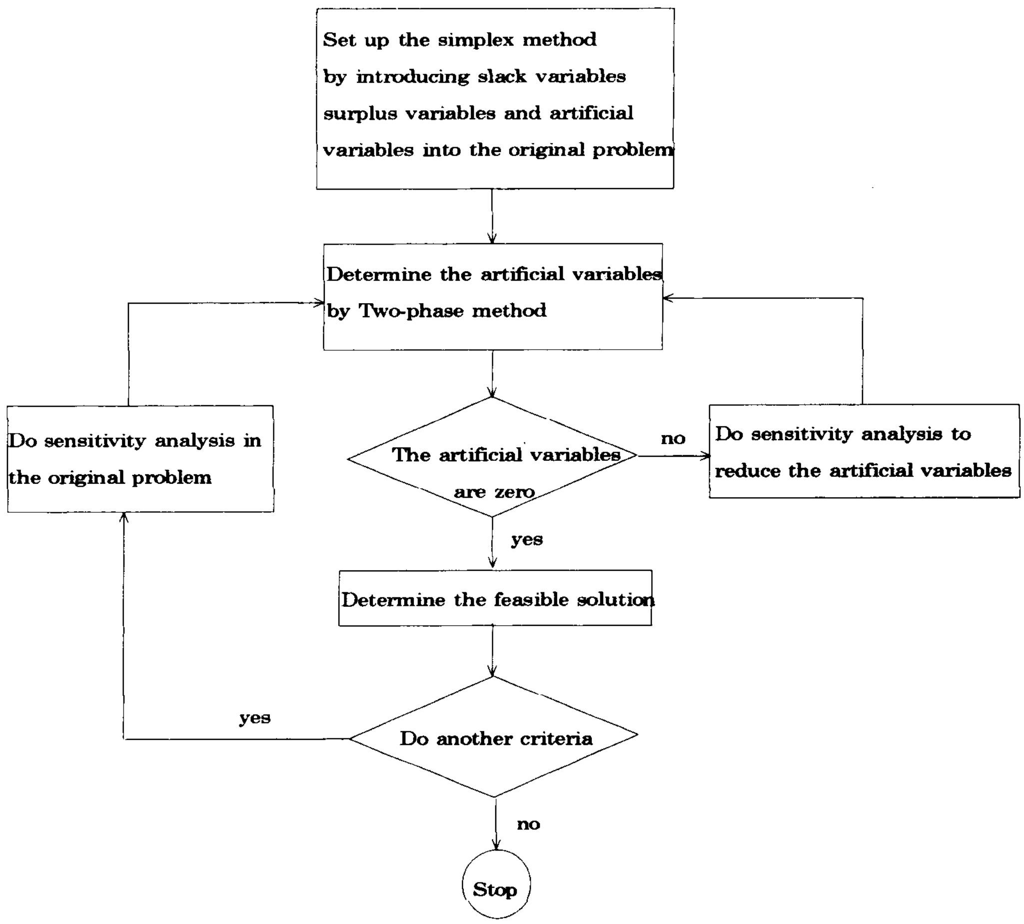

Fig. Ⅳ Flowchart of model analysis

4. Results and discussion

Two LP models are formulated based on different objectives. The objective of the first model is to minimize the intake water from river to improve the rational use of water resource and to provide more river water for domestic use and industrial purpose, while the objective of the second model is to minimize the operation of pump in taking reused water to improve the benefit to the farmer. In this study, data in 1978 which only 75% of total area were allowed to cultivate for rice and 25% of that were made crop diversification because it was over production and drought year, is applied to be input data in these models. The results of both models as shown in Table 2 and 3 are obtained by simplex method after getting rid of all artificial variables.

Table 2 The optimal results of the first model (minimized intake water from river)

Block No.	Net WR. (m^3/s)	Available water supply(m^3/s) Irr.water	Reuse	Total	% of net WR
1	0.351	0.132	0.000	0.132	37.61
2	0.168	0.168	0.000	0.168	100.00
3	0.123	0.123	0.000	0.123	100.00
4	0.240	0.240	0.000	0.240	100.00
5	0.189	0.067	0.122	0.189	100.00
6	0.291	0.000	0.146	0.146	50.17
7	0.154	0.154	0.000	0.154	100.00
8	0.085	0.085	0.000	0.085	100.00
9	0.164	0.000	0.000	0.000	0.00
10	0.179	0.089	0.000	0.089	49.72
11	0.179	0.179	0.000	0.179	100.00
12	0.132	0.000	0.000	0.000	0.00
13	0.132	0.066	0.000	0.066	50.00
14	0.396	0.000	0.000	0.000	0.00
15	0.255	0.000	0.000	0.000	0.00
16	0.203	0.000	0.000	0.000	0.00
17	0.198	0.039	0.000	0.039	19.70
18	0.128	0.051	0.000	0.051	39.84
19	0.198	0.000	0.000	0.000	0.00
20	0.291	0.290	0.000	0.290	99.66
21	0.190	0.000	0.000	0.000	0.00
22	0.498	0.000	0.246	0.246	49.40
23	0.117	0.000	0.081	0.081	69.23
24	0.529	0.000	0.529	0.529	100.00

Table 3 The optimal results of the second model
(minimized operation of pump)

Block No.	Net WR.	Available water supply(m^3/s)			
	(m^3/s)	Irr.water	Reuse	Total	% of net WR
1	0.351	0.351	0.000	0.351	100.00
2	0.168	0.000	0.000	0.000	0.00
3	0.123	0.123	0.000	0.123	100.00
4	0.240	0.000	0.000	0.000	0.00
5	0.189	0.000	0.000	0.000	0.00
6	0.291	0.000	0.288	0.288	98.97
7	0.154	0.154	0.000	0.154	100.00
8	0.085	0.000	0.000	0.000	0.00
9	0.164	0.164	0.000	0.164	100.00
10	0.179	0.128	0.051	0.179	100.00
11	0.179	0.032	0.147	0.179	100.00
12	0.132	0.132	0.000	0.132	100.00
13	0.132	0.000	0.000	0.000	0.00
14	0.396	0.000	0.000	0.000	0.00
15	0.255	0.000	0.000	0.000	0.00
16	0.203	0.203	0.000	0.203	100.00
17	0.198	0.198	0.000	0.198	100.00
18	0.128	0.000	0.057	0.057	44.53
19	0.198	0.198	0.000	0.198	100.00
20	0.291	0.000	0.050	0.050	17.18
21	0.190	0.000	0.000	0.000	0.00
22	0.498	0.000	0.087	0.087	17.47
23	0.117	0.000	0.000	0.000	0.00
24	0.529	0.000	0.529	0.529	100.00

According to these results, this project area can be divided into four groups based on considering 3 days intermittent irrigation system as very sensitive(i.e.0-30% of net crop water requirement can be supplied), moderately sensitive(i.e.30-70% of net crop water requirement can be supplied), rarely sensitive(i.e.70-100% of net crop water requirement can be supplied) and insensitive water shortage area(i.e.100% of net crop water requirement can be supplied) respectively as shown in Fig. V and VI. The block no.9, 12, 14, 15, 16, 17, 19 and 21 in the first model and block no. 2, 4, 5, 8, 13, 14, 15, 20, 21, 22, and 23 in the second model are very sensitive in lacking of water while block no. 1, 6, 10, 13, 18, 22 and 23 in the first model and block no. 18 in the second model are moderately sensitive but block no. 20 in the first model and block no. 6 in the second model are rarely sensitive. On the other hand, block no.2, 3, 4, 5, 7, 8, 11 and 24 in the first model and block no. 1, 3, 7, 9, 10, 11, 12, 16, 17, 19 and 24 in the second model are insensitive water shortage area. These results can assist the irrigation

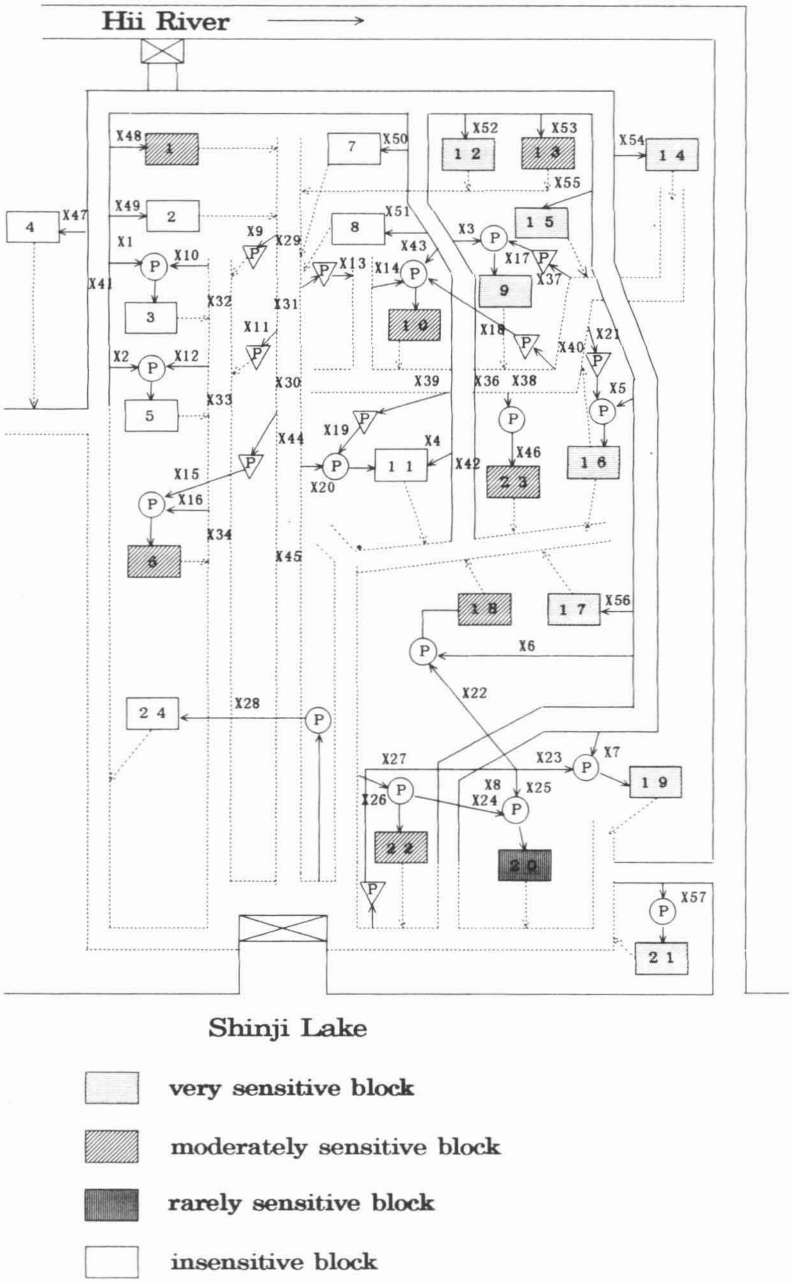

Fig. V The classified area by the first model

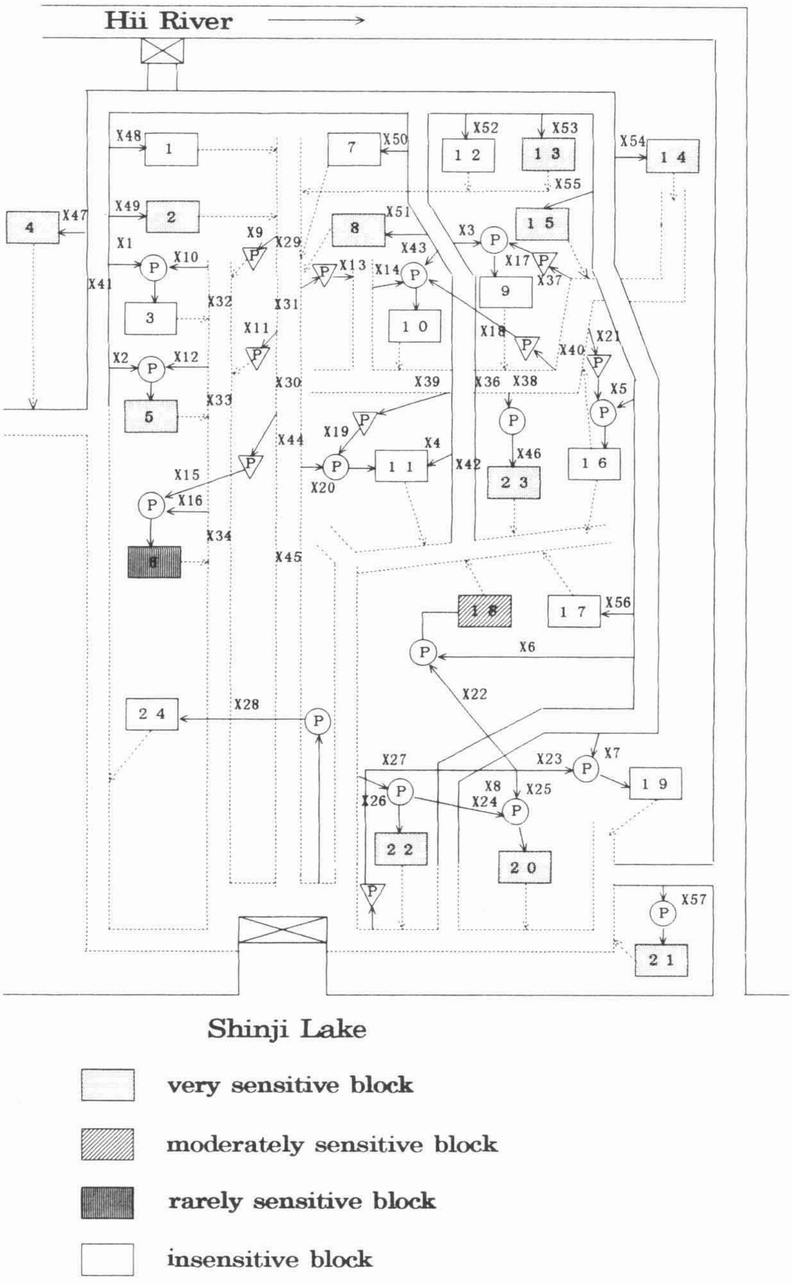

Fig. VI The classified area by the second model

planner in making decision on water operation planning. The very sensitive in water shortage area should be made crop diversification and intermittent irrigation system should be introduced to the moderately sensitive area, whereas usual cultivation can be continued in rarely sensitive and insensitive water shortage area. However, it may cause to the problem among the farmers because of existing water right and individual farming system. Therefore, another criteria based on considering social equity and water saving(i.e. every irrigated area in the project will be allowed to be supplied only 75% of total water requirement) is done. Their results are shown in Table 4 and Table 5 and their classified block areas are shown in

Fig. Ⅶ and Ⅷ. However, some irrigated areas are still very sensitive in lacking of water such as block no. 1, 7, 12, 14 and 16 in the first model and block no.2, 8, 13, 15, 18 and 23 in the second model respectively. Therefore, block no. 1, 7, 12, 14 and 16 should be made crop diversification and block no. 15 and 23 should be operated by intermittent irrigation system during critical water shortage when the first model is selected to conduct for this project. But if the planning by second model is selected to conduct, block no. 2, 8, 13, 15, 18 and 23 should be made crop diversification and block no. 5, and 14 should be operated by intermittent irrigation system.

Table 4 The optimal results of the first model (minimized intake water from river) in case of 75%

Block No.	Net WR.	Available water supply(m^3/s)			
	(m^3/s)	Irr.water	Reuse	Total	% of net WR
1	0.263	0.078	0.000	0.078	29.66
2	0.126	0.126	0.000	0.126	100.00
3	0.092	0.000	0.092	0.092	100.00
4	0.180	0.180	0.000	0.180	100.00
5	0.142	0.141	0.001	0.142	100.00
6	0.218	0.000	0.218	0.218	100.00
7	0.116	0.000	0.000	0.000	0.00
8	0.064	0.064	0.000	0.064	100.00
9	0.123	0.121	0.000	0.121	98.37
10	0.134	0.114	0.000	0.114	85.07
11	0.134	0.134	0.000	0.134	100.00
12	0.099	0.000	0.000	0.000	0.00
13	0.099	0.099	0.000	0.099	100.00
14	0.297	0.076	0.000	0.076	25.59
15	0.191	0.068	0.000	0.068	35.60
16	0.152	0.000	0.000	0.000	0.00
17	0.149	0.149	0.000	0.149	100.00
18	0.096	0.032	0.064	0.096	100.00
19	0.149	0.149	0.000	0.149	100.00
20	0.218	0.009	0.209	0.218	100.00
21	0.143	0.143	0.000	0.143	100.00
22	0.374	0.000	0.374	0.374	100.00
23	0.088	0.000	0.059	0.059	67.05
24	0.397	0.000	0.397	0.397	100.00

Table 5 The optimal results of the second model
(minimized operation of pump) in case of 75%

Block No.	Net WR.	Available water supply(m^3/s)			
	(m^3/s)	Irr.water	Reuse	Total	% of net WR
1	0.263	0.263	0.000	0.263	100.00
2	0.126	0.000	0.000	0.000	0.00
3	0.092	0.092	0.000	0.092	100.00
4	0.180	0.180	0.000	0.180	100.00
5	0.142	0.000	0.047	0.047	33.10
6	0.218	0.000	0.218	0.218	100.00
7	0.116	0.116	0.000	0.116	100.00
8	0.064	0.000	0.000	0.000	0.00
9	0.123	0.123	0.000	0.123	100.00
10	0.134	0.134	0.000	0.134	100.00
11	0.134	0.000	0.134	0.134	100.00
12	0.099	0.099	0.000	0.099	100.00
13	0.099	0.000	0.000	0.000	0.00
14	0.297	0.144	0.000	0.144	48.48
15	0.191	0.000	0.000	0.000	0.00
16	0.152	0.152	0.000	0.152	100.00
17	0.149	0.149	0.000	0.149	100.00
18	0.096	0.000	0.026	0.026	27.08
19	0.149	0.125	0.024	0.149	100.00
20	0.218	0.000	0.218	0.218	100.00
21	0.143	0.106	0.000	0.106	74.13
22	0.374	0.000	0.374	0.374	100.00
23	0.088	0.000	0.000	0.000	0.00
24	0.397	0.000	0.397	0.397	100.00

5. Conclusions

Linear programming technique is a power tool which can be applied to assist the irrigation planner in making decision on proper water management. The sensitive degree of water shortage area in the project can be classified by applying LP technique. Four levels of them are classified to make agricultural planning which should be considered by two points of view as social equity and economic improvement. The very sensitive in water shortage area should be made crop diversification and moderately sensitive one should be operated by the intermittent irrigation system during critical period. However, because of existing water right and individual farming system, some new policies should be established for this project to solve those problems such as integrated farming system and the separation of land owner and cultivator which can reduce the production cost and labor, water right compensation for the farmers who make crop diversification as well as disposition of substitute lots system which can satisfy the original lot owner and the substitute lot owner in making crop diversification. However, the results from LP model depend on its objective function, therefore, the objective of water resource utilization is very necessary to be considered before making agricultural planning.

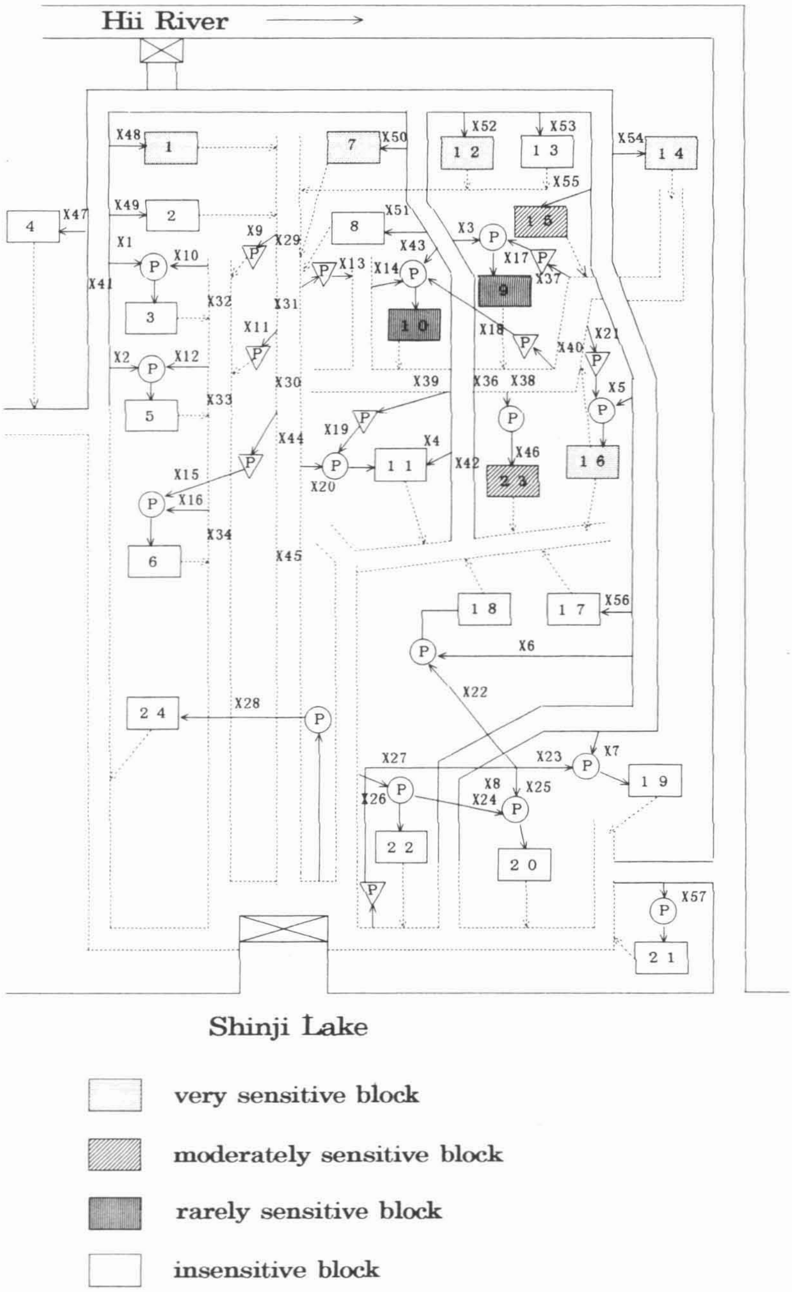

Fig. VII The classified area by the first model in case of 75%

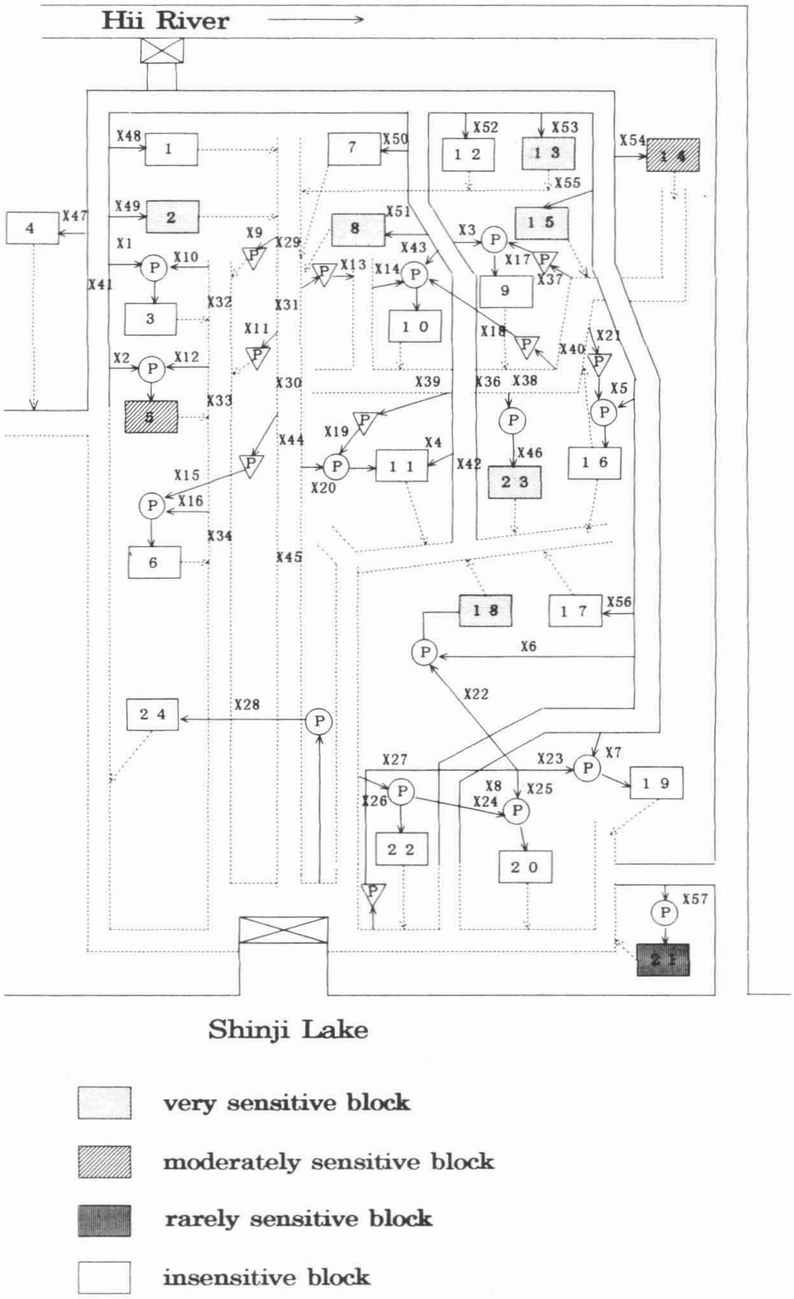

Fig. VII The classified area by the second model in case of 75%

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