MULTICRITERIA DECISION MAKING FOR MULTIRESERVOIR WATER ALLOCATION DURING SHORTAGE : A CASE STUDY OF UPPER MUN BASIN

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ABSTRACT

The objective of this study was to develop the methodology for water allocation during shortage in multipurpose-multireservoir system. The water shortages of the multireservoir system were first identified. The water allocation alternatives taking into account the profitability, equity and reliability of multireservoir system and allowing the stakeholders in diagnosis and making decision for the water allocation were developed. The Upper Mun basin was selected as a case study. HEC-3 was used as a tool to simulate the multireservoir system using 25 years of inflow data and using the selected dry, normal and wet years data for study of the water shortage. The simulated annual water shortage over the whole basin using 25 years of data and in the driest year were 17.79% and 40.03%, occurring in Jul. – Sept. and in Dec – May respectively. The ϵ – constraint linear programming was used to generate 16 optimum alternatives. The alternatives were ranked by the Analytical Hierarchy Process(AHP) based on the three criteria; profitability, equity and reliability. The analysis with AHP found that the priority of water allocation criteria were ranked as profitability(41%) over reliability(32.3%) and equity(26.7%). The highest ranked alternative of 29.38% was the alternative which did not allowed water shortage to the municipal and industrial sector, the downstream requirements for ecology system would lack of water by 55.43 million cubic meters and allows the yield for agriculture reducing to 56% of the maximum yield. Thus, the water allocation methodology developed in this study can help establish the priority in water allocation and define the most preferable alternative for the stakeholders.
KEYWORDS: Multicriteria, Water Allocation, Shortage, Upper Mun Basin

INTRODUCTION

Water is the important natural resources for all lives directly and indirectly. Because of unsure properties of the water that changes all the time and can't predict in each period correctly. Sometimes it can't respond at the right amount and the right time to the demand causing an important flooding and water shortage.

Keller et al. (1996) presented the Integrated Water Resources Management(IWRM) that considered the whole river basin area in order to use water more effective and efficient. This approach is corresponding to the common water management practices in Thailand at the present time. Since most of the large scale water resources systems are the multipurpose type, it needs to study the behavior of the system from the management and operation point of view such as product potential water uses (Molden, 1997) and the effect of water uses on various purposes (Kite and Droogers, 1999) in order to develop the alternatives for the decision makers. Analytical Hierarchy Process(AHP) is one of the methodology for analysis and solving the water problems (Flug et al., 2000; Schwartz, 2000).

Kongjun and Vudhivanich (2001) studied the status of water shortage in the Upper Mun river basin in order to develop the water allocation criteria. The purpose of this research is to analyse the alternatives for water allocation during shortage for the Upper Mun basin such that the maximum benefit, equity and reliability are obtained.

MATERIALS AND METHODS

1. Collect the monthly rainfall and monthly reservoir inflow data for 25 years, from 1975 to 1999, the water demand for agriculture, municipal and industrial water supply, downstream water requirements to preserve the equilibrium of the ecology system of the river downstream of the reservoir and the water requirements at the river basin outlet. Identify the probability distribution function of the annual inflow in order to determine the dry, normal and wet year.
2. Simulate the multireservoir system by using 25 years of inflow data and by using the selected dry, normal and wet year data with HEC – 3 (Hydrologic Engineering Center, 1981) to study the shortage of water in the whole river basin (**Fig. 1**).
3. Generate the alternatives for water allocation among water use sectors in dry year using ε-constraint technique (Goicoechea, 1982)
4. Analyse and select the alternative by the multicriteria decision making with AHP (Sahoo, 1998).

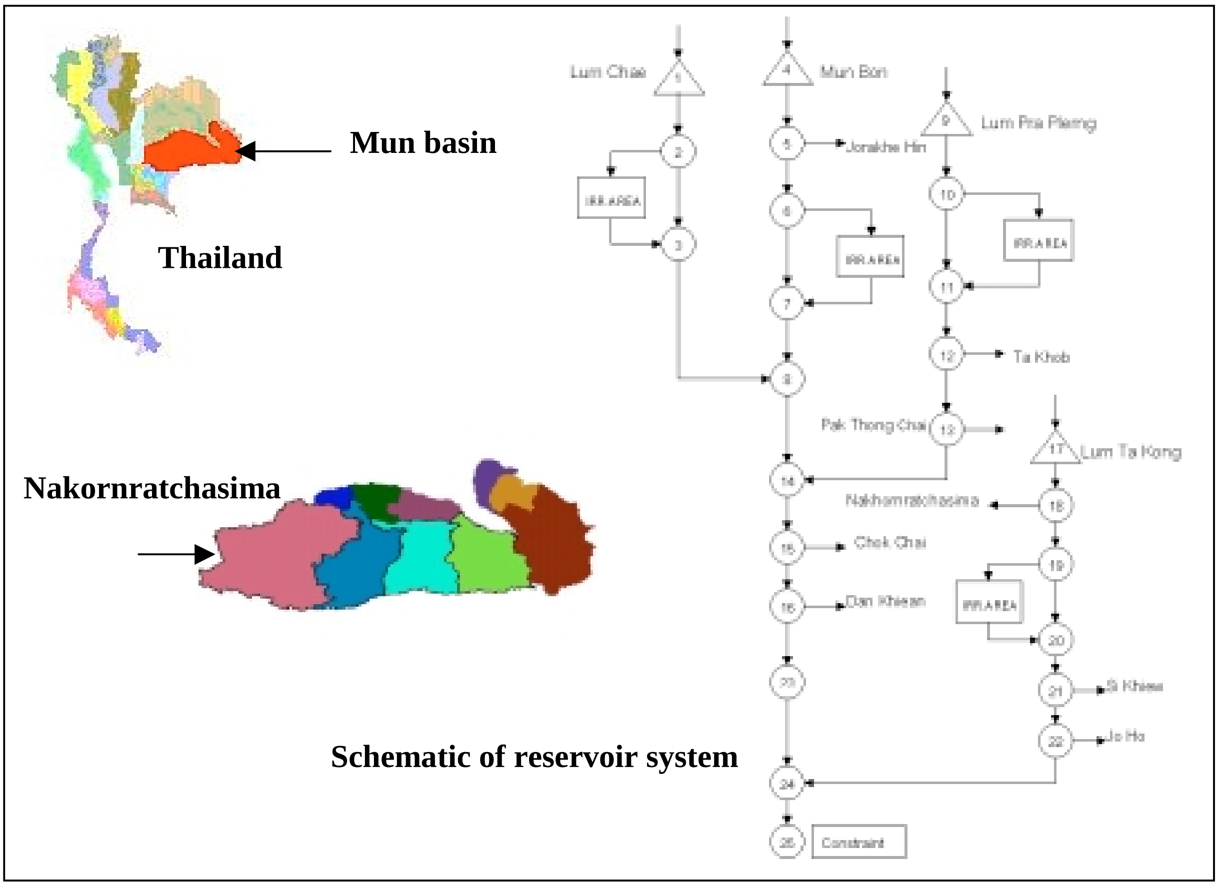

Fig.1 Location of research site and the entire basin map of Mun.

RESULTS AND DISCUSSION

Identification of dry, normal and wet year using probability distribution

The 25 years (1975-1999) annual inflow of Lam Chae , Mun Bon, Lam Phra Pleong and Lam Takong reservoirs were used for probability distribution analysis. The goodness of fit test by Smirnov-Kolmogorov at the significant level 5% showed that both Gumbel and Log Normal 2 parameters were fitted . Gumbel indicated a higher R^2 , except Mun Bon reservoir as **Fig. 2.** Therefore, Gumbel distribution function was used for further analysis. If a probability of inflow is less than or equals 20% or $P(x \leq 0.20)$, it will be defined as dry year. If $P(x \geq 0.80)$, it will be as wet year. If the probability is 20% – 80% or $P(0.20 < x < 0.80)$, it will be a normal year. By this definition each reservoir has 6, 14 and 5 years of dry, normal and wet years. The occurrences of dry, normal and wet year of the 4 reservoirs are not different.

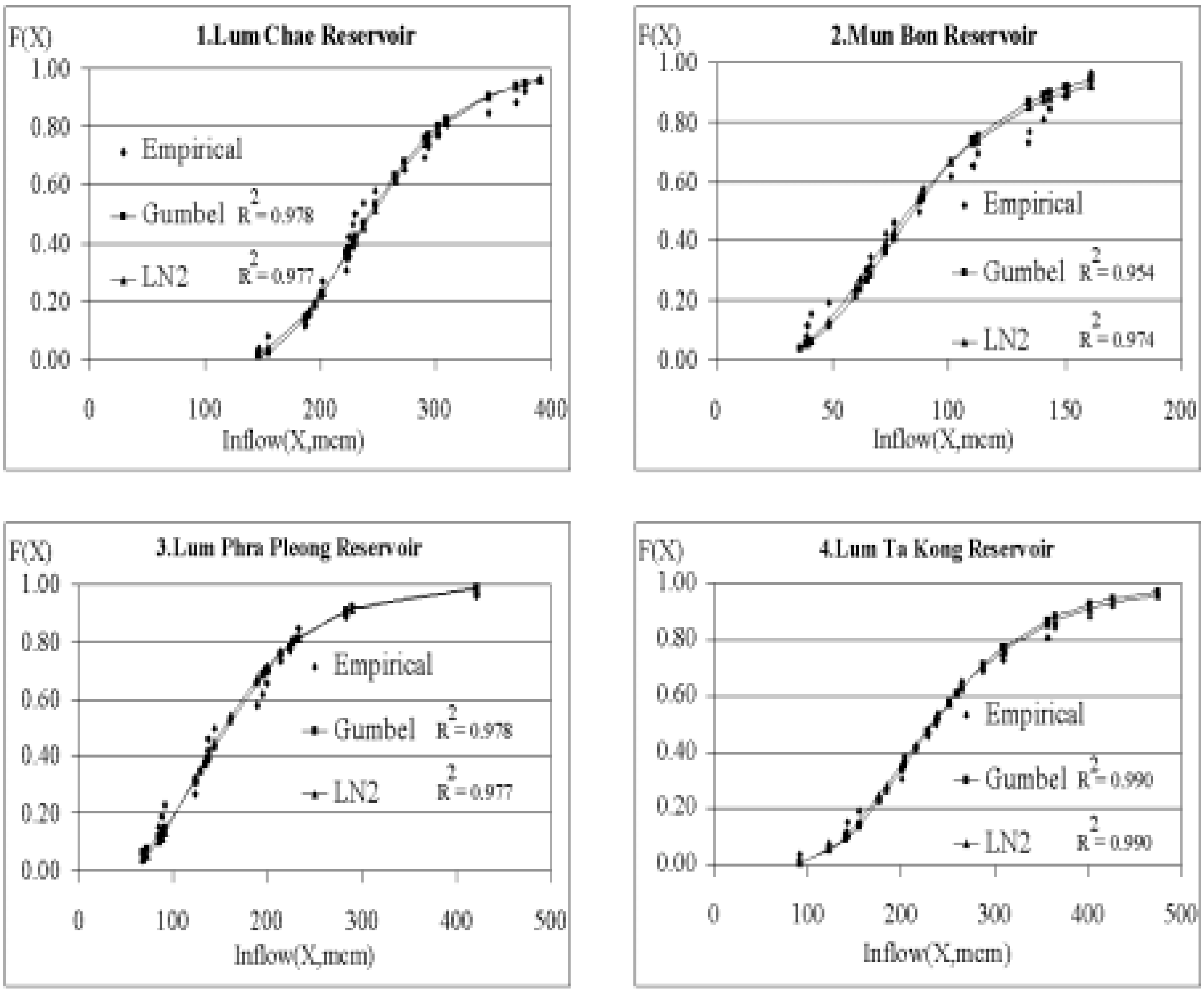

Fig.2 Probability distribution function of the annual reservoir inflow.

Simulated 25 years average water shortage

By simulating the reservoir systems in Upper Mun basin using 25 years of data and HEC-3 the shortage characteristics of the Upper Mun basin was identified as follow.

(1) In case of requirements at the river basin outlet was not considered, the simulated average annual water shortage over the whole basin was 14.88 %, occurred during the dry spell in rainy season (Jul.- Sept.) and in the dry season (Dec.-May). The average annual water discharge volume at the river basin outlet was 151.37 million cubic meter.

(2) In case of water requirements at the river basin outlet equals to the average minimum monthly flowing from the historical data(6.1 mcm), the average annual water shortage over the whole basin was 17.79% and occurred at the same time of the first case. The average annual water discharge volume at the river basin outlet was 252.94 million cubic meter . (**Table 1**)

According to the simulation result, when the water requirements at the river basin outlet was not considered, the discharge volume was lower than the lowest of the record (218.85 million cubic meter). This might have effect to water users on the lower part of river basin. To avoid this problem, the second case was selected. However the water shortage in the Upper Mun basin increased about 2.91% per year. In the simulation, the boundary of a case study was in multireservoir system irrigable area particularly might cause the little amount of side flow. So that to added side flow to return flow estimation. The model was calibrated by comparison with observed gauging discharge at the outlet but not shown in paper.

Table1 The average annual water shortage of the Upper Mun basin simulated by HEC-3 using 25 years of data.

Water Users Group	Avg. Water Requirement (mcm)	Case 1				Case 2			
		Shortage		Duration		Shortage		Duration	
		Volume (mcm)	%	Initiate	Termimate	Volume (mcm)	%	Initiate	Terminate
1.Agriculture	754.81	129.30	17.13	Jul. Jan.	Sept. Apr.	160.83	21.31	Jul. Jan.	Sept. Apr.
2.Municipal-Industrial	35.55	1.04	2.93	Dec.	Apr.	1.04	2.93	Dec.	Apr.
3.Ecology	126.00	6.06	4.81	Dec.	May	7.88	6.26	Dec.	May
4.Outlet	73.20	-	-	-	-	6.31	8.62	Apr.	May
Total	989.56	136.40	14.88	Jul. Dec.	Sept. May	176.06	17.79	Jul. Dec.	Sept. May

Simulated water shortage in dry, normal and wet year.

Based on the selected dry, normal and wet years using the nonexceedence probability of 20% and 80% as mentioned in the previous section and assuming the required minimum flow at the basin outlet of 73.2 mcm per year(or 6.1 mcm per month), the simulation results indicated that the water shortage occurred in dry and normal year . In the dry year, it was divided to extremely dry(Dry1), dry(Dry2) and slightly dry(Dry3) according to the magnitude of water shortage of 40.03%, 24.56% and 28.61% respectively as shown in **Table 2.** In the normal year, it was divided to slightly normal(Normal1), normal(Normal2) and slightly wet (Normal3) corresponding 22.35%, 9.56% and 0.35% of water shortage as shown in **Table 3.** Especially, the agriculture sector had the most serious water shortage of 47.19 %, municipal and industrial sector of 17.74% occuring in Nakorn Ratchasima municipality. Downstream requirements will have the water shortage of 15.64% .

According to the simulation result, the water shortage took place only in the dry and normal years. The dry year showed more serious shortage than the normal year. There were 2 periods of water shortage which was the same as the 25 years data simulation. However the run length was depending on the water year.

Table 2 The annual water shortage of the Upper Mun basin in dry year.

Water Users Group	Water Requirement (mcm)			Inflow Year					
				Dry 1		Dry 2		Dry 3	
	Dry 1	Dry 2	Dry 3	Volume (mcm)	(%)	Volume (mcm)	(%)	Volume (mcm)	(%)
1.Agriculture	761.76	708.8	807.06	359.51	47.19	211.29	29.81	264.90	32.82
2.Municipal-Industrial	35.55	35.55	35.55	0.79	2.22	3.15	8.87	6.31	17.74
3.Ecology	126.00	126.00	126.00	19.71	15.64	7.88	6.26	11.04	8.76
4.Outlet	73.20	73.20	73.20	18.92	25.85	9.46	12.93	15.77	21.54
Total	996.51	943.55	1,041.81	398.93	40.03	231.78	24.56	298.02	28.61

Table 3 The annual water shortage of the Upper Mun basin in normal year.

Water Users Group	Water Requirement (mcm.)			Inflow Year					
				Normal 1		Normal 2		Normal 3	
	Normal 1	Normal 2	Normal 3	Volume (mcm.)	(%)	Volume (mcm.)	(%)	Volume (mcm.)	(%)
1.Agriculture	787.00	754.81	679.14	223.91	28.45	88.30	11.70	0	0
2.Municipal-Industrial	35.55	35.55	35.55	0	0	3.15	8.87	0	0
3.Ecology	126.00	126.00	126.00	4.48	3.55	3.15	2.50	3.15	2.50
4.Outlet	73.20	73.20	73.20	0	0	0	0	0	0
Total	1,021.75	989.56	913.89	228.39	22.35	94.60	9.56	3.15	0.35

Generation of water allocation alternatives

The water shortage was occurred in the dry and normal years for all water use sectors, but there were different in the magnitude of water shortage. In fact, the effect of the water shortage to each water use sector was different even the magnitude of water shortage was the same. Therefore the water allocation alternatives to various water use sectors needed to be developed using the multiobjective optimization. The case of extremely dry year(Dry 1) was used in the analysis. The objective function of agricultural sector was to maximize the yield as follow.

$$\text{Max } Z_1(x) = \sum_{i=1}^{m}\sum_{j=1}^{n} Y_{ij} \qquad (1)$$

where $Z_1(x)$ = agricultural objective ; $Y_{ij} = Y_m[1-K_y(1-ET_a/ET_m)]$; Y_{ij} = the actual yield; Y_m= the maximum yield; ET_a = actual evapotranspiration; ET_m= maximum evapotranspiration; K_y= the yield response factor; i = the number of reservoir; and j = the number of month. The municipal and industrial sector and the downstream requirements for ecology balance would have the minimum shortage by using ε-constraint technique.

$$\text{Max } Z_2(x) = -\sum_{i=1}^{m}\sum_{j=1}^{n} (DM_{ij} - SM_{ij}) \qquad (2)$$

where $Z_2(x)$ = municipal and industrial objective; DM= municipal and industrial demand; and SM = municipal and industrial supply

$$\text{Max } Z_3(x) = -\sum_{i=1}^{m}\sum_{j=1}^{n} (DD_{ij} - SD_{ij}) \qquad (3)$$

where $Z_3(x)$ = downstream requirement objective; DD= downstream requirement demand; and SD = downstream requirement supply

There were 16 examples alternatives. (**Fig. 3** and **Table 4**)

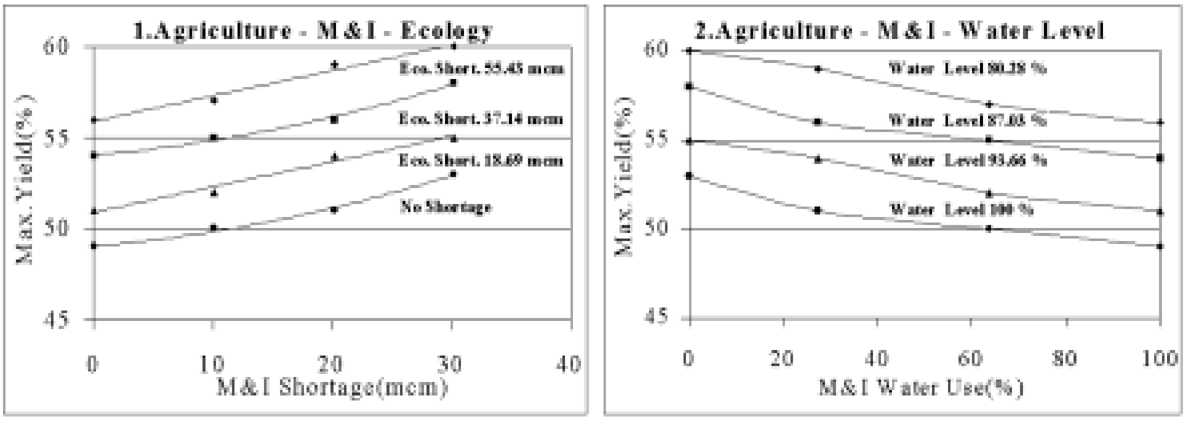

Fig. 3 Trade – off among allocation alternatives.

According to trade-off among the 16 alternatives in the extremely dry year of inflow, the total product was between 49-60% or reduced 40-51%. This indicated that if at all want to have the total product of 60%, the municipal and industrial sector could not use water. The downstream shortage 55.43 million cubic meter or the water level in the river reduced from the normal depth(2.21 m.) by 19.72% or the alternative was the total product reduced 49%, the municipal and industrial sector and the downstream did not have any water shortage.

Analysis and selection of the alternatives by multicriteria decision making.

There were 16 alternatives from trade-off analysis for multicriteria decision making. The questionnaire were developed to ask 26 stakeholders of Upper Mun basin including the 10 water management administrators , an expert, 6 representatives of agricultural sectors, 2 representatives of municipal and industrial sectors, 6 representatives of ecology systems (downstream requirements) and the researchers. Each correspondance selected 4 alternatives based on the three criteria; profitability, equity and reliability. The analysis's outcomes with AHP found that the water allocation in extremely dry year gave an importance to profitability, reliability and equity 41%, 32.3% and 26.7% respectively. It was noticed that the attitude in the water allocation of the correspondance when they were at the turning time, they would consider the profitability more important than reliability and equity (**Table** 5).

Table 4 Trade – off among water allocation alternatives.

Alternatives	Agriculture		Municipal-Industrial		Ecology	
	Max.Yield (%)	Yield Depletion (%)	Min.Shortage (mcm.)	Water Use Depletion (%)	Min.Shortage (mcm.)	Water Level Depletion (%)
1	60	40	30.24	100.00	55.43	19.72
2	59	41	20.16	72.80	55.43	19.72
3	57	43	10.08	36.40	55.43	19.72
4	56	44	0.00	0.00	55.43	19.72
5	58	42	30.24	100.00	37.14	12.97
6	56	44	20.16	72.80	37.14	12.97
7	55	45	10.08	36.40	37.14	12.97
8	54	46	0.00	0.00	37.14	12.97
9	55	45	30.24	100.00	18.69	6.34
10	54	46	20.16	72.80	18.69	6.34
11	52	48	10.08	36.40	18.69	6.34
12	51	49	0.00	0.00	18.69	6.34
13	53	47	30.24	100.00	0.00	0.00
14	51	49	20.16	72.80	0.00	0.00
15	50	50	10.08	36.40	0.00	0.00
16	49	51	0.00	0.00	0.00	0.00

The highest ranked alternative of 29.38% was the fourth alternative. This alternative satisfied 100% of demand for municipal and industrial sector, the downstream requirements would lack of water by 55.43 million cubic meters or the water level in the river be reduced from the normal dept 19.72% and allowed the yield for agriculture reducing to 56% of the maximum yield. This alternative did not allow water shortage to the municipal and industrial sector and the downstream requirements (ecology balance) would use the water from return flow(**Table** 6).

According to the questionnaires, some stakeholder added more 4 alternatives. Those were, 17th , 18th , 19th and 20th that maintained the water level in river at normal depth but resulted water shortage in municipal and industrial sector by 5%, 7%, 15% and 20% of demand. 12 alternatives were selected from 16 alternatives that caused different water shortage.

Table 5 Water allocation criterion developed by AHP(%).

Informant	Profitability	Equity	Reliability	Informant	Profitability	Equity	Reliability
1	69.6	22.9	7.5	14	62.7	28.0	9.4
2	19.9	73.3	6.8	15	75.0	7.8	17.1
3	24.3	5.6	70.1	16	33.3	33.3	33.3
4	76.3	6.1	17.6	17	33.3	33.3	33.3
5	70.9	6.0	23.1	18	77.8	11.1	11.1
6	68.2	23.6	8.2	19	33.3	33.3	33.3
7	6.7	29.3	64.0	20	6.4	13.8	79.8
8	6.8	73.3	19.9	21	6.8	19.9	73.3
9	73.3	6.8	19.9	22	6.4	13.8	79.8
10	48.1	46.3	5.8	23	6.8	19.9	73.3
11	6.0	70.9	23.1	24	79.8	6.4	13.8
12	76.4	11.5	12.1	25	6.6	14.9	78.5
13	15.3	77.7	7.0	26	76.3	6.1	17.6
Mean					41.0	26.7	32.3

Table 6 Overall water allocation criterion developed by AHP (%).

Alternatives	Overall	Priority
2	0.37	16
3	5.78	5
4	29.38	1
6	1.30	10
7	4.67	6
8	24.49	2
10	2.75	7
11	2.74	8
12	14.47	3
14	1.19	11
15	0.63	14
16	8.36	4
17	1.57	9
18	1.11	12
19	0.70	13
20	0.46	15

CONCLUSION

The water demand in Upper Mun basin consisted of agricultural, municipal and industrial water supply, downstream ecological requirements and water requirement at the outlet of basin. The multireservoir system was simulated by HEC-3. In case of unconstraints water allocation at the river basin outlet, the 25 years average water shortage of the whole basin was 17.79%, and 40.03% in the extremely dry year, occurring during the dry spell in rainy season (Jul.- Sept.) and in the dry season (Dec.-May). It was noticed that the capacity of 4 reservoirs in the Upper Mun basin was sufficient for demand in 1999 but occurrence of water shortage because the amount of reservoir inflow in each year. In the future the economic development and expansion of community might cause the water demand increasing. The new water resources development is now limited. To reduce these problems, one has to consider the demand side management. According to these situations, alternatives for water allocation among the water use sectors needed to be developed particularly the case of Dry1. The 16 alternatives from trade-off analysis, the result showed the total agricultural product between 49-60% or the maximum yield was reduced by 40-51%. This showed that if one wanted to maintain the total product of 60%, the municipal and industrial sector couldn't use water and the downstream requirements would lack of water by 55.43 million cubic meters or the water level in the river be reduced from the normal dept 19.72%. If one wanted to have the total product of 49%, there would not be shortage in the municipal and industrial sector and the downstream requirements. There were three decision criteria for the alternatives ranked by AHP, those were profitability, equity and reliability. It was found that the water allocation in the turning point or the extremely dry year(Dry1) gave the priority weight for profitability, reliability and equity at 41%, 32.3% and 26.7% respectively. It was noticed that the attitude in the water allocation of the correspondance when they were at the turning time, they would consider the profitability more important than reliability and equity. The highest ranked alternative of 29.38% was the alternative which did not allowed water shortage to the municipal and industrial sector, the downstream requirements for ecology system would lack of water by 55.43 million cubic meters and allows the yield for agriculture reducing to 56% of the maximum yield. Thus, the water allocation methodology developed in this study can help establish the priority in water allocation and define the most preferable alternative for the stakeholders.

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