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Allocation Strategy Analysis of Water Resources in South Taiwan

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Abstract. The integration of surface water and groundwater resources in south Taiwan was simulated based on the forecasted demand and water supply system in 2011. Three strategies allocating water resources, which are the priority of benefit of water usage, the priority of right of water usage and the priority of purpose of water usage, were tested under different hydrological conditions and constraints of groundwater abstraction. The results indicate that the key factor of water shortages in south Taiwan is the lack of storage infrastructures. Moreover, the irrigation water must be transferred to the industrial sectors for improving the overall benefits of water usage during a water shortage period. In order to meet the future water requirements in south Taiwan, the preferable resolution for government is to construct reservoirs and weirs, so that the strategic storing water can be utilized in wet season and support the shortage of the dry season. Furthermore, it is necessary to set a fair and reasonable compensation standard of water transfer in order to avoid the conflict between traders.

Key words: benefit of water usage, purpose of water usage, right of water usage, water shortage, water transfer

1. Introduction

The shortage of water supply could cause inconvenience in people's daily life and may also have serious impacts to the development of the economy as well as the social development. There are a lot of agricultural areas and industrial parks in south Taiwan. In recent years, municipal and industrial water demands have significantly increased due to the growing population, industry, and a general rise in living standards. Most of the available water resources are used in agriculture, which causes a problem of water supply for municipal and industrial use. The future development of water resources will be more difficult due to the limitations of hydrology, topography and geology. An efficient allocation strategy for water resources has become very important, which should be established, not only from the water usage right point of view, but also from the regional economic point of view for reducing the unfavorable impact of water deficits to the socioeconomic development in south Taiwan.

Recently, there has been a considerable concern regarding to the development and allocation of water resources in south Taiwan. The Republic of China Water Resources Bureau (WRB, 1997) analyzed water supplies and water demands, and proposed feasible development and allocation strategies for water resources according to the river basin characteristics, water supply system, land utilization and industrial development in south Taiwan. Chou (1995) developed a dynamic regional water resources optimal management model that used the network flow programming method (NFP), combining with the Out-of-Kilter algorithm. This model was applied to analyze the transbasin water transport between the Kaoping Chi and Tsengwen Chi river basins. The Water Resources Planning Commission (WRPC, 1992), which is the previous WRB, developed a simulation model of regional water resources for the Chia-nan and Kao-ping areas. This model was applied to analyze impacts on the water supply-demand balance and river water quality in two areas after new water resource projects were incorporated into the water supply system. However, the above research did not provide an in-depth analysis and comparison for different allocation strategies of water resource.

The main topic here is to establish an optimization linear programming model, in which the surface water and groundwater are integrated. Based on projected water demands and water supplies in 2011, three allocation strategies of water resources, which are the priority of benefit of water usage, the priority of right of water usage and the priority of purpose of water usage, are tested under different hydrological conditions and constraints of groundwater pumping. According to this simulation result, the differences in water distribution among the allocation strategies are deeply analyzed and compared. The main contribution of this study is simulations conducted on regional water resources allocation from the viewpoints of law, water usage right and water usage benefit. We believe that the results of this study will greatly help for the concerned authorities in planning the development and allocation strategies of water resources for south Taiwan.

2. Location and Water Resources System

The area of south Taiwan is from the south side of the Peikang Chi to the Linpein Chi, as shown in Figure 1. There are nine major rivers, the Potzu, Pachang, Chishui, Tsengwen, Yenshui, Erhjen, Kaoping, Tungkan, and Linpien in south Taiwan. Among these rivers, Tsengwen Chi and Kaoping Chi have plentiful water resources. Since the water available in these rivers has been used mostly for irrigation, other water demands must be met by the development of reservoirs or other regulating facilities. In this area, there are fifteen reservoirs, and six diversion weirs were studied. Some of these reservoirs, namely Jengyitian, Lan-tan, Tsengwen, Wushantou, Nan-hua, Cheng-Ching Lake and Fungshan are the major sources of public water supply, the others are used primarily for irrigation. Moreover, Tsengwen and Wushantou reservoirs also are the principal sources of irrigation water in Chiayi and Tainan. Among six diversion weirs, Tungkou, and Yuehmei

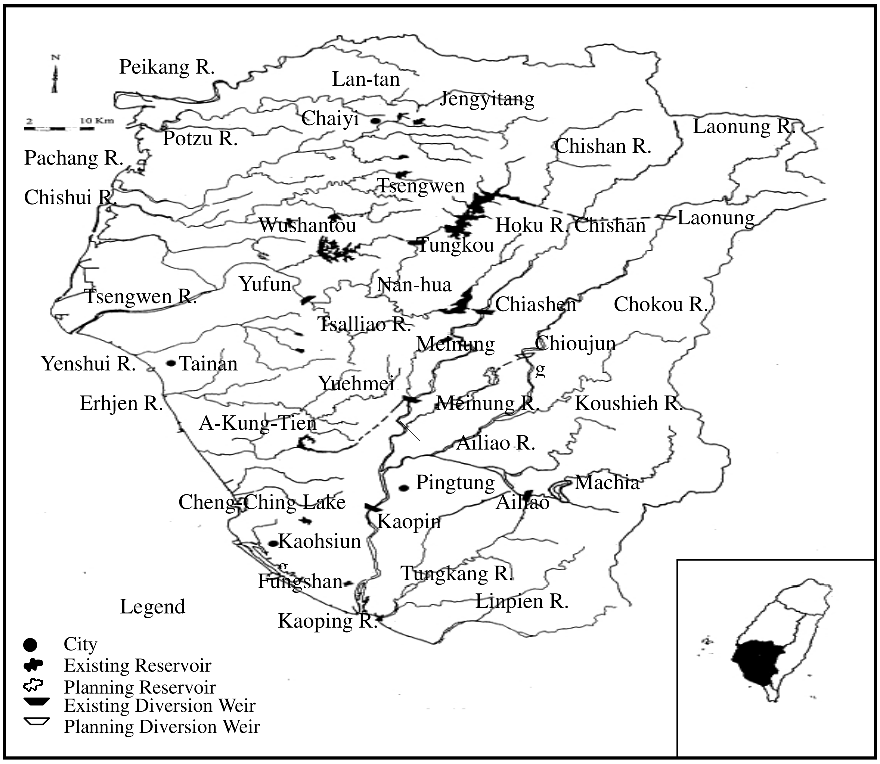

Figure 1. Location map of rivers, reservoirs and weirs in south Taiwan.

are already in operation while Yufung, Ailiao, Chiashen and Kaoping have been recently finished. According to the plan made by the former Taiwan Provincial Government Water Resources Department, Meinung reservoir, Chishan weir and Laonung weir will be constructed and supply water on year 2011. However, the Meinung reservoir project might be delayed due to the protest from local residents (they may need water, but they do not have a reservoir nearby their area for safety and the protection of ecology). Besides, Machia reservoir seems to be an additional supply source for south Taiwan after year 2011. Except surface water, groundwater is another source, used primarily for aquaculture, including fishes, shrimps, shellfishes and other aquatic animals using fresh water. Recently, land subsidence around the coastal areas in south Taiwan becomes very serious, due to the over-pumping groundwater for aquaculture.

The complicated water resource system of south Taiwan of 2011 is illustrated by a network chart (Figure 2). In this chart there are five categories of nodes, namely river inflow, reservoir (No. 1–6), transit (No. 7–38), demand (No. 39–63), and groundwater nodes (No. 64–67). These nodes are linked together with arrows. The arrows are divided into river inflow and general arrows (No. 1–108). A general arrow is used to represent a reach, canal, diversion tunnel or tube. The demand node

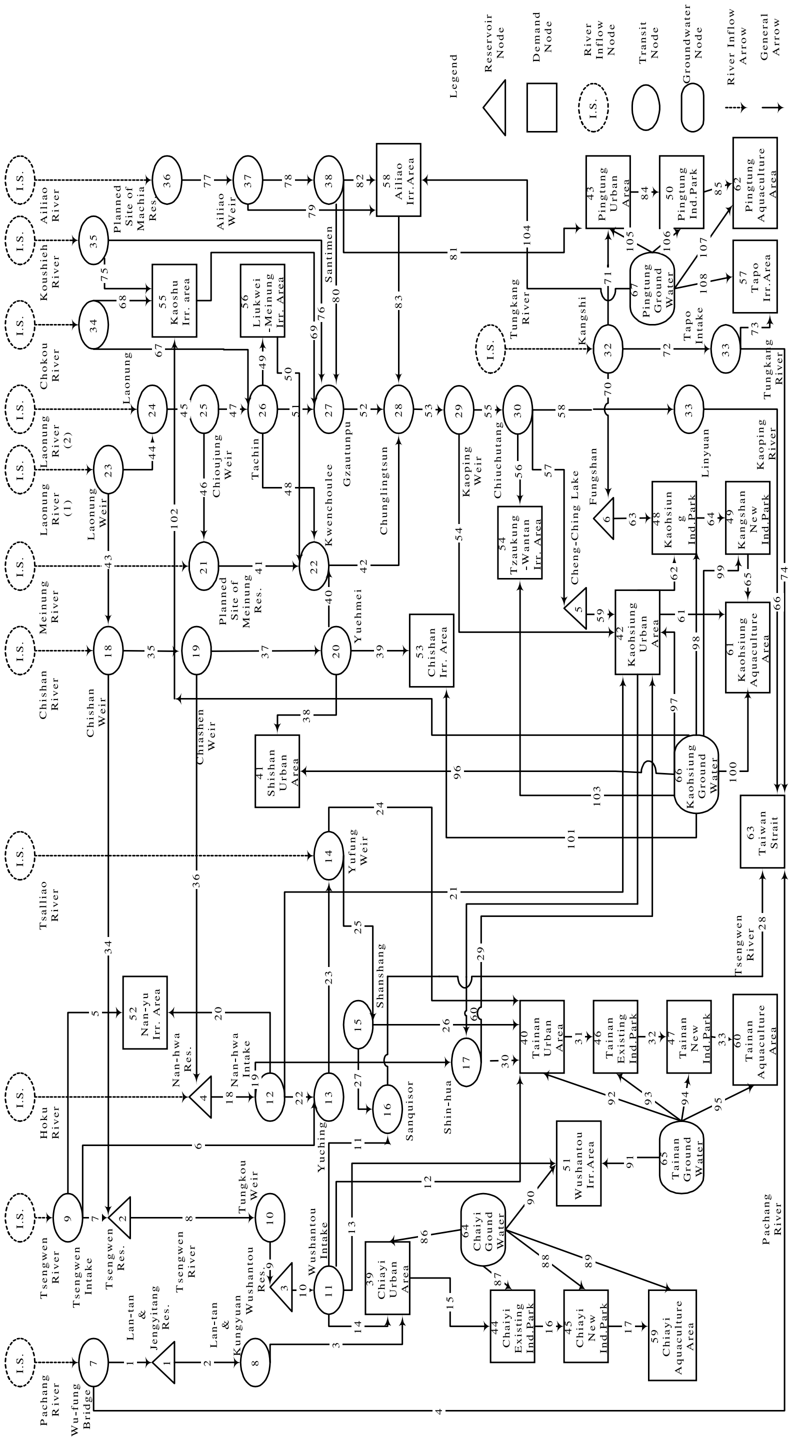

Figure 2. Network chart of water resources system in southern Taiwan.

marked No. 63 is fictitious and used to maintain the water balance in this system. The New Industrial Park in Tainan (node No. 47) includes Tainan Science-Based Ind. Park, Tainan Science and Technology Ind. Park, Bin-nan Ind. Park, Tainan Shin-chi Ind. Park and Ta Shin-ying Ind. Park.

3. Model Formulation

The optimization model of regional water resources allocation can be formulated mathematically by standard linear structure and network framework, as shown in Figure 2.

3.1. OBJECTIVE FUNCTION

In the optimization model, objective functions, associated with three allocation strategies of water resources, can be written as follows:

(1) For the Priority of Benefit of Water Usage

$$\text{Max} \sum_{T=1}^{12} \sum_{m=39}^{62} b_m \times R_{m,T} \tag{1}$$

(2) For the Priority of Right of Water Usage or Purpose of Water Usage

$$\text{Min} \sum_{T=1}^{12} \sum_{m=39}^{62} c_m \times R_{m,T} \tag{2}$$

where b_m = per unit benefit of water usage for demand node m (NT\$ per m^3); c_m = per unit cost of water usage for demand node m; and $R_{m,T}$ = distribution amounts of demand node m in Tth month of the water year. The water year used here, means the period from 1 June to 31 May of the following year. In this study, the simulation is set to be in a period of one month and starts from June. Furthermore, the water year used in this model includes three different periods: wet year (1975/06–1976/05), average year (1985/06–1986/05) and dry year (1984/06–1985/05). These periods were selected from the annual river discharge data of 1974 to 1993.

The per unit benefit of water usage in Equation (1) for industrial, aquaculture, municipal and irrigation use, which were abstracted from Hwang (1996), are NT\$18.2, \$14.5, \$9.0 and \$2.7 per m^3, respectively. The unit cost of water usage in Equation (2) is subjectively assigned by the governor based on the priority of right of water usage or purpose of water usage. As the priority of water usage is preferential, the unit cost is smaller. In this way, the allocation of water resources can be simulated by cost minimization.

The priority of purpose of water usage or right of water usage in this model was decided according to the regulations in the Water Conservancy Law of Taiwan.

It is mentioned in the Water Conservancy Law that the priority of water usage is domestic and public, agricultural, hydropower, industrial and then other use in turn. And when water shortage occurs, the priority to use water is determined by the water usage purpose, however it can also be determined by the sequence of the acquisition of water usage right if the water usage purposes are the same. Furthermore, the water for agriculture is used for irrigation, aquaculture and livestock. Since the sequence of the acquisition of water usage right for irrigation use is prior to aquaculture use. Therefore, the priority of water usage for the irrigation use is in preference to the aquaculture use. From the above descriptions, for the allocation strategy based on the priority of water usage purpose, the priority of water usage is municipal, irrigation, aquaculture and industrial use in turn. Nevertheless, according to the water usage regulation in Taiwan, the owner of water usage right must apply and register with the government for using surface water and groundwater. From the statistical data of water usage rights that already registered in Chia-nan and Kao-ping areas (WRB, 1997), there are large amounts of acquisitions for irrigation, municipal and industrial use instead of aquaculture use. The registered quantities of water usage are decreased from irrigation, municipal to industrial use. In order to respect the registered water usage, the distribution priority is therefore in the sequence of irrigation, municipal, industrial to aquaculture use for the allocation strategy based on the priority of water usage right.

3.2. CONSTRAINTS

The maximization or minimization is subject to minimum or maximum flows constraint in the channels and continuity at each nodes representing the facilities and junctions except for other constraints, such as reservoir storage capacity, groundwater abstraction, etc. These constraints can be described as follows:

(1) Constraints of Continuity at the Reservoir Nodes

$$S_{i,T+1} = S_{i,T} + \sum_y I_{y,i,T} - \sum_y O_{i,y,T} - E_{i,T} \qquad T = 1, \ldots, 12\,, \tag{3}$$

where $S_{i,T+1}$ and $S_{i,T}$ are storage amounts at the end and beginning of the Tth month for reservoir i; $I_{y,i,T}$ = inflow amounts from node y to reservoir i in Tth month; $O_{i,y,T}$ = release amounts from reservoir i to node y in Tth month; and $E_{i,T}$ = evaporation amounts of reservoir i in Tth month.

(2) Constraints of Continuity at the Transit Nodes

$$\sum_y I_{y,j,T} = \sum_y O_{j,y,T} \qquad T = 1, \ldots, 12\,, \tag{4}$$

where $I_{y,j,T}$ = inflow amounts from node y to transit node j in Tth month; and $O_{j,y,T}$ = outflow amounts from transit node j to node y in Tth month.

(3) Constraints of Continuity at the Demand Nodes

$$\sum_{y} I_{y,m,T} + G_{m,T} - \sum_{y} O_{m,y,T} = R_{m,T} \qquad T = 1, \ldots, 12 , \tag{5}$$

where $I_{y,m,T}$ = inflow amounts from node y to demand node m in Tth month; $O_{m,y,T}$ = outflow amounts from demand node m to node y in Tth month; $G_{m,T}$ = groundwater extraction amounts of demand node m in Tth month; and $R_{m,T}$ has been defined earlier.

(4) Constraints of Maximum Flows in the Channels

$$X_{p,q,T} \leq X^{u}_{p,q,T} \qquad T = 1, \ldots, 12 , \tag{6}$$

where $X_{p,q,T}$ = flows in the channel (or reach, canal) between node p and node q in Tth month; and $X^{u}_{p,q,T}$ is the upper limit of $X_{p,q,T}$.

(5) Constraints of Minimum Basic Flows in the River

$$X_{p,q,T} \geq X^{l}_{p,q,T} \qquad T = 1, \ldots, 12 , \tag{7}$$

where $X_{p,q,T}$ has been defined earlier; and $X^{l}_{p,q,T}$ is the lower limit of $X_{p,q,T}$. Equation (7) represents that some reaches of the river must preserve basic flows for the protection of the ecology and environment.

(6) Constraints of Capacity for Reservoirs

$$S_{i,T+1} \leq S^{*}_{i} \qquad T = 1, \ldots, 12 , \tag{8}$$

$$S_{i,1} = k_1 \times S^{*}_{i} , \tag{9}$$

$$S_{i,13} \geq S_{i,1} , \tag{10}$$

where S^{*}_{i} = effective capacity of reservoir i; $S_{i,1}$ = starting capacity on the first month of the water year of reservoir i; $S_{i,13}$ = end capacity on the twelfth (or last) month of the water year of reservoir i; and k_1 = ratio of starting capacity on the first month of the water year to the effective capacity of reservoir i. From Equation (8), it implies that the end capacity cannot exceed its effective capacity of reservoir i in any month. Equation (9) represents that the starting capacity of the first month is in proportion to its effective capacity of reservoir i. According to the monthly report for the operation of Tsengwen reservoir from 1975 to 1996 (Tsengwen Reservoir Management Bureau, 1975–1996), the average end capacity in May was about 20% of its effective capacity. Therefore, we assumed k_1 is equal to 20% in Equation (9). Finally, it was emphasized in Equation (10) that the end capacity at the last month cannot be smaller than the start capacity in the first month of reservoir i.

(7) Constraints of Demand Quantity for Demand Nodes

$$R_{m,T} \le D_{m,T} \qquad T = 1, \ldots, 12\,, \tag{11}$$

$$R_{m,T} \ge k_2 \times D_{m,T} \qquad T = 1, \ldots, 12\,, \tag{12}$$

where $D_{m,T}$ = demand amounts of demand node m in Tth month; $R_{m,T}$ and has been defined earlier. It was implied in Equation (11) that the distribution quantities cannot exceed the demand quantities in Tth month at any demand node m. Equation (12) represents that the distribution quantities of demand node m has to meet a basic amount. Based on the operation rules of Tsengwen reservoir (Tsengwen Reservoir Management Bureau, 1996), we suggested that the value of k_2 for municipal use is 70% and 50% for industrial, aquacultural and irrigation use, respectively.

(8) Constraints of Groundwater Abstraction

$$\sum_{m} \sum_{T=1}^{12} G_{r,m,T} \le G_r^u \qquad r = 1, 2, 3, 4\,, \tag{13}$$

where $G_{r,m,T}$ = groundwater abstraction amounts of demand node m in Tth month in r area; and G_r^u = upper limit of annual groundwater abstraction quantities in r area, r = 1, 2, 3, and 4 represent the area of Chiayi, Tainan, Kaohsiung, and Pingtung, respectively. The maximum groundwater abstraction amounts (G_r^u) are restricted based on the following scenarios: (1) G_r^u = actual abstraction quantities in 1995, (2) G_r^u = annual natural recharge quantities. The first one represents that the groundwater is over-pumping, however, the last one represents just the opposite. The actual abstraction quantities in 1995 for the above areas are 369, 720, 445 and 870 million m^3, respectively (WRB, 1997). The annual natural recharge quantities for the above areas are 246, 120, 187 and 800 million m^3, respectively (WRPC, 1995).

(9) Other Constraints

Using the same method in previous research (WRPC, 1992), the local inflows downstream in Kaoping Chi were estimated by 30, 30, and 100% of the return flows in the irrigation areas of Liukwei-Meinung, Kaoshu, and Ailiao, respectively. The return flows from the above irrigation areas, inflow into the Kaoping Chi, were assumed at the site of Kwenchoulee (node No. 22), Gzautunpu (node No. 27), and Chunglingtsun (node No. 28), respectively. The leakage of stream flows was also considered in this study. The leakage of stream flows is around 4% of the total stream flows between the planned site in Machia reservoir (node No. 36) and Sandiman (node No. 38), and 14.4% between Sandiman and Gzautunpu (WRPC, 1982).

4. Scenario Simulation and Analysis of Results

According to the forecasted demand and the requirement of water resource supply system in 2011, three allocation strategies were tested under different hydrological conditions and the constraint of groundwater. The simulated results were used for the following analysis.

4.1. OVERALL DISTRIBUTION AMOUNTS AND BENEFITS OF WATER USAGE

The results, shown in Table I, indicate that south Taiwan will face a water shortage crisis in 2011. Comparing the water distribution between scenario 1 (the groundwater is over-pumping) and scenario 2 (the groundwater is not over-pumping), the shortage rate for scenario 2 is over 17.9%, with respect to scenario 1. Apparently, if the governor wants to prevent land subsidence by controlling the groundwater abstraction for aquaculture, the shortage rate of water in south Taiwan will become more serious if no new sources of surface water are available. For a wet and average year, the river inflows are larger than the distribution amounts. It shows that the water shortage in south Taiwan during a wet and average year, will be primarily resulted from the lack of storage infrastructures in the Kaoping river basin. The development of Meinung and Machia reservoirs thus become urgent in order to improve the utilization of water resources and meet the future demands in south Taiwan.

For the overall benefits of water usage, strategy E and strategy R are superior to strategy P under scenario 1 but strategy E and strategy P are superior to strategy R under scenario 2. Comparing the difference of water usage benefits between strategy E and strategy P or R. Under scenario 1, it is NT$2016 or $1537 million (wet year), NT$2363 or $1802 million (average year) and NT$6255 or $4772 million (dry year), respectively. Under scenario 2, it is NT$2644 or $3223 million (wet year), NT$2628 or $3215 million (average year) and NT$2867 or $3761 million (dry year), respectively.

4.2. SHORTAGE RATE FOR WATER USAGE PURPOSE

According to Table II, as the groundwater is over-pumping, for allocation strategy E, the shortage rate for irrigation use is 5.6% (wet year), 6.6% (average year) and 17.3% (dry year), respectively. For allocation strategy P, the shortage rate for industrial use is 13.9% (wet year), 16.3% (average year) and 43.1% (dry year), respectively. For allocation strategy R, the shortage rate for aquaculture use is 9.8% (wet year), 11.5% (average year) and 30.4% (dry year), respectively. While the groundwater is not over-pumping, considering the above three strategies to allocate water resources, the demands of all water usage purposes will be deficient. For allocation strategy E, the shortage rate for irrigation use is separately 9% (wet year), 9.9% (average year) and 20.4% (dry year) but the shortage rate for municipal, industrial and aquaculture use is 22.5–23.3%, 24.6–24.8% and 35.6%, respectively.

Table I. Overall distribution amounts and benefits of water usage for different strategies

Maximum groundwater pumping (G_r^u)	Actual abstraction quantities in 1995 (Scenario 1)								
Hydrologic condition	Wet year			Average year			Dry year		
Allocation strategy	E	P	R	E	P	R	E	P	R
Total distribution amounts (MCM)		5352			5329			5080	
Total shortage rate (%)		2.4			2.8			7.4	
Total water usage benefits (million NT$)	50254	48238	48717	50192	47829	48390	49519	43264	44747

Maximum groundwater pumping (G_r^u)	Annual natural recharge quantities (Scenario 2)								
Hydrologic condition	Wet year			Average year			Dry year		
Allocation strategy	E	P	R	E	P	R	E	P	R
Total distribution amounts (MCM)		4369			4347			4095	
Total shortage rate (%)		20.3			20.7			25.3	
Total water usage benefits (million NT$)	37185	34541	33962	37095	34467	33880	36371	33504	32610

1. E: The priority of benefit of water usage. P: The priority of purpose of water usage. R: The priority of right of water usage.
2. Total demand amounts are 5483 million m^3 for south Taiwan in 2011.
3. Total river inflows are 10 996, 8268 and 5252 million m^3 in wet, average and dry year, respectively.
4. NT$: New Taiwan dollars.

Table II. Shortage rate for water usage purpose and demand region in 2011

Maximum groundwater pumping (G_r^u)			Actual abstraction quantities in 1995 (Scenario 1)									Annual natural recharge quantities (Scenario 2)								
Allocation strategy			E			P			R			E			P			R		
Hydrological condition			W	A	D	W	A	D	W	A	D	W	A	D	W	A	D	W	A	D
Demand region	Node No.	Demand amounts (MCM)	Shortage rate (%)									Shortage rate (%)								
Chiayi	39	89.25	–	–	–	–	–	–	–	–	–	30.0	30.0	30.0	–	–	–	21.3	21.1	30.0
Tainan	40	274.05	–	–	–	–	–	–	–	–	–	30.0	30.0	30.0	7.8	7.9	10.7	20.5	20.5	28.2
Shishan	41	160.52	–	–	–	–	–	–	–	–	–	30.0	30.0	30.0	20.3	17.7	17.7	30.0	30.0	30.0
Kaohsiung	42	280.04	–	–	–	–	–	–	–	–	–	14.5	14.5	17.1	0.2	2.5	–	13.1	14.5	17.1
Pingtung	43	76.32	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Municipal use subtotal		890.18	–	–	–	–	–	–	–	–	–	22.5	22.5	23.3	6.2	6.5	6.5	18.2	18.6	22.7
Existing Ind. park in Chiayi	44	70.33	–	–	–	32.6	10.0	49.8	–	–	–	–	–	–	50.0	50.0	50.0	50.0	50.0	50.0
New Ind. Park in Chiayi	45	12.94	–	–	–	8.3	12.4	45.9	–	–	–	–	–	–	50.0	50.0	50.0	50.0	50.0	50.0
Existing Ind. Park in Tainan	46	210.35	–	–	–	13.5	21.3	46.4	–	–	–	20.1	22.5	31.0	50.0	50.0	50.0	46.4	47.8	50.0
New Ind. Park in Tainan	47	205.71	–	–	–	15.4	15.9	50.0	–	–	–	21.5	25.7	17.0	50.0	50.0	50.0	43.0	41.5	50.0
Existing Ind. Park in Kaohsiung	48	348.16	–	–	–	13.4	18.9	46.0	–	–	–	40.7	37.6	37.4	50.0	50.0	50.0	47.7	47.6	48.0
New Ind. Park in Kaohsiung	49	6.60	–	–	–	–	8.6	29.2	–	–	–	24.8	21.1	8.6	50.0	50.0	50.0	33.8	37.4	37.9
Existing Ind. Park in Pingtung	50	81.99	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

W: Wet year, A: Average year, D: Dry year.

Table II. (continued)

Maximum groundwater pumping (G_r^u)			Actual abstraction quantities in 1995 (Scenario 1)									Annual natural recharge quantities (Scenario 2)								
Allocation strategy			E			P			R			E			P			R		
Hydrological condition			W	A	D	W	A	D	W	A	D	W	A	D	W	A	D	W	A	D
Demand region	Node No.	Demand amounts (MCM)	Shortage rate (%)									Shortage rate (%)								
Industrial use subtotal		936.08	–	–	–	13.9	16.3	43.1	–	–	–	24.6	24.8	24.8	45.6	45.6	45.6	42.3	42.3	44.8
Wushantou	51	999.66	8.4	8.8	32.8	–	–	–	–	–	–	14.3	14.3	37.7	4.4	4.4	26.1	–	–	17.8
Nan-yu	52	0.98	–	–	–	–	–	–	–	–	–	–	–	31.6	–	–	9.2	–	–	–
Chishan-Erhjen	53	205.93	20.6	19.6	24.6	–	–	–	–	–	–	29.2	30.2	35.1	29.2	30.2	35.1	3.0	11.4	14.7
Tzaukung-Wantan	54	315.99	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Kaoshu	55	81.68	5.0	30.2	31.2	–	–	–	–	–	–	8.6	30.2	31.2	8.6	30.2	31.2	–	1.5	8.9
Liukwei-Meinung	56	137.82	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tapo	57	309.37	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ailiao	58	275.62	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Irrigation use subtotal		2327.05	5.6	6.6	17.3	–	–	–	–	–	–	9.0	9.9	20.4	4.8	5.6	15.4	0.3	1.1	9.3
Chiayi	59	322.88	–	–	–	–	–	–	25.2	16.9	33.6	28.4	28.4	28.4	50.0	50.0	50.0	50.0	50.0	50.0
Tainan	60	612.54	–	–	–	–	–	–	0.4	4.4	36.8	49.0	49.0	49.0	46.4	46.4	50.0	50.0	50.0	50.0
Kaohsiung	61	161.75	–	–	–	–	–	–	28.8	44.2	43.2	50.0	50.0	50.0	44.5	44.3	50.0	50.0	50.0	50.0
Pingtung	62	232.14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aquaculture use subtotal		1329.31	–	–	–	–	–	–	9.8	11.5	30.4	35.6	35.6	35.6	38.9	38.9	40.7	41.3	41.3	41.3

W: Wet year, A: Average year, D: Dry year.

For allocation strategy P, the shortage rate for irrigation use is separately 4.8% (wet year), 5.6% (average year) and 15.4% (dry year) but the shortage rate for municipal, industrial and aquaculture use is 6.2–6.5%, 45.6% and 38.9–40.7%, respectively. For allocation strategy R, the shortage rate for irrigation use is separately 0.3% (wet year), 1.1% (average year) and 9.3% (dry year) but the shortage rate for municipal, industrial and aquaculture use is 18.2–22.7%, 42.3–44.8% and 41.3%, respectively.

The governor can replace strategy P (or strategy R) with strategy E in order to improve the overall benefits of water usage. Under scenario 1, the shortage rate for irrigation use will increase but contrarily, it will decrease for industrial (or aquaculture) use. For example, during the dry year period, the total shortage rate for irrigation use will increase by 17.3%, but it will decrease by 43.1% (or 30.4%) for industrial (or aquaculture) use. Under scenario 2, the shortage rate for irrigation and municipal use will increase but contrarily, it will decrease for industrial and aquaculture use. For instance, during the dry year period, the total shortage rate for irrigation and municipal use will increase by 5 and 16.8% (or 11.1 and 0.6%), but it will decrease by 20.8 and 5.1% (or 20 and 5.7%) for industrial and aquaculture use.

4.3. SHORTAGE RATE FOR DEMAND REGION

According to Table II, except for Pingtung municipal, industrial, aquaculture regions of water usage and Tapo, Ailiao, Liukwei-Meinung, Tzaukung-Wantan irrigation areas, other demand regions may face a water shortage in 2011

For allocation strategy E, the water demands for Wushantou, Chishan-Erhjen and Kaoshu irrigation areas will be deficient. Under scenario 1 in dry year, the shortage rate for the above areas is 32.8, 24.6 and 31.2%, respectively. Under scenario 2 in dry year, it is 37.7, 35.1 and 31.2%, respectively. For allocation strategy P, the water demands of industrial parks in Chiayi, Tainan and Kaohsiung will also not be sufficient. Under scenario 1, in a dry year, the shortage rates for the above areas are between 46 and 50%. But they are all 50% under scenario 2 in a dry year. For allocation strategy R, the water supplies of aquaculture regions in Chiayi, Tainan and Kaohsiung cannot meet the requirement as well. The shortage rate for the above areas is 33.6, 36.8 and 43.2%, respectively, under scenario 1 and 50% under scenario 2 in a dry year. Furthermore, other municipal regions of water usage will be short of water for allocation strategy E in a dry year under scenario 2 except for Pingtung area (node No. 43). For Chiayi, Tainan and Chishan and Kaohsiung areas, the shortage rate will be 30, 30, 30 and 17.1%, respectively.

This shows that the predicted water shortages in south Taiwan in 2011 will be mainly due to the lack of storage infrastructures. In order to meet the future water demands in south Taiwan, the preferable resolution is to build reservoirs and weirs, which can store water in wet season and supply water in dry season. Addition to the traditional water resources, the construction of seawater desalination plants on the coast of Tainan could provide additional water source to the nearby areas, such as Tainan Science and Technology and Bin-nan industrial Parks. In order to improve the utilization of water resources, the government could have an integrated use between reservoirs and diversion weirs or between the surface water and groundwater. For diversion weir and reservoir, diversion weir is conceived as the major water source, and reservoir as a supplemental source for storing water to be used in the dry season. For surface water and groundwater, surface water is the major water source and groundwater is a supplemental source to store water by using artificial recharge in wet season and support the deficit of the dry season. Nevertheless, under the policy to prevent land subsidence, the government should enhance management and guidance to the aquaculture in order to reduce the impact of restricting groundwater abstraction to the water supply in south Taiwan. The potential alternatives are to develop the marine culture, brackish water pond, and encourage the recycling and reuse of aquaculture water. On the other hand, the irrigation water will be transferred to the industrial sectors in order to improve the overall benefits of water usage during water shortage period. Based on the system of water supply in Figure 2, the irrigation water from the Wushantou reservoir can be transferred to the industrial parks in Chiayi and Tainan areas. The irrigation water in the areas of Chishan-Erhjen, Tzaukung-Wantan and Tapo can be transferred to the industrial parks in Kaohsiung area. However, the beneficial side must pay for all damages caused by the water transfer. In Taiwan, the compensation of water transfer is presently decided by private negotiation between the purchaser and the seller. Since no standard of compensation can be referred, conflicts often occur. In order to reduce the cost and avoid conflict, it is necessary to set a fair and reasonable compensation standard for water transfer.

5. Conclusions

In this article, a regional water-resource optimization model was established using linear programming. The simulated results show that south Taiwan will face a water shortage crisis in 2011 due to the lack of storage infrastructures. The analytical results also indicate that the irrigation water must be transferred to the industrial sectors in order to improve the overall benefits of water usage during water shortage period. Therefore, the preferable resolution for the government is to develop Meinung and Machia reservoirs and set a fair and reasonable compensation standard for water transfer. Furthermore, the government should be well evaluated and planned for the other problems arising due to water transfer, such as the impact on environment, ecology and third party, and the design of transfer and storage infrastructures.

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