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DIVERSION REQUIREMENT ESTIMATION FOR PADDY RICE IRRIGATION SYSTEMS

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ABSTRACT

A methodology for estimating the diversion requirement of lowland rice is presented using a cropping pattern based on rainfall distribution and dependable streamflow in the Bicol River basin. The case study involves some 8,000 hectares to be irrigated. Results of the study showed decadal irrigation diversion requirement varying from 0.07 to 1.76 liters/second/ha depending upon effective rainfall and crop growth stage. These figures are useful for system design and operation including water management.

INTRODUCTION

Rice is a staple food of about half of the world's population and more than ninety percent of it is produced in the Far East and Asia. Production involves diverse cultural methods varying from unflooded or rainfed conditions where the soil is intermittently moist to flooded condition where the crop is grown continuously submerged. Water is considered one of the most important factor of production (Grist, 1959). A deficiency below recommended water depth or excess above tolerable flooding depth during a safe duration period will significantly affect the yield. Thus, the right amount of water supply must be applied at the right time to insure proper land preparation, healthy crop growth and development.

Diversion requirement refers to the gross amount of water diverted from a water source at the headwork of an irrigation system. It is affected by such factor as potential evapotranspiration rate, distribution and conveyance efficiencies and in general on-farm water management practices. Paddy rice is basically flooded rice where water is maintained at a certain depth for varying periods of time depending on crop growth stage. A paddy bund or dike is needed to hold the water, observed to be effective in preventing the growth of weeds.

PROJECT AREA DESCRIPTION

The project area used to illustrate the methodology is located in the Bicol River Basin, Luzon Island, Philippines. It has humid tropical environment with annual rainfall exceeding 2000 millimeters and annual evaporation of about 1650 millimeters. Mean temperature is about 27 degrees with a range of plus or minus 5 degrees. Mean relative humidity varies from 70-90%. The area is subject to frequent flooding during the months of October to December with its generally flat topography (USBR, 1967). The flood plain consists mostly of rich agricultural lands of clayey soils and low percolation rates. There is no pronounced dry season but with heavy rainfall from July to December.

The major source of water supply is the Bicol River with a catchment area of 1714 sq. km. at proposed diversion site. Actually, several water resources consultants have already studied the area for irrigation development. The latest study was undertaken by 2 foreign firms in association with 2 local consulting groups with technical assistance fund provided by UNDP and the Japanese government through the Asian Development Bank (ADB). The specific project area used for estimation of diversion requirement is some 8000 hectares most of which have well planned irrigation system.

Climatic condition in the area allows the cultivation of a wide variety of crops. There is, however occurrence of inadequate rainfall and irrigation water during the dry season especially in drought years. Rice is extensively cultivated with prevalence of rice-rice cropping system.

METHODOLOGY

The estimation of diversion requirement starts with the estimate of potential evapotranspiration (PET). Fig. 1 shows a schematic flow chart of the methodology showing various data requirements and components. The National Irrigation Administration has used either the Hargreaves method or the Blaney-Criddle equations, both of which were developed in the U.S. to estimate potential evapotranspiration (NIA, 1987). Most water resources consultants who worked in the Bicol River basin had also used the equations even if they over-estimate the actual PET values due to almost uniform temperature throughout the year.

The project feasibility study staff of BCEOM-HALCROW (1990) decided to use a modified Penman method to estimate PET using available data at Pili, Camarines Sur which is centrally located in the basin. Daily values of PET had been computed for period 1979-1988 using methodology as presented by FAO (1983). A computer program written in GW Basic language was used to compute daily PET after the incorporation of suggested modifications in Penman (1979). The value of A and B for the global radiation regression equation are 0.16 and 0.43, respectively.

The consumptive use or amount of water used up by the crop for evaporation and transpiration was estimated by applying a crop factor, KC which relates to the actual ET under optimum soil moisture condition and is given by equation:

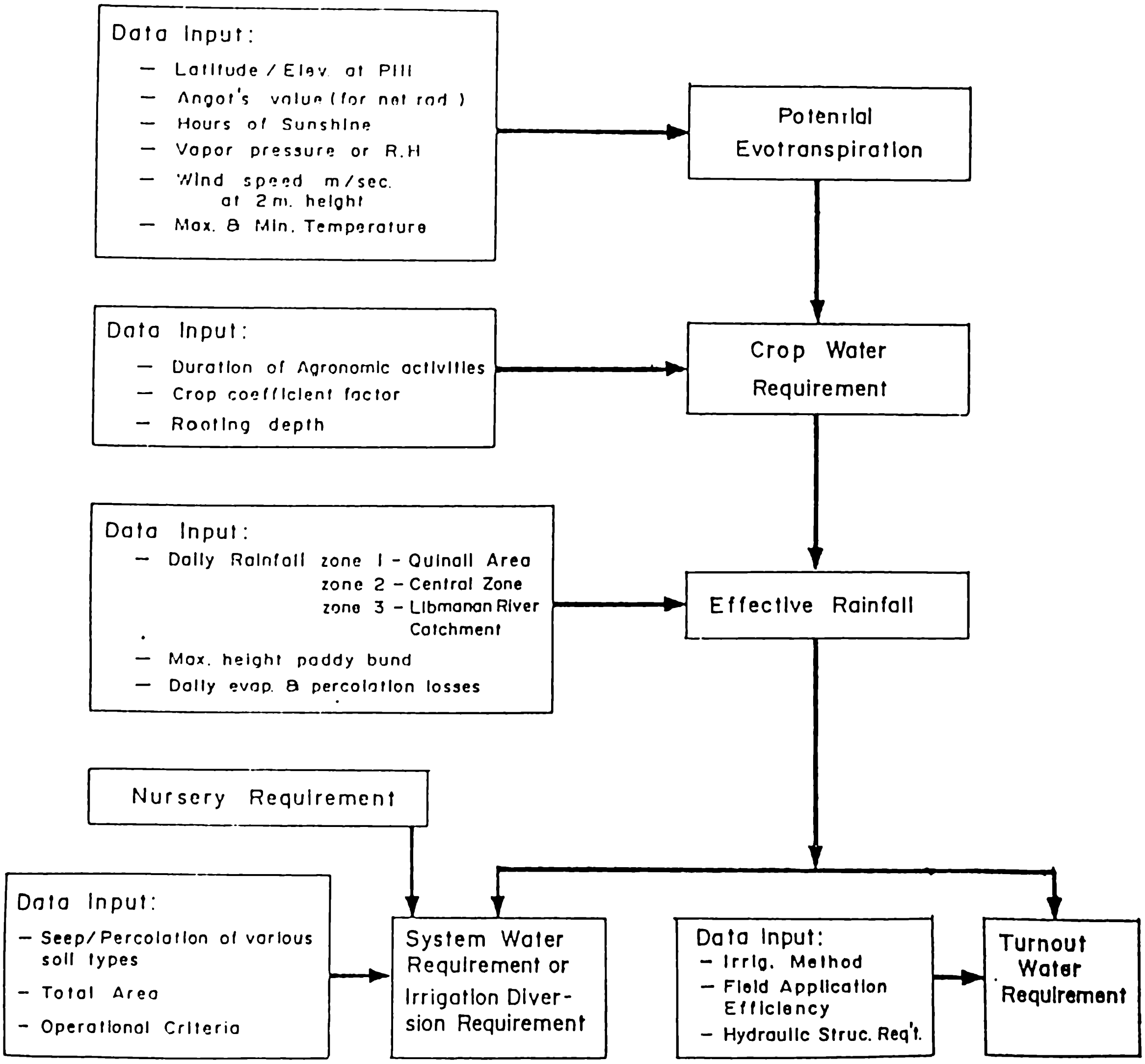


Fig. 1. SCHEMATIC FLOW CHART OF IRRIGATION DIVERSION REQUIREMENT ESTIMATION

CU = KC * PET

where

KC = crop factor or coefficient
PET = potential evapotranspiration

Based on studies by Tomas and O'Toole (1980) the values of crop growth coefficient factor (ET/EP) is 1.0 at transplanting reaching about 1.15 at maximum tillering stage and around 1.3 at flowering stage. Unlike most of irrigated crops the factor for lowland rice do not vary significantly. Fig. 2 shows the crop coefficient as affected by 2 climatic conditions as adopted from FAO (1977).

EFFECTIVE RAINFALL

With paddy bund enclosure some amount of rainfall is trapped or stored in the field as effective rainfall (ER). Standard guides adopted in the Philippines are as follows:

1. From period of land soaking to maturity ER 0; there is effective rainfall.

2. Rainfall R 5.00 mm over area on an individual day is considered non-effective; "individual" day is preceded or followed by 2 rainless days.

3. Water holding capacity of paddy field = 40.00 mm and loss of moisture through natural causes is assumed at 1 mm/day for all conditions. Thus, rainfall between 5 mm and 41 mm for any given day is considered 100% effective rainfall.

4. Initial water depth at start of land preparation equals zero.

All available annual rainfall data for Legaspi City and Pili, Camarines Sur have been subjected to 5-year moving average analysis to determine the driest 5 year series. It was found that the period 1983-1987 is the driest period for both Legaspi City and Pili.

A computer program was employed for daily water balance accounting at the paddy level. In general, the equation for daily effective rainfall for condition where daily rainfall is greater than or equal to maximum paddy retention (HMAX) is as follows:

ER = HMAX - H (previous day) + CU + PERC

where:

ER = effective rainfall
HMAX = 40 mm
H = water depth of previous day HMAX
CU = consumptive use, PET x crop factor
PERC = percolation loss

If rainfall (R) for the day is less than HMAX all of it are considered effective rainfall except when R is less than 5 mm where daily rainfall up to 2 days backward and 2 days forward are considered. If these are all zeros then ER for the day is zero.

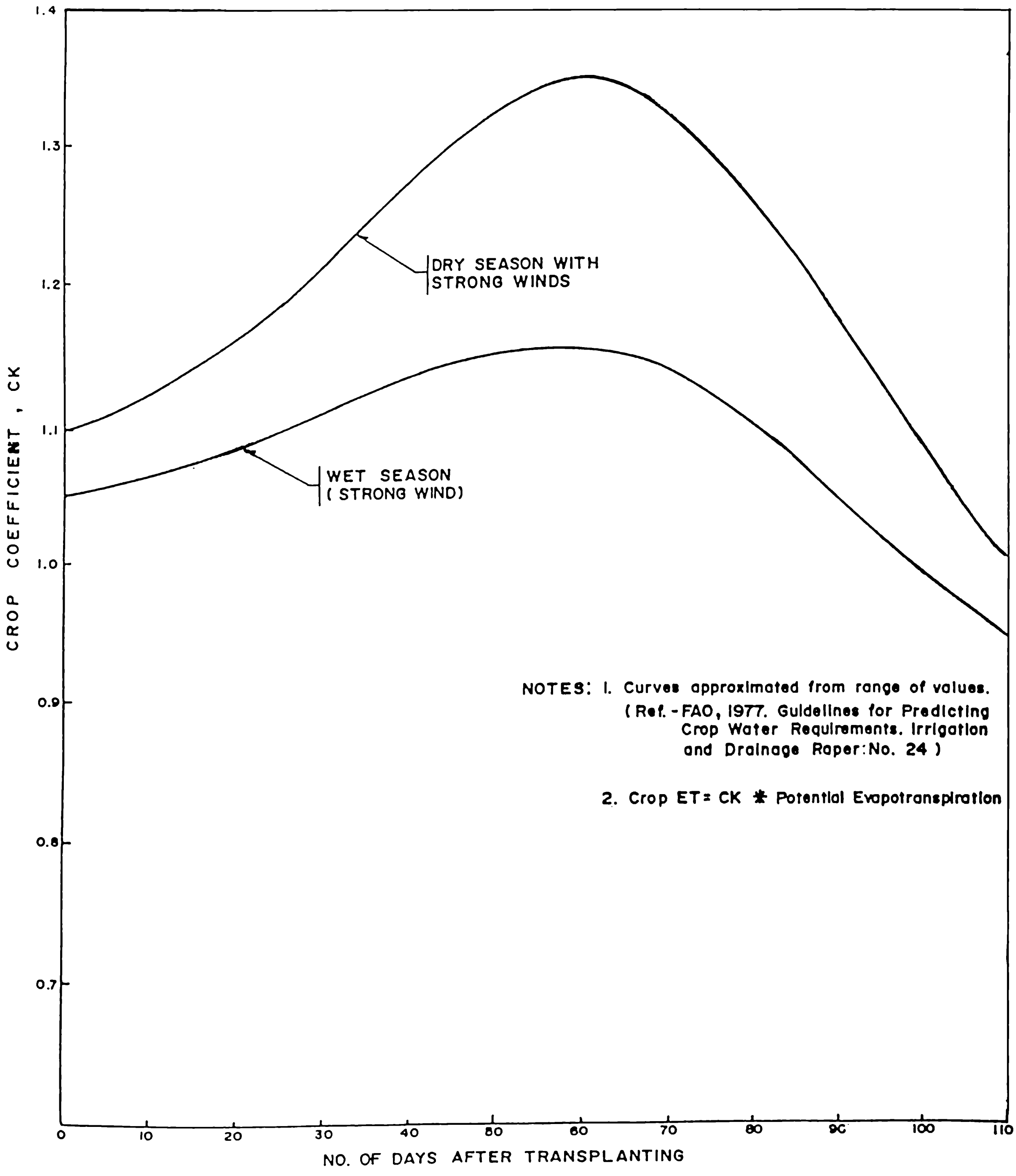


Fig. 2. CROP COEFFICIENT FOR ESTIMATE OF IRRIGATION WATER REQUIREMENT

SEEPAGE AND PERCOLATION LOSSES

Seepage account for the horizontal flow of water from the paddy field while percolation refers to the vertical movement of water. It is related to the texture of the soil and the depth of water table. For heavy soils with high water table, percolation rates are often negligible and there can even be a general upward supply of water through the soil under favorable topographic condition. Light soils and deep water table can combine to cause percolation losses in excess of 5 mm/day.

The percolation loss varies not only with soil type but also with depth of water. Normally during the wet season when water table is high its value will be less than during the dry season. For clay soils value of 1.0 mm/day is normally adopted. In view of lack of data on seepage losses which occur simultaneously with percolation loss, a value of 0.5 mm/day was added to the above figure.

LAND SOAKING AND LAND PREPARATION REQUIREMENT

In preparing the field for planting some amount of water is required for land soaking to soften the field for plowing, harrowing and other operations before planting. This was estimated using the soil physical properties as reported by NIA (1987).

The field capacity represents the maximum amount of water held against gravity force. For the Bicol area where rainfall may be considered evenly distributed, a residual moisture (RMC) equivalent to 70% of field capacity is adopted. The depth of water required for land soaking, Dls is given by equation:

$$Dls = Drz * (P - Rmc) * BD/100$$

where:

Drz = rootzone depth for rice = 300 mm
P = % porosity
Rmc = residual moisture content = 0.70 * FC
BD = bulk density = 1.1

In preparing the field it is assumed that irrigation for the whole system area could be completed in 30-40 days. The percentage of area prepared at any given time is proportional to the time duration. Thus, 50% of area must be prepared for planting within 14 days. The land soaking requirement has been calculated using Van de Goor-Zilstra formula reported by HALCROW (1989) as follows:

$$\text{Land Soaking requirement} = \frac{M \exp^{(MT/S)}}{\exp(M/S) - 1} \times 115.2$$

Where:

I = water required during pre-saturation (li/sec/ha)

M = supply required to replace seepage, percolation and consumptive uses (m/day)

T = duration of land saturation period (days)

S = water required for pre-saturation and establishing a water layer (m)

e = base of natural logarithm

The value of M is (Dls + S), Dls being equal to water for soil saturation which is given by the above equation and S is a water layer above soil surface assumed equal to 40 mm. The value 115.2 is a factor for I to be in liters per second per hectare.

NURSERY REQUIREMENT

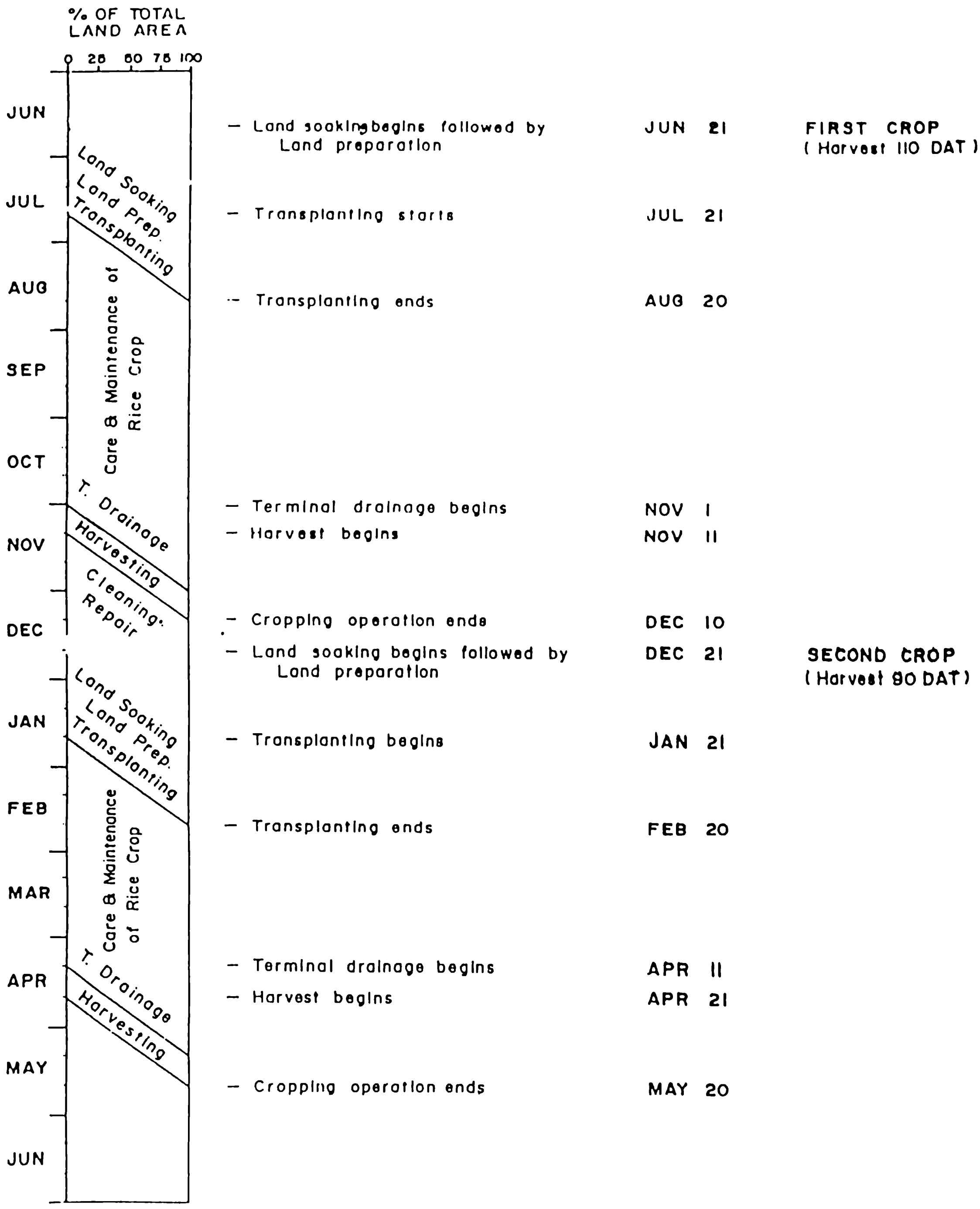
Seedling production requires an area equivalent to about 1/25 of production area. In the Bicol Region seedling matures in 20-30 days, except for the "dapog" seedbed preparation where seedlings are ready for transplanting in 10-12 days after sowing. Water required for nursery for seedling production is assumed to be only 1 mm/day over the whole production area.

CROPPING PATTERN CALENDAR

An analysis of annual rainfall distribution is needed for development of the cropping pattern calendar. In the Bicol R. Basin flood plain the months of October to December have very heavy rainfall and high frequency typhoon occurrence which results to flooding problems. Thus, the cropping pattern is adjusted such that the rice crop will not be badly affected. Fig. 3 shows a cropping pattern calender with the indicated dates of major farm operations. The slanting lines show start and end of activity normally completed in 20 days.

IRRIGATION EFFICIENCIES

The various irrigation efficiencies reported by the National Irrigation Administration shows on-farm losses of about 20%, conveyance losses at 25%. Latest data on national irrigation systems in the Philippines showed about 50% system efficiency in dry season and 43% in the wet season on the average. The following figures were used in the study:



NOTE: DAT - Days After Transplanting

Fig. 3. PROPOSED CROPPING CALENDAR
Flood Free Areas - BALIWAG-SAN VICENTE

Table 1a. IRRIGATION REQUIREMENT
CROPPING: Wet Season at Baliwag - San Vicente Project

Irrigated Area: 8,000 ha

Month	June			July			August			September			October	
Decade	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Field Status	Land Soaking	Land Prep		Transplanting			CARE AND MAINTENANCE OF CROP						T. Drainage	Harvest
Area Factor	0.25	0.25	0.50	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75	0.25
Pot. Evapotranspiration	49.26	40.03	37.35	40.04	38.38	45.06	36.05	40.51	47.89	37.76	34.42	38.45	33.08	34.37
Crop Coefficient	1.05	1.05	1.05	1.05	1.05	1.07	1.10	1.12	1.14	1.15	1.12	1.08	1.00	0.95
Consumptive Use (CWR)	51.73	42.03	39.22	42.05	40.30	48.22	39.65	45.37	54.59	43.43	38.55	41.53	33.08	32.65
Mean Rainfall (mm/10d)	16.25	80.41	69.55	145.00	123.30	74.67	41.11	41.35	80.83	70.47	51.61	64.17	109.70	82.35
80% Effective RFL	7.94	37.09	37.57	73.65	29.29	34.56	22.16	17.27	21.08	28.25	38.38	24.92	45.55	32.18
Percolation/Seep (mm/10d)	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Land Soaking WR (li/sec)*	1.44	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Land Soaking & Preparation	46.90	46.90	46.90	46.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Farm Irrigation WR **	115.80	77.04	63.74	30.49	26.20	28.85	32.69	43.30	48.71	30.38	15.37	31.81	2.73	15.67
Weighted Farm WR	28.97	19.26	31.87	22.87	26.20	28.85	32.69	43.30	48.71	30.38	15.37	31.81	2.73	11.75
Turnout WR (mm/10d)	44.57	29.63	49.03	35.18	40.31	44.38	50.29	66.62	74.94	46.73	23.64	48.93	4.20	18.08
System Efficiency	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
IDR: Depths (mm/10d)	67.53	44.39	74.29	53.31	61.08	67.25	76.20	100.90	113.50	70.81	35.83	74.15	6.37	27.40
IDR: q (li/sec/ha.)	0.78	0.51	0.85	0.61	0.70	0.77	0.88	1.16	1.31	0.81	0.41	0.85	0.07	0.31
IDR: Q (cu.m/sec)	6.23	4.07	6.80	4.88	5.59	6.15	7.03	9.27	10.47	6.48	3.27	6.80	0.56	2.48

CWR = Crop Water Requirement
RFL = Probable Effective Rainfall
WR = Water Requirement
IDR = Irrigation Diversion Requirement

* = Land Soaking Requirement estimated using Van de Goor-Zilstra Formula
** = Includes nursery requirement of 10 mm during the first 2 decades

	Dry Season (%)	Wet Season (%)
On-farm irrigation efficiency............	75	65
Conveyance efficiency....................	67	66
System (overall) efficiency	50	43

The higher system efficiency during the dry season cropping reflects greater awareness on efficient water management practices by farmers. These values vary with different irrigation systems.

DISCUSSION OF RESULTS

The various components in estimating the diversion requirement are shown in Table 1a and 1b for both wet and dry season, respectively. It also shows the month, decade and field status indicating farm operations. It can be noted that the mean rainfall is much higher than the 80% effective rainfall which is considered to be the most probable from the results of the paddy daily water balance analysis. Thus, a lot of runoff or excess water is expected from the paddy field during the heavy rainfall months. The land soaking requirement (li/sec) is required for the first 20 days and in addition the land preparation requirement is required for the next 20 days. The weighted irrigation farm water requirement (WR) which already includes the nursery requirement during the first 2 decades is simply the consumptive use minus the 80% effective rainfall plus percolation/seepage plus land soaking/land preparation requirement and the result multiplied by the area factor which is a fraction of area served during the decade. The irrigation diversion requirement (IDR) is weighted farm WR divided by the product of on-farm irrigation efficiency and conveyance efficiency. It must be noted that during the first 40 days when theoretically no crop is growing the consumptive use rate is assumed to be occurring mostly as evaporation for purposes of the analysis. The tables show straightforward presentation of the estimation procedure.

The diversion requirement at the diversion site is simply the unit IDR (li/sec/ha) multiplied by the total net irrigation service area as shown in the last row. These values are then compared with the available irrigation water supply.

Table 2 shows the results of water availability analysis for Bicol R. at proposed diversion site. Daily streamflow data for period 1960 to 1983 were analyzed to determine the various parameters on water availability. Comparison of mean Q, 80% dependable Q and 80% probable Q (see table subscript explanation) shows that the 80% dependable Q is intermediate between the mean Q and 80% probable Q. In most irrigation project studies the 80% dependable Q has been used for design purposes. It must be pointed out that some amount of flow is required downstream of diversion site for environmental consideration. Naga City and several towns with combined population of some 200,000 people will therefore be assured of good quality water. An amount of 8 cubic meters/sec was allocated for the purpose. Thus, the amount available for irrigation diversion will be limited by such requirement which could be critical during the dry season period. From Table 1b the peak irrigation diversion requirement is 14.07 cu.m/sec during the third decade of March when the available irrigation water is 13.31 cu.m/s after deducting 8 cu.m/s from

Table 1b IRRIGATION REQUIREMENT
CROPPING: Dry Season at Baliwag - San Vicente Project

Irrigated Area: 8,000 ha

Month	December		January			February			March			April	
Decade	2	3	1	2	3	1	2	3	1	2	3	1	2
Field Status	Land Soaking	Land Prep		Transplanting			CARE AND MAINTENANCE OF CROP					Drainage	Harvest
Area Factor	0.25	0.25	0.50	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75	0.25
Pot. Evapotranspiration	29.94	34.38	37.99	33.13	36.18	35.96	39.09	34.10	40.58	43.91	51.24	52.34	55.52
Crop Coefficient	1.10	1.10	1.10	1.10	1.12	1.14	1.18	1.24	1.30	1.34	1.20	1.10	1.00
Consumptive Use (CWR)	32.93	37.82	41.79	36.45	40.52	40.99	46.13	42.28	52.75	58.84	61.49	57.55	55.52
Mean Rainfall (mm/10d)	50.95	23.55	2.42	18.23	27.47	11.11	2.12	13.59	18.79	13.23	3.00	21.79	14.51
80% Effective RFL	21.85	11.68	0.68	2.21	14.99	3.09	0.92	0.00	0.00	3.33	0.00	4.91	3.09
Percolation/Seepage (mm/d)	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Land Soaking WR (li/sec)*	1.30	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Land Soaking & Preparation	46.90	46.90	46.90	46.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Farm Irrigation WR **	83.18	98.23	103.20	96.34	40.72	53.10	60.40	57.48	67.95	70.72	76.69	67.64	67.53
Weighted Farm WR	20.79	24.55	51.60	72.25	40.72	53.10	60.40	57.48	67.95	70.72	76.69	50.88	16.90
Turnout WR (mm/10d)	27.72	32.74	68.80	96.34	54.30	70.80	80.54	76.65	90.60	94.29	102.20	67.84	22.54
System Efficiency	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
IDR: Depths (mm/10d)	41.38	48.87	102.70	143.70	81.04	105.60	120.20	114.40	135.20	140.70	153.60	101.20	33.65
IDR: q (li/sec/ha.)	0.47	0.56	1.18	1.66	0.93	1.22	1.39	1.32	1.56	1.62	1.76	1.17	0.38
IDR: Q (cu.m/sec)	3.75	4.48	9.43	13.27	7.44	9.76	11.11	10.56	12.47	12.96	14.07	9.35	3.03

CWR = Crop Water Requirement
RFL = Probable Effective Rainfall
WR = Water Requirement
IDR = Irrigation Diversion Requirement

*** = Land Soaking Requirement estimated using Van de Goor-Zilstra Formula**
**** = Includes nursery requirment of 10 mm during the first 2 decades**

Table 2. Decadal Streamflow Characteristics at
Bicol R Div(Baliwag Nuevo) D.A. (km2)= 1714
Period: 1960 - 1983 Ref. G. Sta: Bicol R (Sto Domingo)

Mon	Decade	Max Q	Min Q	Median Q	Mean Q	80% Dep Q	80% Prob Q
Jan	1	345.688	9.583	86.429	110.064	48.683	31.653
	2	297.982	8.500	67.518	82.824	37.225	24.606
	3	194.029	7.369	53.314	58.591	31.771	25.073
Feb	4	205.528	5.939	46.314	54.367	29.653	19.916
	5	119.690	7.288	37.327	45.918	26.136	22.849
	6	82.457	7.764	37.677	40.581	24.924	21.752
Mar	7	99.128	7.182	29.685	36.793	23.257	18.910
	8	137.840	6.220	28.002	36.676	22.352	11.597
	9	108.608	5.014	24.247	32.957	21.314	11.552
Apr	10	91.670	4.284	21.479	29.502	19.702	11.887
	11	91.298	3.829	22.495	28.030	17.339	11.082
	12	136.459	3.737	21.794	31.387	15.970	6.777
May	13	90.437	4.504	21.261	28.048	14.947	9.303
	14	90.451	4.731	20.630	27.322	16.824	8.531
	15	130.672	3.514	22.500	36.210	17.710	9.466
Jun	16	160.074	3.595	26.903	41.615	18.310	9.001
	17	206.729	3.750	27.452	46.187	20.519	7.112
	18	175.351	5.695	38.863	60.444	26.428	17.609
Jul	19	256.600	9.650	67.045	79.359	26.772	25.140
	20	265.878	17.393	86.422	95.794	48.740	40.335
	21	264.858	17.107	104.279	105.666	71.893	51.906
Aug	22	190.756	18.403	99.497	95.149	69.958	59.214
	23	250.092	22.493	103.236	100.422	71.490	63.711
	24	231.412	36.122	101.960	93.836	56.214	57.323
Sep	25	250.069	34.780	101.855	96.660	53.938	51.058
	26	363.198	32.481	103.503	99.932	45.928	42.387
	27	315.056	26.750	116.258	110.830	64.380	57.042
Oct	28	272.725	25.735	114.946	119.757	82.994	67.499
	29	349.789	38.560	101.325	129.087	69.766	55.856
	30	334.114	36.157	95.690	108.793	63.644	50.727
Nov	31	300.906	28.072	95.951	111.001	65.776	50.052
	32	259.499	21.170	97.035	104.042	57.462	49.619
	33	315.565	24.257	110.027	113.955	51.572	47.608
Dec	34	290.560	20.023	80.956	112.879	59.015	45.246
	35	271.486	14.197	91.846	113.933	73.730	57.226
	36	341.160	11.350	93.616	116.576	51.394	46.276

Note: 1. Q in cu.meter/second
2. 80% dependable flow is flow that occurs 80% of the time (based on flow duration analyses)
3. 80% probable flow is based on equation: X=Xbar-0.821*Std (K computed using Chow Frequency Factor Formula, T=1.25yrs

the 80% dependable flow. Thus, there is a slight deficit in amount available for diversion. A re-adjustment of the cropping pattern calendar may be necessary especially if significant amount of irrigation water deficit will be expected.

CONCLUSIONS AND RECOMMENDATIONS

The results of the analysis show that a straighforward estimation of diversion requirement for paddy rice irrigation systems can be easily developed provided climatic and soils data are available; in addition to operational and irrigation management data. One must be willing to accept reasonable assumptions which can be incorporated in the computerized procedure. The values of the unit IDR which range from 0.07 to 1.76 li/sec/ha depending on decade period are within reasonable heavy rainfall and sunny condition. For purposes of design the value of 1.76 li/sec/ha could be adopted.

It is recommended that for paddy rice irrigation systems the diversion requirement must be estimated using as much as possible available local climatic, soils and operational data. Since the question of water availability can be misleading a criteria must be adopted with respect to streamflow characteristics. Using only the mean daily or monthly streamflow can result to overdesign of irrigation systems. Such criteria as 80% dependable flow, 80% probable flow or other criteria may be worth investigating through research and development activities.

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