WATER BALANCE ANALYSIS IN EA KNIR CATCHMENT, DAK LAK, VIETNAM

Tran Thi Trieu[1]

Introduction

The rising demands for water resources will make their allocation a struggle in the near future. Global water consumption has increased about sevenfold since the beginning of the twentieth century (Zbigniew and Kundzwiez, 1997). Irrigated agriculture presents the largest demand for water, consuming over 70 percent of developed global water supplies (Seckler et al., 1999). The operation and management of irrigation systems is a growing concern worldwide. This is especially true for developing countries, particularly in Asia, where the need to enhance agricultural productivity is faced by diminishing water supplies for agriculture owing to rapid industrialization and ever-increasing municipal needs.

Nowadays, the improper use of water resources has become a serious issue in many countries, including Vietnam. The Srepok Basin is a catchment within the Mekong Basin, which is affected by water resource development. Many irrigation systems, including reservoirs, have been constructed to store water from the tributaries of the Srepok River. They play an important role not only in contributing to water resource protection of the Mekong River but also in irrigation supply for ethnic communities living in Dak Lak Province. However, in recent years, especially in the dry season, these water supply systems have inadequately supplied irrigation needs, resulting in very low crop yields. Therefore water resource availability in Ea Knir Catchment needs improvement to sustain the livelihoods of the farmers in the area who mainly depend on subsistence agriculture.

This study aimed to make a water balance analysis in Ea Knir Catchment through assessment of the water demand of the cultivated areas and crop intensity and the inflow to the reservoir. Within the limited time available, the study focused on the Ea Kao irrigation scheme only.

The study area

The Ea Knir Catchment lies in Buon Ma Thuot District, central Dak Lak Province, in southern Vietnam. The total area of the entire catchment is 240 km^2. The north is bordered by the Ea M'dhar tributary, the east by the Ea Pour tributary, the west by the Ea Tuor tributary, and the south by the Srepok River (Figure 1). The catchment has a relatively high amount of rain fluctuating from 1 300 to 2 500 mm annually.

The area is dominated by coffee and rice farming which strain the available water resources; most cultivated land is located at elevations of 300 to 780 metres above sea level (masl). The prevailing topography is high mountains, some of which reach 2 000 masl; the catchment gradient is between 3 and 5 percent. There are gently sloping basaltic hills in the north and the centre of Ea Knir Catchment. The narrow plains are concentrated in the western part of the catchment. The average annual rainfall from 1977 to 2000 was about 1 881 mm. The average annual evaporation was 1 526 mm.

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The population comprises the M'Nong and Ede minority groups and the Kinh. The total population is 73 937 persons belonging to 14 323 households — 11 286 are Kinh, 2 189 are Ede, 12 are M'Nong, and 836 are other groups. Basic public services like health posts and schools are poorly equipped, understaffed, and inadequate in number. Total production in the catchment covers less than 75 percent of the necessary subsistence costs and lack of capital and expertise prevents further expansion. The irrigated area is small and the infrastructure is poorly developed. Area-wise, 12 274 ha are used for agriculture, 2 706 ha for housing estates, and 1 750 ha for forest land. Commercial logging was estimated to be around 4 000 m^3 per year and no replanting takes place.

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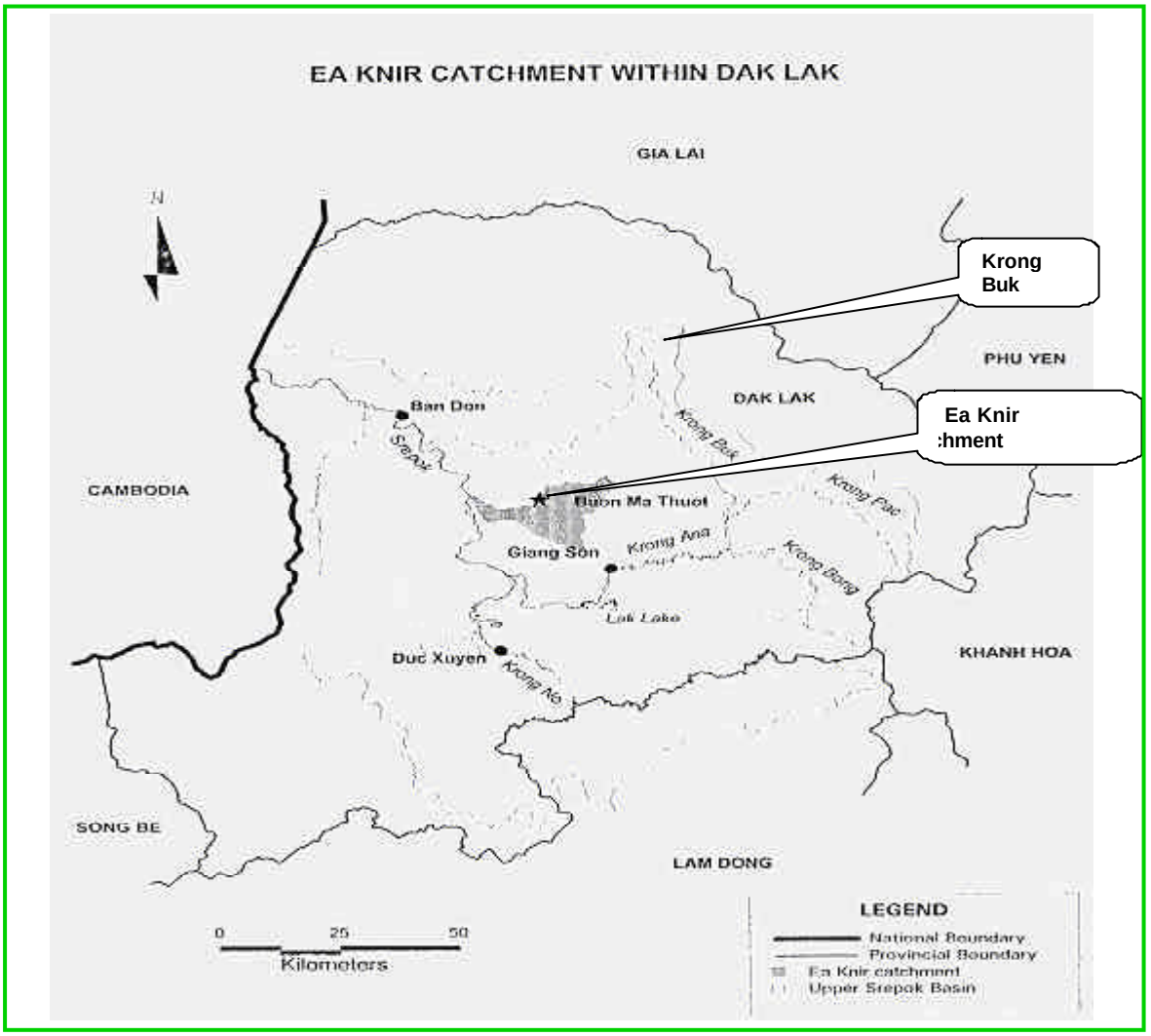

Figure 1. Maps of (a) Ea Knir Catchment within Dak Lak and (b) Ea Knir Catchment

The Ea Kao irrigation scheme was constructed from 1977 to 1983 for the Ea Knir tributary of Ea Kao Village. It irrigated Ea Kao and Ea Tam villages, Khanh Xuan and Tan Thanh communes in Buon Ma Thuot District and Hoa Xuan, Hoa Khanh, and Hoa Phu villages in Cu Jut District. Ea Kao reservoir is located at 12° N latitude and 108° 30' E longitude. It is about 10 km from Buon Ma Thuot town. The designed normal water level is set at 419 m. The reservoir capacity is 14.818 million m^3 and

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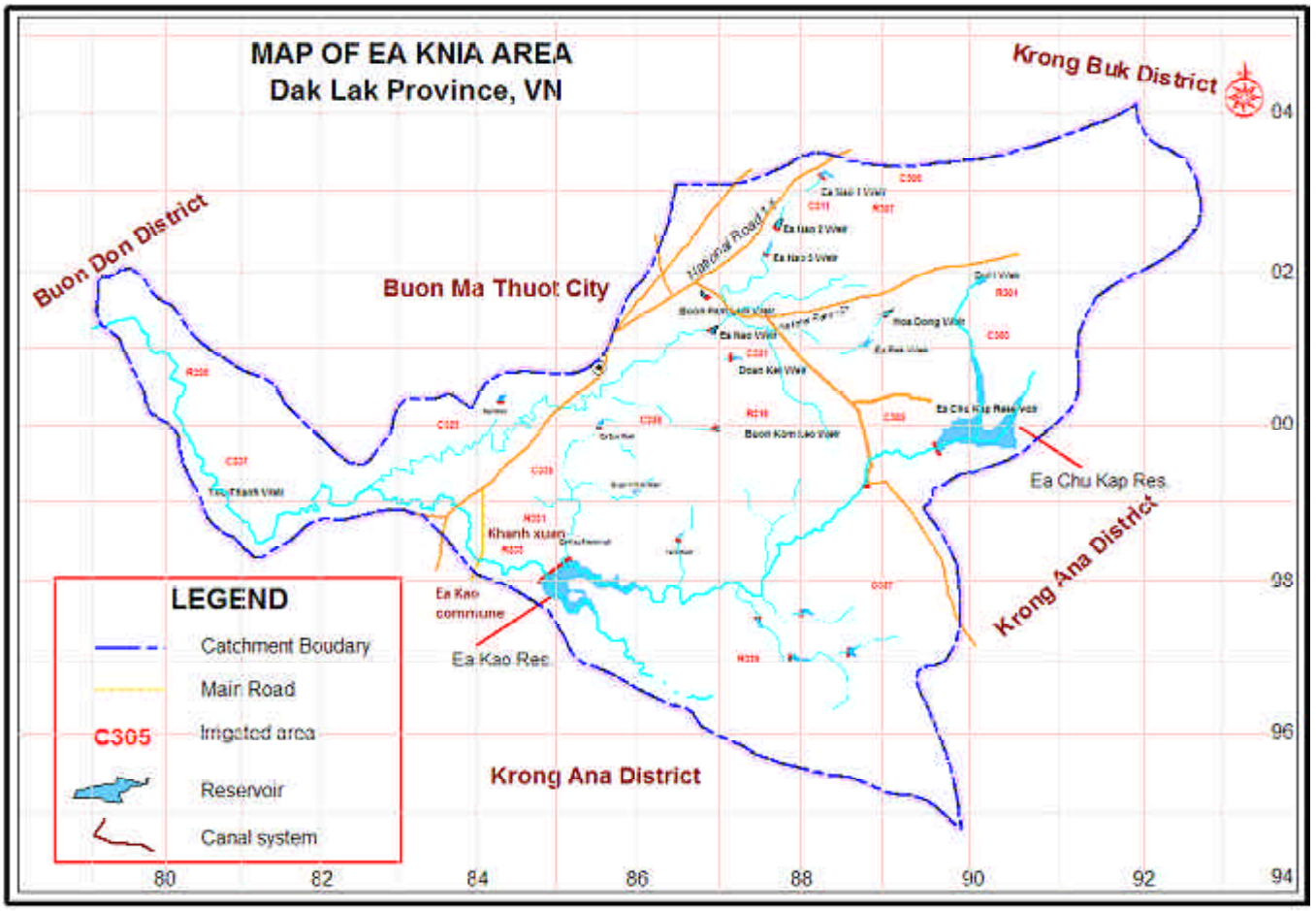
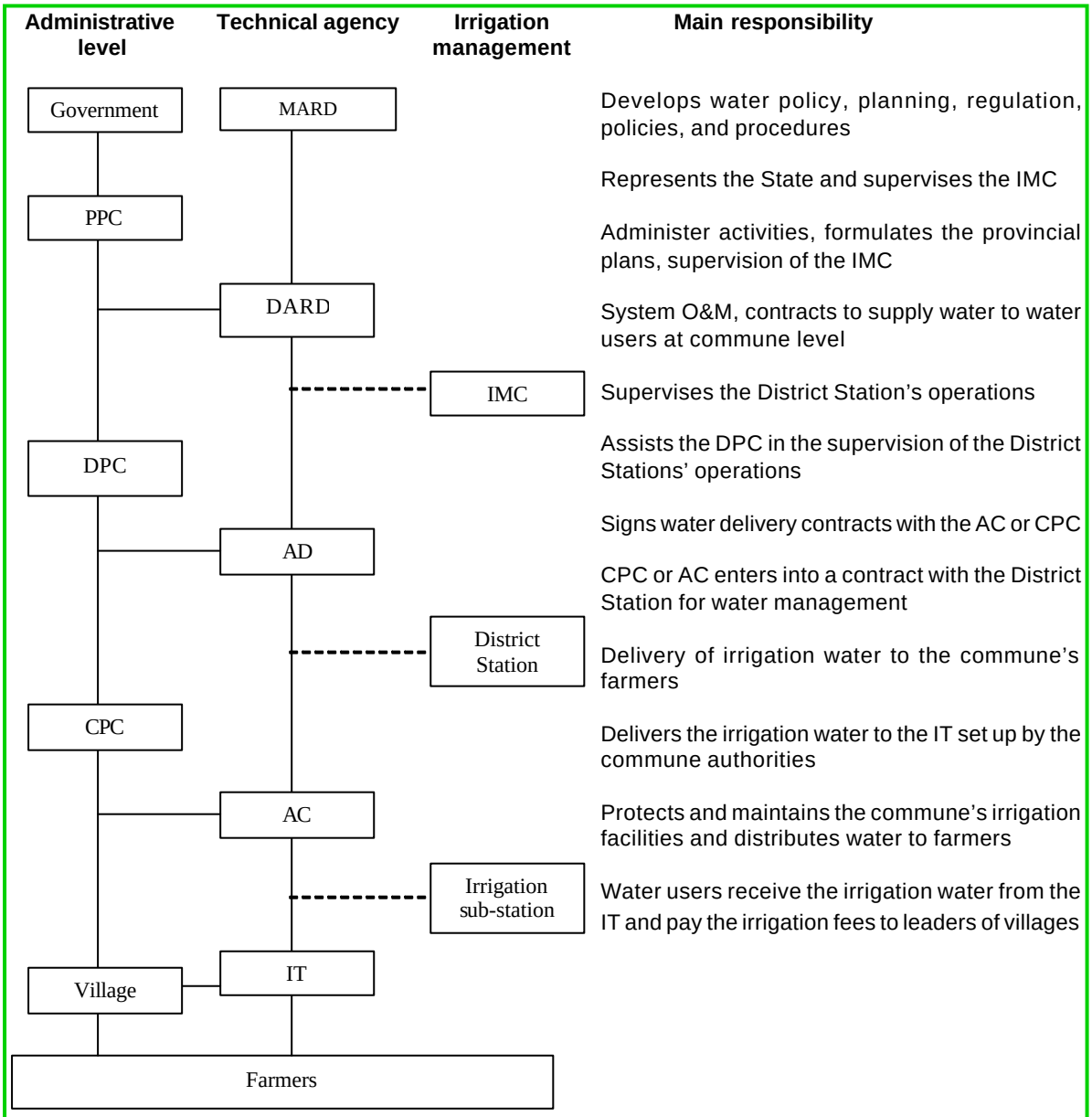


there is one main and one emergency spillway and two intake sluices. The earth dam is 2 400 m in length and 17 m in height.

The irrigation system includes the headwork (earth dam, spillway, and intake sluice) and a lined canal system was designed to supply water for the 580 ha of rice and 1 670 ha of coffee. In addition, the system is useful for aquaculture and transportation, as well as tourism and improving the ecological environment. However, degradation has occurred in recent years and water in the reservoir has never reached the normal water level due to leaks in the earth dam. In addition, the canal system has not been completed, canal schemes have not been built properly and have become badly degraded, resulting in water loss. The control valve at the off-takes was out of order causing much water loss. Due to poor management, farmers split the canal bank to extract water for their fields. Therefore, water insufficiency occurred at the end of the season every year. The system was not properly maintained because of lack of funds. Now, the system supplies water for only 350 ha of rice and 335 ha of coffee and only 1 094 households benefit from it. The organizational structure for irrigation management in Dak Lak is presented in Figure 2.



Source: Sinh and Tiep (2002)
MARD: Ministry of Agricultural and Rural Development
PPC: Provincial People's Committee
DARD: Department of Agricultural and Rural Development
IMC: Irrigation Management Company
DPC: District People's Committee
AD: Agricultural Division
CPC: Commune People's Committee
AC: Agricultural Cooperatives
IT: Irrigation Team (Irrigation Groups)

Figure 2. Institutional frameworks for irrigation management in Vietnam

Methodology

Secondary and primary data were collected and used as input for the CROPWAT and MIKE Basin models and institutional assessment. The secondary data were collected from the Irrigation Management Company (IMC), Hydrometeorological Forecast Station of Dak Lak Province, Geological Team 704, and communes in the study area.

Characteristics of the reservoirs

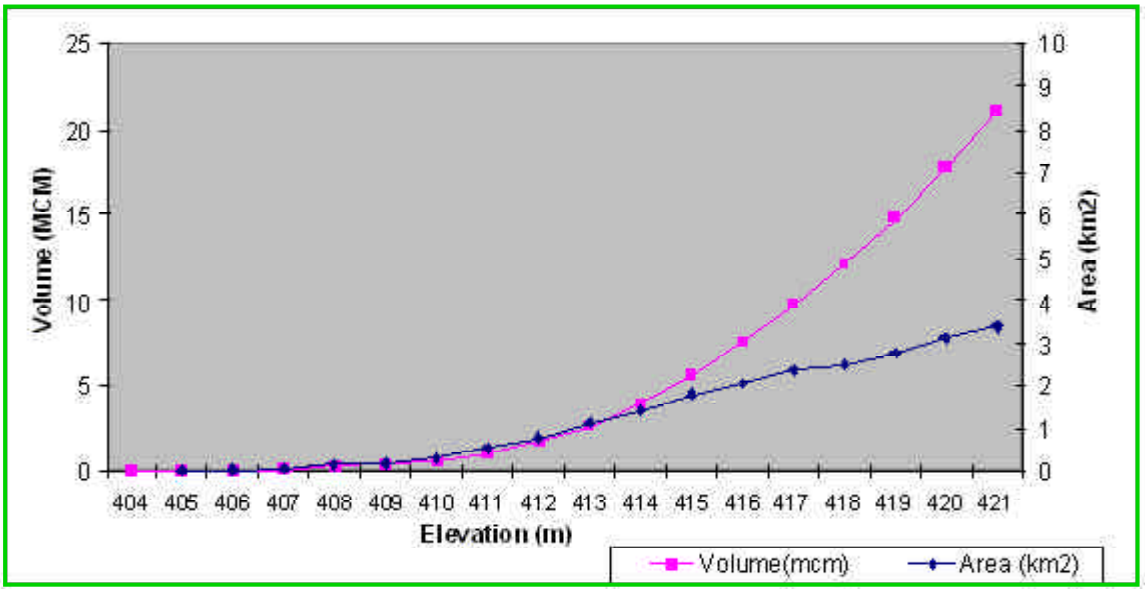


Figure 3. Characteristics of Ea Kao reservoir

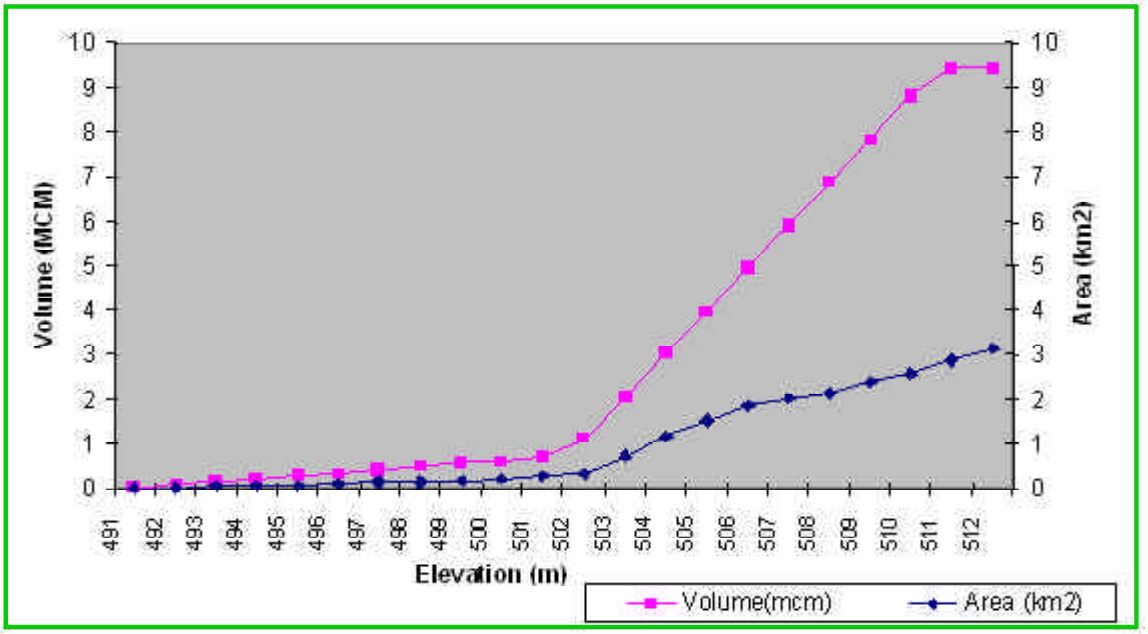


Figure 4. Characteristics of Ea Chukap reservoir

The operational rules for Ea Kao reservoir (Figure 3) were: full reservoir level, 421 m; minimum operation level, 419 m; top of dead storage, 414 m; bottom level, 404 m; minimum downstream flow requirement, 0.13 m^3/s; and maximum downstream flow, 220 m^3/s.

Operational rules that applied for Ea Chukap reservoir (Figure 4) were: full reservoir level, 511.62 m; minimum operation level, 502 m; top of dead storage, 501.62 m; bottom level, 491.12 m; minimum downstream flow requirement, 0.09 m^3/s; and maximum downstream flow, 77 m^3/s.

Rainfall

The average rainfall from 1977 to 2000, measured at Buon Ma Thuot meteorological station, was about 1 881 mm. The rainy season lasts for six months from May to October. The rainfall of the rainy season covers 85 percent of the total rainfall in one year. The other six months are dry. The highest average rainfall was observed in August with 306 mm and the lowest average rainfall was in January with 4 mm.

Temperature and humidity

The mean monthly temperature at Buon Ma Thuot ranges from 21°C (December to January) and 26°C (April to May); average monthly relative humidity is 70 percent in March and 89 percent in September. The average annual evaporation is 1 526 mm, the highest evaporation occurring in March (193 mm) and the lowest in September (59 mm).

Flow generation

There are 17 irrigation schemes in the catchment, including reservoirs; most of them are small reservoirs. Ea Chu Kap and Ea Kao reservoirs are medium-sized irrigation schemes. The rest are weirs that take water directly from tributaries for irrigation. In addition to the existing hydraulic schemes, some areas of coffee are irrigated by pumping from the tributary, especially the areas along both sides of Ea Knir and Ea Tam.

The correlation between rainfall and runoff at Doan Ket station from 1977 to 1984 is $y = 0.37X - 250.3(mm)$, $r^2 = 0.698$ where the average runoff coefficient (α) is 0.31, the average annual rainfall (X) is 1 912 mm, and the average annual runoff (y) is 596 mm. The Ea Kao reservoir has a catchment area of 108 km^2 and approximately 50 percent is in the catchment of Doan Ket station. As a result, the runoff data collected at the Doan Ket station are strongly affected by the operation of the Ea Kao reservoir. This can be proved by the runoff coefficient of Doan Ket station, which is 0.31 in comparison with the average runoff coefficient in other catchments on the basaltic plateau which fluctuates between 0.41 and 0.48.

At Buon Ho meteorological station, the correlation between rainfall and runoff from 1977 to 1987 is $y = 0.611X - 294(mm)$, $r^2 = 0.817$ where the average runoff coefficient (α) is 0.483, the average annual rainfall (X) is 1 417 mm, and the average annual runoff (y) is 694 mm. The runoff at the Ea Nao station is too low and cannot represent the original runoff of the catchment. The basic parameters at Ea Nao hydrological station in 1994 and 1995 are the average runoff coefficient (α), which is 0.41, the average annual rainfall (X), which is 1 529 mm, and the average annual runoff (y), which is 630 mm.

The correlation between the rainfall and runoff at Buon Ho station (upper Krong Buk) is rather close; the average runoff coefficient is rather high. Irrigation abstraction is not considerable; therefore the runoff data at Buon Ho station are considered the original runoff of the upper Krong Buk tributary.

The runoff of Ea Knir was calculated based on its rainfall and runoff coefficient at Buon Ho station in Krong Buk Catchment. The two catchments are 40 km apart but they have similar climatic conditions and have the same basic features of the catchment (Table 1).

Table 1. Basic natural features of the upper catchment of the Krong Buk and Ea Knir tributaries

Characteristics	Ea Knir Catchment	Krong Buk Catchment
Catchment area	240 km^2	178 km^2
Length of catchment	21 km	30 km
Average width of catchment	8.5 km	8.0 km
Gradient of catchment	5.0%	4.0%
Average rainfall	1 881 mm	1 524 mm
Average evaporation	1 526 mm	1 429 mm
Relative average humidity	80.8%	85%
Soil type	Red basalt	Red basalt

The relation of monthly rainfall between Buon Ho and Buon Ma Thuot stations from 1977 to 2000 is $y = 0.7307X + 14(mm)$, $r^2 = 0.94$, where y is the monthly rainfall of Buon Ho station and X is the monthly rainfall of Buon Ma Thuot station. This relation was used to calculate the runoff for the Ea Knir Catchment. The monthly runoff of the Ea Knir Catchment was based on the scales distributed by Buon Ho station.

Crop data

Paddy rice and coffee are the major crops grown in the area. Rice is grown in two main seasons, spring paddy (from December to April) and monsoon paddy (from June to September). Other crops are considered negligible compared to the main crops. Coffee requires water throughout the year, so in the dry season irrigation for coffee is a problem. For rice, there are six growth stages: nursery, land preparation, initial, development, middle, and late stages. Coffee has a long life of 15 to 20 years. To calculate the annual irrigation water requirement for coffee, its growth is assumed in four stages: initial, development, middle, and late. The crop coefficients of rice and coffee are important factors in the crop water requirement calculation (Allen et al., 1998).

Water balance analysis

CROPWAT model

The irrigation water requirement at the field level is determined from:

$$I_{req,\,field} = \left(ET_{crop} + I_{perc} + L_{prep}\right) - P_{eff} \quad [mm]$$

where: $I_{req,field}$ = irrigation water requirement at the field level [mm]
ET_{crop} = crop evapotranspiration [mm]
I_{perc} = percolation to groundwater [mm]
L_{prep} = water required for land preparation [mm]
P_{eff} = effective rainfall [mm]

The potential crop evapotranspiration is determined from the potential or reference evapotranspiration times:

$$ET_{crop} = Kc \; x \; ET_0 \quad [mm]$$

where: ET_{crop} = crop evapotranspiration [mm]
ET_0 = reference evapotranspiration [mm]
Kc = crop coefficient [-]

The reference evapotranspiration according to the Penman-Monteith approach, which was adopted by FAO in May 1990, is the evaporation from a hypothetical reference crop height of 0.12 m, no shortage of water with a fixed surface resistance of 70 s/m, and an albedo or crop reflection coefficient of 0.23.

$$ET_0 = \frac{0.408\,\Delta\left(R_n - G\right) + g\,\dfrac{900}{T+273}\,u_2\left(e_s - e_a\right)}{\Delta + g\left(1 + 0.34\,u_2\right)} \quad [mm/day]$$

where: ET_0 = reference evapotranspiration [mm/day]
R_n = net radiation at crop surface [MJ/(m^2.day)]
G = soil heat flux density [MJ/(m^2.day)]
T = mean daily air temperature at 2 m height [^{o}C]
u_2 = wind speed at 2 m height [m/s]
e_s = saturation vapour pressure [kPa]
e_a = actual vapour pressure [kPa]
$e_s - e_a$ = saturation vapour pressure deficit [kPa]
$\triangle$ = slope of function $e_s = f(T)$
γ = psychrometric constant [kPa/^{o}C]

The crop coefficient is the ratio of the potential crop evapotranspiration to ET_0. The outputs of the model are the monthly irrigation water requirement for each crop. It is used as input for the MIKE Basin model.

MIKE Basin Model

MIKE Basin 2002 was applied to assess the available water in Ea Knir Catchment, and to assess the potential of the current irrigation supply of the Ea Kao reservoir. MIKE Basin is a river basin simulation model. It uses the water quantity mass balance approach for every node and branch of the schematized river network. Model input data are specific runoff, land use, and the characteristics of Ea Kao and Ea Chukap reservoirs.

Ea Knir Catchment has a node and branch structure (Figure 5). Branches represent the main river or its tributaries. The nodes present the control points where water activities take place such as the transfer of water from branch to branches, supply of water for the irrigation system, and storage and release of water from reservoirs. The catchment is divided into five sub-catchments (Table 2).

The system has 24 nodes including two reservoirs, 23 branches, and is formed as follows:

- Lumping of the small river into one simple branch upper stream of an intake point
- Lumping of the small irrigation area into one single scheme with one intake point
- Water intake to the system can be specified through a fictitious branch to the intake node

The stream flow at each river node is basic input for a mass balance computation. In case the reservoir is located at the node, the water balance computation is based on the reservoir sub-model.

Table 2. Sub-catchment in Ea Knir Catchment

Sub-catchment	Sub-catchment area (km²)	Scheme	Crop	Area (ha)
Ea Chukap	41.5	R301	Rice	50
		C303	Coffee	110
		C305	Coffee	2 376
Ea Nao	26.0	R307	Coffee	188
		C309	Rice	50
		C311	Coffee	363
Ea Tam	82.0	R319	Rice	16
		C321	Coffee	327
		R323	Rice	251
		C325	Coffee	1 705
Ea Kao	68.0	C327	Coffee	994
		R329	Rice	184
		R331	Rice	126
		R333	Rice	224
		C335	Coffee	335
Hoa Phu	22.5	C337	Coffee	351
		R339	Rice	141
Total	240		Coffee	**6 749**
			Rice	**1 042**

Source: Hao (2002)

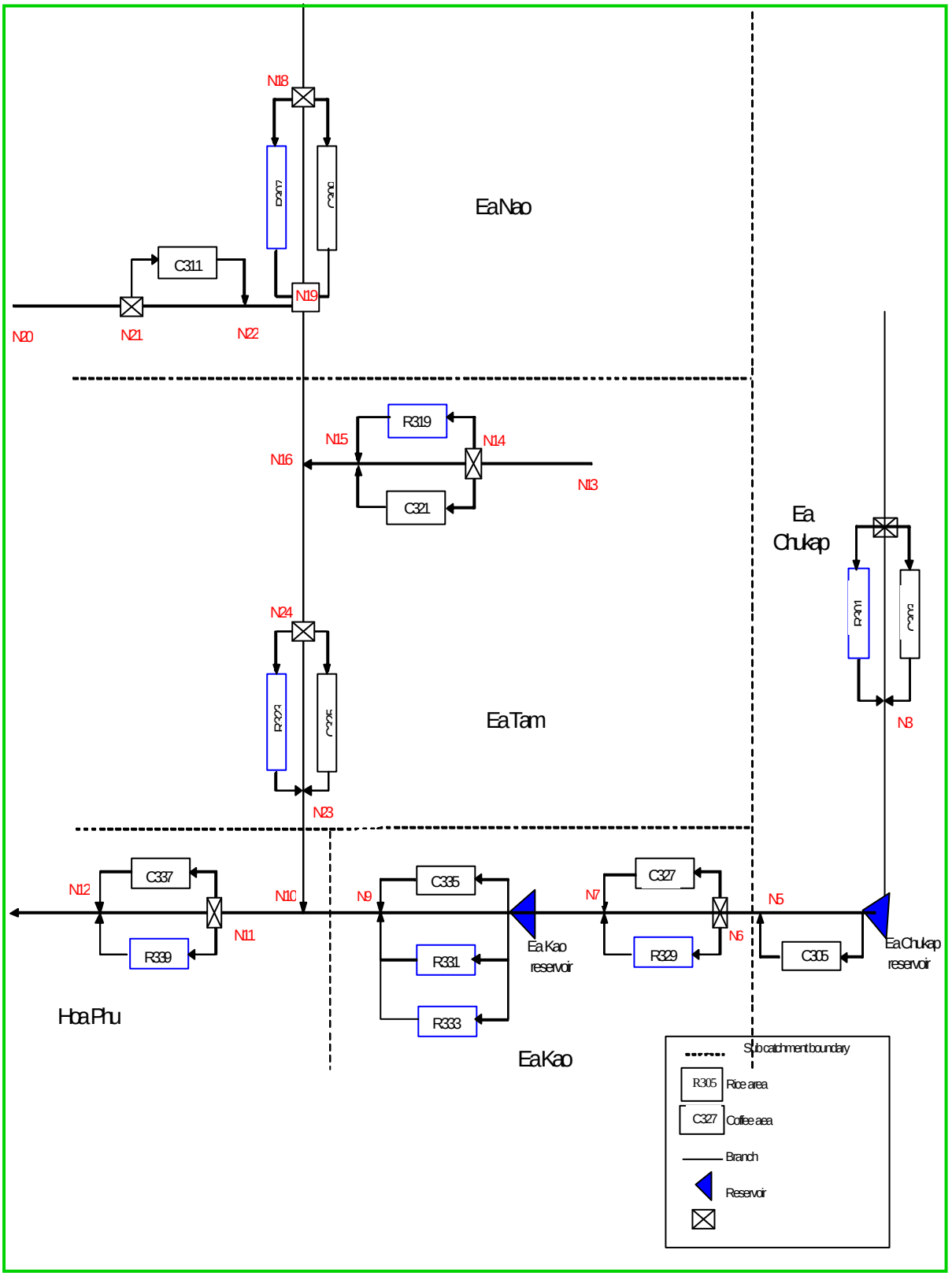


Figure 5. Schematic of Ea Knir Catchment

Reservoirs

Input data for reservoirs include inflow to the reservoir, rainfall, evaporation, infiltration, and water irrigation requirement. For each time step (e.g. each month), the reservoir water balance was simulated as follows:

- Inflow from the upstream river(s) is added to the reservoir storage;
- The reservoir level and the surface area are calculated based on the reservoir height-area-volume curves;
- Precipitation is added to the reservoir main storage (based on the actual reservoir surface area);
- Evaporation losses are extracted from the reservoir main storage (based on the actual reservoir surface area);
- Bottom infiltration, based on the actual reservoir surface area and a user-defined infiltration velocity, is extracted from the reservoir main storage;
- If the reservoir water level, after releasing water to ensure minimum release and distributing water to the users, is still above the flood control level, water will be released to the downstream river in order to lower the reservoir level to the flood control level. The total release rate from the reservoir, however, will not exceed the user-specified maximum downstream release rate (normally equal to the maximum non-damaging release rate).

Results and discussion

In this study, the CROPWAT 7.0 and MIKE Basin 2002 models were used. The CROPWAT model output gives the irrigation water requirement of the cropped areas. This output was used as input in the MIKE Basin model together with the specific runoff of the catchment and data of the reservoirs. The output of the model will show the situation of irrigation water availability for each irrigated area in Ea Knir Catchment, as well as the operation rules of Ea Kao and Ea Chu Kap reservoirs.

Crop irrigation water requirement

Table 3. Average monthly water requirement of coffee areas in the dry season

Sub-catchment	**Eachukap**	**Eachukap**	**Eanao**	**Eanao**	**Eatam**	**Eatam**	**Eakao**	**Eakao**	**Hoa phu**
Scheme	**C303**	**C305**	**C307**	**C311**	**C321**	**C325**	**C327**	**C335**	**C337**
Area	110	2376	187.5	362.5	327	1705	994	335	351
Water req.	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
Nov	0.0245	0.5287	0.0417	0.0807	0.0728	0.3794	0.2212	0.0668	0.0781
Dec	0.0492	1.0628	0.0839	0.1622	0.1463	0.7627	0.4446	0.1342	0.1570
Jan	0.0697	1.5052	0.1188	0.2296	0.2072	1.0801	0.6297	0.1901	0.2224
Feb	0.0773	1.6701	0.1318	0.2548	0.2298	1.1984	0.6987	0.2109	0.2467
Mar	0.0755	1.6308	0.1287	0.2488	0.2244	1.1702	0.6822	0.2059	0.2409
Apr	0.0409	0.8828	0.0697	0.1347	0.1215	0.6335	0.3693	0.1115	0.1304

(*) the areas shown in the map (Figure 1a)

Table 4. Average monthly water requirement of the spring rice areas

Sub-catchment	Eachukap	Eanao	EaTam	Eatam	Eakao	Eakao	Eakao	Hoa phu
Scheme	R301	R309	R319	R323	R329	R331	R333	R339
Area	50	50	16	251	184	126	224	141
Water req.	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	$m^3.s$
Nov	0.000	0.000	0.000	0.002	0.002	0.001	0.002	0.001
Dec	0.082	0.082	0.026	0.409	0.300	0.206	0.365	0.230
Jan	0.069	0.069	0.022	0.346	0.254	0.174	0.309	0.194
Feb	0.077	0.077	0.025	0.385	0.282	0.193	0.344	0.216
Mar	0.076	0.076	0.024	0.382	0.280	0.192	0.341	0.214
Apr	0.012	0.012	0.004	0.060	0.044	0.030	0.054	0.034

(*) the area is shown in Figure 1a

Table 5. Average monthly water requirement of monsoon rice areas

Sub-catchment	Eachukap	Eanao	EaTam	Eatam	Eakao	Eakao	Eakao	Hoa phu
Scheme	R301	R309	R319	R323	R329	R331	R333	R339
Area	50	50	16	251	184	126	224	141
Water req.	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	$m^3.s$
May	0.002	0.002	0.001	0.009	0.006	0.004	0.008	0.005
Jun	0.036	0.036	0.012	0.182	0.133	0.091	0.162	0.102
Jul	0.019	0.019	0.006	0.094	0.069	0.047	0.084	0.053
Aug	0.016	0.016	0.005	0.082	0.060	0.041	0.073	0.046
Sep	0.008	0.008	0.003	0.039	0.029	0.020	0.035	0.022
Oct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(*) the area is shown in Figure 1a

CROPWAT 7.0 was used to estimate the water requirement for each irrigated area (scheme). There are 17 irrigation schemes — nine for coffee trees and eight for rice. The cropping patterns are the same for all schemes. Spring rice starts on 20 December and monsoon rice on 15 June. For coffee, the water requirement period is year long, starting on 15 December as the first irrigation of the year.

October is the break between the two rice seasons, so no irrigation water is needed during this time. During the dry season, coffee has the highest water demand in February (Table 3), and rice in December (Tables 4 and 5).

Available water in Ea Knir Catchment

Monthly hydrological data of 23 years were used to simulate the water balance in the area.

From the result of the simulation, the reliability of irrigation areas was analysed. An irrigation scheme is considered reliable if its water deficit does not exceed 20 percent of the given time period (Hashimoto et al., 1982). According to the simulation, most of the areas exceeded 20 percent from 1990 to 2000. Table 6 shows that 11 out of the 17 irrigation schemes were not reliable, implying the catchment has a serious lack of water.

Table 6. Reliability of the irrigation schemes

Catchment	Irrigation scheme	Total months in period	No. of water deficit months	Percentage	Water deficit period	Reliable scheme
Ea Chukap	C303	288	108	37.5	Oct-Apr	N
	R301	288	85	29.5	Dec-Apr	N
	C305	288	69	24.0	Jan-Apr	N
Ea Nao	C311	288	101	35.1	Oct-Apr	N
	C307	288	101	35.1	Oct-Apr	N
	R309	288	0	0.0	Dec-Apr	Y
Ea Kao	C327	288	70	24.3	Oct-Apr	N
	R329	288	91	31.6	Nov-Apr	N
	C335	288	0	0.0	Mar-Apr	Y
	R331	288	0	0.0	Mar-Apr	Y
	R333	288	1	0.3	Mar-Apr	Y
Ea Tam	C321	288	79	27.4	Nov-Apr	N
	R319	288	51	17.7	Nov-Apr	Y
	C325	288	78	27.1	Oct-Apr	N
	R323	288	88	30.6	Nov-Apr	N
Hoa Phu	C337	288	0	0.0	Dec-Apr	Y
	R339	288	1	0.3	Dec-Apr	YY

Table 7. Water deficit of Ea Knir Catchment (m^3/s)

Sub-catchment	Irrigation Scheme	Water deficit in months during the dry season					
		Nov	Dec	Jan	Feb	Mar	Apr
EaChukap	C303	0.005	0.043	0.059	0.062	0.059	0.027
	R301	0.000	0.049	0.057	0.059	0.047	0.000
	C305	0.000	0.357	0.764	1.428	1.506	0.691
Eanao	C311	0.018	0.089	0.146	0.156	0.109	0.035
	C307	0.000	0.062	0.071	0.080	0.068	0.000
	R309	0.000	0.059	0.099	0.107	0.086	0.000
EaTam	C321	0.006	0.008	0.134	0.155	0.058	0.000
	R319	0.000	0.005	0.062	0.052	0.012	0.000
	C325	0.000	0.027	0.642	0.821	0.694	0.000
	R323	0.000	0.015	0.416	0.531	0.431	0.000
Ea Kao	C327	0.000	0.099	0.197	0.380	0.372	0.000
	R329	0.000	0.096	0.276	0.299	0.274	0.000
	C335	0.000	0.000	0.012	0.019	0.017	0.000
	R331	0.000	0.000	0.008	0.015	0.015	0.000
	R333	0.000	0.000	0.015	0.026	0.025	0.000
Hoa Phu	C337	0.000	0.000	0.000	0.000	0.000	0.000
	R339	0.000	0.000	0.003	0.000	0.000	0.000

As shown in Table 7, the biggest water shortage (1.428 m^3/s) occurs in the coffee area (C305) because the coffee area expanded quickly from 1995 to 2000. The areas C335, R331, and R333 have not faced shortage of water because they are supplied by Ea Kao reservoir. Lack of water frequently occurs in the dry season for many areas such as Ea Chukap (C303, C305, R301) and Ea Kao (C327, R329). In 2000, the area of wet rice was 1 042 ha and the area of coffee was 6 713 ha; the total area in the catchment lacked irrigation water, especially in the dry season.

From the simulation, total available water at every node is much greater than demand. However, the water entering the nodes fluctuates sharply. Most water entering the nodes during the rainy season is released downstream because at that time, crops do not need irrigated water or need less and it is not stored. However, no node satisfied the irrigation needs for irrigation areas in the dry season. Thus, lack of water still occurs in the nodes. Node N 24 in Ea Tam sub-catchment needs more than 9.27 MCM, node N6 in Hoa Thang and Ea Tieu communes belonging to Ea Kao sub-catchment needs more than 5 MCM of irrigated water for irrigation in the dry season. Nodes N18 and N21 in Ea Nao, and N2 in Ea Chukap also need 1.63 MCM, 1.87 MCM, and 1.23 MCM respectively (Table 8).

Table 8. Comparison of water requirement and water reliability at nodes

Sub-catchment	Node		Average monthly water (m^3/s)						Total (m^3/s)	Total MCM
			Nov	Dec	Jan	Feb	Mar	Apr		
		W. Av	0.098	0.022	0.004	0.006	0.024	0.095		
Ea Chukap	N2	Demand	0.025	0.122	0.128	0.143	0.137	0.049		
		Shortage	0.000	-0.100	-0.124	-0.137	-0.113	0.000	-0.47	**-1.23**
		W. Av	1.328	0.518	0.372	0.261	0.263	0.447		
EA Kao	N6	Demand	0.223	0.713	0.845	0.940	0.909	0.398		
		Shortage	0.000	-0.195	-0.473	-0.679	-0.646	0.000	-1.99	**-5.16**
		W. Av	0.701	0.157	0.030	0.044	0.174	0.686		
Ea Tam	N14	Demand	0.073	0.170	0.226	0.251	0.244	0.124		
		shortage	0.000	-0.013	-0.196	-0.207	-0.070	0.000	-0.49	**-1.26**
		W. Av	0.160	0.036	0.007	0.010	0.040	0.156		
Ea Nao	N18	Demand	0.042	0.157	0.177	0.197	0.190	0.077		
		Shortage	0.000	-0.121	-0.170	-0.187	-0.150	0.000	-0.63	**-1.63**
		W. Av	0.302	0.068	0.013	0.019	0.075	0.295		
Ea Nao	N21	Demand	0.081	0.162	0.230	0.255	0.249	0.135		
		Shortage	0.000	-0.094	-0.217	-0.236	-0.174	0.000	-0.72	**-1.87**
		W. Av	2.859	1.086	0.316	0.175	0.354	1.345		
Ea Tam	N24	Demand	0.382	1.128	1.374	1.527	1.479	0.673		
		Shortage	0.000	-0.042	-1.058	-1.352	-1.125	0.000	-3.58	**-9.27**

(*) Water availability

Table 9. Comparison of water availability and demand at reservoirs in Ea Knir Catchment (m^3/s)

Reservoir		**Ea Kao**			**Ea Chukap**	
Node		**R8**			**R4**	
	W. Av	**Demand**	**Shortage**	**W. Av**	**Demand**	**Shortage**
Nov	2.324	0.070	0.000	0.831	0.529	0.000
Dec	0.821	0.644	0.000	0.706	1.063	-0.357
Jan	0.565	0.600	-0.035	0.741	1.505	-0.764
Feb	0.608	0.669	-0.061	0.242	1.670	-1.428
Mar	0.58	0.637	-0.057	0.125	1.631	-1.506
Apr	0.245	0.166	0.000	0.192	0.883	-0.691
Total (m^3/s)		**2.787**	**-0.153**		**7.280**	**-4.746**
	Total MCM	**7.463**	**-0.410**		**15.237**	**-12.711**

The storage of Ea Kao reservoir seems to be enough for irrigation of 350 ha of rice (schemes R331 and R333) and 335 ha of coffee (scheme C335) in comparison with other schemes as shown in Table 7. For the Ea Chukap reservoir, total water shortage for coffee in scheme C305 in the dry season is 12.711 MCM (Table 9). The worst water shortage occurs in January with 0.764 m^3/s. The shortage lasts from December to April of the following year.

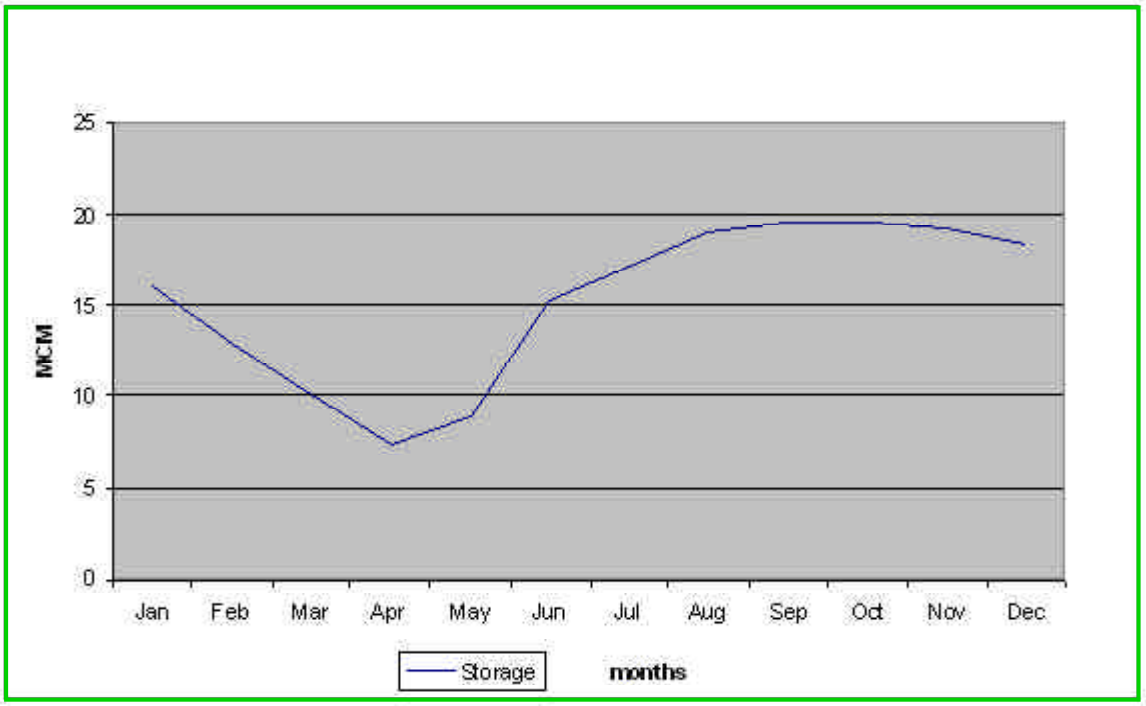


Figure 6. Operation curve of Ea Kao reservoir

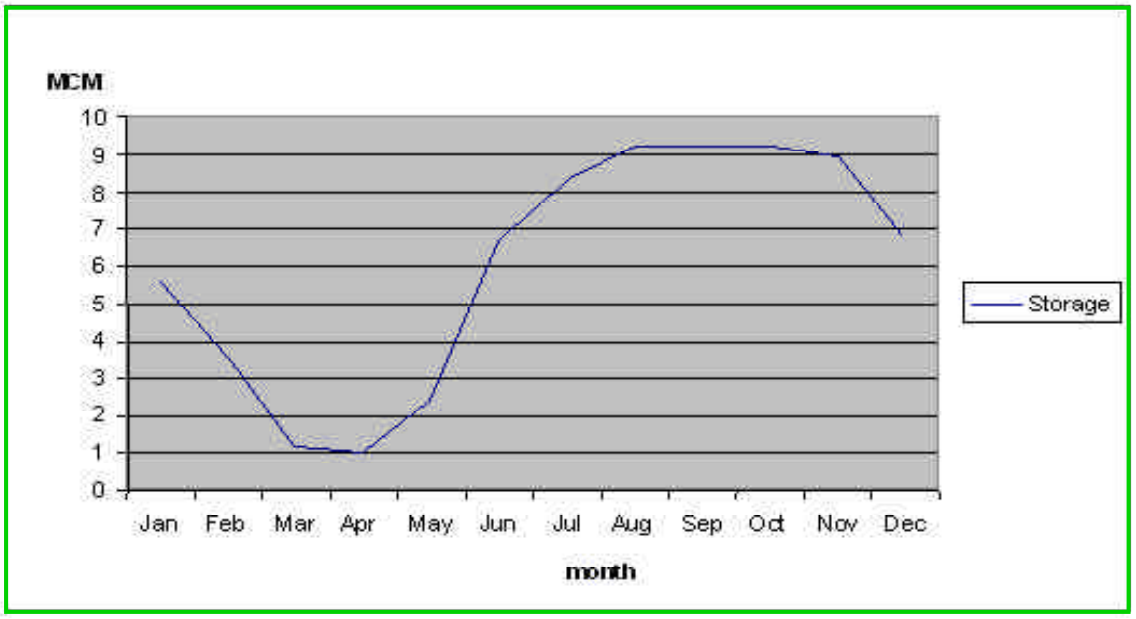


Figure 7. Operation curve of Ea Chukap reservoir

Irrigation areas under Ea Kao reservoir lack 0.41 MCM in the dry season. In the rainy season, if inflows to the reservoir exceed the storage of 17.763 MCM, the extra water will be released downstream. Throughout the year, the storage of the reservoir is always kept more than or equal to the dead storage (4 MCM) and its outflow ensures slow flow of the canals downstream for ecological purposes. Assuming that the storage of the reservoir at the beginning of the simulation time was 17.763 MCM, Figure 6 shows the monthly operation curve of Ea Kao reservoir.

Because of the serious lack of water, Ea Chukap reservoir always keeps full storage of 9.4 MCM when possible. Assuming that at the beginning of the simulation the reservoir level was 509 m (storage = 7.8 MCM), in the rainy season, the extra water will be released when the storage reaches 9.4 MCM. The operation curve of Ea Chukap reservoir is shown in Figure 7.

Water balance in the catchment

Based on the land and water resource capacity in the catchment, in the current situation, the requirement for irrigation exceeds the capacity of available water sources. Therefore, future options will lean towards alleviating irrigation demand in two ways: the paddy rice should be replaced by crops which demand less irrigation, or the area of coffee should be reduced. The water shortage response to the reduction of irrigated areas in the dry season is shown in Table 10.

Table 10. Water shortage response to irrigated area reduction (MCM)

Sub - catchment	Node	Percentage of reduction area							
		0%	10%	20%	30%	40%	50%	60%	70%
Ea Chukap	N2	1.23	0.90	1.00	0.86	0.71	0.57	0.43	0.28
EA Kao	N6	5.16	2.98	2.52	2.04	2.10	1.04	0.62	0.25
Ea Tam	N14	1.26	1.14	0.94	0.74	0.60	0.47	0.34	0.20
Ea Nao	N18	1.63	1.23	1.33	1.13	0.94	0.74	0.54	0.35
Ea Nao	N21	1.87	1.54	1.55	1.30	1.05	0.80	0.55	0.33
Ea Tam	N24	9.86	8.13	7.01	5.94	4.84	3.73	2.62	1.49
Total		21.01	15.91	14.35	12.01	10.24	7.35	5.09	2.90

Node N2 covers the supply of irrigated water for schemes R301 and C303
Node N6 covers the supply of irrigated water for schemes R329 and C327
Node N14 covers the supply of irrigated water for schemes R319 and C321
Node N18 covers the supply of irrigated water for schemes R307 and C309
Node N21 covers the supply of irrigated water for scheme C311
Node N24 covers the supply of irrigated water for schemes R323 and C325

As shown in Table 10, reduction of 70 percent of the irrigated area almost addresses the water shortage problem. However, the shortage of water at nodes N18 and N21 does not seem to decrease with a reduction of irrigated area. Moreover, coffee is the main crop in the area so the continued reduction of the irrigated area of coffee will affect the income of many farmers. Therefore, the reduction of 30 percent of the irrigated area is reasonable. The remaining shortage of irrigation water will be partly satisfied by irrigation techniques for saving water (e.g. drip irrigation system) and irrigation management.

The coffee area in the catchment should be replaced by other crops such as cashew or orchards in sub-catchments Ea Chukap (C303), Ea Nao (C307, C311), and Ea Tam (C321, C325) and 30 percent of the rice area should be changed to other crops which demand less or no water. The coffee area under Ea Chukap reservoir has been reduced by 30 percent. It should keep the same crop

regime as Ea Kao reservoir (C335, R331, and R333) and in Hoa Phu sub-catchment (C337 and R339). The total area of coffee is 4 930 ha and the total area of the two rice crops is 701 ha under the proposed scheme (Table 11).

Table 11. Proposed agricultural areas in Ea Knir Catchment

Sub-catchment	No. of irrigated area	Crop	Current area (ha)	Future area (ha)	Remark
Ea Chukap	301	Rice	50	35	Reduced 30%
	303	Coffee	110	77	Reduced 30%
	305	Coffee	2 376	1663	Reduced 10%
	307	Coffee	188	132	Reduced 30%
Ea Nao	309	Rice	50	35	Reduced 30%
	311	Coffee	363	254	Reduced 30%
	319	Rice	16	11.2	Reduced 30%
Ea Tam	321	Coffee	327	229	Reduced 30%
	323	Rice	251	175	Reduced 30%
	325	Coffee	1 705	1 194	Reduced 30%
	327	Coffee	994	695	Reduced 30%
	329	Rice	184	128	Reduced 30%
Ea Kao	331	Rice	126	126	Kept the same
	333	Rice	224	224	Kept the same
	335	Coffee	335	335	Kept the same
Hoa Phu	337	Coffee	351	351	Kept the same
	339	Rice	141	141	Kept the same
	Total	**Coffee**	**6 749**	**4 930**	
		Rice	**1 042**	**701**	

Under the proposed plan, Ea Chukap sub-catchment lacks 0.86 MCM of irrigation water. At node N6 along the Hoa Thang and Ea Tieu area belonging to Ea Kao sub-catchment, shortage of water (2.04 MCM) occurs from January to March; the total deficit has been reduced to 0.79 m^3/s from 1.93 m^3/s. The deficit is partly compensated by three weirs: Ea Tieu 1, Ea Tieu 2, and Ea Ung (see Figure 1a). At node N24 (the lower section of the Ea Tam Catchment) belonging to the precinct of Tan Lap, Tu An, there is a shortage of water from January to March; the deficit fluctuates from 0.6 m^3/s to 0.9 m^3/s. The total shortage of water is 5.94 MCM in the dry season. Due to urbanization, the area is converting to residential or industrial sites, so the irrigated water demand will decrease in the future. Irrigated areas C335, R331, and R333, supplied by Ea Kao reservoir, are unchanged; there is no water shortage in these areas.

Figure 8 shows that in Ea Kao reservoir, during the beginning of the rainy season (May to June), all inflow seems to be stored until full storage is reached. The inflow in the rainy season generates a huge amount of water in the year. The reservoir is full from August to November, thus all extra water in this period is released through the spillway, downstream.

Similarly, Ea Chukap reservoir supplies irrigated water for the coffee area (C305) of Viet Duc coffee plantation in Ea Chukap sub-catchment. Total water shortage in the dry season has been reduced from 12.711 MCM to 8.705 MCM. Hoa Dong and Ea Pak weirs can supply 0.16 MCM; but Ea Chukap reservoir still cannot supply the rest of the water deficit in the area. Although from April to November the reservoir stores water, it cannot satisfy demand in the dry season. Viet Duc Coffee

Plantation should have a plan to solve water problems in its plantation. The operation curve of Ea Chukap reservoir under the proposed plan is shown in Figure 9.

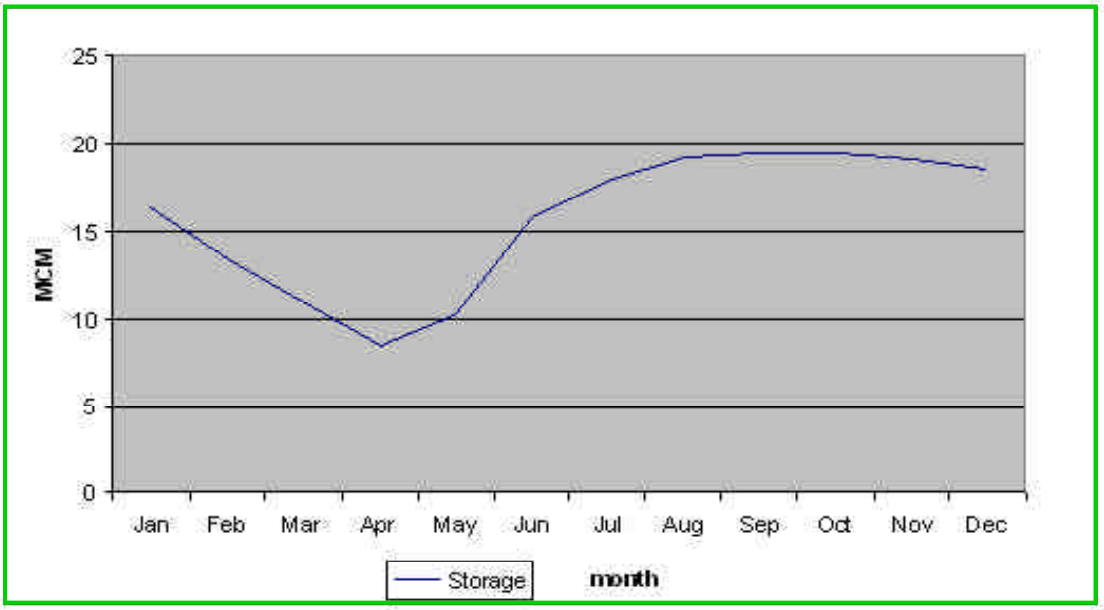


Figure 8. Operation curve of Ea Kao reservoir under the proposed plan

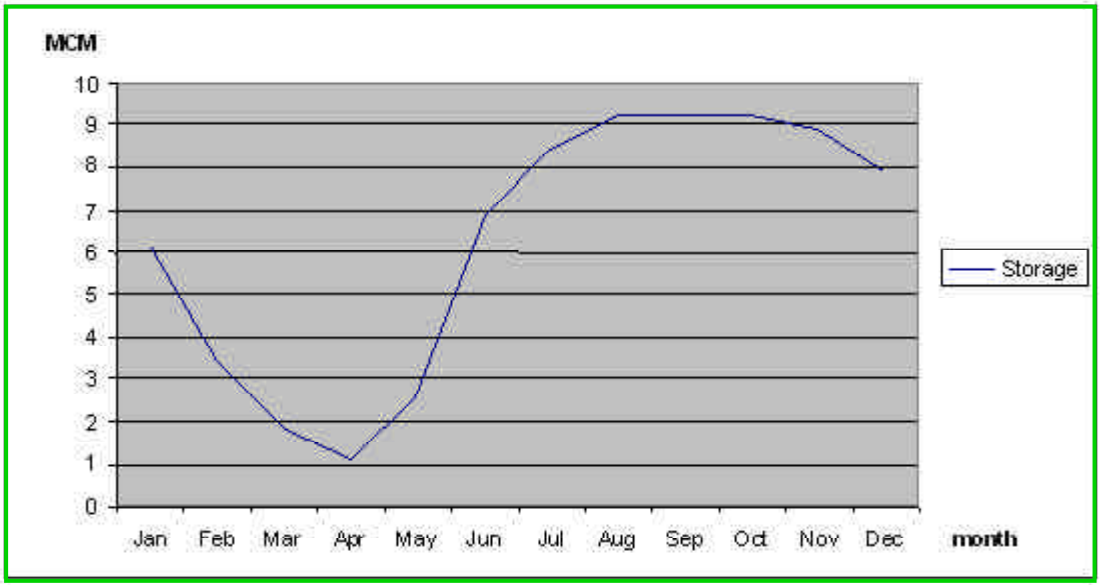


Figure 9. Operation curve of Ea Kao reservoir under the proposed plan

Evaluation of irrigation potential

Performance of irrigated agriculture is a criterion to assess irrigation systems. According to Douglas (1996), performance refers to whether an irrigation system is achieving its objectives or meeting the user's expectation. Agricultural performance includes changes in cropping pattern, cropping intensity, and yield rates. These indicators are also influenced by other variables such as availability of markets, modern inputs, and technology; all these variables need irrigation facilities (Ostrom and Shivakoti, 2002). The Ea Kao irrigation system was chosen to assess the irrigation potential.

Cropping pattern

The areas originally planned for irrigation and the actually irrigated areas in all communities within the Ea Kao irrigation schemes are given in Table 12. The proportions of the actually irrigated areas to the areas originally planned for irrigation vary widely between communities and between crops (i.e., coffee and rice). Lower proportions of actually irrigated areas are generally observed at higher elevations and in areas located further away from the water source. This applies particularly to the rice growing areas in Hoa Phu and Tan Thanh communes.

Table 12. Planned and actually irrigated areas in Ea Kao irrigation schemes

Commune	Coffee (ha)			Rice (ha)		
	Designed	Irrigated	Percentage	Designed	Irrigated	Percentage
Ea Kao	355	85	24	218	120	55
Ea Tam	85	35	41	45	16	36
Tan Thanh	275	52	19	13	0	0
Khanh Xuan	105	50	48	140	137	98
Hoa Khanh	390	65	17	90	60	67
Hoa Phu	155	15	10	41	0	0
Hoa Xuan	305	33	11	33	17	52
	Total	**1 670**	**335**		**580**	**350**

Source: Survey (2003)

Cropping intensity

Table 13. The cropping intensities in Ea Kao Catchment

Commune	Spring rice	Monsoon rice	Intensity
Ea Kao	120	218	155
Ea Tam	16	45	136
Tan Thanh	0	13	100
Khanh Xuan	137	140	198
Hoa Khanh	60	90	167
Hoa Phu	0	41	100
Hoa Xuan	17	33	152
	Total	**350**	**580**

Source: Survey (2003)

Cropping intensity was measured based on the data of actual cropped areas and cultivated command areas from the cropping year of 2003 in seven communes. A cropping intensity of 100 percent means that all land in an irrigation system is under one full crop for one season or partial use over multiple seasons, amounting to the same coverage. Similarly, the crop intensity of 200 percent is full use of all land for two seasons. The designed area is also the actual cropped areas in Ea Kao; in the monsoon rice crop, all land is used for rice planting, however, in spring, only some of the land is used. The cropping intensity is shown in Table 13.

Crop yields

Crop yield reflects whether water supply is adequate, timely, and reliable in irrigation systems. So crop yield is affected by irrigation management. The average crop yields were assessed in general for the whole area and compared with the national yield. Average rice yield in Ea Kao was much lower than the national yield (Tables 14 and 15). This implies that water is not adequately supplied in the dry season.

Table 14. The change of paddy rice and coffee yield in t/ha in Ea Kao and Vietnam

Crop	1995	2000	2001	2002
Rice				
Ea Kao	2.98	3.85	3.55	4.49
Vietnam	4.43	5.17	5.06	5.18
Coffee				
Ea Kao	1.65	2.55	2.31	2.20
Vietnam	1.80	2.52	2.54	2.30

Source: Statistic Yearbook (2002)

Table 15. Rice yield in Ea Kao area

Location	1995	2000	2001	2002
Ea Kao	2.40	4.23	3.60	3.14
Ea Tam	2.89	3.50	3.40	3.44
Tan Thanh	3.33	4.00	3.67	4.33
Khanh Xuan	3.00	3.90	3.56	6.14
Hoa Khanh	3.20	3.80	3.40	4.20
Hoa Phu	3.00	4.00	3.60	3.89
Hoa Xuan	3.00	3.50	3.60	3.72
Average	2.98	3.85	3.55	4.12

Source: MARD (2001)

Within the Ea Kao area, Ea Kao and Ea Tam fields have lower rice yields than other communes because of the ignorance of the ethnic minority living in the area. Rice yields in Hoa Xuan and Hoa Phu communes are not much higher because they have never been supplied with enough water in the dry season; 41 ha of rice in Hoa Phu are not irrigated. In 2002, Khanh Xuan commune's leaders mobilized farmers to upgrade secondary and inner-field canals for conveying water to all parcels in their area, which resulted in peak rice yield of 6.14 t/ha. Except for Khanh Xuan, most of the communes have low yield (3.55 t/ha) compared to national yield (5.05 t/ha).

Water delivery in the schemes

The aim of an irrigation system is to meet varying water requirements at the field level. An irrigation system that does not take into account operational capacity and farmers' participation will suffer improper management, conflicts, and deterioration of the system with all the related social and economic effects (Depeweg, 1999). Crops grow optimally with an adequate supply of water, which is allocated as uniformly as possible over the land. The model simulation showed that most of the irrigation schemes lacked water except Ea Kao. The water availability for irrigation schemes under the Ea Kao reservoir is adequate. Although water deficit occurs in schemes C335, R331, and R333 from December to April, they are compensated by Ea Kao reservoir. The total water shortage in the dry season is 0.84 MCM which is not much compared to other schemes

Reliable water delivery is defined as temporal uniformity of the ratio of delivered amount of water to the required or scheduled amount. Equity in irrigation means the delivery of a fair share of water to the water users throughout the system. Many farmers who have parcels at higher elevations said that their farming activities are late because of delay in water delivery to their farms which causes their crop yields to be lower than others.

In detail, the operation of an irrigation system is based on the following issues:

- The actual decision making on water delivery to the tertiary off-take, that is, who decides on the water delivery to the tertiary units
- The method of water delivery to the off-farm distribution system, that is, how the water is allocated to the tertiary units
- The method of water division through the conveyance system, that is, how the water is conveyed and divided through the main system.

Ea Kao irrigation system is a large system which belongs to the IMC. Under the IMC, the Irrigation Station manages water delivery to the distribution system. It seems that nobody decides on water delivery to the tertiary unit. When water comes to the field, farmers must be in the field to conduct water to their parcels. The staff of the station has authority to sign water-use contracts with farmers. Farmers can request water for a certain duration at a certain time. The requests are evaluated and balanced against water availability. The processing of the water requests and the response time of the conveyance system often delays the actual water delivery.

Water can be delivered to the tertiary unit according to the flow type. Proportional delivery is applied for flow in the conveyance system which is diverted at a fixed ratio of the flow to the tertiary unit. To divert the water at the off-take, an ungated divisor is required. Intermittent delivery is applied for an on/off flow which is allocated to the tertiary unit. To divert the intermittent flow, an on/off gate in the off-take is needed. There are few gates to conduct water to the tertiary units in the Ea Kao system; the flow is adjusted from the main canals. The water is allocated according to the schedule of the irrigation staff. So, when water deliveries arrive, each farmer whose parcels are in the area must conduct farming activities at the same time. The amount of water delivery to the tertiary units is carried out based on the experience of irrigation staff and farmers.

Water division through the main system of Ea Kao is carried out by off-takes. Two main off-takes distribute water from the reservoir to the main canal. One is now out of order, so much water is lost through this off-take. On the main canals, there are many on/off off-takes to divert water to the distribution system. Except in Khanh Xuan commune, all secondary canals of the system are not concrete. In the dry season, many farmers break the canal to get more water for their fields which causes the disparity in water delivery. Sixty percent of interviewed farmers proposed that in order to

get the irrigation system operating more effectively, the government should invest in construction and upgrade the system, then management should be transferred to local people.

The operation of Ea Kao irrigation system is not perfect although water availability is sufficient. Gates are required at every off-take and their number will increase with the number of movable cross regulators in the system. Operation plans for the irrigation system should be established to obtain optimal agricultural production. Operation of the conveyance and distribution system is an important tool to improve the performance of irrigation schemes.

It seems that there is no farmers' participation or ownership of the low level canal system (secondary and inter-field canals). In recent years, agricultural prices have decreased, leading to lower farmers' income. This is also one of reasons why water fee collection for irrigation operation and maintenance has failed, causing degradation of the irrigation scheme and low yields in these areas.

Conclusions

This study was conducted to simulate a water balance in Ea Knir Catchment in Dak Lak, Vietnam. Based on weather and climatic data available from 1977 to 2000, water demand was also simulated using the CROPWAT model to determine the irrigation water requirement for rice and coffee. The estimated water supply and demand were then used as inputs into the MIKE Basin model which simulates water balance in the catchment. The results indicated that there is shortage of water in many areas in the catchment during the dry season despite the presence of two small reservoirs. Since water demand for the current agricultural land use has exceeded the available water supply during the dry season, a reduction in irrigable area has to be undertaken. Based on the simulation runs to evaluate the effective area that can be fully supplied with water during the dry season, it was found that only 70 percent of the area for rice can be irrigated, which is around 701 ha. The coffee plantation on the other hand has to be reduced by 30 percent to avoid shortage of water. The yields in Khanh Xuan commune were higher than other areas because of the participation of farmers in operation of the irrigation scheme.

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