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MULTI-CRITERIA IRRIGATION PLANNING FOR DRY SEASON CROPS

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A linear programming simulation model and a multi-objective analysis model have been developed and applied to a large irrigation system, Phitsanulok Irrigation Project, Thailand, to optimize water resources release planning from a reservoir during the dry season. The simulation model carries out sensitivity analysis to sort out promising pareto-optimal irrigation policies in terms of the system's primary objectives: net economic benefit, equity and security. The multi-objective analysis model analyzes the trade-offs between the contrasting, conflicting and non-commensurable objectives. The irrigation policy, ranked top by the model, is compared with the observed and preseason planned irrigation policy. For the effective implementation of this optimized irrigation policy, empirical relationships are developed analyzing the historical data to quantify the water availability at the field from a particular reservoir release. These empirical relationships enable prediction of the necessary reservoir release required to satisfy the irrigation system demand.

INTRODUCTION

Since about 65-70% of total annual rainfall in tropical regions occurs during the monsoon season which lasts only for three to four months, irrigated agriculture following a diversified cropping pattern faces accumulated pressure to deliver the right quantity of water at the right time during the dry season. As many users rely on reservoir storage during the dry season, water distribution planning is integrated into an overall basin framework. Competing demands from urban, industrial and recreational interests are imposing increased pressure on irrigated agriculture for higher cost-effective water use. Therefore, strategic planning for an improved irrigation water delivery system requires the exploration of system wide alternative strategies to estimate their potential impacts over the long term (Gates et al., 1991). Water resources analysts recognize that water resources planning should be comprehensive and multi-objective. Mujumdar et al. (1992) discussed performance assessment of various optimal irrigation policies for an irrigation system. Raman et al. (1992) and Onta et al. (1995) described methods of linear programming, dynamic programming and combinations of both for irrigation system optimization.

This paper describes the innovative integration of technological and managerial skill for decision support to frame optimum reservoir operating policy for a large irrigation system. A linear programming is developed and used for irrigation system simulation to search for some pareto-optimal irrigation policies in terms of benefit, equity and water supply security using both surface and groundwater. Multi-objective analysis, which involves stake holders, farmers, researchers and irrigation managers for contribution of preference value judgments of one objective over another, is carried out for selection of the most preferred optimal policy. Empirical relationships are developed between the storage reservoir and the water availability based on historical data. A reservoir water release pattern is presented that implements the proposed irrigation policy.

STUDY AREA

The Phitsanulok Irrigation Project (Figure 1) is one of the major components of the overall development of the Chao Phraya River basin. It lies between the Nan and Yom Rivers, latitude 17º 04’ N to 15º 53’ N and longitude 100º 00’ E to 101º 30’ E and covers an irrigable command area of 91,580 ha. The overall length of the irrigated area is about 131 km. The system has been divided administratively, into three sub-systems, called (from upstream to downstream) Phlai Chumphol, Dong Setthi and Tha Bua respectively as shown in Figure 1. The Phitsanulok Irrigation System draws its surface water from a single gravity intake on the Nan River, 16 km ahead of the Naresuan Diversion Dam and 175 km down from the Sirikit Reservoir. The Sirikit Reservoir, which taps the runoff of the Nan River, one of the major tributaries of the Chao Phraya River, regulates the down stream flow during both rainy and dry season. This study mainly focuses on a dry season water delivery planning for the Phlai Chumphol sub-system.

Irrigated agriculture

The irrigation system’s principal product is paddy, which is the only crop grown in the wet season. Paddy is also the dominant crop in the dry season. However, upland crops like vegetables, sugarcane, soybeans etc. are also grown in the dry season. The timing of the cropping calendar is a source of significant water management planning. Water management planning is based on the assumption that the dates of paddy planting will be spread over a range of 5 weeks (the first week of January to the end of the first week of February) as illustrated in Figure 2.

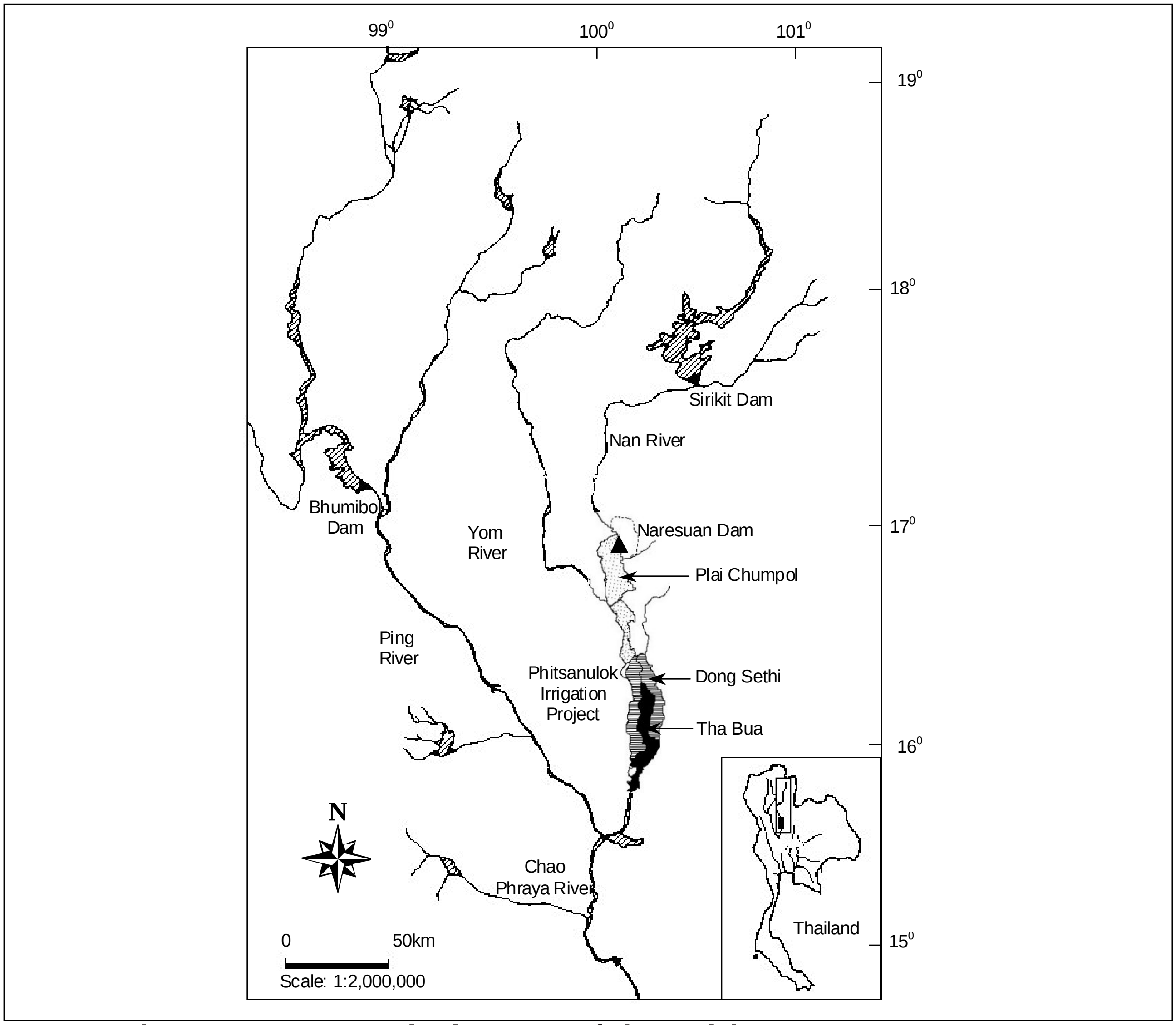

Figure 1. The Nan River Basin and Sub-Projects of Phitsanulok Irrigation.

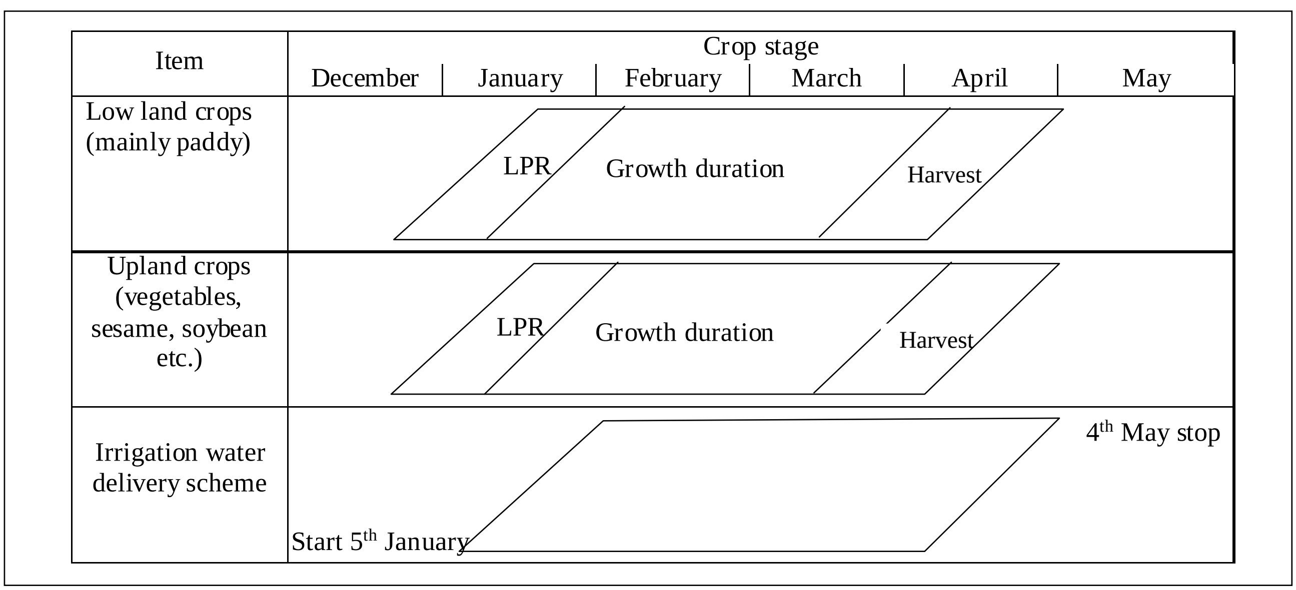

Figure 2. Dry season cropping pattern and water distribution of Phlai Chumphol sub-project. LPR stands for land preparation.

Reservoir release policy for irrigation

The major problems in water distribution and management in the irrigation system occur during the dry season, which lasts approximately from January to May. Some weeks before the dry season begins, in mid-December, the amount of water that can be released from the Sirikit Reservoir during the coming season is assessed by EGAT (Electricity Generating Authority of Thailand), RID (Royal Irrigation Department) and DEDP (Department of Energy Development and Promotion) and an initial allocation plan is drawn up for the integrated river basin framework. In the planning process, the priority is first given to the fixed water supply of Bangkok Metropolitan City, salinity control at the river mouth, navigation and domestic water users along the rivers. The remaining water is then planned for irrigation. Power generation is produced according to these planned release patterns for all users. Irrigation managers are informed of the water allocation in terms of irrigable land area. The weekly water distribution policy for the irrigation system is done at two levels, pre-season and in-season.

Pre-season planning process

To draw a weekly pre-season plan, irrigation managers of Phitsanulok Irrigation use the modified Penman Method for estimation of reference crop evapotranspiration and 50% rainfall exceedence for future rainfall expectation in the assessment of irrigation water requirements. Overall irrigation efficiency is assumed at 50% on average. Prior to this, irrigation managers of the irrigation systems are informed of the total water allocation from the reservoir during the dry season. Based on this assumption, the irrigation water requirement for each week for the whole season is planned. Farmers are not involved in the pre-season processes and experience has shown that their plantings of dry-season crops do not conform to this plan. Figure 3 shows the weekly total water requirements for the official pre-season plan, the actual cultivated crops and the actual water supplied. Note that the data are available for this study from RID, Phitsanulok, EGAT and DOA (Department of Agriculture), Phitsanulok as mentioned before. It is obvious in Figure 3 that farmers, in general, plant significantly more land in the dry season than the official pre-season plan expects. Accordingly, the pre-season plan needs modification.

In-season Planning Process

In-season irrigation water requirement is planned week by week as illustrated in Figure 4. The information from one week is used for the planning of the subsequent week. Therefore the in-season plan supplies irrigation water on a real time basis since it is conducted with the actual information of supply discharge, crop water requirement and rainfall.

The modified Penman method is used for calculation of reference crop evapotranspiration, future rainfall is assumed according to a 50% probability of exceedence, and overall irrigation efficiency is assumed to be 50% on average. Based on these assumptions the in-season plan is made, and revised each week. Often, it is observed (see Figure 4) that the water taken into the system is not enough to conform to the weekly in-season plan. This means it does not conform to the reservoir release pattern. In this case, the sub-systems try to make up the temporary deficits by augmenting the next week's plan. These procedures create some uncertainties, and may not lead to optimum levels of cropping intensity and economic returns. These are the points studied in this paper.

OPTIMIZATION MODEL DEVELOPMENT AND SIMULATION

A linear programming model was developed to optimize the efficient use of available surface and sub-surface water on a weekly basis in terms of system benefit and equity. The equity emphasizes

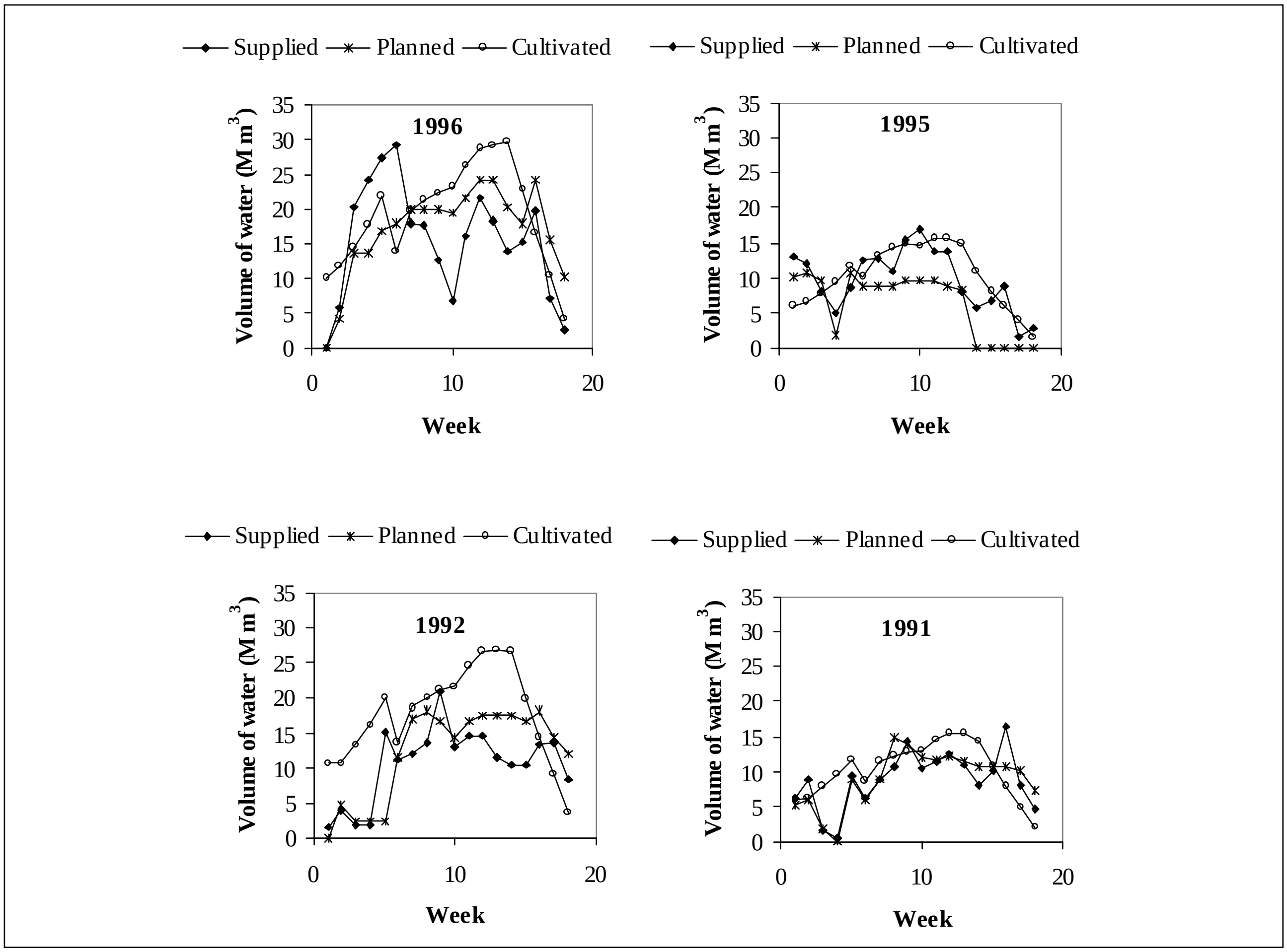

Figure 3. Dry season weekly water supplied, pre-season planned requirement and water requirement for the actually planted crops of four years.

area-maximization so that more beneficiaries can be included in the system benefit by adopting crops that require less irrigation water such as vegetables, sesame, maize, and soybeans.

Model inputs

Principal model inputs were the gross crop irrigation requirement, agricultural yield and corresponding net economic value, available potential water resources and irrigation conveyance, and application efficiency parameters. In order to maximize the system benefit, equity and security

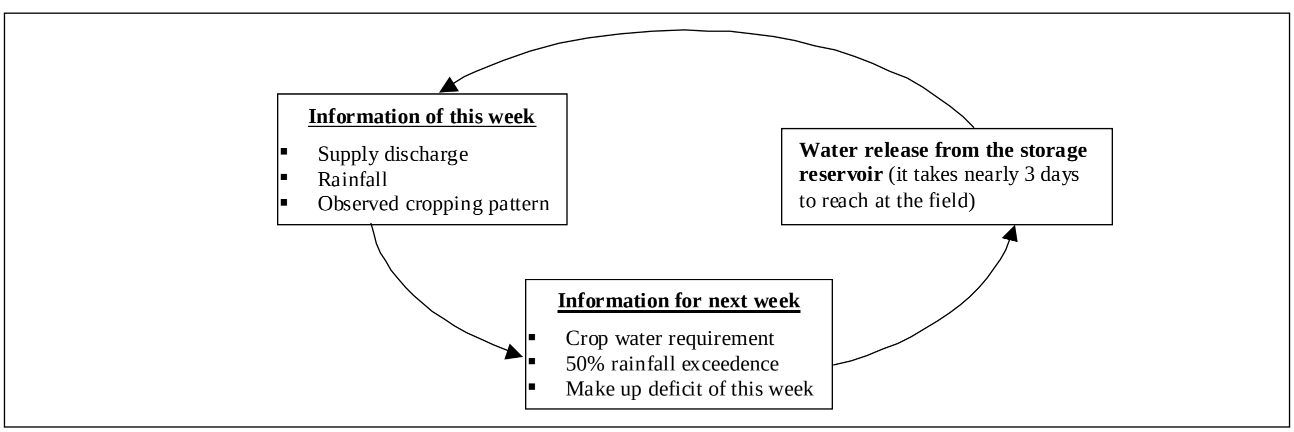

Figure 4. Real time planning of water release patterns from the storage reservoir for irrigation.

of probable rainfall expectation, sensitivity analysis was carried out for various irrigation policies for wet, normal and dry years statistically defined as 20%, 50% and 80% rainfall probability exceedence levels respectively (Smith, 1992).

The net crop irrigation requirement

The net irrigation requirement of the crops is estimated using the field water balance as below,

$$NIR_{non\text{-}paddy} = ET_{crop} - ER - GW - SM \tag{1}$$

$$NIR_{paddy} = ET_{crop} - ER + LPR + P - SM \tag{2}$$

where, NIR = net irrigation requirement (mmd^{-1}); ET_{crop} = potential crop evapotranspiration (mm d^{-1}); ER = effective rainfall (mm); GW = groundwater contribution (mm); LPR = land preparation and nursery requirement (mm); P = deep percolation requirement (mm); and SM = initial stored soil water (mm).

Daily meteorological parameters, maximum air temperature (^{o}C), minimum air temperature (^{o}C), maximum relative humidity (%), minimum relative humidity (%), evaporation (mm) from class A pan, sunshine hour (hr), and wind velocity (km hr^{-1}) for 16 years (1981-1996) of the Phitsanulok Meteorological Center were collected from the Meteorological Office, Bangkok. These meteorological parameters and information from the Phitsanulok Meteorological Center location (latitude = 16.78^{0} N, longitude =100.27^{0} E, elevation = 44 meter from MSL, and grass reference) were used in the calculation of daily reference crop evapotranspiration (mm d^{-1}), ETo, using the microcomputer software "REF-ET". The mean weekly ETo based on the Penman Montieth Method and modified Penman Method were estimated and compared with the observed values of 1996. The estimated ETo based on the Penman Montieth Method was found to agree better with the observed values. Although weekly ETo does not vary greatly along the Phlai Chumphol sub project, it does vary significantly from year to year. As meteorology is uncertain, 16 years (1981-1996) of average weekly ETo values were used for generation of 50 years of equi-probable average weekly ETo for planning purposes. The first 10 years of data were discarded as it might provide bias. In this case, the mean of average weekly ETo of the next 40 years of generated data was considered for planning purposes. The Thomas Fiering model was used for time series data generation since it preserves the mean, standard deviation and correlation of the past data in the generated data. Crop water requirement depends on the growth stage of the crop. The crop coefficients account for the crop characteristics of crops starting from the date of planting to harvest. The dry season weekly crop coefficients of different crops (K_c) were collected from Chalong Kirdphitak; Water Management in Thailand, Bangkok and used for the computation of ET_{crop}, potential crop evapotranspiration ($ET_{crop} = ETo \times K_c$).

Thirty six years (1961-1996) of daily rainfall data from the Phitsanulok Meteorological Center were collected from the Meteorological Office, Bangkok and used for this analysis. Rainfall data were summarized on a weekly basis and different probability distributions were tested to find the best-fit distribution for the weekly basis. The best-fit distribution was selected applying two goodness of fit tests, the Kolmogorov-Smirnov (K-S) test and the Chi-square test. The rainfall probability values from the fitted distributions for the wet, normal and dry year as defined above were considered for planning purposes as shown in Figure 5.

There were many studies of effective rainfall in the Phitsanulok Irrigation Project. In this study, the latest study of the Phitsanulok Irrigation Project Stage II Project Feasibility Report (ELC-NK-SEATEC, 1981, case 4) was considered for the effective rainfall computation. The percentage of monthly effective rainfall was estimated by the daily water balance method, using the daily rainfall

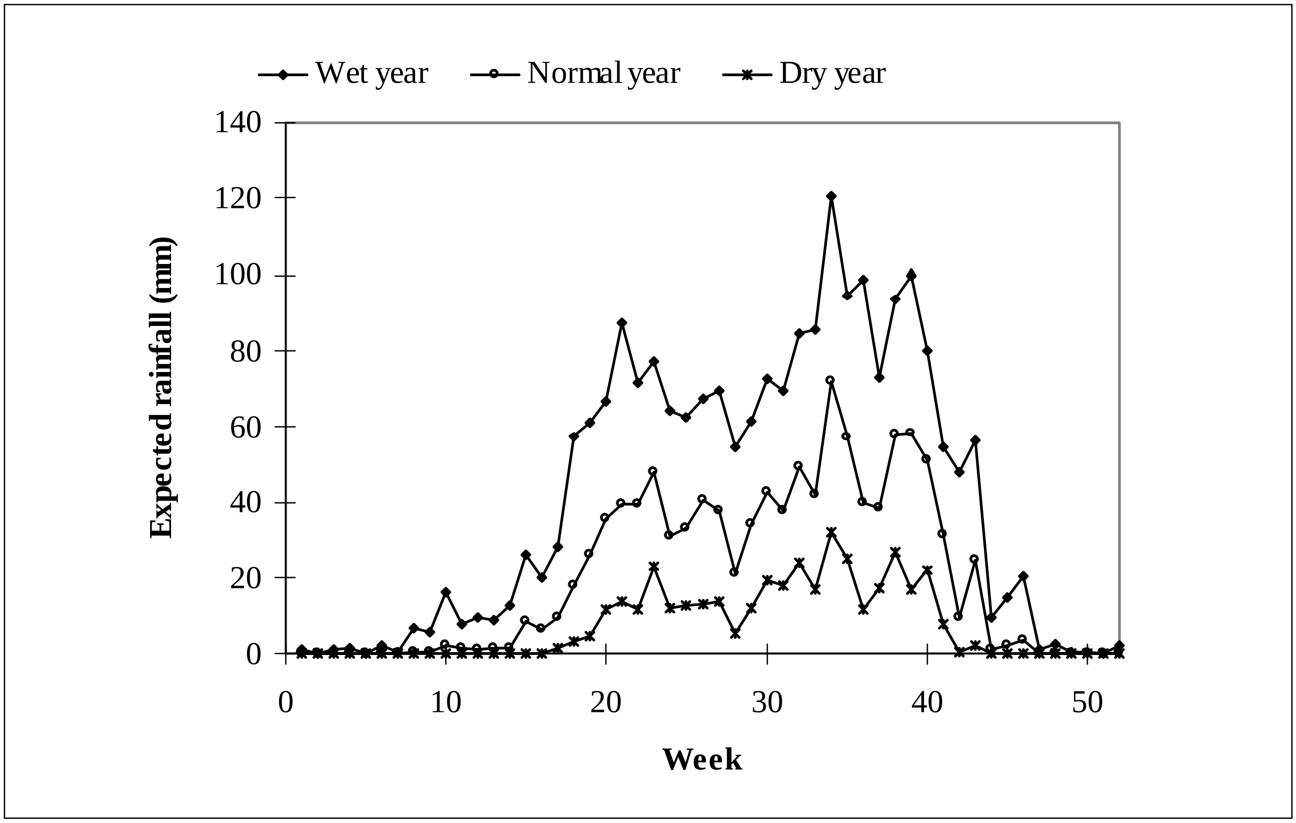

Figure 5. Weekly expected rainfall (mm) during a wet, normal and dry year.

data observed at a selected rain gauge in the project area during 1952 to 1978. Some weight to monthly rainfall was given to find out the effective rainfall.

The timing of the cropping calendar is a significant aspect of water management planning. Water management planning is based on the assumption that the dates of paddy planting will be spread over a range of 5 weeks as shown in Figure 2 dividing the whole Phlai Chumphol sub-project into 5 sub areas. There is no hard and fast rule in the division of 5 sub areas. The main idea behind this is that the peak growth and corresponding crop water requirement of each sub area lags one week to the previous subarea. So the peak crop water requirement of the whole area does not occur at the same time over the peak growth period. This facilitates better hydraulic accommodation in the canal system as well as the better regulation of resource availability for crop production requirement. The net irrigation requirement of paddy crop and non-paddy upland crops were estimated using Equations 1 and 2 at different rainfall probabilities of exceedence.

The Gross Irrigation Requirement (GIR) was the total irrigation requirement for crops at the main intake point of the source. The gross irrigation requirement was calculated after giving allowance for the water loss during the conveyance, distribution and application in the field.

Conveyance efficiency and gross irrigation water requirements

Overall irrigation efficiency was estimated from field measurements to be 56.2%. Seepage and percolation under paddy crops was assumed to be 1 mm d^{-1}, and land preparation water was assumed to be 200 mm for paddy and 25 mm for other crops.

The gross irrigation requirement is calculated after giving allowance for the water loss during the conveyance, distribution and application on the farm. It can be expressed as:

$$GIR = \sum_{1}^{n} \frac{10xAxNIR}{IE} \tag{3}$$

Where, GIR = gross irrigation requirement ($m^3 d^{-1}$); NIR = net irrigation requirement of a given crop (mm d^{-1}); IE = irrigation efficiency (product of conveyance, distribution and application efficiency); A = area under a given crop (ha); n = no of crops.

Planning scenarios

The following seven crop planning scenarios for different levels of irrigation application under different cropping area conditions were tested for decision support.

i. Single level of irrigation (no deficit)

ii. Single level of irrigation (10% deficit)

iii. Two levels of irrigation (no deficit, 10%)

iv. Two levels of irrigation (no deficit and 20% deficit)

v. Three levels of irrigation (no deficit, 10% deficit and 20% deficit)

vi. Three levels of irrigation (no deficit, 20% deficit and 30% deficit)

vii. Total area under irrigation (at single level, two level and three level irrigation application)

Agricultural yield and corresponding net economic value

In the planning, design, and operation of irrigation schemes, it is necessary to analyze the effect of water supply on crop yield. When water supply does not meet the crop water requirement fully, the actual evapotranspiration falls below the potential evapotranspiration. Under this condition, water stress is developed in the plant, which adversely affects the crop growth and ultimately the crop yield. As in the planning model, different levels of irrigation application were simulated, therefore actual crop yields relating to these supplies had to be quantified for the analysis of cost-benefit. The relative yields of different crops due to deficit irrigation supply were calculated using an empirical crop water production function presented by Doorenbos and Kassam (1979), which is stated as follows:

$$\frac{Y_a}{Y_P} = 1 - K_y\left(1 - \frac{ET_a}{ET_P}\right) \tag{4}$$

where, Y_a = the actual yield; Y_P = the potential yield that will be obtained at potential evapotranspiration; ET_a = actual evapotranspiration; ET_P = potential evapotranspiration; and K_y = the yield response factor.

The yield response factors for the total growing period of different crops given by Doorenbos and Kassam (1979) were used to compute the relative yield (Y_a/Y_P). Therefore, the actual yield, cost of production and net benefit at no deficit, 10%, 20% and 30% deficit irrigation supply at 20% (wet year), 50% (normal year) and 80% (dry year) probability of exceedence were estimated for model simulation and decision support. The information regarding the yield, cost investment and unit price of different crops of the year 1996 were collected from the Agricultural Office, Phitsanulok.

Model application

The model was applied to the available water resources of the 1996 dry season. Available groundwater was approximated by the fixed amount of 10.9 Mm^3/dry season for 1893 pumps in operation. Total surface water supplied to the Plai Chumpol sub-project during this dry season was 277.1 Mm^3/dry season. Twelve most promising irrigation policies, each consisting of three pareto-optimal alternatives for three defined rainfall expectations were considered. Thirty six 36 pareto-optimal alternatives in total were sorted out and compared with the dry season events of 1996 as shown in Figure 6.

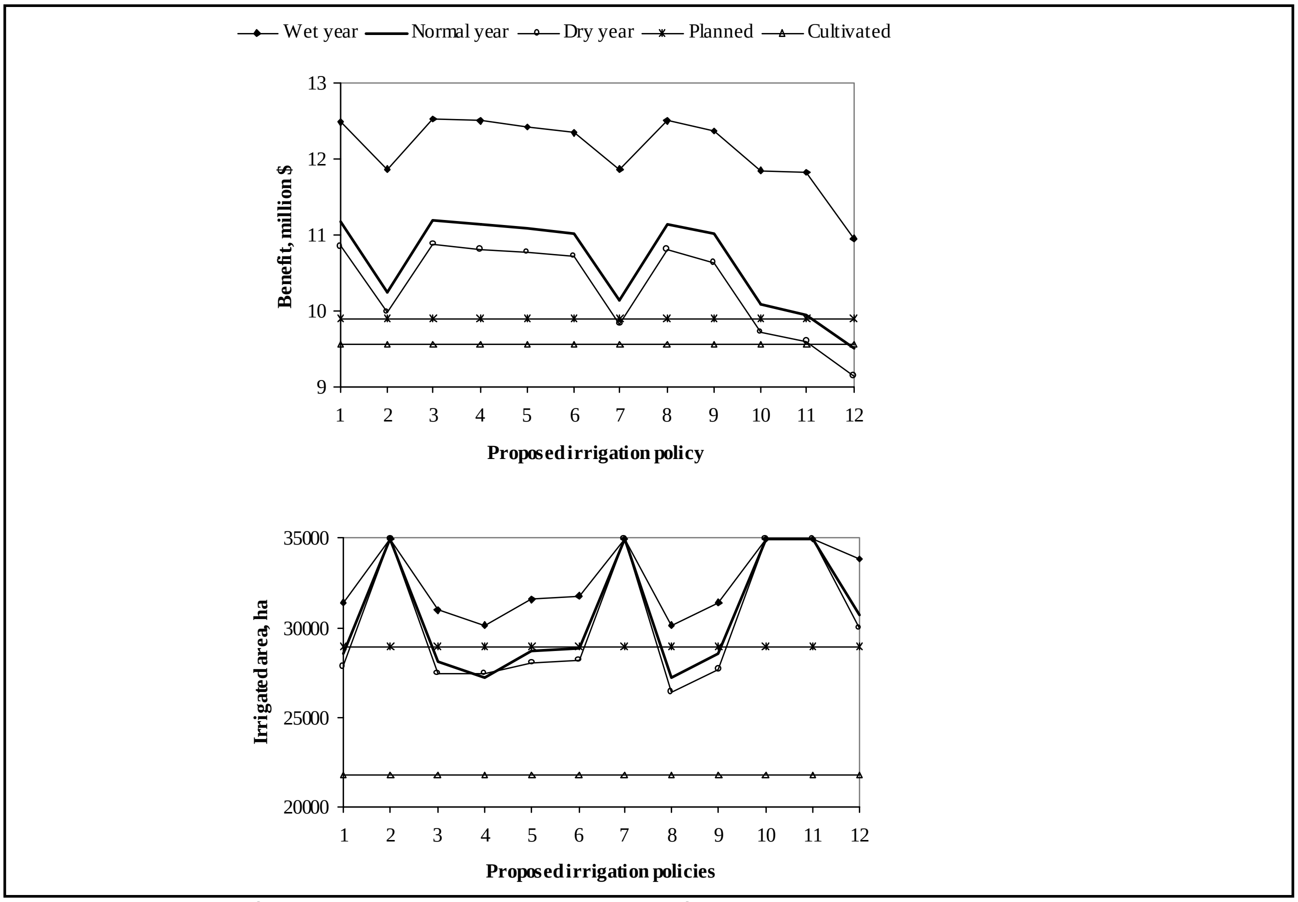

Figure 6. Net benefit and irrigated area under each of 12 scenarios, each having 3 pareto-optimal alternatives.

MULTI-OBJECTIVE ANALYSIS (ANALYTICAL HIERARCHY PROCESS)

The model results in Figure 6 were found to be contrasting, conflicting and non-commensurable to each of the three system objectives: maximization of net benefit, equity (irrigated area), and resources availability (mainly expected rainfall since other two resources, the reservoir release and the ground water extraction, are fixed). Trade-offs between them, which involve preference value judgments and strategy judgments that vary among people, was carried out through multi-objective analysis. The Analytical Hierarchy Process was used to resolve the problems. In this model, complex multi-objectives are hierarchically broken down to smaller elements and then compared pair-wise.

Four groups of farmers in the irrigation system (discussing collectively and arriving at consensus preferences), four irrigation managers of the system and two external researchers were asked to give their value judgment preferences on a 17 point scale, from +9 which represents absolute preference of criterion A over criterion B, to -9 which represents absolute preference of B over A as illustrated in Table 1a.

Table 1a. Importance of Value Judgment Preferences

Criteria	Criteria A is prefered over B									Criteria B is prefered over A								Criteria
	Absolute Importance		Very Strong Importance		Strong Importance		Weak Importance		Equal Importance		Weak Importance		Strong Importance		Very Strong Importance		Absolute Importance	
Criteria A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Criteria B**

Sixteen sets of pair-wise preferences as illustrated in Tables 1b to 1d for the above 36 pareto-optimal alternatives were analyzed mathematically by the Analytical Hierarchy Process (AHP) model. The irrigation policy, ranked number 1 by the AHP model, proposes a normal rainfall assumption in the planning and a crop diversification with no deficit irrigation supply. The significant gain of planning for a normal year preference may be due to the general aim of risk-avoidance. Since net benefit reduces under deficit irrigation policies, farmer groups strongly disagreed. The irrigation managers supported the equity objective that can be augmented by promoting a diversified cropping pattern. The profitability of the land and water in the Phlai Chumpol subproject could be increased significantly as shown in Table 2, if the proposed irrigation policy ranked 1 can be applied.

Table 1b. Group of Main Criteria - 3 Criteria

Criteria A	Criteria A is prefered over B									Criteria B is prefered ove								Criteria B
Maximization of net benefit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Maximization of area
Maximization of net benefit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Resouce reliability
Maximization of area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Resouce reliability

Table 1c. Group of Resources Reliability Sub-Criteria - 3 Sub-Criteria

Criteria A	Criteria A is prefered over B									Criteria B is prefered ove								Criteria B
Resouce Reliability 80%	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Resouce Reliability 50%
Resouce Reliability 80%	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Resouce Reliability 20%
Resouce Reliability 50%	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Resouce Reliability 20%

Table 1d Group of Maximization of Area Sub-Criteria - 5 Sub-Criteria

Criteria A	Criteria A is prefered over B									Criteria B is prefered ove								Criteria B
No deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	10% deficit irrigation
No deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	20% deficit irrigation
No deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	30% deficit irrigation
No deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Total area
10% deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	20% deficit irrigation
10% deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	30% deficit irrigation
10% deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Total area
20% deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	30% deficit irrigation
20% deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Total area
30% deficit irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Total area

Table 2. Profitability of Land and Water

	Actually observed	Pre-season planned	Optimized proposal
Area cultivated (ha)	29,001	21,768	28,950
Decrease, compared to actual pattern	-	***24.9%***	***1.4%***
Water required (Mm^3)	344.9	304.3	288.2
Decrease, compared to actual pattern	-	***11.8%***	***16.4%***
Net benefit (million US$)	9.557	9.900	11.176
Increase, compared to actual pattern	-	***3.6%***	***16.9%***
Net benefit per cultivated hectare (US$)	329.5	454.8	390.0
Increase, compared to actual pattern	-	***38.0%***	***18.4%***
Net benefit per developed hectare (US$)	276.4	286.3	323.2
Increase, compared to actual pattern	-	***3.6%***	***16.9%***
Net benefit per m^3 of water used (cents/m^3)	2.77	3.25	3.88
Increase, compared to actual pattern	-	***17.4%***	***39.9%***

Water availability at the field for a particular reservoir release

The released water from the Sirikit Reservoir covers a distance of 175 km before it is finally diverted to the system. There are many unknown stakeholders who are sharing the release water. Moreover, additional flow from two tributaries of the Nan River in between the Sirikit reservoir and the system contributes to the river. To quantify the available water for particular reservoir release, attempts were made to establish the relationships between the point of source and the system.

The Phitsanulok Irrigation Project started to operate fully in 1991. Therefore, the six years of data were analyzed and the following linear relations were best fitted for the available data. Table 3 shows the relation between the amount of water released from the Sirikit dam and the total amount of water available at the Naresuan diversion dam.

Table 3. Linear Relationships Between Sirikit Storage Reservoir Release (R_S), Naresuan Dam Inflow (I_N) and Phitsanulok Irrigation Project Intake (Q_p) (R^2 = Coefficient of Determination)

Month/ Season	Relation between I_N and R_S		Relation between Q_P and I_N	
	Linear relation	R^2 (%)	Linear relation	R^2 (%)
January	$I_N = 0.8677*R_S - 23.787$	99.56	$Q_P = 0.2518*I_N - 24.128$	95.59
February	$I_N = 0.8730*R_S - 22.821$	99.08	$Q_P = 0.2827*I_N - 41.212$	86.07
March	$I_N = 0.9342*R_S - 37.277$	97.70	$Q_P = 0.2367*I_N - 29.626$	71.17
April	$I_N = 0.9785*R_S - 34.864$	97.79	$Q_P = 0.1547*I_N - 1.854$	47.72
Dry season	$I_N = 1.1661*R_S - 134.58$	98.74	$Q_P = 0.2199*I_N - 106.27$	77.89

The squared value of determination coefficient for the month of April is only 47.22%. This may be because of nonuniform release of water to Phitsanulok Irrigation Project from Naresuan dam in the years 1993 and 1994. These two years were drought years and no release was made during April.

Of the six years of available data, four non-drought years of data were analyzed to assess the pattern of water distribution among three sub-projects. The water distribution pattern among the three sub-projects was calculated as the average of allocated percentage to each sub-project of the total intake to PIP at the head regulator. The monthly and dry seasonal water distribution patterns were calculated.

There are three major regulating systems involved in the movement of water from the source to the field. Although, the deviations from the established relations at each regulating system level accumulated during the calculation process from the source to the field, the deviations from the actual were in an acceptable range for 1991, 1995 and 1996, but varied significantly for the year 1992. The reason for this is the system management had no suitable established relationships between the canal network and intake. The operation of head regulator at the intake point is done by a non-technical person and no specific in-seasonal information about water intake from the release regulating authority was communicated to the managers of the Phitsanulok Irrigation Project. Intake was made as per the time-based thinking and demand, causing non-uniformity.

Water Supply Performance

Table 4 shows the monthly volumes of the actually supplied, the predicted availability by established relationships (see Table 3), pre-season planned demands, and optimal irrigation requirements for the 1996 dry season. It is found that the predicted values closely match the actually supplied values, but neither conforms to the optimal irrigation requirements. The pre-season planned requirements and actually supplied varies significantly.

Table 4. Monthly Crop Water Requirement, Supplied Canal Water and Predicted Volume (million cubic meters) in the 1996 Dry Season

Month	Canal supply (M m^3)		Irrigation requirement (M m^3)		
	Actually supplied	Proposed Prediction	Pre-season Planned	Actually cultivated	Proposed Optimal
January	77.58	68.44	48.99	54.44	49.97
February	74.18	77.13	78.02	76.68	72.53
March	75.51	80.83	89.16	129.61	102.66
April	49.87	47.20	88.13	84.11	63.03
Seasonal	277.14	273.60	304.30	344.84	288.19

10.9 Mm^3 of ground water was used which is the difference between the actually supplied 277.14 Mm^3 and proposed optimal irrigation requirement 288.19 Mm^3

Figure 7 shows the weekly actually supplied, and water demand for crops of actually cultivated, pre-season planned and proposed optimal crop pattern for satisfactory growth for the 1996 dry season. As found above, the weekly water release pattern in the dry season of 1996 was very poor in compliance with the crop water requirement. Inadequate water supply develops water stress in crop growth. The crop can recover from deficit supply if the failure period does not persist long and is within certain limits.

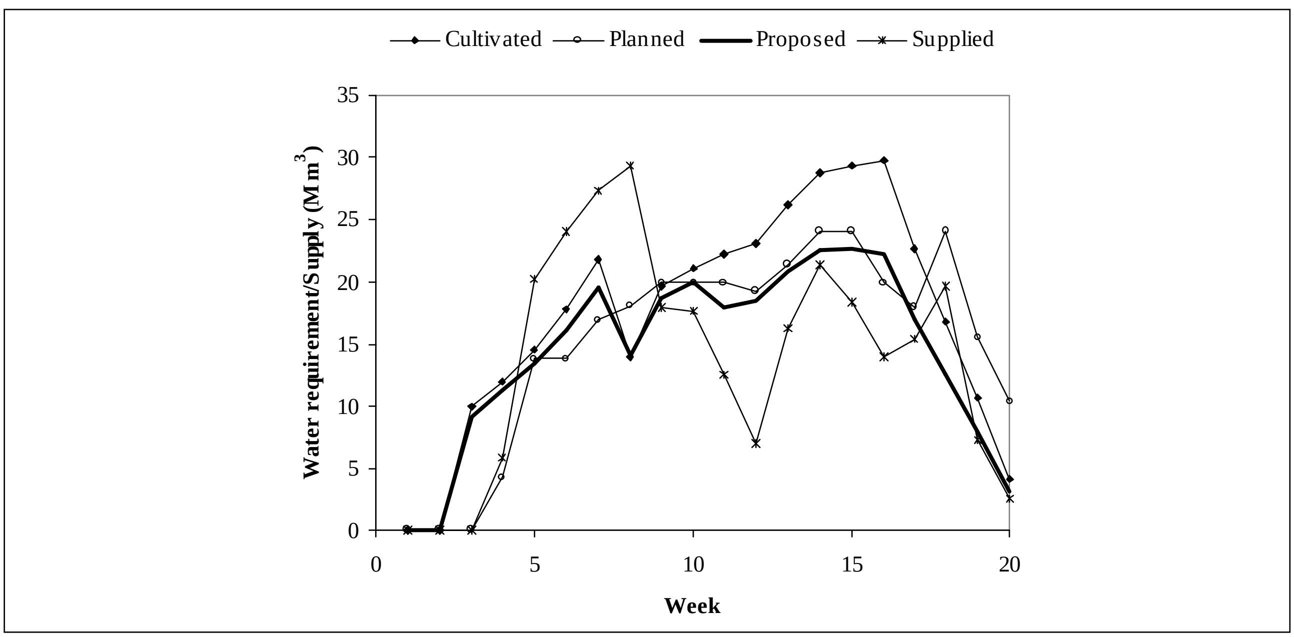

Figure 7. Weekly water requirement (M m^3) of the system and the supply during the1996 dry season.

CONCLUSIONS

The irrigation system in the dry season depends on the release pattern from a reservoir. The linear programming model and multi-objective analysis can be used for optimized crop and water planning decisions in any irrigation system. The monthly and seasonal empirical relations enable prediction of the water availability at the field for a particular release from the reservoir and thus assist in making a water supply and distribution plan of a higher order of reliability. The constraints, which prevent the effective implementation of the optimized irrigation policy, include erratic and untimely water release patterns from the reservoir, lack of prompt data processing and communication, effective water distribution inside the system, and farmer's participation in the planning process.

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