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Security of Upland Irrigation Water through the Effective Storage Management of Irrigation Dams

관개용 댐의 효율적 저수관리를 통한 밭 관개 용수 확보

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Abstract

In Korea, upland irrigation generally depends on the ground water or natural rainfall since irrigation water supplied from dams is mainly used for paddy irrigation, and only limited amount of irrigation water is supplied to the upland area. For the stable security of upland irrigation water, storage level of irrigation dams was simulated by the periods. A year was divided into 4 periods considering the irrigation characteristics. Through the periodical management of storage level, water utilization efficiency in irrigation dams could be enhanced and it makes available to secure extra available water from existing dams without new development of water resources.

Two study areas, Seongju and Donghwa dam, were selected for this study. Runoff from the watersheds was simulated by the modified tank model and the irrigation water to upland crops was calculated by the Penman-Monteith method. The analyzed results showed that relatively sufficient extra available water could be secured for the main upland crops in Seongju area. In case of Donghwa area, water supply to non-irrigated upland was possible in normal years but extra water was necessary in drought years such as 1998 and 2001.

Keywords : Periodical management of storage level, Security of upland irrigation water, Water utilization efficiency

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I. Introduction

About 75,000 ha of upland, which is more or less 10% of total upland area, has been consolidated through the Upland Infrastructure Improvement Project until 2003 and the upland irrigation water is mainly supplied from the tube wells. On the other hand, large amount of in-effective release from small irrigation dams have been occurred due to the insufficient flood control capacity of them. Total water use demand is expected to increase continuously to some extent but the development of new water resources is very difficult, and for this reason, the enhancement of utilization efficiency of agricultural water through efficient management is inevitable.

The aim of this study is to show that the water utilization efficiency of the irrigation dams could be improved by the periodical management of storage level (PMSL) for the stable security of upland irrigation water. It was possible to secure "extra available water" from existing dams without development of new water resources. The optimum storage level to minimize the ineffective release from the irrigation dam was investigated by the simulation approach using the storage management model for small dams. And the possible amount of extra available water for upland irrigation was calculated. Through the simulation, the possible amounts for upland irrigation could be calculated. Evapotranspiration and effective rainfall of main upland crops in the studied area were analyzed for the supply possibility of extra available water. Using this result, the water demand for upland irrigation was calculated.

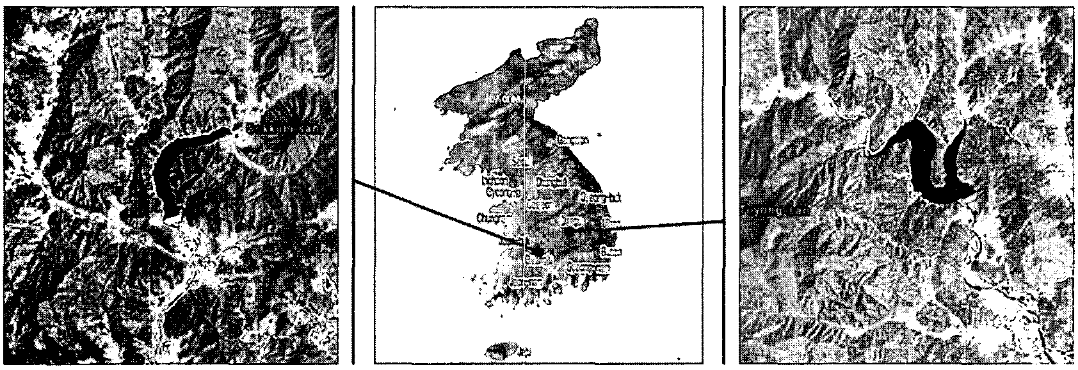
Two typical irrigation dams, Seongju and Donghwa dam, were selected and analyzed for this study. The storage level of dams was managed by the four different periods considering irrigation characteristics.

Ⅱ. Materials and Methods

1. Study area

Seongju and Donghwa dams were chosen for this study to investigate the applicability and effectiveness of PMSL approach. These two dams, which are well equipped with tele-metering and tele-control system basically were constructed to supply irrigation water including extra water for domestic use and river maintenance as well. Fig. 1 show the location and the watershed of studied area.

The main upland crops in Seongju area are soybean, red pepper, Chinese cabbage, radish, sesame, sweet potato, onion and garlic, and the



(a) Donghwa dam (b) Seongju dam

Fig. 1 Location and watershed of studied area

Table 1 Specifications of Seongju and Donghwa dam

Dam	Watershed area (ha)	Irrigation area (ha)	Total storage (ha·m)	Full water level (m)		Dead water level (m)
				Summer	Winter	
Seongju	14,960	3,160	3,824	EL. 184.7	EL. 187.9	EL. 162.0
Donghwa	7,400	3,000	3,110	EL. 322.6	EL. 321.6	EL. 271.0

Table 2 Cultivation area of main upland crops in study area (unit: ha)

Area	Soybean	Red pepper	Chinese cabbage	Radish	Sesame	Sweet potato	Onion	Garlic	Total
Seongju	197	147	67	64	99	109	5	14	652
Donghwa	167	343	197	81	42	-	-	-	830

total cultivation area is 652 ha. The main upland crops in Donghwa are soybean, red pepper, Chinese cabbage, radish and sesame, and the total cultivation area is 830 ha. Table 1 shows the specifications of Seongju and Donghwa dam, and Table 2 shows the respective current cultivation area of main crops.

2. Periodical management of storage level (PMSL) and extra available water

This research has been focused on irrigation dams that support water supplies in fixed periods. From the characteristics of irrigation dams, there exist many factors causing drought and flood because of the double objectives of

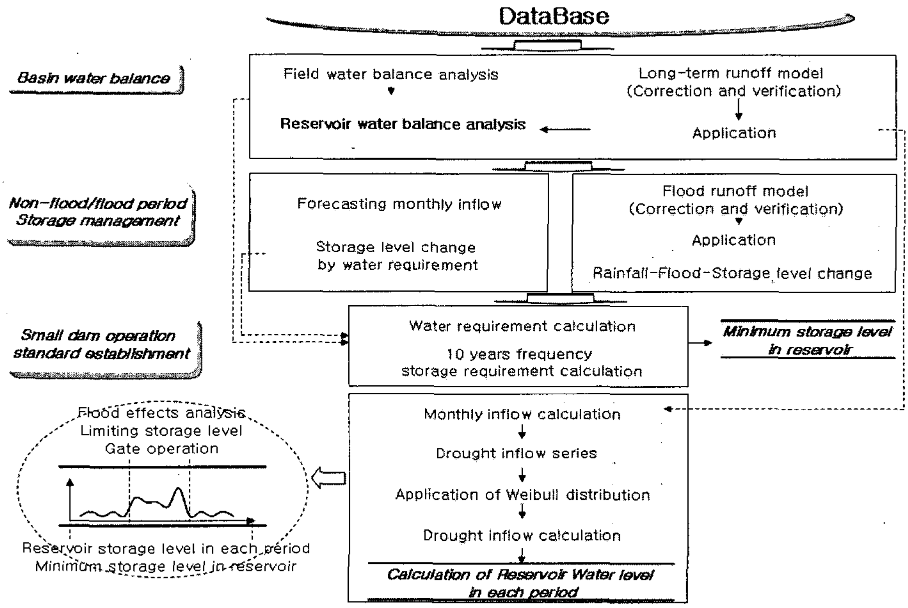


Fig. 2 Application of storage management model and establishment process of operation standard

insuring water during the irrigation period and flood control during the flood period. This causes low water use efficiency for most of dams. For the efficient water management, a PMSL was developed to secure flood control capacity without affecting the irrigation water insurance. Fig. 2 shows the application of storage management model and the establishment process of operation standard.

From the characteristics of irrigation dams, irrigation dams secure an excessive storage of water for maintaining a full reservoir level (or full supply level in winter) at the end of the flood period. And dams are faced with the shortage of available storage capacity for flood control due to the full storage level of summer period. To solve these problems a year was divided into 4 periods. The important operation goal is to improve flood control capacity during the flood period by maintaining the full level not in winter but at the beginning of the irrigation period. It was attempted to minimize the ineffective release and the flood damage by increasing the use of the reservoir water before the flood period.

To minimize the ineffective release from dam, storage level of dam was changed by the periods. And the extra available water, without influencing to the normal water supply to paddy rice land, was calculated. A year was divided into four periods considering the irrigation characteristics for this simulation. The minimum runoff and the water use frequency by the periods were analyzed.

The storage level was determined on the basis of the analyzed water balance in the watershed and other hydrological statistics. Minimum storage level and PMSL were determined using storage management model[1),2)] for the management of dams. The storage management model manages database for hydrologic analysis and storage management. Each model was linked to the database. A model consists of basin water balance model and storage management model during the flood period and the non-flood period. By the increase of flood control capacity of dams having insufficient pre-release capacity, the amount of water use could be maximized during the non-flood period through PMSL.

The four operation periods are: 1) January-March: securing winter full level to maintain water for the irrigation period, 2) April-June: water use for irrigation and preparation for the flood period, 3) June-September: irrigation and flood periods, and 4) October-December: period for securing a winter full level and other water uses. In case of Seongju dam, this(Oct.-Dec.) is the period to secure water for power generation. The minimum storage to be secured annually was calculated by the 10-year frequency required storage with the results of storage level behavior analysis. Based on this result it is not difficult to supply water while maintaining the minimum storage as the lowest limit of PMSL. Table 3 shows the appropriate operation standard for the four different periods. Statistically, flood period starts from June 21 to Sept. 21 in Korea, however considering the current weather pattern such as rainfall events and typhoons, flood period extended to Sept. 30.

The management simulation was attempted to maintain the water level close to the management storage level while providing the normal and additional water demands. The additional supply was avoided to exceed the maximum release

Table 3 Periodical operation of irrigation dam

Period	1st Period	2nd Period	3rd Period	4th Period
	1/1~3/31	4/1~6/20	6/21~9/30	10/1~12/31
Operation	Period of securing full water level in winter	Period of transplantation of paddy rice and preparation for flood	Period of irrigation, and flood	Period of securing full water level in winter and power generation

capacity of the intake, and water was released every month within the operational range of the storage management model. Since it was not realistic for the dam operation for daily adjustment of the intake release rate and sluice gate operation the water level was attempted to maintain close to the management storage level with fixed monthly additional release. In this study, this additional release is defined as "extra available water".

3. Calculation of water demand for upland irrigation

Evapotranspiration and effective rainfall were considered to calculate the net duty of water, but infiltration was not considered because available moisture of upland is calculated in the range of field capacity.[7] Gross duty of water was calculated considering the irrigation efficiency to the net duty of water. Evapotranspiration of crops and effective rainfall were calculated for the estimation of irrigation water demand. Penman-Monteith method was used to calculate the upland

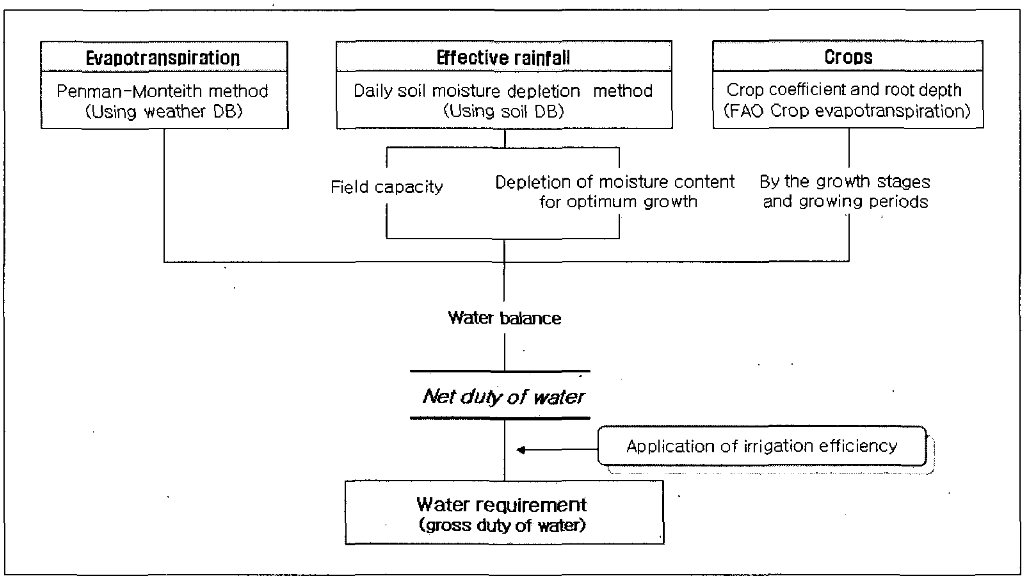


Fig. 3 Calculation chart of water demand for upland irrigation

crop evapotranspiration and daily soil moisture depletion method was used to calculate the effective rainfall.

Crop coefficient and root depth of crops in each of the growth stages and growing periods were determined by applying the values suggested in FAO Crop evapotranspiration.[12] Root depths of crops were determined considering the soil moisture depletion pattern. The effective rainfall was calculated by daily soil moisture depletion method considering the characteristics of soil. Total loss of irrigation water was calculated considering the irrigation efficiency including the application and water conveyance efficiency in the field. Fig. 3 shows the calculation chart of water demand for upland irrigation. In this study, water demand for upland irrigation of 10 yr frequency was calculated using the database of 20 year irrigation water supply for the use of extra available water.

Ⅲ. Results and Discussion

1. Periodical management of storage level

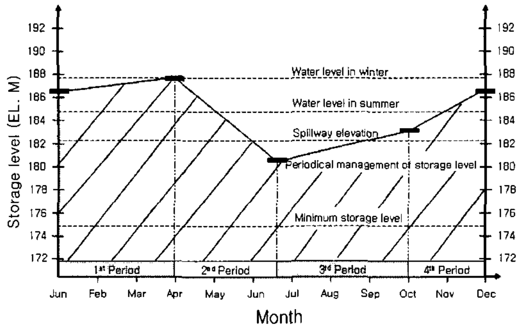
The storage level of periodical management was determined on the basis of the analyzed water balance in watershed and other hydrological statistics such as Table 4. The storage level of periodical management for calculation of extra available water was determined 187.9, 180.7, 183.4 and 186.5(EL. m) in Seonju dam, respectively. The minimum storage level at Seongju dam is 17.2 million m^3, which include 13.5 million m^3 of 10yr frequency storage requirement, and 3.7 million m^3 as a safety.[4] This requires the water level elevation at EL. 175 m. The storage level of periodical management of Donghwa dam was determined 322.6, 321.1, 321.1, 322.5(EL. m), respectively. The minimum storage level at Donhwa dam is EL. 300 m. The extra available water was calculated using the storage level of periodical management.

Table 4 Periodical management of storage level in Seongju and Donghwa dam

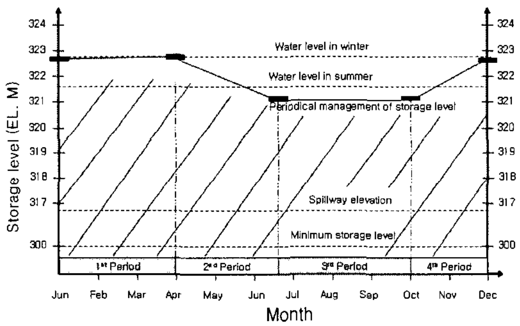
Period		1st Period	2nd Period	3rd Period	4th Period
		1/1~3/31	4/1~6/20	6/21~9/30	10/1~12/31
Standard date		Mar. 31	Jun. 20	Sept. 30	Dec. 31
Seongju dam	Management water level (EL. m)	187.9	180.7	183.4	186.5
	Minimum storage level (EL. m)	175			
Donhwa dam	Management water level (EL. m)	322.6	321.1	321.1	322.5
	Minimum storage leve (EL. m)	300			

2. Calculation of extra available water

Extra available water by the year was calculated through the periodical management of storage level in the two irrigation dams, Seongju and Donghwa dams. Table 5 shows that the extra available water in 1998 and 2001 were smaller than that of the other years because of severe drought.



(a) Seongju dam



(b) Donghwa dam

Fig. 4 Periodical management of storage level

Especially, the extra available water of Donghwa dam in 2001 could not be secured after the 2nd period by severe drought. The extra available water of Seongju dam was secured at least more than 35.0 million m^3 every year, and that of Donghwa dam could be secured more than 30.0 million m^3 except for 1998 and 2001.

3. Water demand for upland irrigation

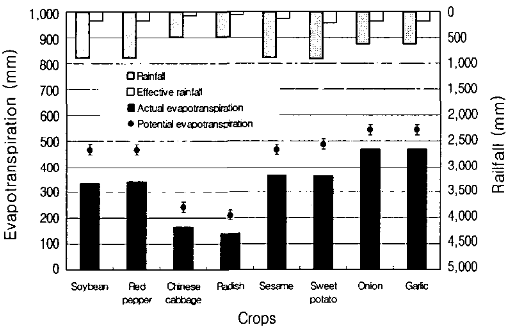
The irrigation water demand for main upland crops in the studied area was calculated using Penman-Monteith method, daily soil moisture depletion method and irrigation efficiency. The calculated period was from 1998 to 2002, and the kind of upland crops for the calculation in Seongju and Donghwa areas were eight and five kinds,

Table 5 Extra available water in Seongju and Donghwa dam (unit: $10^3 m^3$)

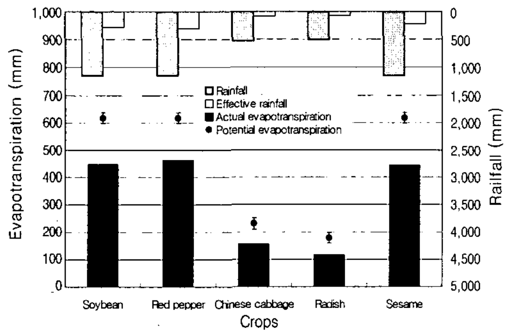
		1998	1999	2000	2001	2002
Seongju dam	1st period	0	4,915	865	4,160	386
	2nd period	17,436	17,350	5,672	16,020	8,912
	3rd period	14,397	23,974	41,178	12,599	34,541
	4th period	6,615	9,419	7,610	5,206	2,888
	Total	38,448	55,658	55,325	37,985	46,727
Donghwa dam	1st period	0	1,442	0	1,906	0
	2nd period	1,262	2,095	1,720	0	864
	3rd period	7,564	30,682	27,835	0	31,368
	4th period	925	863	1,382	0	1,752
	Total	9,751	35,082	30,937	1,906	33,984

Table 6 Five year average data of main upland crops (1998~2002) (unit: mm)

Crops		Soybean	Red pepper	Chinese cabbage	Radish	Sesame	Sweet potato	Onion	Garlic
Cop periods		5.20~9.30	5.20~9.30	8.10~11.20	8.20~11.20	5.20~9.30	5.20~10.10	3.10~8.10	3.10~8.10
Seongju area	Potential ET	467	467	244	212	467	488	543	543
	Actual ET	335	340	165	141	363	362	469	469
	Rainfall	898	898	507	489	898	916	629	629
	Effective rainfall	174	176	68	64	138	215	190	190
	Net duty of water	161	164	97	77	225	147	279	279
Donghwa area	Potential ET	616	626	232	179	560	-	-	-
	Actual ET	446	463	156	118	441	-	-	-
	Rainfall	1,160	1,160	532	530	1,160	-	-	-
	Effective rainfall	293	306	84	74	228	-	-	-
	Net duty of water	153	157	72	44	213	-	-	-



(a) Seongju



(b) Donghwa

Fig. 5 Five year average rainfall and evapotranspiration of main upland crops (1998~2002)

Table 7 Water demand for upland irrigation

(unit: 10^3m^3)

Year	1998	1999	2000	2001	2002
Seongju dam	1,363.4	1,316.4	1,339.2	1,719.1	2,115.1
Donghwa dam	1,873.0	1,557.0	1,643.0	1,959.0	1,772.1

respectively. Table 6 and Fig. 5 show the average evapotranspiration, rainfall and net duty of water of main upland crops in the studied area, and the total period is from 1998 to 2002.

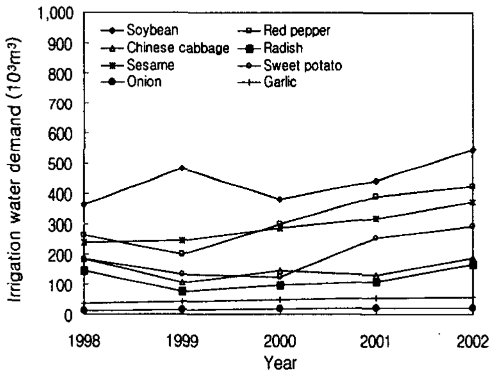
As shown in Table 7, the calculated total water demands in Seongju area was less than 1.4 million m^3 from 1998 to 2000 and the water demand highly increased in 2001 and 2002 because of the severe drought and the decrease of effective rainfall, respectively. The calculated total water demands in Donghwa area were high in 1998 and 2001 because of the severe drought.

4. Use of extra available water

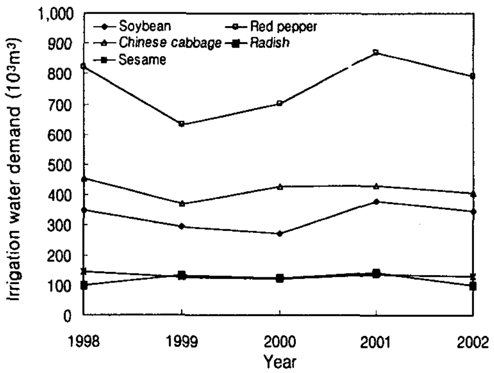
From the periodical management of storage level, the total calculated extra available water

Table 8 Extra available water and water demand for upland irrigation (unit: 10^3m^3)

		1998	1999	2000	2001	2002
Seongju dam	Extra available water	38,448	55,658	55,325	37,985	46,727
	Extra available water (except for flood period)	19,968	36,758	29,585	21,446	24,827
	Water demand for upland irrigation	1,363.4	1,316.4	1,339.2	1,719.1	2,115.1
	Water demand for upland irrigation (10yr frequency)	2,033				
Donghwa dam	Extra available water	9,751	35,082	30,937	1,906	33,984
	Extra available water (except for flood period)	2,187	4,400	3,102	1,906	2,616
	Water demand for upland irrigation	1,873.0	1,557.0	1,643.0	1,959.0	1,772.1
	Water demand for upland irrigation (10yr frequency)	2,274				



(a) Seongju



(b) Donghwa

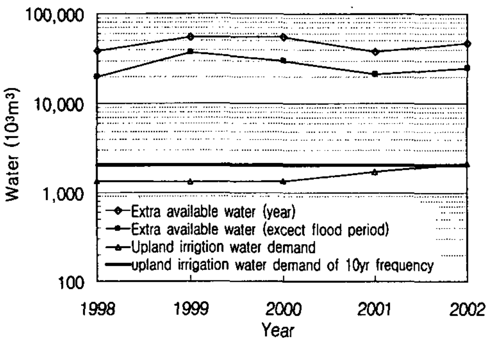
Fig. 6 Water demand for upland irrigation

of Seongju dam during the whole period was more than 37.0 million m^3, and that of Donghwa dam during the whole period was more than 30.0 million m^3 except for 1998 and 2001 as shown in Table 8. Table 8 shows the extra available water and water demand for upland irrigation in Seongju and Donghwa dams.

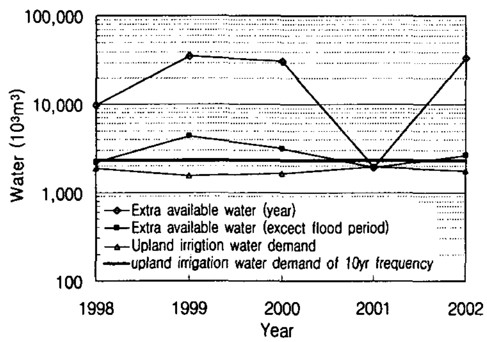
Since large amount of ineffective release from the dam occurred during the flood season, extra available water except for flood period was calculated. The calculated extra available water of Seongju dam except for flood period was more than 20.0 million m^3. The calculated extra available water of Donghwa dam except for flood period was more than 2.6 million m^3 in 1999, 2000 and 2002, but lower than 2.2 million m^3 in 1998 and 2001. And now this extra available water is released only for the purpose of power generation of small hydro power plant.

Water demand of 10yr frequency for the main upland crops was estimated as 2.0 million m^3 in Seongju area. The extra available water of Seongju dam except for flood period was much higher than the 10yr frequency water demand, so it could be used for irrigation to the non-irrigated upland.

Water demand of 10yr frequency for the main upland crops was estimated as 2.3 million m^3 in Donghwa area. The extra available water of Donghwa dam except for flood period was higher than the 10yr frequency water demand in 1999, 2000 and 2002, but lower than the 10yr frequency water demand in 1998 and 2001. Therefore, the irrigation water supply to non-irrigated upland in Donghwa area is possible in normal years, but the development of extra available water resources is needed in drought years such as 1998 and 2001.



(a) Seongju



(b) Donghwa

Fig. 7 Extra available water and water demand for upland

Ⅳ. Conclusions

In this study, the possibilities to secure extra available water for upland irrigation from the efficient management of irrigation dams without new development of water resources were tested. The storage levels of irrigation dams were simulated by the periods. The water demand for upland irrigation of studied areas were calculated, and then the extra available water other than the designed duty of water for paddy was estimated through the simulation study.

The storage level of periodical management for calculation of extra available water was determined 187.9, 180.7, 183.4 and 186.5(EL. m) in Seonju dam, respectively. The storage level of periodical management of Donghwa dam was determined 322.6, 321.1, 321.1, 322.5(EL. m), respectively. From the periodical management of storage level, the total calculated extra available water of Seongju dam during the whole period was more than 37.0 million m^3, and that of Seongju dam except for flood period was more than 20.0 million m^3. These Figures show that large amount of ineffective release occurred during the flood season. The total extra available water of Donghwa dam during the whole period was more than 30.0 million m^3 except for 1998 and 2001, and that of Donghwa dam except for flood period was more than 2.6 million m^3.

The evapotranspiration and effective rainfall of main upland crops were analyzed for the supply possibility of extra available water. Using this result, the water demand for upland irrigation was calculated. The 10yr frequency water demand for the main upland crops was estimated 2.0 million m^3 in Seongju area, and 2.3 million m^3

in Donghwa area, respectively. The extra available water of Seongju dam except for flood period was much higher than the 10 yr frequency water demand, so it could be used for irrigation to the non-irrigated upland. However, the extra available water of Donghwa dam except for flood period was higher than the 10 yr frequency water demand in 1999, 2000 and 2002, and lower than the 10 yr frequency water demand in 1998 and 2001 which shows that the development of extra available water resources is required.

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