IMPROVEMENTS IN HYDROLOGIC PLANNING OF AN IRRIGATION PROJECT -A CASE STUDY

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree of

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in

WATER RESOURCES DEVELOPMENT

(C I V I L)

By

FADLUN NISA

WATER RESOURCES DEVELOPMENT TRAINING CENTRE

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≡ June, 2004 ≡

CADIDATE'S DECLRATION

I hereby certify that the work which is being presented in the thesis entitled " **IMPROVEMENTS IN HYDROLOGIC PLANNING OF AN IRRIGATION PROJECT – A CASE STUDY",** in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Water Resources Development (Civil), submitted in the Water Resources Development Training Centre, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during the period from July 2004 to May 2004 under the supervision of **Dr. U.C. Chaube,** Professor and Head WRDTC, Indian Institute of Technology Roorkee, Roorkee.

I have not submitted the matter embodied in this thesis for the award of any other degree.

Date 13 June 2004

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

13.6.04

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ABSTRACT

The main objective of this study was to investigate possible improvements in irrigation planning particularly with regard to crop water and irrigation water requirement/demand, water distribution planning (irrigation scheduling) and analysis of cropping pattern based irrigation development scenarios. To meet this objective, conventional practices in India and Indonesia have been critically examined and analysis of Pandanduri Irrigation Project in Indonesia has been carried out.

There is empiricalism and gross simplification in conventional approach for irrigation planning. With availability of computer technology and analytical tools it is possible to simulate long term behavior and analyze several alternatives (options) under variety of conditions such as variation in cropping pattern, variation in irrigation demand, consideration of group system of irrigation, irrigation scheduling option etc. Some important guidelines on requirement of hydrologic data and for simulation study are reviewed and highlighted

Too ambitious or too pessimistic cropping pattern may cause several errors in sizing of an irrigation project. In planning stage a design-cropping pattern is evolved and assumed to be constant over the years. Design and actual cropping pattern could be significantly different depending on several factors as seen in project command areas in India.

Irrigation scheduling at field level and water distribution planning for the command area should form part of irrigation planning at project preparation stage itself. Computer software's such as CROPWAT and others can be used for water distribution planning on more scientific basis as illustrated in chapter 5.

Case study of Pandanduri Irrigation Project has been carried out as an exercise to illustrate (i) proper analysis of climatic data (rainfall, radiation), (ii) use

of standard Penman-Monteith Method for estimation of crop water requirement, (iii) application of golongan (group) concept in crop calendar and estimation of peak diversion requirement, (iv) analysis of different cropping patterns and (v) analysis of irrigation scheduling options.

This study has been limited to water planning only. Economic financial environmental and social aspects of irrigation project planning have not been covered in this study. It is hoped that such type of study will lead to further work in bringing further improvements in conventional planning procedures.

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E	:	Evaporation mm/day (when an albedo of 0.05 is used $E=E_0$; when albedo is 0.25, $E=ET_0$)
W	:	Temperature Related Weighting Factor
R_n	:	Net Radiation in equivalent evaporation , mm/day
a	:	Albedo
R_a	:	Atmospheric Radiation
f(u)	:	Wind Related Function
(e_a-e_d)	:	Difference between Saturation Vapour Pressure at Mean Air Temperature and Mean Actual Vapour Pressure (mbar)
c	:	Adjustment Factor to compensate for differences between day and night conditions
R_s	:	Solar Radiation
R_a	:	Atmospheric Radiation
n	:	Actual Sunshine Hours
N	:	Maximum Possible Sunshine Hours
a,b	:	Constant
ETo	:	Evapotranspiration (mm/day)
FR	:	Field Requirement (mm/day)
LP	:	Land Preparation (mm/day)
LPT	:	Total Land Preparation (mm)
E_0	:	Open Water Evaporation (mm/day)
P	:	Percolation (mm/day)
ET_c	:	Consumptive Use ($=ET_0$ x Kc)
Kc	:	Crop Coefficient
WLR	:	Water Layer Replacement
C1 & C2	:	Half Monthly Coefficients
P	:	Percolation (mm/day)
$R_{effective}$	:	Effective Rainfall (mm/day)

$R_{1\text{-in }5\text{ year}}$	:	I-in-5 year Rainfall (mm/day)
NFR	:	Net Field Requirement (mm/day)
DR	:	Diversion Requirement (l/s/ha)
Δ	:	Water Depth
w_f	:	Moisture Content at Field Capacity as proportion of dry soil weight
w	:	Moisture Content at the time in question
Z	:	Effective Root Zone Depth
γds	:	Specify Dry Unit Weight of the Soil
T	:	Time Interval to Next Irrigation
ETa	:	Actual Evapotranspiration per unit of time
Date	:	either the date of a rainfall/calculated irrigation event or the date in the season
TAM	:	Total Available Moisture in the soil for the crop at this date (mm).
RAM	:	Readily Available Moisture in the soil for the crop at this date (mm).
RAIN	:	Rainfall amount calculated for this date (assuming 5 rain events per month)
Etc/Etm	:	Ratio of actual crop ET to the maximum crop ET. This useful developing user defined irrigation schedules it should be 100% for an unstressed crop.
SMD	:	Soil Moisture Deficit on this date (mm)
Irr. Interval	:	The interval depth applied (mm)
Loss Irr.	:	Irrigation water that is not stored in the soil – i.e. either surface runoff or percolation.
User Adjust	:	Adjustment you make to the SMD

CHAPTER 1

Introduction

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INTRODUCTION

1.1. GENERAL

Water is a prime natural resource, a basic human need and a precious asset. The growth process and expansion of economic activities inevitably lead to increasing demands of water for diverse purposes: domestic, industrial, agricultural, hydropower, navigation, recreation, etc. So far, the principal consumptive use of water in India has been for irrigation (GOI 1980). Similar is the case with many developing countries in Asia.

Due to particular characteristics of the tropical monsoon, about 80% of the annual river runoff occur in three to four monsoon months of an year. During this period, maximum utilization of the water can be made from the river flows with small regulation and very little storage. However for use in subsequent dry season, there is need to store surplus water of monsoon season in reservoirs and tanks.

Sizing of storage and diversion capacity for the purpose of water utilization is an important component of the water resources development studies. If the planned storage and or division capacity is not sufficient, project may not serve the purpose effectively, for which it has been designed and may cause wastage of scarce water resource. On the other hand, over estimation of the storage capacity can result in considerably high cost of the project rendering the project to be an uneconomical alternative. Planning of a river valley project to meet a pattern of demand (within year and over the year) is often difficult task not only because of socio economic and physical constraints, but also due to stochastic variability of the inflow and multipurpose demand variation within and over the years.

Irrigation and hydroelectric generation are two major purposes for which a multipurpose reservoir project is generally taken up. Some of the concept, basis and approach followed in planning for irrigation water supply and hydroelectric generation are given below. It is proposed to critically examine planning procedure for irrigation projects and analyze some of the possible improvements, through a case study.

	Hydro electric generation		Irrigation supply
1.	Electricity cannot be stored	1.	Irrigation water can be stored
2.	Production has to match with demand instant by instant	2.	A few days mismatch between demand and supply is tolerable
3.	No normal way of constraining quantity of supply	3.	Rotational delivery is possible in case of inadequate water supply
4.	Seasonal demand for power is widely divergent from pattern of river inflows	4.	Irrigation demand is also widely divergent from pattern of river inflows
5.	90% dependability of power generation is the criteria	5.	75 % dependability of water supply is the criteria
6.	Storage helps in increasing head and dependable discharge	6.	storage helps in increasing dependable discharge
7.	MDDL is based on silting and safe limit of operating head	7.	MDDL is based in silting
8.	Alternate source for electricity supply possible through grid	8.	No alternate source for irrigation water supply in project command if conjunctive use not planned
9.	Water is through put for conversion of potential energy into electrical energy. No loss of water	9.	Water is resource input for consumptive use, considerable loss of water
10.	Benefit of hydropower are in terms of cost of alternate project for similar dependable energy/capacity and energy supplied to power grid	10	Benefit are in terms of increased crop production, social welfare, self reliance in food crop production, etc.

In case of multipurpose development where major benefit is irrigation, the releases are made primarily in the interest of irrigation and power generation follows the pattern of irrigation. Normally, 75% dependability criteria on annual basis are being followed in the case of irrigation projects: Power benefits in such a year would be higher than in 90% year. It would be desirable to assess the power benefits corresponding to irrigation releases made in a 90% year also. Hence, in the case of multipurpose storage projects, studies should be carried out for different levels of dependability for irrigation and hydropower. Wherever possible, multipurpose storage projects should provide for specific releases in the interest of power or irrigation during periods, which are considered critical from the point of view of power generation or irrigation water supplies *(IWRS, 1999)*.

In a river basin interlinkages occur in different projects serving single or multipurpose. In addition, hydropower projects are part of a larger energy generation system comprising of thermal, nuclear and other power plants (Agung ,2002).

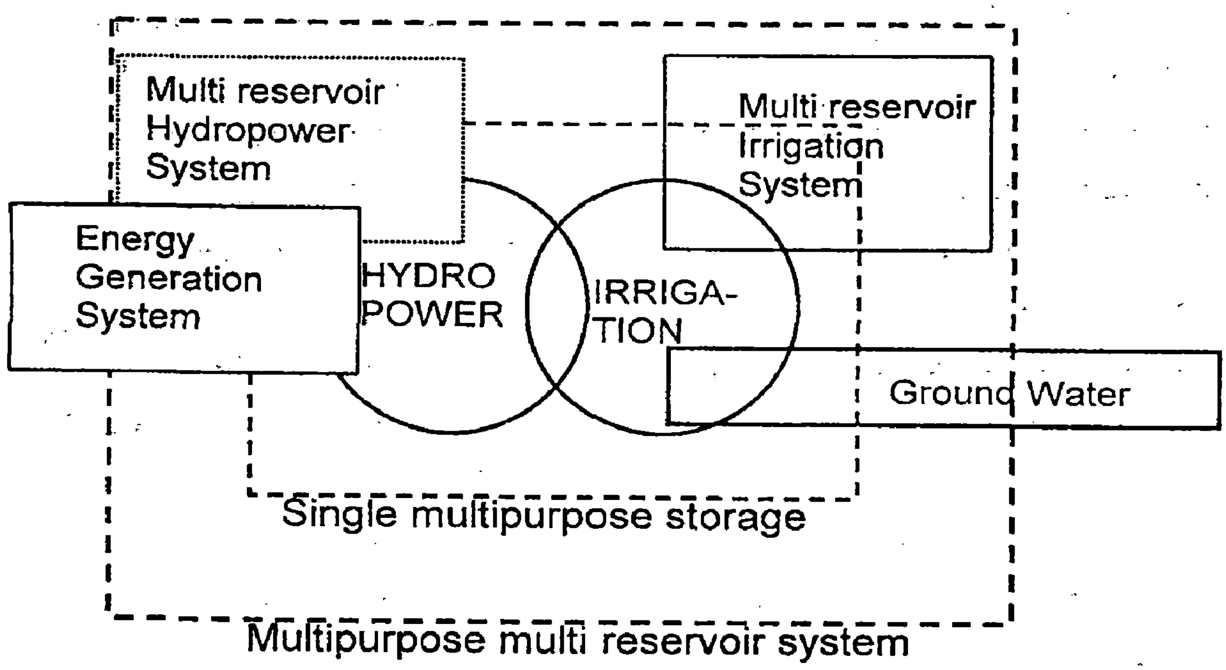

Figure 1.1 shows the various interlinkages in River valley project

1.2. STUDY AREA

The Pandanduri Irrigation Project is located in West Nusa Tenggara Province of Indonesia. The dam site is located on the Palung River. The primary function of dam is to store and regulate the flow of the Palung river (Area 66.6 km^2 and main stream length 23.55 km) during the wet season for use in the irrigation service area of about 65,332 ha. For the Pandanduri Irrigation Project existing irrigation area is 2,566.7 ha and proposed extent 2,720 ha, length of main canals 12,463 km and length of secondary canals 50,586 km. The land elevation varies between + 237.00 m upstream and + 4.00 m downstream, calculated from average sea level. Figure 1.2 shows the schematic plan canals and irrigation areas. As seen in diversion canals have done the figure interlinkage among different rivers.

1.3. OBJECTIVES OF STUDY

The main objective of the study is to investigate possible improvements in reservoir planning and irrigation planning particularly with regard to crop water and irrigation water requirement, water distribution planning (irrigation scheduling) and analysis of cropping pattern based irrigation development scenarios.

To meet the stated objective conventional procedures are critically examined and analysis of Pandanduri irrigation project in Indonesia is proposed.

1.4. SCOPE OF STUDY

I. It deals with the introduction of the issues and statement of the objective, scope and study area.
II. Review of guidelines and conventional procedures for irrigation project planning and identification of possible improvements in irrigation planning
III. Analysis of climatic parameters, cropwater and irrigation water requirements for the command area of Pandanduri Project.
IV. Study of irrigation development scenarios based on different possible cropping patterns in the command area of Pandanduri project.
V. Illustration of irrigation scheduling using a computer software
VI. Summary and conclusions
VII. Compilation of relevant references

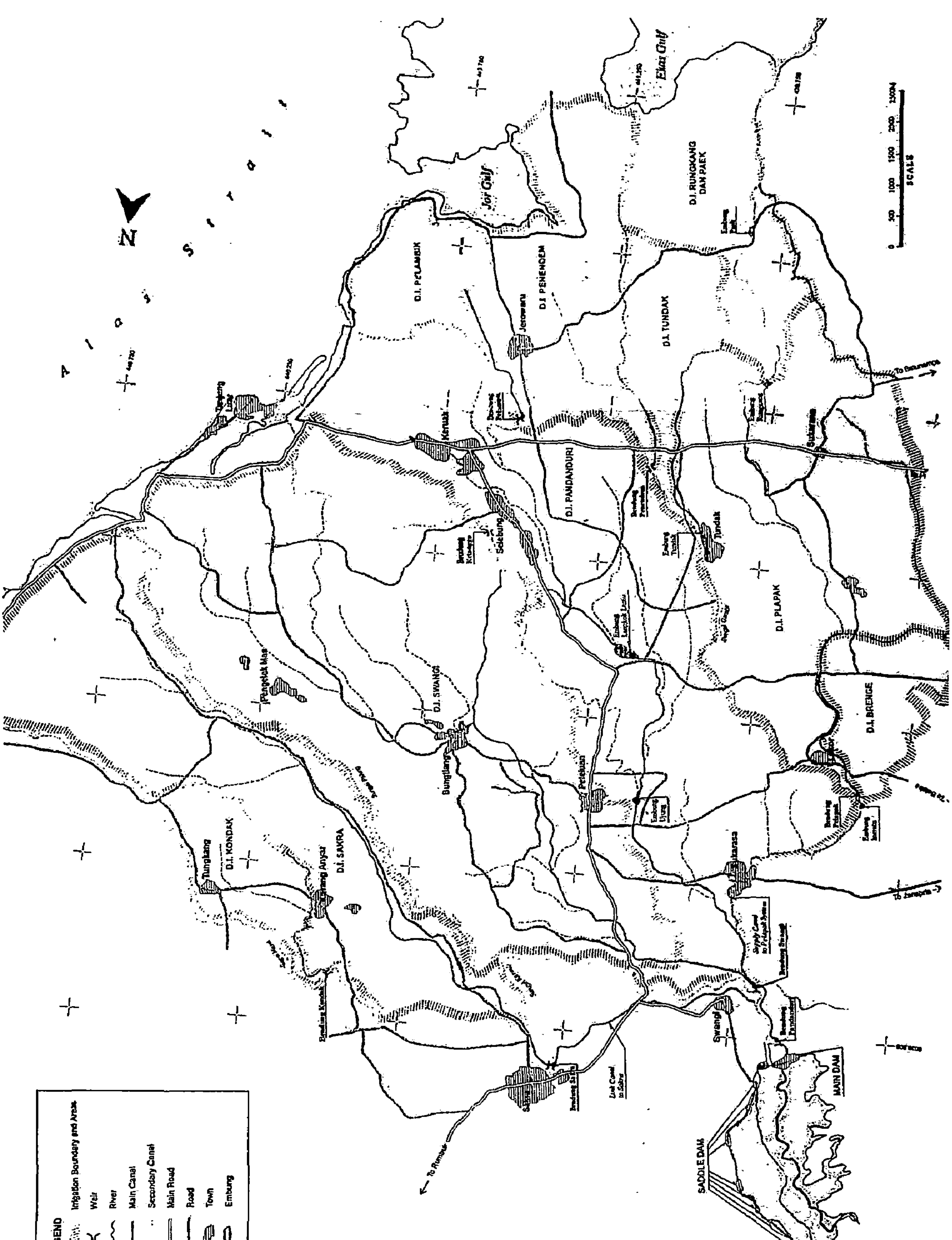

Figure 1.2 Pandanduri Irrigation Project (Indonesia)

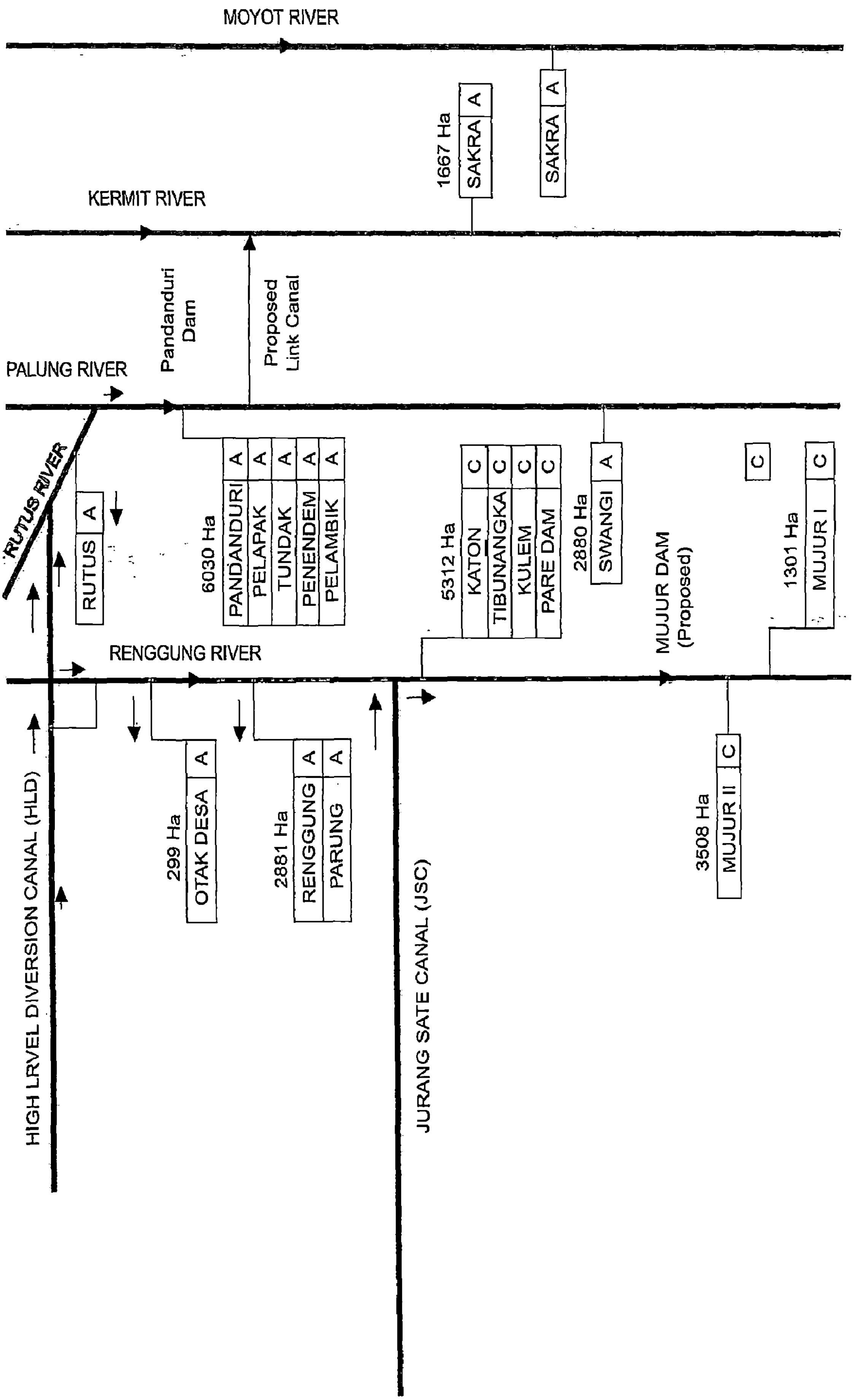

Figure 1.3. Schematic Plan of Diversion Canal and Irrigation Areas

CHAPTER 2

Improvements In Irrigation Planning

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IMPROVEMENT IN IRRIGATION PLANNING

2.1. GENERAL

Available literature on irrigation project planning shows several deficiencies in conventional planning procedure. With the availability of data, analytical techniques and computer technology, it is possible to make irrigation project planning more realistic and reliable by incorporating certain improvements. The improvements in project hydrology and irrigation planning can be made with regard to (i) consideration of change in live storage capacity and elevation-area-capacity curve with time over the simulation period (ii) storage capacity-irrigation withdrawal-reliability analysis (iii) trade off analysis between various uses (power generation, irrigation withdrawal municipal and industrial supply) and reliability in case of multi purpose project (iv) consideration of tolerable deficit in assessing the reliability and use of seasonal irrigation reliability index in addition to annual reliability (v) dividing irrigation command area into groups and staggering of crop calendar to reduce peak demand (vi) consideration of variation in irrigation demand over the years and alternate irrigation development scenario (area, cropping intensity) (vii) consideration of conjunctive use in planning of project (viii) consideration of variation in net gain/loss of water from reservoir over the years due to the randomness in rainfall (ix) better approximation of average reservoir area and average reservoir elevation during a time interval, (x) objective evaluation of project performance on the basis of improved criteria (xi) accurate assessment of crop water use based on the FAO-Penman-Monteith method , (xii) irrigation scheduling and water distribution planning.

Based on literature review some useful guidelines have been discussed on improvement in project planning aspects. Economic, environmental and other aspects of project planning are not considered here.

2.2. PROJECT HYDROLOGY AND WATER PLANNING

It, is observed that reports prepared by project authorities are not in conformity with the standard guidelines and procedures and do not contain the data and details required for technical, economic and environmental impact assessment. Sometimes important aspects of the project are not dealt with in sufficient detail, thus causing delay in technical examination and approval of project for implementation GOI (1980).

Government of India, Ministry of Irrigation (now Water Resources) has prepared guidelines (GOI 1980) based on which project report should be formulated.

Rapid changes are taking place in methods for hydrologic design of irrigation project mainly due to the following,

1) Availability of computer and computer software.
2) New techniques for considering uncertainties and inadequacies in data.
3) Growing complexities of engineering system and interdependence of projects.

Conventional short cuts of dependable flow analysis, critical, cycle analyses etc. are being dispensed with and detailed simulation and performance testing techniques are being applied now.

Project planning process is sensitive to hydrologic inputs. Further, consequent ecologic effects of project development have been receiving more attention of society as well as water resources planners.

2.2.1. Hydrologic Data Requirement

An irrigation project is implemented to meet demand during the life of project in future. Demand and supply estimates have to be based on adequate data. The type and extent of hydrological data depend on the proposed plan of development. Table 1.1 shows classification of development plan (according to type of use and type of project), type of hydrologic data and time unit for simulation studies. Minimum length of data for use in simulation is indicated below:

- ✓ Diversion projects with pondage: 10 years
- ✓ Diversion projects without pondage: 10 years
- ✓ Within the year' storage projects: 25 years
- ✓ Over the year' storage projects: 40 years

Complex systems involving above combination: minimum length of data depends upon one of above predominant type of project.

In addition, hydrologic data are required to estimate the following

a. Design floods for safety of Structures.
   i). Observed storm rainfall and flood hydrograph to determine unit hydrograph and use the same along with estimate of design storm to find design flood hydrograph.
   ii). Observed annual maximum floods for at least 20 years to carry out flood frequency analysis and estimate flood corresponding to a design return period.
b. Design floods and flood levels for flood control works and drainage works, design floods for diversion arrangement during construction of project.
c. Studies for determination of levels for locating structures on rivers banks or for location of outlets.
d. Tail water rating curves

2.2.2. Simulation studies

Guidelines followed in India (GOI 1980) stipulate that following aspects should be considered in simulation studies.

1. Where economic evaluation is based on discounting procedures the period of simulation shall be same as with the period of discounting.
2. Where carry over storage is involved, it is desirable and necessary to consider a long time series containing cycles of dry years.
3. The series used in the simulation, single historical, many likely historical or synthetic shall be indicated with reasons.
4. Physical capacity constraints on storage, canal, spillway etc. and policy considerations such as required minimum and maximum reservoir levels in different time intervals should be satisfied.
5. Losses / gains to the flows, should be explained.

6. The basic for demands of all the projects (existing and future) considered in the system for simulation studies.
   a. Sanctioned or approved utilizations and legal right demand
   b. Historical actual use.
   c. Reassessed demands of the existing projects.
7. In case detailed study is based on economic evaluation where the entire period of simulation is taken into account for working out the average annual benefits, the firm and secondary demands, priority of uses, sharing for shortages etc. shall be discussed with basis.
8. In the case of multipurpose projects involving flood control storages, rules curves(s), flood release rules shall be framed
9. In case of multi-reservoir system rules for sharing of deficit and priorities of releases between reservoirs both for conservation and flood control purposes shall be indicated.
10. Impact of sedimentation in live storage zone over the years should be accounted

2.2.3. Dependability Criteria

Sizing of storage and diversion capacity for the purpose of water utilization is an important component of water resources development. The practice followed in India is to plan a project for a target demand of not more than the yield of river corresponding to 75 % dependability on annual basis (with associated temporal distribution) and then test the performance of the system so planned to ensure 75 % success of the project in melting the target demand. Thus the two concepts namely planning for utilization 75 % dependable yield and planning to achieve 75% success of the project are two different concepts.

Prevalent criteria for irrigation planning have several drawbacks as given below:

- Planning is based on annual reliability only. Seasonal reliability is also important, as crops having different economic value to farmer and the society are grown in different seasons.
- Quantum of failure (water deficit), time length of failure, period of failure vis a vis planned growth, crop specific failure (sustenance crop, cash crop), randomness and sequential failure are not reflected in the prevalent criteria. Similarly spatial

distribution of reliability in head reach, middle reach and tail reach occurs due to existing misdistribution practices, is not considered.

- Region specific characteristics such as drought proneness, differences in hydrologic characteristic of catchments and location of storage site (upper catchments or terminal site of basin) may necessitate adoption of different planning criteria, in different regions.

For irrigation apart from the quantum of failure, the time length of the failure, the period of the failure vis-à-vis the planned growths are important. Failure in sustenance crop could hurt a farmer more than that of marketed cash crop. A few random failures may not hurt as much as sequence of failures where his meager savings have been wiped out earlier. Many of these complications are not reflected in the prevalent performance evaluation criteria. However no performance index can be perfect, and each could have some advantage.

At present annual planned utilization of water is kept approximately equal to 75 % dependable flow. It is an empirical decision based on experience and judgment. The controversy on this issue raised from time to time stems from this empirical nature of the criteria. Water resources system varies widely in their characteristics with respect to the pattern of the flow in the river within the year and year to year and range of flow variation of flow and range of flow. It seems prudent to plan the terminal sites in a river basin for maximum possible storage capacity especially in water scarce regions (IWRS 1994).

Storage-yield-reliability relationship for a reservoir can be worked an online basis of long-term simulation study. Such relationships provide more useful information for planning of project rather than considering fixed 75 % dependability criteria. Edy Juharsyah (2002) has carried out a detailed analysis of storage-yield-reliability (seasonal, annual) for a project in India.

2.3. CROP WATER REQUIREMENT– NEED FOR STANDARD ETo METHOD:

Advances in research on more accurate procedures in assessment of crop water use have revealed weaknesses in the existing methodologies for estimation of crop water requirement. Numerous researchers have analyzed the performance of the existing methods

(FAO,1977) for different locations. Although the result of such analyses could have been influenced by site or measurement conditions or by bias in weather data collection, it became evident that the proposed methods do not behave the same way in different locations around the world. Deviations from computed to observed values were often found to exceed ranges indicated by FAO.

The comparative studies of various methods indicate the following:

- The Penman methods may require local calibration of the wind function to achieve satisfactory results.
- The radiation methods show good results in humid climates where the aerodynamic term is relatively small, but performance in arid conditions is erratic and tends to underestimate evapotranspiration.
- Temperature methods remain empirical and require local calibration in order to achieve satisfactory results. A possible exception is the 1985 Hargreaves' method, which has shown reasonable ETo, results with a global validity.
- Pan evapotranspiration methods clearly reflect the shortcomings of predicting crop evapotranspiration from open water. The methods are susceptible to the microclimatic conditions under which the pans are operating and the rigour of station maintenance. Their performance proves erratic.
- The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies.

The analysis of the performance of the various calculation methods reveals the need for formulating a standard method for the computation of ET_0. The FAO Penman-Monteith method (Annexure 1) is recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_0 in a wide range of locations and climates and has provision for application in data short situations. The use of older FAO or other reference ET methods is no longer encouraged.

The Penman-Monteith approach includes all parameters that govern energy exchange and corresponding latent heat flux (evapotranspiration) from uniform expanses of vegetation. Most of the parameters are measured or can be readily calculated from whether data. The equation can be utilized for the direct calculation of any crop evapotranspiration as the surface and aerodynamic resistances are crop specific. Thus use of Penman-Monteith method eliminates the need for a two step process to estimate crop evapotranspiration or ET_0 and a crop coefficient Kc.

2.4. CROP PLANNING AND CROPPING PATTERN

2.4.1. Crop Planning

The objective of crop planning is to evolve a cropping pattern, which maximizes the socio-economic benefits of irrigation. Crop pattern means the proportion at area under different crops at a particular period of time. A change in cropping pattern means a change in the proportion of area under different crops. Canal operation schedule is based on cropping pattern and crop water demand.

Development of a realistic cropping pattern needs no emphasis. With introduction of irrigation water, farmers go for their own selection of crops.

Correct evaluation of economic, social and ecological factors (rainfall, temperature, soil etc) is necessary to make the crop planning realistic. A designed cropping pattern should have a fair chance of being implemented in field. A too ambitious or pessimistic design can throw the planning machinery into disarraw and cause lot of confusion and manipulations at the implementation stage. Factors influencing a cropping pattern and source of information are briefly explained in table 2.2.

2.4.2. Trends in Cropping Pattern

With assured irrigation, farmers tend to adopt commercial crops (cash crops). Wide discrepancies have been observed in design cropping pattern and actual cropping pattern.

Irrigation demand, planning and design of irrigation facilities and economic feasibility of the project as a whole depend upon the designed cropping pattern. Actual cropping pattern are drastically different from the designed cropping pattern for several project in India indicating serious deficiencies in socio-economic survey/investigations during the planning stage (table 2.3.). Economic considerations, unreliability and inadequacy of water supply and lack of on-farm development work have mainly influenced adoption of particular cropping patterns by the farmers in these project commands. Several other inputs and support services are needed for realization of design pattern.

Table 2.1. Project Classification and Data Requirement for Simulation

Type of use	Type of project	Data for simulation	
		Data type	Time units
Irrigation	Diversion with pondage	River inflows Evapotranspiration & rainfall	10 days
	Within year storage		Monthly
	Over the year storage		Monsoon/non monsoon
Hydropower	Diversion without pondage	River flows	Instantaneous discharge everyday or at smaller units
	Diversion without pondage	-do	1 day to 10 days depending on extent of pondage.
	Within year storage	River flows, lake evaporation	Monthly
	Over the year storage	- do	Monthly/seasonal
Flood Control	Within year storage	Flood peak, hydrograph	1 hr to 24 hr depending on damping effect of catchments
	Diversion with pondage		
Navigation, Salinity Control, water quality, recreation fish, wild life	Diversion with or without pondage	River flows, lake evap., Low flow inputs	1 day to 10 days depending upon extent of pondage
	Within year or over the year storage		
Water supply & industrial use	Diversion without pondage	River flows	Instantaneous discharge everyday
	Diversion with pondage	River flows	1 day to 10 days
	Within year storage	River flows and Lake evaporation.	Monthly
	Over the year storage	- Do	Monthly/seasonal
Multipurpose	All type	All Type depending on individual uses	Minimum of individual time units for each type of use. However for type no.3 and 4 or shorter time units required.

Table2.2 Factors & Source of Information for Crop Planning

ITEM	REFERENCE	ITEM WHICH IS INFLUENCED
Rainfall	National Commission on Agriculture's Report on State Rainfall and Cropping Pattern	a. Type of crops: b. Sowing dates and harvesting dates
Sunshine hours Pan evaporation Relative Humidity, Wind Velocity	1. Meteorology Departement. 2. Agricultural University/Research Stations. 3. Major Project Stations	Crop Water requirement of different crops in different fortnights
Soil and Topography	1. National Bureau of Soil Survey & Land Use Planning. 2. State Agriculture Departments	1. Type of crops 2. Frequency of irrigation. 3. Method of irrigation
General status of farmer (owner, owner-tenant, tenant Ethnographic descriptions)	Socio-economic survey reports	Farmer's choice orientation of crops will be based on socio-cultural factors.
Communications, cultivated area, cash and credit, availability of farmyard manure, bullock power, holding size, education.	Socio-economic survey reports	Farmer's choice of crops.
Support price and market price of crops	Radio, Television, Newspaper and market surveys	Farmer's choice of cash crops supplemental to his consumption needs
Marketability-means of communication	District Planning Reports	1. Farmer's choice of crops which produce market-able surplus. 2. Choice of perishable crops.
Location of Agro Industries	District Planning Reports	Crops required by and supported by the Industry will be preferred by farmers
Livestock population	Agr. & Animal husbandry Dept., Socio-economic survey	Choice and extent of fodder crops.

2.4.3. Contingency Planning

In the economic analysis of irrigation project, we generally assume that the data on cropping pattern, crop yield, crops prices etc., are known with certainty. They are not in the real world. Prices and yields change causing risk and uncertainty in crop planning.

Risk: Future outcome is not known with certainty. However, it is known what the future outcomes could be and the probabilities associated with them. Examples are fire, hail. Rain wind and floods. One can insure against these risk.

Uncertainty: Manager is not aware of different and cannot assign any probabilities to these items. One can insure against these risk.

In every business there are risk but farming probably has more than its share. Heavy rains may drown out some or all of the crops; a severe drought may burn them up. Right up to the day of harvest, a hailstorm may destroy them.

Insects or diseases of crops may reduce the crop yield seriously or wipe it out entirely; likewise a disease of epidemic proportions may attack certain livestock and causes heavy losses. The magnitude of risks and uncertainties to which a farmer's fortunes are exposed could be very large, if contingency planning is carried out.

Changes in agricultural technology make fixed assets become obsolete rapidly when whole new production systems are adopted. The government and other institutions can change tax laws, credit programs, farm program and other factor relating to rain fed / irrigated farming, causing uncertainty in crop planning.

2.5. IRRIGATION DEMAND VARIATION AND DEVELOPMENT

2.5.1 Irrigation Demand Variation

In conventional planning procedure, irrigation demands are assumed to be constant over the period of project life; though its variation within an average year is considered. In is known that in reality irrigation demand changes from year to year depending on:

(i). Changes in cropping pattern
(ii). Randomness of rainfall
(iii). Reliability of water supply,
(iv). Physical performance of delivery system and other infrastructure development.

Change in cropping pattern is the most significant long-term factor. With availability of computer technology, and reliable technique for forecasting of variables, it is now possible to consider variation in irrigation demand from year to year in long-term simulation study for planning of project.

2.5.2 Irrigation Development Scenario

Usually design irrigation area and design cropping pattern are kept fixed. There can be several possible scenarios on irrigation area cropping pattern in future. Therefore in the planning stage itself the different possible scenarios should be analyzed. Irrigation system is a real life system with imperfect knowledge on several physical, socio economic hydrologic variables. Thus fallacy of optimum exists for an irrigation system. There is nothing like optimum cropping pattern or optimum irrigation development for irrigation.

Table 2.3. Design and Actual Cropping Pattern (percent area)

	Chambal				Barna				Tawa	
Name of crops	Original (1954 report)	Revised (1963 report	As in CAD Report	Actual	Before project	Original report	Revised report	Actual	As in 1971 report	As in CAD report
Kharif Paddy	20	8	14	11.7	0.3	17.3	10	0.003	33	3.7
Sugar-cane	5	2	3.5	0.2	-	-	-	-	-	-
Cotton	5	2	3.5	0.2	-	-	-	-	5	8.3
Groundnut	0.0	3	2	0.0	-	0.73	-	-	5	-
Soyabean	-	-	2	-	-	12.7	40	13	-	34.3
Fodder	-	4	3.5	-	-	0.73	-	-	2	4
Pulses	-	-	-	-	-	3.65	-	8.3	5	9
Rabi Wheat	70	70	19.5	16.2	29.3	11.0	15	20.0	25	49.7
Wheat (HYV)			18	25.0	-	58.2	40	14.5	30	
Gram	-	-	9	12.5	50.1	1.83	35	31.0	7	13.7
Rabi - vegetables	-	-	-	16.5	-	0.73	-	6.0	1	7

Note: (i) . CAD command area Development
(ii). Actual cropping pattern in Tawa command not available.
Proposed in CADA report is assumed to respect farmer choice.
(iii). Only important crops are mentioned

2.6 PLANNING FOR CONJUNCTIVE USE-PERMISIBLE WITHDRAWAL OF GROUNDWATER

The need for conjunctive use is well recognized and is part of the National Water Policy of India. The subject matter has been dealt with by Irrigation Commission and National Commission of Agriculture of Government of India but formulation of guidelines for planning and implementation of irrigation project on the basis of conjunctive use of surface water and ground water took a long time. Central Water Commission (CWC, 1995) has brought out useful guidelines for this purpose after discussing these at various forums.

Major and medium irrigation projects are planned as surface water system. Such large-scale use of surface water without giving any attention to the ground water has resulted in water logging and turning the fertile land into barren in some cases. On the other hand pumpage of ground water in excess of aquifer recharge has lead to lowering of water table with subsequent decrease in dry weather stream flow and desertification of

land. Irrigation planner needs to follow these guidelines in planning a new irrigation project as well as in introducing ground water use in existing irrigation commands for rehabilitation or modernization

Thus, to prevent and rectify the problem, the conjunctive use of surface and ground water is of utmost importance. The concept of treating surface and ground water independently should now give place to their being considered in an integrated manner to achieve optimal utilization of the water and ground water for irrigation has several advantages as discussed below.

2.6.1 Permissible Withdrawal of Groundwater.

Permissible withdrawal of ground water is linked to :

i. The additional groundwater recharge as added in the " with conjunctive use project" condition and

ii. The trend shown by the previous groundwater status.

The "minimum necessary" and the "maximum desirable" additional withdrawals are given in table 3. The minimum necessary withdrawal is in order to avoid large imbalance leading to large rise in groundwater level. The maximum permissible withdrawals are intended to cater to the need for maintaining ecology and in not allowing groundwater to deplete, unless such depletion is likely to be beneficial due to the very high groundwater table or rising tendency in the " without conjunctive use project" condition itself.

These general guidelines would require the command area to be divided into zones depending upon the present groundwater status and to plan conjunctive use separately for these zones. In general, it is envisaged that the zone size may vary from minimum of around 30,000 ha. to a maximum of around 30,000 ha. for the purpose of planning conjunctive use depending on homogeneity.

Table.2.4. Minimum and Maximum withdrawals

Present Groundwater Depth of groundwater	Status Trend	Minimum necessary additional withdrawals. As percentage of the additional recharge caused by the project	Maximum permissible withdrawal as percentage of the additional recharge caused by the project
Less than 2 m	Rising	70 %	100 %
- do -	General steady	50 %	80 %
- do -	Falling	30 %	60 %
2 m to 6 m	Rising	60 %	90 %
- do -	Steady	40 %	70 %
- do -	Falling	20 %	60 %
More than 6 m	Rising	50 %	80 %
- do -	Steady	30 %	60 %
- do -	Falling	0 %	40 %

Notes: *A general long-term rise or fall of more than 0.2 m/s-year in case of alluvial condition and more than 0.5 m/year in case of hard rock areas would qualify for reclassifying the trend as "rising" or falling".*

2.6.2. Modification in Withdrawal Undercertain Conditions

The general guidelines given above would require modifications under certain conditions as follows:

i. Coastal areas: For coastal areas say within 50 km of the sea, depending upon the local hydro geological set up, all values may be reduced by 20 % to avoid the possibility of saline ingress due to heavy conjunctive use.

ii. Saline and shallow Groundwater: Where the groundwater is saline(conductivity > 4 m mhos/cm) and in shallow, say less than 6 m depth (and particularly less then 3 m depth) the area should normally be considered unfit for either surface irrigation or groundwater use.

It may however be possible to irrigate such areas for crops, which require less water, or by adopting drip or sprinkler irrigation methods with provision of adequate drainage facilities including sub-surface drainage or vertical drainage. Measures indicated under (iii) (a) below can also be adopted.

Generally, when groundwater is of good quality, conjunctive use will have priority over drainage and if it is poor quality, drainage will have priority over conjunctive use. However conjunctive use is not replacement for drainage.

iii. Saline, deep-seated groundwater: where groundwater is saline but is deep seated (that is more than 6 m depth), area is problematic but irrigation along with conjunctive use of groundwater can be planned after careful studies, The general strategy in such areas could be:

a. Plan for reduction of additional recharge into the command area by lining the canals, by not planting paddy crop, and by planning irrigation in frequent short douses in order to avoid deep percolation.

b. Conjunctive use may be planned to mop up the unavoidable additional deep percolation and canal losses, through shallow open wells, horizontal sub surface drainage etc. before it reaches the main saline water table.

c. While quantifying the minimum required and the maximum permissible groundwater use, the normal as stated earlier may be increased by say 20 % of the additional recharge.

d. If conjunctive use involves pumping of saline groundwater, this may have to be mixed with good quality fresh water so that the quality of the irrigation water is acceptable.

e. Areas with soil salinity where the groundwater is deep seated and is not saline but the command area soils are problematic and have salinity. The following precautions maybe necessary in planning irrigation through conjunctive use.

a. Leaching dose, which leaches out soil salinity to deeper layers, may have to be planned.

b. Quantity of conjunctive use, both minimum necessary and maximum desirable could be considered as lower than what is shown in the general guidelines.

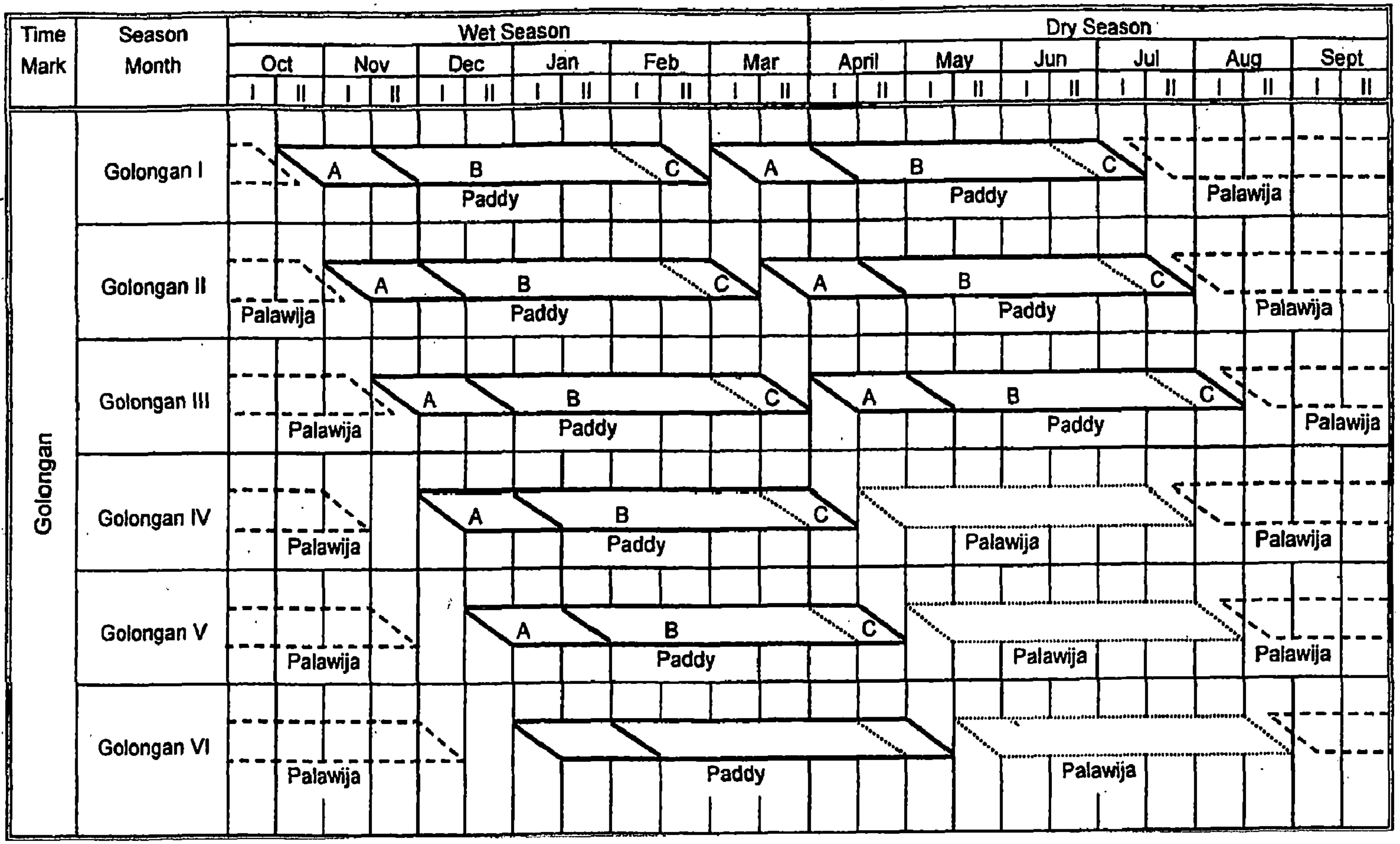
c. Where the problem are more serious, sub surface drainage may have to be planned

2.7. GROUP SYSTEM OF WATER DISTRIBUTION TO REDUCE PEAK DEMAND

Water distribution is an important component of irrigation system design and implementation. Each irrigation project has its own specific water distribution plan to achieve project target. In Indonesia, water distribution plan is based on group system. The peak irrigation demand is reduced due to staggering of crop calendar in golongans Agung Budi Waskito (2002) has shown that. In case of Batutegi Project Indonesia, peak demand is 5003 m^3/month/ha (without Golongan System) if was reduces to 3686 m^3/month/ha staggering crop calendar in six golongans. Thus the concept of golongan is useful both in irrigation system design and in irrigation system operation. Use of golongan concept in system design results in lower capacities of canal network at head and helps in equitable sharing of deficit water supplies.

Figure 2.1. shows the crop calendar and staggering golongan to lower the peak water requirement for a project in Indonesia (Agung, 2002). It also helps in lowering the peak labor requirement.

In the rainy season, the land preparation in golongan 1 starts in the second half of October and with time lag of half a month, the other golongan starts one by one. In the dry season, paddy land in golongan 1 is prepared in the first half of March by Golongan 1 and 3.



Month	Monthly water requirement (m^3/month/ha)	
	Without system golongan	Apply system golongan
OCT	1529	418
NOV	5003	2761
DEC	3188	3501
JAN	3340	3487
FEB	855	2425
MAR	3551	2198
APR	4147	3686
MAY	3888	3243
JUN	3188	3110
JUL	0	1157
AUG	0	0
SEP	0	0

Note:

A : Nursery + Land Preparation (1 month)
B : Planting + Growing (2.5 months)
C : Graining (0.5 month)

Fig. 2.1 Proposed Crop Calendar and Golongan

2.8. EFFECTIVE OF SILTATION IN LIVE STORAGE ZONE

In the prevalent procedure for reservoir planning and operation studies, live storage capacity is often assumed to be constant over the project life whereas actually live storage capacity keeps on decreasing due to progressive deposition of sediment in live storage zone. Thus, elevation-area-capacity relationship keeps on changing during project life. In conventional simulation study, the elevation-area-capacity curve as anticipated after half of project life is first derived using area reduction method (or any other appropriate method) and assumed to apply uniformly from first year up to end of project life in the simulation study. Usually for storage projects, 100 years life is assumed and adjusted elevation area capacity curve after 50 years is assumed to apply from first year up to 100 year. With the availability of computer technology it is now possible to revise elevation-area capacity relation at regular interval say 5 to 10 year and incorporate the relationship in the long-term reservoir simulation study.

Among the empirical methods of estimation of sediment accumulation and distribution, the Area Reduction Method proposed by Borland and Miller (1958) is most suitable and widely used on account of its simplicity and minimum data requirement. The Reservoir Sediment committee' appointed by the Government of India has also recommended use of this method (Government of India, 1985).

2.8.1 Discrepancies in Predicted and Observed Deposition Patterns

Kulkarni and Desmukh (1997) studied the observed sediment deposition pattern of Bhakra , Gandhisagar , Pagara, Panchet, Maithon and Tungabhadra reservoirs in India to check how far these reservoirs behaved differently from the standard deposition patterns indicated by Area Reduction Method.

It's was found that none of the reservoirs totally behaves as per type estimated by the standard procedure given in Area reduction Method.

Under estimation in dead storage may effect operation of hydropower plant and irrigation project due to entry of sediment into penstock and canal. Some reservoirs like Bhakra and Ghandisagar be have as per different types at different depths. This shows that adoption of only single type of deposition pattern to such reservoirs can lead to errors in estimation of sediment deposition patterns.

2.8.2. Effect of Reduced Capacity on Irrigation Water Utilization

The reduced capacity would lead to reduced water availability for the irrigation area and this may in turn affect the crop types and cropping pattern. However over the years irrigation efficiencies also tend to improve. Due to deposition of sediment in live storage zone, water available for irrigation decreases over the years. Effect of sedimentation on cropping intensity is illustrated in chapter 4.

2.9. IRRIGATION EFFICIENCIES

Normally empirical assumptions are made regarding field application and conveyance efficiencies. These are assumed to be constant over the project life while planning for water use and fixing canal capacity. Experience has shown that field application efficiencies improve with time as improvement in irrigation and agriculture technology adoption by farmers takes place. Similarly actual conveyance efficiencies may be quite different from the assumed efficiencies depending on several management factors. Water use efficiencies tend to improve under water deficit conditions. Sometimes artificial scarcity can be created to improve efficiencies.

Field application efficiencies are usually different for crops. Usually it is higher for paddy crop compared to other crops (palawija crops). Field water supply (Litres/sec/ha) is affected by field application efficiency. As illustrated in chapter 5 on irrigation scheduling, available computer programs such as CROPWAT can be used to simulate effect of irrigation efficiencies.

CHAPTER 3

Crop Water Requirement

CHAPTER – 3

CROP WATER AND IRRIGATION REQUIREMENT

3.1. GENERAL

Demand for Irrigation water varies from place to place over the irrigable command area due to variation in soil properties, crop characteristics (crop type, growth stage) climate (rainfall, factor affecting evapotranspiration process). Irrigation efficiencies etc. Irrigation water demand may also very over the years due to changes in cropping pattern, randomness in rainfall, changes in irrigation policy etc.

Estimation of crop water requirement is the first step in estimation of irrigation demand (Volume of water and rate of supply). Different methods have been suggested in literature for estimation of evapotranspiration or consumptive use requirement. Practices also vary from country to country with regard to estimation, procedures and assumptions, which are required to be made in absence of adequate data or field observations.

This chapter deals with study of climatic factors and scientific estimations of crop water requirement and field irrigation requirement. Modified Penman and Penman Monteith methods are the two recommended methods for estimations of evapotranspiration FAO has developed a software for estimation of crop water using Penman Monteith method requirements and irrigation scheduling, which has been used in present study . FAO Penman Monteith method is now accepted as the standard method. Annexure 1 provides details of this method.

3.2. ANALYSIS OF CLIMATIC DATA

There are three-climate stations in Lombok with reasonably extensive record. Two of these are in the study area-Kopang (on the lower slopes of G. Rinjani, almost at the geographical center of the study area), and Keruak close to the south-east coast; the third station is at Rembiga (Selaparang Airport), just north of Mataram . The Average monthly and annual climatic data for Kopang and Keruak are given in table 3.1. mean monthly temperature varies in narrow range of 24^0 C to 30^0C. Relative Humidity is higher at Kopang compared to Keruak. Over the months it is constantly uniform. Several

rainfall stations exist in the region. Mean annual rainfall at these stations were analyzed for topographic variation. Contrary to expected increase in rainfall at higher elevation, it is seen that different stations at similar elevations show different observed rainfall as seen in figure 3.1. It is therefore necessary that variation of rainfall over the command area should be accounted for in irrigation planning.

In recent years the average recorded temperature at Kopang has been virtually the same as that at Keruak a most unlikely scenario in view of the different altitudes (over 350 m and below 50 m above sea level respectively) and the differences in Rainfall and sunshine.

Most probable reason could be that there had been significant changes in the exposure of the climate station, including the construction of houses and the growth of trees close to the sites. The greater shelter probably explains the reduced wind speeds and high night-time temperatures, and might explain the slight increase in daytime maximum temperatures because of the creation of the heat trap.

Table. 3.1. Average Monthly and Annual Climate Data

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Kopang													
Tem (^{0}C)	25.8	25.6	25.6	25.8	25.5	24.5	24	23.8	24.7	25.8	26.4	26.2	25.3
Max Tem (^{0}C)	30.3	29.4	29.9	30.2	31.3	29.3	29.4	29.8	30.6	31.2	31.1	30.6	30.2
Min Temp (^{0}C)	21.3	21.8	21.3	21.4	19.7	19.6	18.6	17.7	18.8	20.3	21.6	21.8	20.8
RH (%)	84	82	82	81	82	83	81	81	80	79	81	83	82
Max RH (%)	92	90	91	89	92	92	91	90	89	89	93	92	91
Min RH (%)	76	74	73	72	72	74	71	72	70	68	69	73	72
Sunshine (%)	40	38	46	54	57	55	57	59	58	60	52	38	51
Win speed (km/day)	109	98	66	39	40	45	58	61	62	66	57	60	63
Keruak													
Tem (^{0}C)	27.2	27.2	27.3	27.5	27.1	26.3	25.8	25.9	26.6	27.6	28.1	27.7	27
Max. Tem (^{0}C)	29.9	30.1	29.8	29.6	29.8	29.1	28.3	28.5	28.8	29.4	30.6	30.5	29.5
Min Temp (^{0}C)	24.4	24.2	24.8	25.3	24.4	23.4	23.3	23.3	24.5	25.7	25.6	24.8	24.5
RH (%)	72	74	74	73	71	71	73	71	71	69	71	72	72
Max RH (%)	85	82	82	80	78	77	80	78	79	76	79	84	80
Min RH (%)	59	65	65	65	63	64	66	63	63	61	63	60	65
Sunshine (%)	43	44	56	64	62	68	74	78	75	74	63	47	63
Win speed (km/day)	119	96	62	53	66	82	102	110	123	111	106	98	94

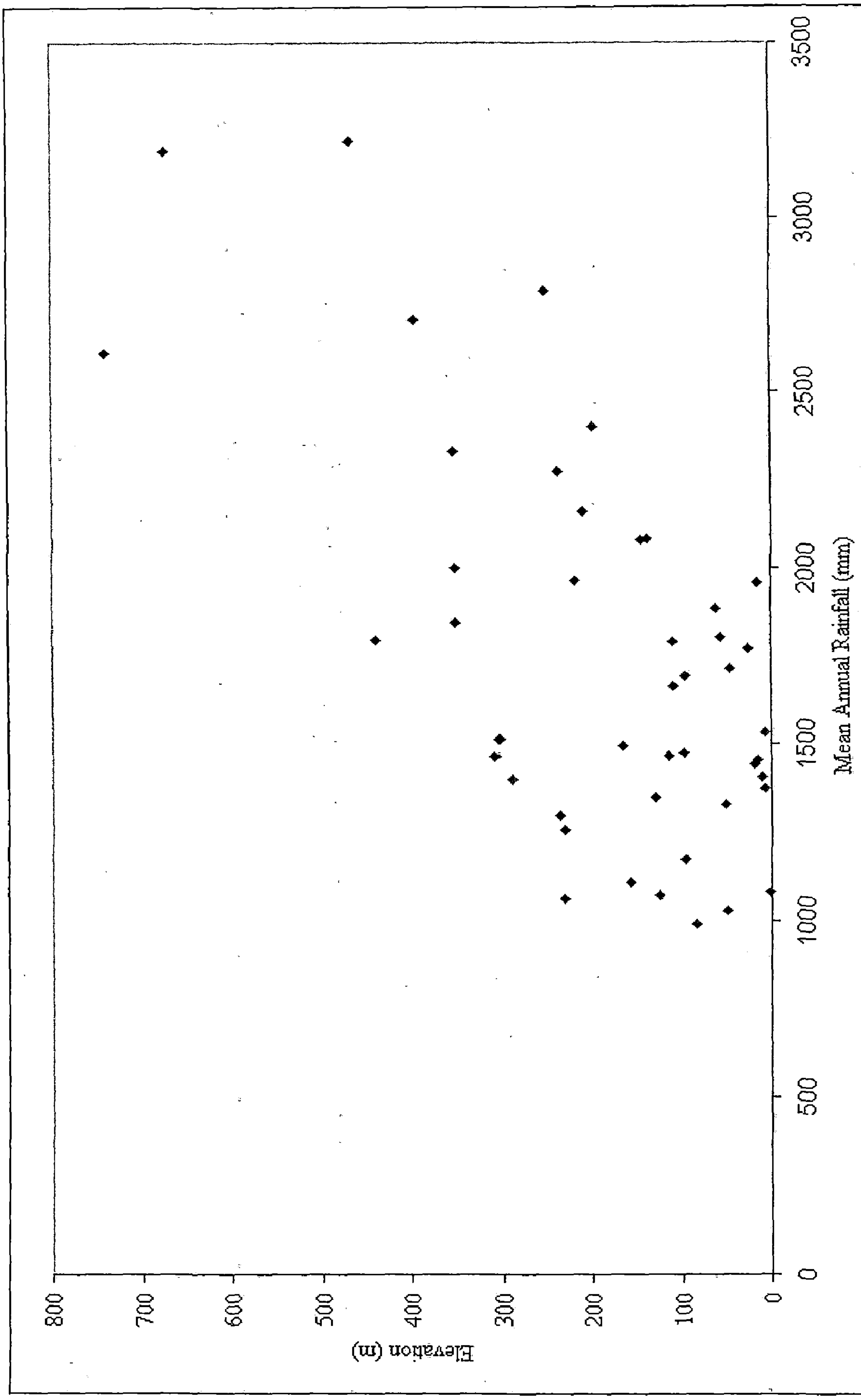


Figure 3.1. Variation of Mean Annual Rainfall with elevation

3.3. EVAPOTRANSPIRATION

Estimates of open water evaporation (E_0) and reference crop evaporation (ET_0) are required for assessing reservoir losses and for estimating crop water requirements respectively. At Kopang and Keruak climate stations, measured data on temperatures, humidity, wind, sunshine duration or radiation are available (table 3.1). From this data evaporation estimates may be made using the modified Penman Equation (FAO, 1977), which is based on a sound theoretical approach. Detailed explanation of the modified Penman Equation is given in various text books on hydrology and water resources planning.

The Penman Equation consists of two terms; the radiation term and the aerodynamic (wind and humidity) term. The relative importance of each term varies with climatic conditions :

$$\mathbf{E = c.\{W. R_n + (1\text{-}W)\text{-}f(u).(e_a\text{-}e_d)\}}$$

radiation term aerodynamic term

Where :

E : evaporation mm/day (when an albedo of 0.05 is used $E=E_0$; when albedo is 0.25, $E=ET_0$)

W : temperature related weighting factor

R_n : net radiation in equivalent evaporation , mm/day

$R_n = (1\text{-}a)\ R_a$; where a = albedo and R_a = atmospheric radiation

f(u) : Wind related function

$(e_a\text{-}e_d)$: difference between saturation vapour pressure at mean air temperature and mean actual vapour pressure (mbar)

c : adjustment factor to compensate for differences between day and night conditions

Parameters in the equation are not always directly available but can be derived from measures data. Net radiation, for example can be derived from measured solar radiation or sunshine duration, if measurement of temperature and humidity are also available. However, wind data must be measured at the site or transposed from another station.

In a earlier study, the data at Rembiga, Keruak and Kopang were used to estimate open water evaporation and crop evapotranspiration on a mean monthly basis for planning various components of the West Nusa Tenggara (DPW, 1996). These evaporation estimates were considered low compared with estimates obtained for other parts of Indonesia. There is evidence suggesting that this may be partly attributable to underestimation of solar radiation due to lack of recalibration of the radiometer (bimetallic actinography require recalibration every six months and replacement of sensors every few years)

In subsequent water balance study (DPW, 1996) daily climate data was processed for Kopang and Keruak to provide daily estimates of open water evaporation and reference crop evapotranpiration. Suspiciously low values of solar radiation were replaced with more realistic minima, which resulted in a slight increase in evaporation estimates over those previously obtained.

For the present study the climate data used in the (DPW, 1996) has been reprocessed. The main change is that the uncertain radiation data has been excluded and the radiation is estimated from observed, sunshine data, which is more complete and is generally more reliable.

Solar radiation may be estimated from sunshine, as follows :

$$\mathbf{(R_s/R_a) = a + b * (n/N)}$$

where R_s	=	Solar radiation
R_a	=	atmospheric radiation
n	=	actual sunshine hours
N	=	maximum possible sunshine hours
a,b	=	constant

R_a and N depend on latitude and may be found from meteorological tables.

FAO paper 24 contains standard values for the constants a and b but recognizes that these do not necessarily apply in all regions, locally derived values may be appropriate. Figure 3.2 shows that the standard FAO equations lead to far higher values of radiation than any of the recorded data. In view of the possible error in observed radiation data it would be unwise to derive a "best fit" line from the data as shown in figure 3.2. This effectively assumes that some of the radiation data is accurate, while some in the low side. The adopted values of the constants in previous studies are shown in table 3.2 together with the standard FAO values and those derived by other studies in the region.

Monthly values of ET_0 and E_0 are shown in table 3.3. Overall mean values are slightly higher than those in the previous SLWBS study. Penman method gives higher values compared to Penman-Monteith method as seen in figure 3.3.

3.4. CROP WATER REQUIREMENT

The essential estimates for determining crop and irrigation water requirement are as follows:

- Open water evaporation (E_0)
- Reference crop evapotranspiration (ETo)
- Effective rainfall
- Percolation
- Land preparation and water layer replacement
- Crop coefficient (for consumptive use)
- Efficiencies
- Cropping pattern and intensities

Half monthly values of E_0 and ET_0 for Keruak are shown in table 3.4.

3.4.1. Effective Rainfall

Guidelines as followed in West Nusa Tenggara Province of Indonesia for determining water requirements define effective rainfall as 70 % of the half-monthly rainfall. In south and east Lombok, rainfall shows large variability from year to year, and the use of average conditions may not be sufficiently accurate. This applies in particular to the dry season when one or two wet years may produce a significant average rainfall even though there is no rain at all in most years. As an example, the average rainfall series for the Pandanduri Reservoir command area shows a mean rainfall of 9 mm in the second half of September, but 15 years out of 23 had no rainfall and only 4 had more than 9 mm; the mean is substantially influenced by the occurrence of 131mm in one year.

Table 3.4. shows mean rainfall, mean rainfall by excluding two highest and lowest values and 1 in 5 year rainfall. Figure 3.4 shows variation of mean rainfall and 1 in 5 year rainfall over the months.

In the previous South Lombok water balance study (DPW,1999 it was concluded that the use of average rainfall to estimate effective rainfall was not a sufficiently severe criterion for this area, and accordingly the study used actual rainfall. The use of actual rainfall leads to reduced diversions requirement in wet period and increased requirement in dry periods. The overall average requirement is unlikely to change by very much, but there may be a substantial impact on reservoir reliability because the increased requirements are likely to coincide with low reservoir inflows, and hence increase the risk of reservoir failure; the periods of reduced requirements may make little difference to the reservoir because if it is full the result will simply be the increased spill. The SLWBS found that basing effective rainfall on actual rather than mean rainfall reduced the reliable cropping intensity of Pengga by more than one tenth (270% to 240 %). Although actual rainfall may be used in , it is not practicable for purpose because the half monthly rainfall may only be found at the end of the periods for which it is required to determine diversion requirements. Theoretically, diversion requirements could be calculated each day using up to date daily rainfall data, but this is not considered feasible in practice.

To determine the design releases, effective rainfall has been set as 70 % of the average half monthly rainfall with extreme high and low values (top two and bottom two out of 23) being omitted from the calculation. Table 3.4. Shows that this has little effect in wet season month, but the derived values are more realistic in the dry season. For the case of the Pandanduri area in the second half of September (referred to above) the adjustment mean is about 2.5 mm which is closer to "typical" condition.

3.4.2. Percolation

Most of the soils in the command areas are heavy cracking clays with low infiltration rates. Wet season percolation tests carried out during the SLWBS in January and February 1986 indicated averages of 1.2 mm/day in Pandanduri. For this study, a conservative value of 2 mm/day has been assumed.

3.4.3. Land Preparation and Water Layer Replacement

A period of one month has been assumed for land preparation. For wet season rice 300 mm is required (250 mm for presaturation and paddling, and 50 mm for water layer replacement after transplanting. In the case of dry season rice immediately following the harvesting of wet season rice, the total requirement is reduced to 250 mm. Irrigation requirements during land preparation are calculated as follows:

$$FR = LPT/31 + 0.6 * (E_0 + PERC)$$
$$(=LP)$$

Where: FR = Field requirement (mm/day)

LP = Land preparation (mm/day)

LPT = Total land preparation (mm)

E_0 = Open water evaporation (mm/day)

PERC = Percolation (mm/day)

Additional water layer replacement in required after the water level has been drawn down for fertilizer application or weeding. Two replacements, each of 50 mm, have been allowed for at 1 and 2 month after transplanting. In each case this is converted to a rate in mm/day over half-month period.

3.4.4. Consumptive Use

Consumptive use has been calculated in accordance with FAO paper 24. Crop coefficients are defined for each half-month period, and actual evapotranspiration (ET_0) is found by multiplying the reference value (ET_0) by the crop coefficient.

For most of the crops in the existing and proposed cropping patterns, crop coefficients have been taken from previous report, though with adjustment in the final half month period if the growing period is completed part way through the period. For peanut coefficient were derived from FAO paper 24. All coefficients are given in table 3.5.

3.4.5. Overall Fields Requirement

The overall field requirement is calculated as follows

For rice during land preparation **FR** = **LP**

After transplanting **FR** = $ET_c + P + WLR$

For Polowijo crops **FR** = ET_c

Where : LP = Land preparation

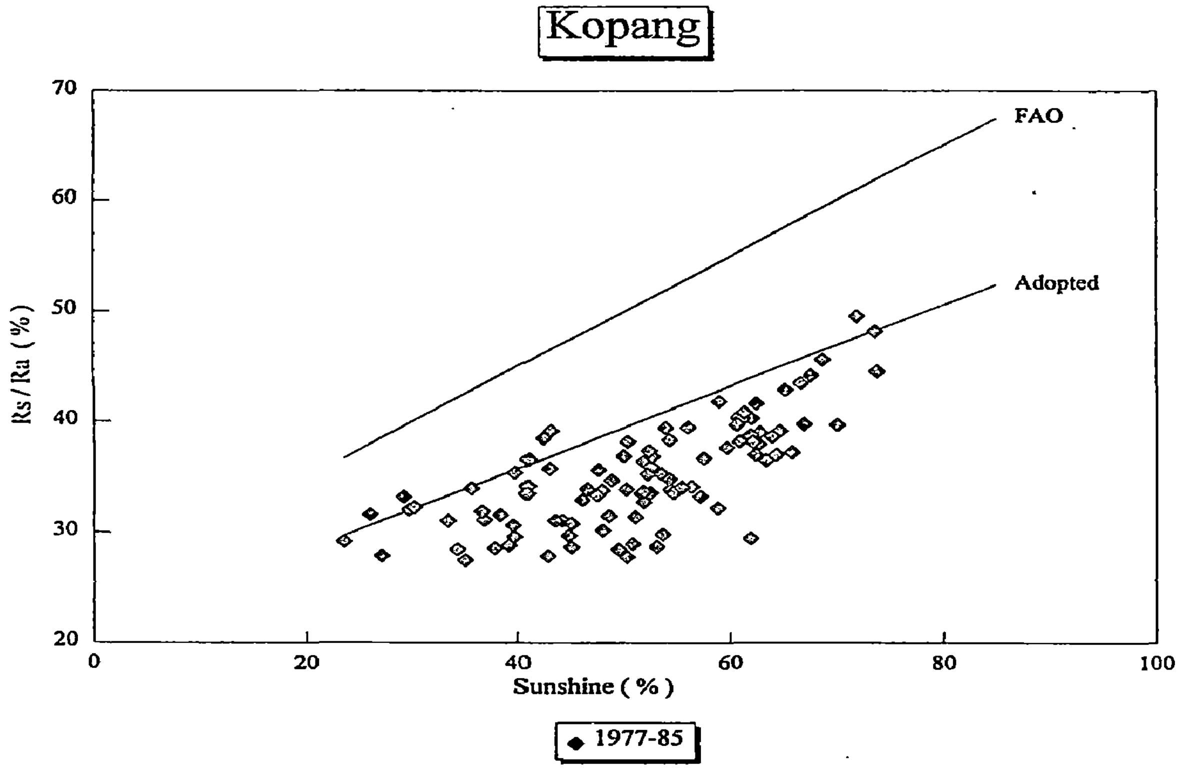
ET_c	=	Consumptive use (=ET_0 x Kc)
Kc	=	crop coefficient
P	=	percolation
WLR	=	water layer replacement

The consumptive use is calculated using an average crop coefficient with planting of half the area occurring one half month after the other half. As shown in table 3.6 crop coefficient C1 are for half of the area and crop coefficient C2 for other half of area where planting is staggered by half month. Field requirement calculations for rice are illustrated in table 3.6. in which land preparation is assumed to start at the beginning of December. Table 3.7. shows the calculations for an example polowijo crop (maize), the timing of which is consistent with the rice example.

3.4.6. Consideration of Crop Calendar and Golongans

Water distribution is an important component of irrigation system design and implementation. Each irrigation project has its own specific water distribution plan to achieve project target. In Indonesia, water distribution plan is based on group system. The peak irrigation demand is reduced due to staggering of crop calendar in golongans Agung Budi Waskito (2002) has shown that. In case of Batutegi Project Indonesia, peak demand is 5003 m^3/month/ha (without Golongan System) it was reduced to 3686 m^3/month/ha by staggering crop calendar in six golongans. Thus the concept of golongan is useful both in irrigation system design and in irrigation system operation. Use of golongan concept in system design results in lower capacities of canal network at head and helps in equitable sharing of deficit water supplies.

In accordance with standard practice in Lombok, a three golongan system has been used. For the above example, land preparation would begin on December 1st for one third of the area. December 16th for a second third and January 1st for the remaining third. This reduces the peak diversion requirement (and also smoothes out labour requirements). The calculations in the examples tables have been repeated for the two subsequent starting dates. Computations tables for rice and maize are shown in tables3.8. table 3.9. table 3.10. and table 3.11. The result are averaged to obtain the overall field requirement. These are shown in the table 3.12. for a start date of December 1st and in the tables 3.13. for starting date of December 16th.



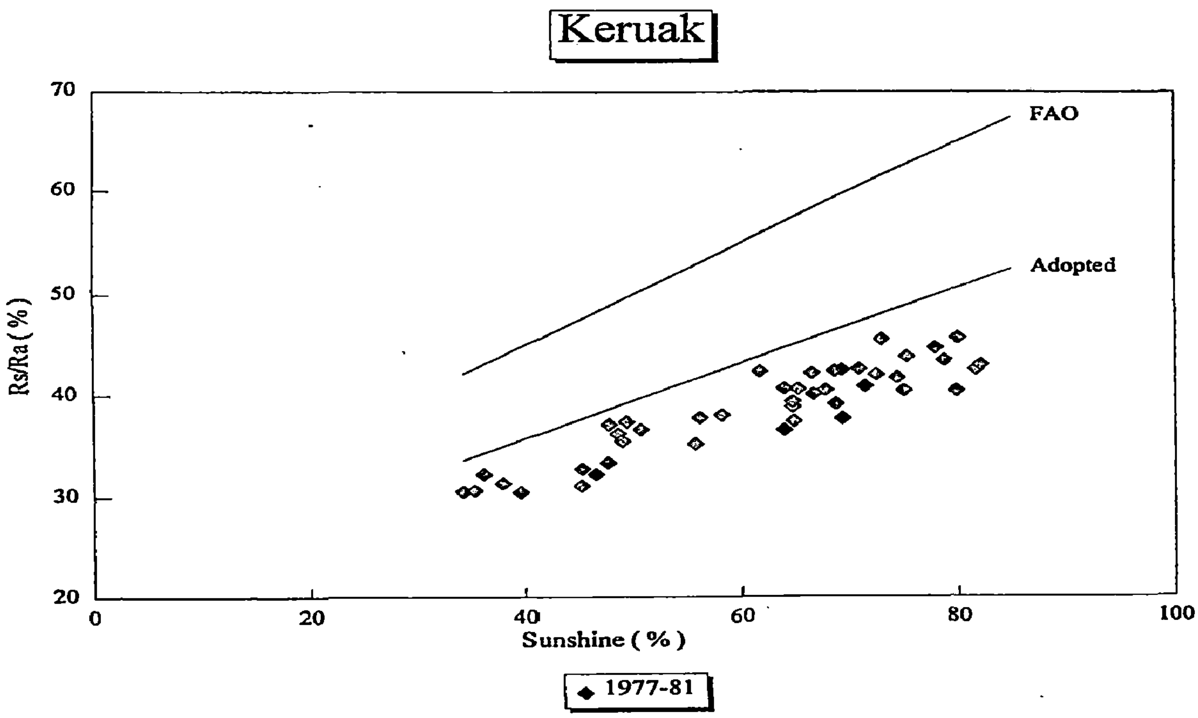


Figure 3.2
Relationship Between Sunshine and Radiation

Table 3.2 Coefficient in the Sunshine/Radiation Relationship

Location	a	b	Source
General	0.25	0.50	FAO,1977
Keruak	0.25	0.36	DPW,1999
Kopang	0.23	0.33	DPW, 1999
Keruak/Kopang	0.25	0.28	DPW, 1999
Keruak/Kopang	0.21	0.37	This study
Plampang,Sumbawa	0.20	0.35	DPW, 1999
Plampang(revised)	0.24	0.33	DPW, 1999

Table 3.3 Monthly Mean Values of Evaporation and Reference Evapotranspiration (mm/day)

	Penman Equation				Penman Monteith	
	Kopang		Keruak		Kopang	Keruak
	E_0	ET_0	E_0	ET_0	ET_0	ET_0
January	4.36	3.48	5.05	4.15	3.23	3.61
February	4.27	3.41	4.99	4.07	3.36	3.73
March	4.26	3.36	5.22	4.15	3.72	4.15
April	4.14	3.22	5.04	4.98	4.00	4.46
May	4.79	3.94	4.46	4.54	4.02	4.50
June	4.42	3.65	4.32	4.42	3.77	4.43
July	4.59	3.79	4.46	4.54	3.86	4.60
August	4.95	3.07	5.10	4.05	4.01	4.89
September	4.42	3.45	5.68	4.55	4.07	4.90
October	4.98	3.92	6.15	4.94	4.03	4.74
November	4.79	3.77	5.99	4.85	3.49	4.17
December	4.22	3.34	5.29	4.29	2.98	3.54
Year	4.18	3.28	5.14	4.46	3.71	4.31

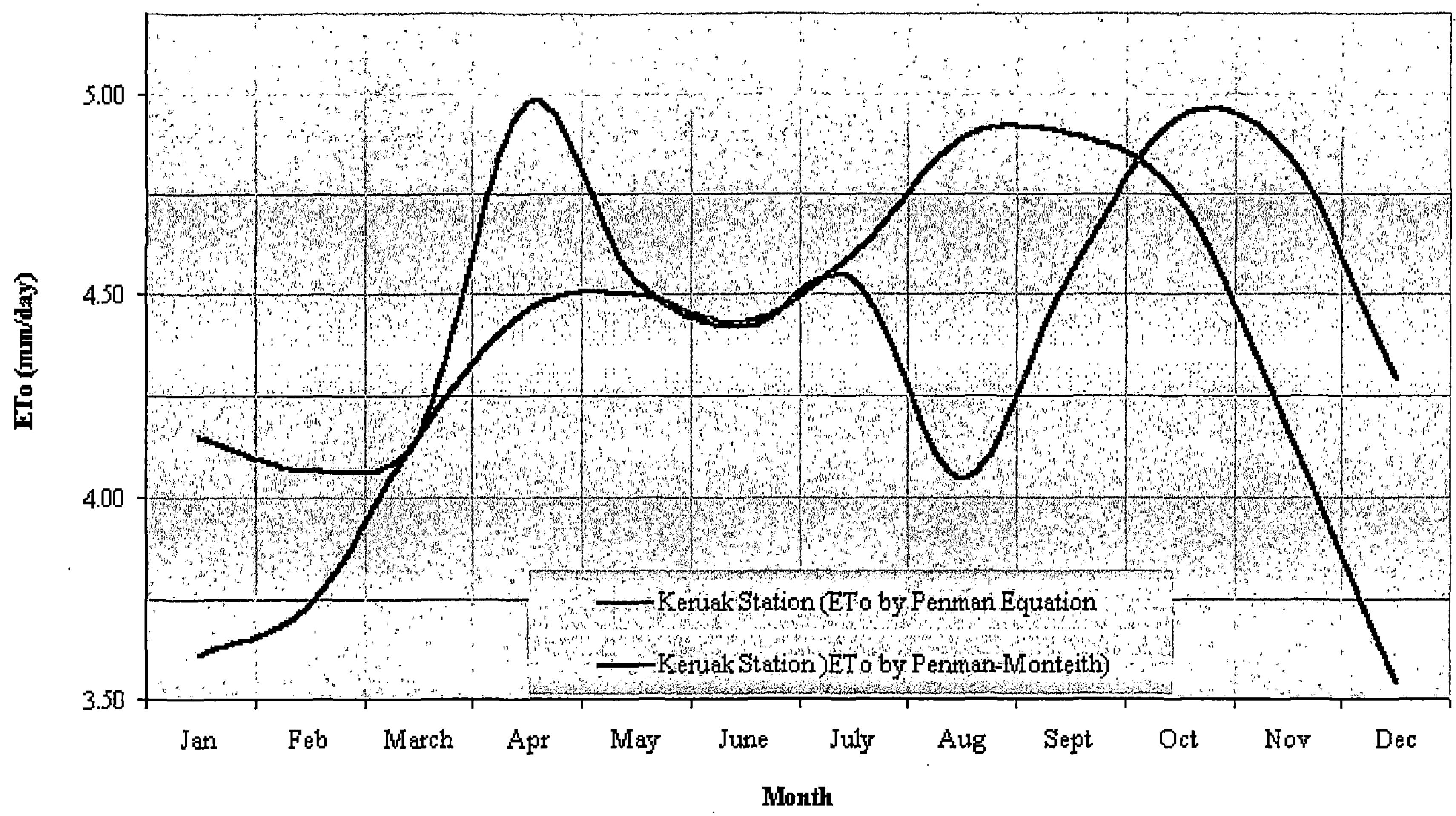


Figure 3.3 Monthly Mean Values Evapotranspiration (mm/day)

Table 3.4. Average Evapotranspiration, Evaporation and Rainfall in the command areas (mm)

Half-Month Period	Keruak		Rainfall in the command area		
			Pandanduri		
	ET_0	E_0	(1)	(2)	(3)
Jan 1	60	74	111	107	73
2	68	82	125	124	65
Feb 1	63	77	124	121	67
2	52	64	94	93	56
Mar 1	61	76	100	89	38
2	68	85	57	52	16
Apr 1	62	78	41	39	13
2	58	73	13	11	0
May 1	54	68	28	15	0
2	55	70	12	6	0
Jun 1	51	65	18	7	0
2	52	65	14	6	0
Jul 1	51	64	9	4	0
2	59	74	2	1	0
Aug 1	59	73	4	2	0
2	67	85	3	1	0
Sep 1	67	84	7	4	0
2	70	86	9	2	0
Oct 1	72	90	16	12	0
2	81	101	16	7	0
Nov 1	77	95	33	28	8
2	68	84	85	68	15
Dec 1	67	83	84	82	43
2	66	81	89	84	33

Note : (1) Mean Rainfall
(2) Mean Rainfall excluding two highest and two lowest values
(3) I-in-5 year rainfall

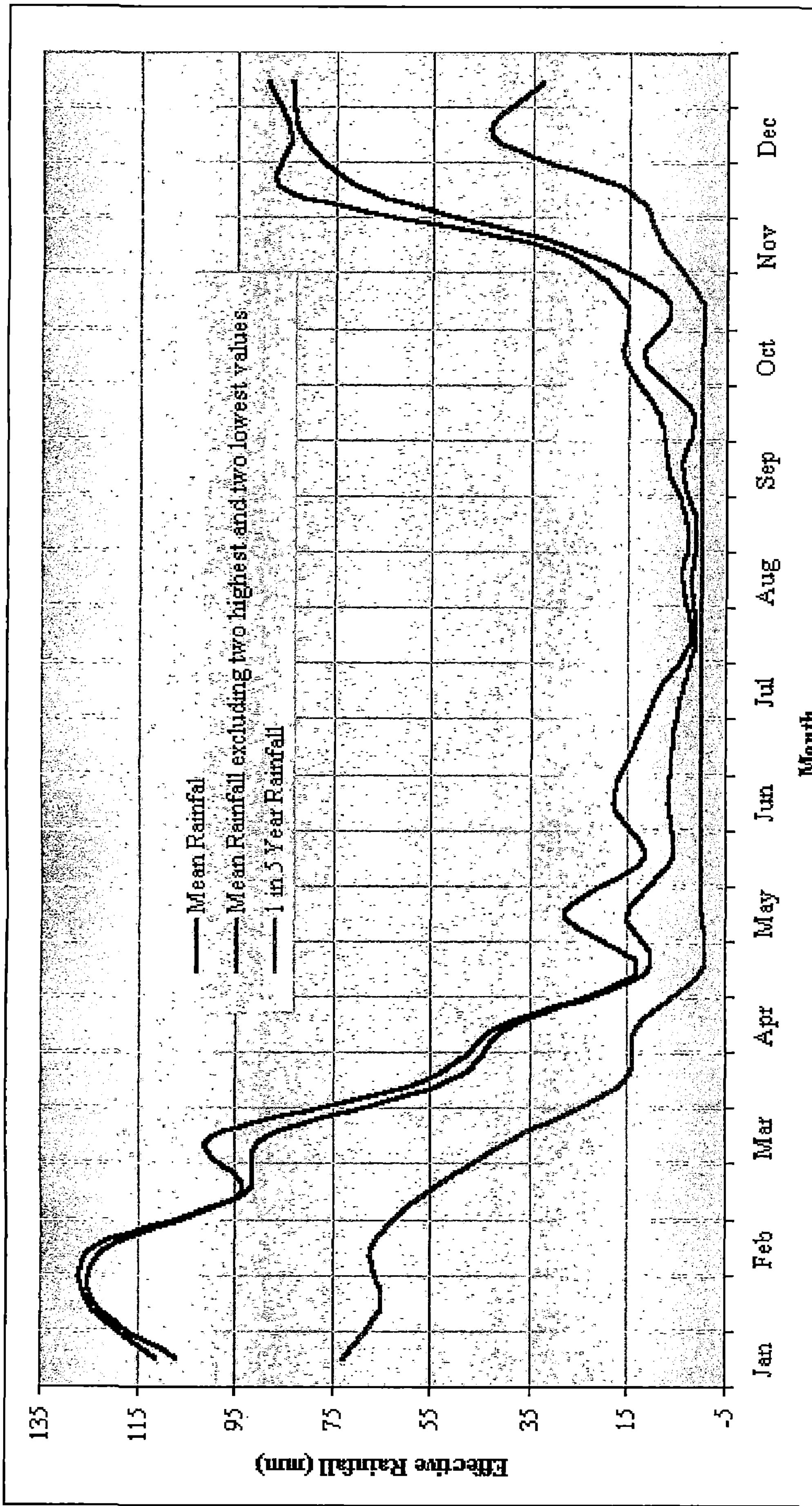


Figure 3.4. Rainfall in the Command Areas (mm)

Table 3.5. Crop Coefficient

Crop	Growing period (days)	Half – month period						
		1	2	3	4	5	6	7
Rice	90		1.10	1.10	1.05	1.05	0.95	0.00
Maize	90	0.5	0.59	0.96	1.05	1.02	0.95	
Soybeans	85	0.5	0.75	1.00	1.00	0.82	0.30	
Chilies	105	0.5	0.50	0.65	0.80	0.95	0.95	0.80
Onions	70	0.5	0.51	0.69	0.90	0.63		
Peanuts	90	0.5	0.50	0.95	0.95	0.95	0.55	
Tobacco	90		0.50	0.50	0.80	0.80	0.80	0.50

Notes :

1. *Rice begins in periods 2 because the first part of the area is assumed to be transplanted during the second half of the land preparation period*
2. *Tobacco is planted later than other dry season crops; a delay of one half-month has been assumed*
3. *Where sunbeams are defined in the cropping pattern they are combined with soyabeans*

Net field requirements are found by subtracting the effective rainfall (70 % of mean (2) in table 3.4.. from the field requirement. For the purpose of sizing the canal this was repeated using 70 % of the 1 in 5 year rainfall (also in table 3.6.) the maximum half-monthly requirement is used for canal design (after allowing for efficiencies) The peak requirement occur during land preparation for rice; it is 1.41 l/s/ha for Pandanduri (where effective rainfall is higher). The respective peak diversion requirement is 14.4 m^3/s for the largest development option. Calculation are shown in table 3.14., incorporating the adopted system efficiency outlined below.

Table 3.6. Crop Water Requirement for Rice-Land preparation starting 1st December

Half-month	LP (mm)	LP (mm/d)	WLR (mm/d)	Crop coefficient			ET_0 (mm/d)	ET_c (mm/d)	FR (mm/d)
				C1	C2	Cavg			
Dec 1	150	14.19					4.49	14.19	14.19
2	150	13.92		1.10			4.10	13.92	13.92
Jan 1				1.10	1.10	1.10	4.03	4.44	6.44
2			3.13	1.05	1.10	1.08	4.26	4.58	9.71
Feb 1				1.05	1.05	1.05	4.20	4.40	6.40
2			3.77	0.95	1.05	1.00	3.92	3.92	9.69
Mar 1				0.00	0.95	0.48	4.06	1.93	3.93
2					0.00	0.00	4.23	0.00	0.00
Apr 1	125	12.39					4.12	12.39	12.39
2	125	12.39		1.10			3.83	12.18	12.18
May 1				1.10	1.10	1.10	3.62	3.98	5.98
2			3.13	1.05	1.10	1.08	3.47	3.72	8.85
Jun 1				1.05	1.05	1.05	3.41	3.58	5.58
2			3.33	0.95	1.05	1.00	3.43	3.43	8.77
Jul 1				0.00	0.95	0.48	3.39	1.61	3.61
2					0.00	0.00	3.68	0.00	0.00

C1 & C2 : half monthly coefficients from table 3.5 staggered by half month

Table.3.7. Crop Water Requirement for Example Dry Season Crop (maize)

Half-month period	ET_0 (mm/d)	Crop coefficient			ET_c (mm/d)
		C1	C2	C avg	
Apr 1	4.12	0.50		0.25	1.03
2	3.83	0.59	0.50	0.55	2.09
May 1	3.62	0.96	0.59	0.78	2.80
2	3.47	1.05	0.96	1.01	3.48
Jun 1	3.41	1.02	1.05	1.04	3.53
2	3.43	0.95	1.02	0.99	3.38
Jul 1	3.39		0.95	0.48	1.61
2	3.68				
Aug 1	3.91	0.50		0.25	0.98
2	4.19	0.59	0.50	0.55	2.28
Sep 1	4.47	0.96	0.59	0.78	3.46
2	4.64	1.05	0.96	1.01	4.66
Oct 1	4.81	1.02	1.05	1.04	4.98
2	5.07	0.95	1.02	0.99	4.99
Nov 1	5.13		0.95	0.48	2.44
2	4.56				

Table.3.8. Crop water Requirement for Rice- Land Preparation starting 16th December

Half-month	LP (mm)	LP (mm/d)	WLR (mm/d)	Crop coefficient			ET_0 (mm/d)	ET_c (mm/d)	FR (mm/d)
				C1	C2	Cavg			
Dec 1							4.49		
2	150	13.92					4.10	13.92	13.92
Jan 1	150	13.84		1.10			4.03	13.84	13.84
2				1.10	1.10	1.10	4.26	4.69	6.69
Feb 1			3.33	1.05	1.10	1.08	4.20	4.51	9.84
2				1.05	1.05	1.05	3.92	4.11	6.11
Mar 1			3.33	0.95	1.05	1.00	4.06	4.06	9.39
2				0.00	0.95	0.48	4.23	2.01	4.01
Apr 1					0.00	0.00	4.12	0.00	0.00
2	125	12.39					3.83	12.18	12.18
May	125	12.00		1.10			3.62	12.00	12.00
2				1.10	1.10	1.10	3.47	3.81	5.81
Jun 1			3.33	1.05	1.10	1.08	3.41	3.67	9.00
2				1.05	1.05	1.05	3.43	3.61	5.61
Jul 1			3.33	0.95	1.05	1.00	3.39	3.39	8.72
2				0.00	0.95	0.48	3.68	1.75	3.75
Aug 1					0.00	0.00	3.91	0.00	0.00
2							4.19		

Table.3.9. Crop water Requirement for Rice- Land Preparation starting 1st January

Half-month	LP (mm)	LP (mm/d)	WLR (mm/d)	C1	C2	C	ET_0 (mm/d)	ET_c (mm/d)	FR (mm/d)
Dec 1							4.49		
2							4.10		
Jan 1	150	13.84					4.03	13.84	13.80
2	150	13.96		1.10			4.26	13.96	14.00
Feb 1				1.10	1.10	1.10	4.20	4.61	6.00
2			3.77	1.05	1.10	1.08	3.92	4.21	10.00
Mar 1				1.05	1.05	1.05	4.06	4.26	6.30
2			3.13	0.95	1.05	1.00	4.23	4.23	9.40
Apr 1				0.00	0.95	0.48	4.12	1.96	4.00
2					0.00	0.00	3.83	0.00	0.00
May 1	125	12.00					3.62	12.00	12.00
2	125	11.88		1.10			3.47	11.88	11.88
Jun 1				1.10	1.10	1.10	3.41	3.75	5.75
2			3.33	1.05	1.10	1.08	3.43	3.69	9.02
Jul 1				1.05	1.05	1.05	3.39	3.56	5.56
2			3.13	0.95	1.05	1.00	3.68	3.68	8.81
Aug 1				0.00	0.95	0.48	3.91	1.86	3.86
2					0.00	0.00	4.19	0.00	0.00

Table.3.10. Crop Water Requirement for maize Golongan 2(Land Preparation for rice starting 16th December)

Half-month period	ET_0 (mm/d)	Crop coefficient			ET_c (mm/d)
		C1	C2	C avg	
Apr 1	4.12				
2	3.83	0.50		0.25	0.96
May 1	3.62	0.59	0.50	0.55	1.97
2	3.47	0.96	0.59	0.78	2.69
Jun 1	3.41	1.05	0.96	1.01	3.43
2	3.43	1.02	1.05	1.04	3.55
Jul 1	3.39	0.95	1.02	0.99	3.34
2	3.68		0.95	0.48	1.75
Aug 1	3.91				
2	4.19	0.50		0.25	1.05
Sep 1	4.47	0.59	0.50	0.55	2.43
2	4.64	0.96	0.59	0.78	3.59
Oct 1	4.81	1.05	0.96	1.01	4.84
2	5.07	1.02	1.05	1.04	5.24
Nov 1	5.13	0.95	1.02	0.99	5.06
2	4.56		0.95	0.48	2.16
Dec 1	4.49				
2	4.10				

Table.3.11. Crop Water Requirement for maize Golongan 3-Land Preparation for rice starting 1st December

Half-month period	ET_0 (mm/d)	Crop coefficient			ET_c (mm/d)
		C1	C2	C avg	
Apr 1	4.12				
2	3.83				
May 1	3.62	0.50		0.25	0.90
2	3.47	0.59	0.50	0.55	1.89
Jun 1	3.41	0.96	0.59	0.78	2.65
2	3.43	1.05	0.96	1.01	3.45
Jul 1	3.39	1.02	1.05	1.04	3.51
2	3.68	0.95	1.02	0.99	3.63
Aug 1	3.91		0.95	0.48	1.86
2	4.19				
Sep 1	4.47	0.50		0.25	1.12
2	4.64	0.59	0.50	0.55	2.53
Oct 1	4.81	0.96	0.59	0.78	3.73
2	5.07	1.05	0.96	1.01	5.09
Nov 1	5.13	1.02	1.05	1.04	5.31
2	4.56	0.95	1.02	0.99	4.49
Dec 1	4.49		0.95	0.48	2.13
2	4.10				

Half-month	Type of crop											
	Wet Season				Dry season 1				Dry season 2			
	Rice	Rice	Maize	Soya	Chilies	Onions	Peanut	Tobacco	Maize	Soya	Chilies	Peanuts
Dec 1	4.73											
Dec 2	9.28											
Jan 1	11.37											
Jan 2	10.12											
Feb 1	7.62											
Feb 2	8.60											
Mar 1	6.53											
Mar 2	4.45											
Apr 1	1.32	4.13	0.34	0.34	0.34	0.34	0.34					
Apr 2		8.12	1.02	1.12	0.96	0.96	0.96	0.32				
May 1		9.99	1.89	2.11	1.60	1.63	1.78	0.90				
May 2		8.85	2.69	2.89	2.08	2.19	2.51	1.62				
Jun 1		6.78	3.20	3.17	2.47	2.46	2.99	2.22				
Jun 2		7.80	3.46	2.83	2.92	2.15	3.03	2.58				
Jul 1		5.96	2.82	1.83	3.05	1.22	2.23	2.54				
Jul 2		4.18	1.79	0.87	2.73	0.39	1.26	2.09				
Aug 1		1.29	0.62	0.20	1.66		0.36	1.17	0.33	0.33	0.33	0.33
Aug 2					0.56			0.35	1.11	1.22	1.05	1.05
Sep 1									2.34	2.61	1.97	2.20
Sep 2									3.59	3.86	2.78	3.36
Oct 1									4.52	4.47	3.49	4.21
Oct 2									5.11	4.17	4.31	4.47
Nov 1									4.27	2.77	4.62	3.38
Nov 2									2.22	1.08	3.38	1.56

Table.3.12. Field Requirements-Land Preparation Starting 1st December (mm/day)

Half-month	Type of crop											
	Wet Season				Dry season 1				Dry season 2			
	Rice	Rice	Maize	Soya	Chilies	Onions	Peanut	Tobacco	Maize	Soya	Chilies	Peanuts
Dec 1												
Dec 2	4.640											
Jan 1	9.230											
Jan 2	11.540											
Feb 1	10.140											
Feb 2	7.470											
Mar 1	8.450											
Mar 2	6.600											
Apr 1	4.470											
Apr 2	1.270	4.060	0.320	0.320	0.320	0.320	0.320	0.300				
May 1		8.000	0.960	1.050	0.900	0.910	0.900	0.870				
May 2		9.860	1.810	2.020	1.530	1.570	1.700	1.590				
Jun 1		8.870	2.650	2.840	2.050	2.160	2.470	2.230				
Jun 2		6.800	3.220	3.190	2.490	2.470	3.000	2.540				
Jul 1		7.750	3.420	2.790	2.880	2.120	2.990	2.760				
Jul 2		6.140	3.060	1.990	3.310	1.330	2.420	2.210				
Aug 1		4.370	1.900	0.920	2.900	0.410	1.340	1.260				
Aug 2		1.330	0.660	0.210	1.780		0.380	0.370	0.350	0.350	0.350	0.350
Sep 1					0.600				1.180	1.300	1.120	1.120
Sep 2									2.430	2.700	2.050	2.280
Oct 1									3.730	4.010	2.890	3.490
Oct 2									4.750	4.700	3.670	4.430
Nov 1									5.180	4.230	4.360	4.540
Nov 2									3.790	2.460	4.100	3.000

Table.3.13. Field Requirements-Land Preparation Starting Mid-December (mm/day)

Table.3.14. Determination of Peak Diversion Requirements

Parameter	Unit	Dec		Jan		Feb		Mar		Apr	
		1	2	1	2	1	2	1	2	1	2
Pandanduri											
FR	mm/d	4.73	9.28	11.37	10.12	7.62	8.60	6.53	4.45	1.32	0.0
$R_{1\text{-in-}5year}$	mm	43	33	73	65	67	56	38	16	13	0.0
	mm/d	2.85	2.08	4.90	4.08	4.47	4.25	2.54	1.03	0.84	0.0
$R_{effective}$	Mm/d	1.99	1.46	3.43	2.85	3.13	2.98	1.78	0.72	0.59	0.0
NFR	Mm/d	2.74	7.82	7.94	7.27	4.49	5.62	4.75	3.73	0.73	0.0
DR	mm	4.21	12.03	12.22	11.18	6.90	8.65	7.31	5.74	1.12	0.0
	L/s/ha	0.49	1.39	1.41	1.29	0.80	1.00	0.85	0.66	0.13	0.0
Max DR	L/s/ha			1.41							

3.4.7. Efficiencies

The diversion requirement at the reservoir is more than the net field requirement because of losses in the distribution system. The efficiency of the system is usually broken down into the following components:

- Field
- Tertiary head
- Secondary canals
- Main canals

The adopted efficiencies, and the calculated overall efficiencies, are shown below:

Table 3.15. Efficiencies (%)

Element	Wet Season Rice		Dry Season Crop	
	For element (%)	Total (%)	For element (%)	Total (%)
Field	100	100	75	75
Tertiary head	80	80	80	60
Secondary canals	90	72	90	54
Main canals	90	65	90	49

100 x 0.8 x 0.9 x 0.9 = 65%
75 x 0.8 x 0.9 x 0.9 = 49 %

The field efficiency for wet season rice is assumed to be 100 % because in most of the area "losses" are simply spill into the next field. With dry season rice this would not be the case because only a very small proportion of the area is devoted to rice. The adopted overall efficiencies are 65 % for the wet season and 50 % for the dry season; these conform to standard Indonesian practice.

When return flows from part of the command area contribute to the supply for another part the overall efficiency will be higher than these figures It has been assumed that the area contributing such return flows has an effective efficiency 15 % higher (i.e. 80% and 65% for wet and dry season); this means that in the wet season about 40% of the losses are in fact re-used and 30% in the dry season.

An overall basin efficiency is calculated as a weighted average of areas with and without return flows. For Pandanduri 1470 ha provide return flows (partly from rutus and partly within the Pandanduri command area); wet season basin efficiency is as follows:

$$\text{Basin eff.} = \frac{1470 \text{ x } 80 \text{ x } 8727 \text{ x } 65}{10197} = 67.2\%$$

CHAPTER 4

Irrigation Development Option

CHAPTER – 4

IRRIGATION DEVELOPMENT OPTION

4.1. GENERAL

In conventional planning procedure, irrigation demands are assumed to be constant over the period of project life; though its variation within an average year is considered. In is known that in reality, irrigation demand changes from year to year depending on:

(i). Changes in cropping pattern

(ii). Randomness of rainfall

(iii). Reliability of water supply,

(iv). Physical performance of delivery system and other infrastructure development.

Change in cropping pattern is the most significant long-term factor. With availability of computer technology, and reliable technique for forecasting of variables, it is now possible to consider variation in irrigation demand from year to year in long-term simulation study for planning of project.

With assured irrigation, farmers tend to adopt commercial crops (cash crops). Wide discrepancies have been observed in design cropping pattern and actual cropping pattern.

Irrigation demand, planning and design of irrigation facilities and economic feasibility of the project as a whole depend upon the designed cropping pattern. As discussed in chapter 2, in command areas of several project in India, actual cropping pattern are drastically different from the designed cropping pattern indicating serious deficiencies in socio-economic survey/investigations during the planning stage. Economic considerations, unreliability and inadequacy of water supply and lack of on-farm development work have mainly influenced adoption of particular cropping patterns by the farmers in these project commands. Several other inputs and support services are needed for realization of design pattern.

There are several factors which influence crop planning in a season and variation in cropping pattern over the years. Some of these are discussed below.

Rainfall: It influences choice of crops, sowing dates and harvesting dates, surfaces and groundwater availability. Rainfall is random in nature and its coefficient of variability in some regions could be high .

Meteorological Parameters: These influence crop water requirement of different crops. Generally these parameters do not vary significantly over the years. However relative humidity in the command area could be significantly higher in irrigation crop areas as compared to before project day condition.

Infrastructure Development: It has significant influence in choice of crops and farm profitability. Electricity supply is found to be erratic, command area development works may be poorly managed or inadequate and so on.

Agriculture policy: These may not be consistency in agriculture policy over the years. Support prices various crops keep on changing over the years. Growth of agro-industries depends on various markets conditions.

Agriculture Technology: Rapid changes are occurring in technology sector. Fixed assets are becoming absolute rapidly.

The above-mentioned discussion suggests that the magnitude of risks and uncertainties to which a farmer for line are exposed could be very large. Thus, in additions to planning an irrigation project for normal conditions, contingency should be an important part of the study.

While the planning an irrigation project, likely future convenient to simulate a variety of irrigation development scenarios with the availability of computer based models and softwares.

4.2. OPTION FOR PANDANDURI

Cropping pattern need to be worked out for the existing conditions, future without project and future with project under three major options A, B, C explained in following paragraph.

4.2.1 Current Condition

There is no reservoir but the system as a whole has a degree of storage behind the weirs and in the canals themselves. The current command areas are 5550 Ha i.e. the Pandanduri and Swangi areas but not the remaining areas which require constructions or upgrading of link canals. Cropping intensity is close to 100% in both wet and dry seasons with a small area cropped in the second dry season availability water supplies in Palung River do not come close to meeting the demands of the reported cropping pattern and intensities. Rutus extensions has been receiving an average 25% of its share from the HLD canal. And for this analysis this is assumed to apply throughout the month.

4.2.2. Future Without Project

The conditions for this scenario are same as for the current conditions. The design allocation of 50% to the Rutus extension is assumed.

4.2.3. Future With Project-Alternate Cropping Pattern

Three different cropping pattern has been proposed as shown table 4.1. There are three crop seasons in a year; wet season, first day season and second dry season. 100% cropping intensity is assumed in wet season under the three alternatives in the rice as the only crop.

Pattern II provides an alternative scenario for the scale of tobacco development increasing from to 30 to 45% at the expense of maize and soybeans. Overall cropping intensity is unchanged. The cropping pattern I excludes rice in dry season because it is clear that water is ultimately the limiting resource and rice requires for more water than polowijo crops (typically by a factor of 3).

Pattern III contains 10% rice with 5% reductions for maize and soybeans.

Alternate Schemes

Three different sizes of live storage capacity and services areas as shown below are considered.

	Scheme A	Scheme B	Scheme C
Reservoir size	**24.4 MCM**	**21.0 MCM**	**13.0 MCM**
Command areas	**10,197 Ha**	**8,190 Ha**	**5,550 Ha**

4.3. DIVERSION REQUIREMENTS

Diversion requirements are work out in table 4.2 and table 4.3 for different alternative cropping pattern, reservoir storages schemes. Effective rainfall is taken as 70% of average. Overall annual requirements are generally similar for the three cropping pattern. Figure 4.1 shows variation of diversion requirements over different months for three different cropping patterns when the command area is 10197 ha and reservoir size is 24.4 MCM similarly figure 4.2 and figure 4.3. correspond to other reservoir sizes and related command areas.

Table 4.1. Cropping Patterns (%)

	Pandanduri		
	I	II	III
Wet Season			
Rice	100	100	100
Dry Season 1			
Rice	-	-	10
Maize	15	10	10
Soyabeans/mungbeans	15	5	10
Chilies	15	15	15
Onions	15	15	15
Peanuts	10	10	10
Tobacco	30	45	30
Dry Season 2			
Maize	20	20	20
Soyabeans/mungbeans	40	40	40
Chilies	20	20	20
Peanuts	20	20	20

Note : all values refer to the area actually planted, not the command area

4.4. IMPACT OF SEDIMENTATION IN PANDANDURI RESERVOIR

Following construction of the dam most of the sediment load carried by the river will be trapped in the reservoir area. Some of this will be deposited in the dead storage zone, but most will be in the live storage zone (particularly at the upstream end of the reservoir). It has been estimated that about 87% of the overall sediment will be deposited within the live storage zone i.e. 4.2 Mm^3 over the assumed 50-year design life of the Pandanduri reservoir. The effective storage of the reservoir will therefore be reduced at an average rate of just under 0.1 Mm^3/year.

As the effective storage drops, there will be a reduction in reliability. In the conventional procedure sediment deposit is assumed to occur in deed storage zone and it is assumed that same live storage capacity is available throughout the project life which is not true.

Gradual deposition of part of the sediment in live storage zone would keep on depleting the available water for irrigation over the years and thus design service area would not be receiving adequate water. Further elevation-area-capacity relation also is not unique. Due to sediment deposit in the reservoir occurring at various levels the elevation-area capacity curve should also be revised at regular intervals and revision incorporated in long term simulation study. Table 4.2 shows effect of sedimentation in Pandanduri reservoir on cropping intensity.

Table 4.2. shows effect of sedimentation in Pandanduri reservoir on cropping intensity (Scheme A).

Year	Total sediment in live storage zone	Overall Average cropping Intensity (%)
1	0	199
22	1.8	198
23	1.9	194
36	3.0	193
37	3.1	187
50	4.2	187

Also as effective storage drops, there is reduction in performance reliability. However other factors such as improvements in efficiencies may compensate for the effects of sedimentation. Seasonal cropping intensities also affect the reliability with decrease in target cropping intensity in first dry season from 90%, reliabilities can be restored to the levels before sedimentation.

Such type of analysis is possible through computer based long-term simulation study and irrigation planning can be more realistic, has been done by Agung (2002).

Table 4.3. Diversion Requirements- Pandanduri (Mm^3)

	Scheme A			Scheme B			Scheme C		
Crop pattern	I	II	III	I	II	III	I	II	III
Reservoir size (MCM)	24.4			21.0			13.0		
Command area (ha)	10197			8190			5550		
CI (%)	225	225	200	230	230	205	240	240	225
Jan 1	14.53	14.53	14.53	11.58	11.58	11.58	8.17	8.17	8.17
2	11.36	11.36	11.36	9.06	9.06	9.06	6.39	6.39	6.39
Feb 1	4.53	4.53	4.53	3.61	3.61	3.61	2.55	2.55	2.55
2	7.41	7.41	7.41	5.91	5.91	5.91	4.17	4.17	4.17
March 1	5.43	5.43	5.43	4.32	4.32	4.32	3.05	3.05	3.05
2	5.30	5.30	5.30	4.22	4.22	4.22	2.98	2.98	2.98
April 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.80	0.48	2.04	0.67	0.41	1.74	0.48	0.29	1.41
May 1	2.31	1.84	3.35	1.94	1.54	2.85	1.38	1.10	2.31
2	5.77	5.24	5.58	4.83	4.38	4.75	3.45	3.13	3.85
June 1	6.45	6.05	5.49	5.40	5.06	4.68	3.86	3.62	3.79
2	6.98	6.79	6.10	5.84	5.68	5.20	4.17	4.06	4.20
July 1	5.98	6.14	5.15	5.00	5.13	4.39	3.57	3.67	3.55
2	4.70	5.10	4.09	3.93	4.27	3.48	2.81	3.05	2.82
Aug 1	2.01	2.36	1.71	1.67	1.96	1.45	1.23	1.44	1.19
2	1.44	1.59	1.33	1.16	1.29	1.07	1.02	1.11	0.98
Sep 1	1.90	1.90	1.90	1.51	1.51	1.51	1.44	1.44	1.44
2	2.97	2.97	2.97	2.36	2.36	2.36	2.25	2.25	2.25
Oct 1	3.22	3.22	3.22	2.56	2.56	2.56	2.44	2.44	2.44
2	3.88	3.88	3.88	3.09	3.09	3.09	2.94	2.94	2.94
Nov 1	2.00	2.00	2.00	1.59	1.59	1.59	1.51	1.51	1.51
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec 1	2.02	2.02	2.02	1.61	1.61	1.61	1.13	1.13	1.13
2	13.63	13.63	13.63	10.86	10.86	10.86	7.67	7.67	7.67
Year	**114.61**	**113.75**	**113.00**	**92.71**	**92.00**	**91.87**	**68.65**	**68.14**	**70.77**

Table 4.4. Diversion Requirements- Pandanduri (m^3/s)

	Scheme A			Scheme B			Scheme C		
Crop pattern	I	II	III	I	II	III	I	II	III
Reservoir size (MCM)	24.4			21.0			13.0		
Command area	10197			8190			5550		
CI (%)	225	225	200	230	230	205	240	240	225
Jan 1	11.21	11.21	11.21	8.93	8.93	8.93	6.30	6.30	6.30
2	8.22	8.22	8.22	6.55	6.55	6.55	4.62	4.62	4.62
Feb 1	3.49	3.49	3.49	2.78	2.78	2.78	1.97	1.97	1.97
2	6.47	6.47	6.47	5.16	5.16	5.16	3.64	3.64	3.64
March 1	4.19	4.19	4.19	3.34	3.34	3.34	2.35	2.35	2.35
2	3.83	3.83	3.83	3.06	3.06	3.06	2.16	2.16	2.16
April 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.62	0.37	1.57	0.52	0.31	1.34	0.37	0.22	1.08
May 1	1.78	1.42	2.58	1.49	1.19	2.20	1.07	0.85	1.78
2	4.18	3.79	4.04	3.50	3.17	3.44	2.50	2.26	2.78
June 1	4.98	4.67	4.24	4.17	3.91	3.61	2.97	2.79	2.92
2	5.39	5.24	4.71	4.51	4.38	4.01	3.22	3.13	3.24
July 1	4.61	4.73	3.97	3.86	3.96	3.39	2.76	2.83	2.74
2	3.40	3.69	2.96	2.84	3.09	2.52	2.03	2.21	2.04
Aug 1	1.55	1.82	1.32	1.29	1.52	1.12	0.95	1.11	0.92
2	1.04	1.156	0.96	0.84	0.93	0.77	0.74	0.81	0.71
Sep 1	1.47	1.47	1.47	1.17	1.17	1.17	1.11	1.11	1.11
2	2.29	2.29	2.29	1.82	1.82	1.82	1.73	1.73	1.73
Oct 1	2.48	2.48	2.48	1.97	1.97	1.97	1.88	1.88	1.88
2	2.81	2.81	2.81	2.23	2.23	2.23	2.13	2.13	2.13
Nov 1	1.54	1.54	1.54	1.22	1.22	1.22	1.17	1.17	1.17
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec 1	1.56	1.56	1.56	1.24	1.24	1.24	0.88	0.88	0.88
2	9.86	9.86	9.86	7.86	7.86	7.86	5.54	5.54	5.54
Year	**3.63**	**3.60**	**3.58**	**2.94**	**2.92**	**2.91**	**2.18**	**2.16**	**2.24**

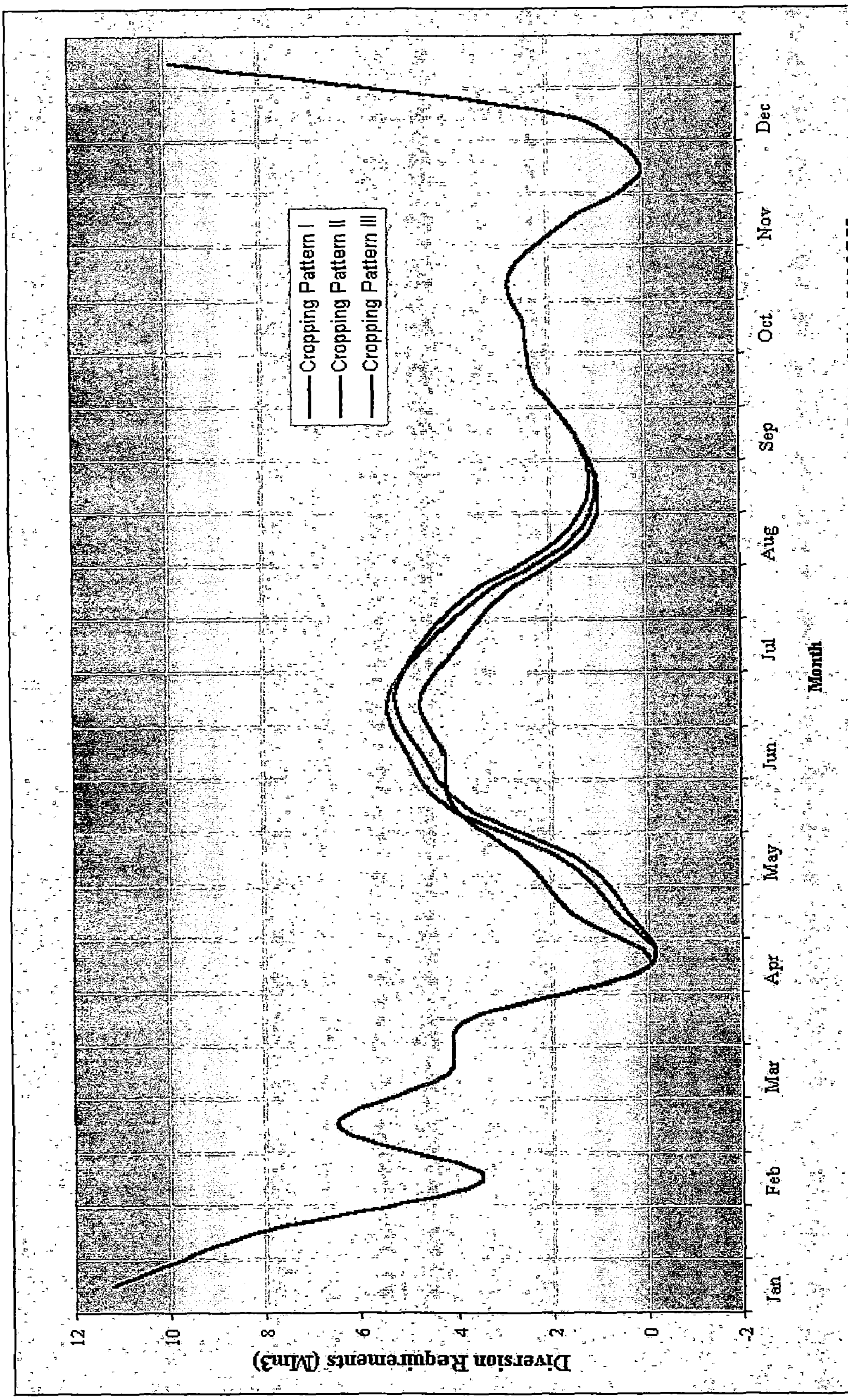


Figure 4.1. Diversion Requirements (Scheme A) Reservoir Capacity 24.4 MCm CCA 10197 Ha

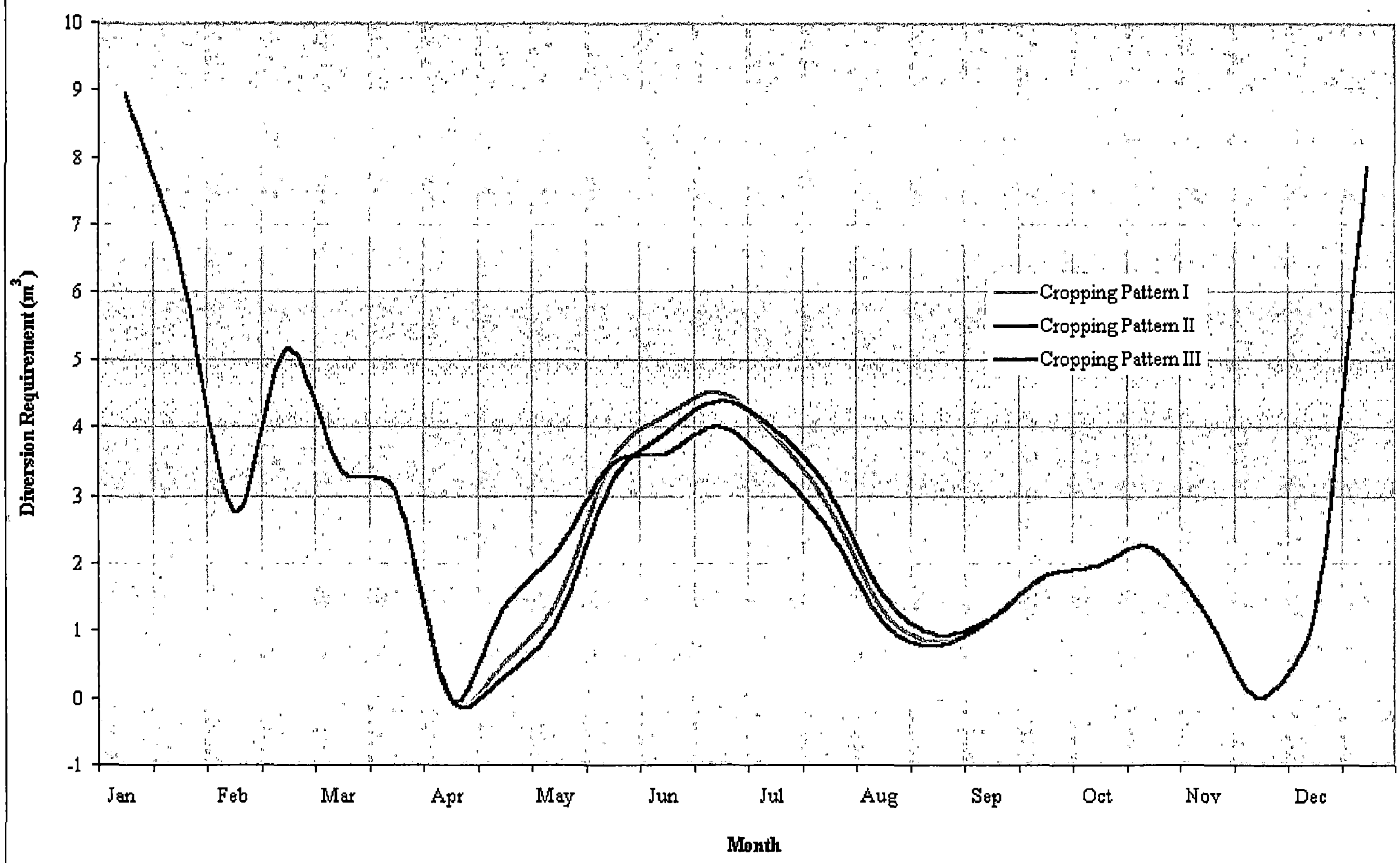


Figure 4.2. Diversion Requirement (Scheme B) Reservoir Capacity 21 MCM, CCA 8190 Ha

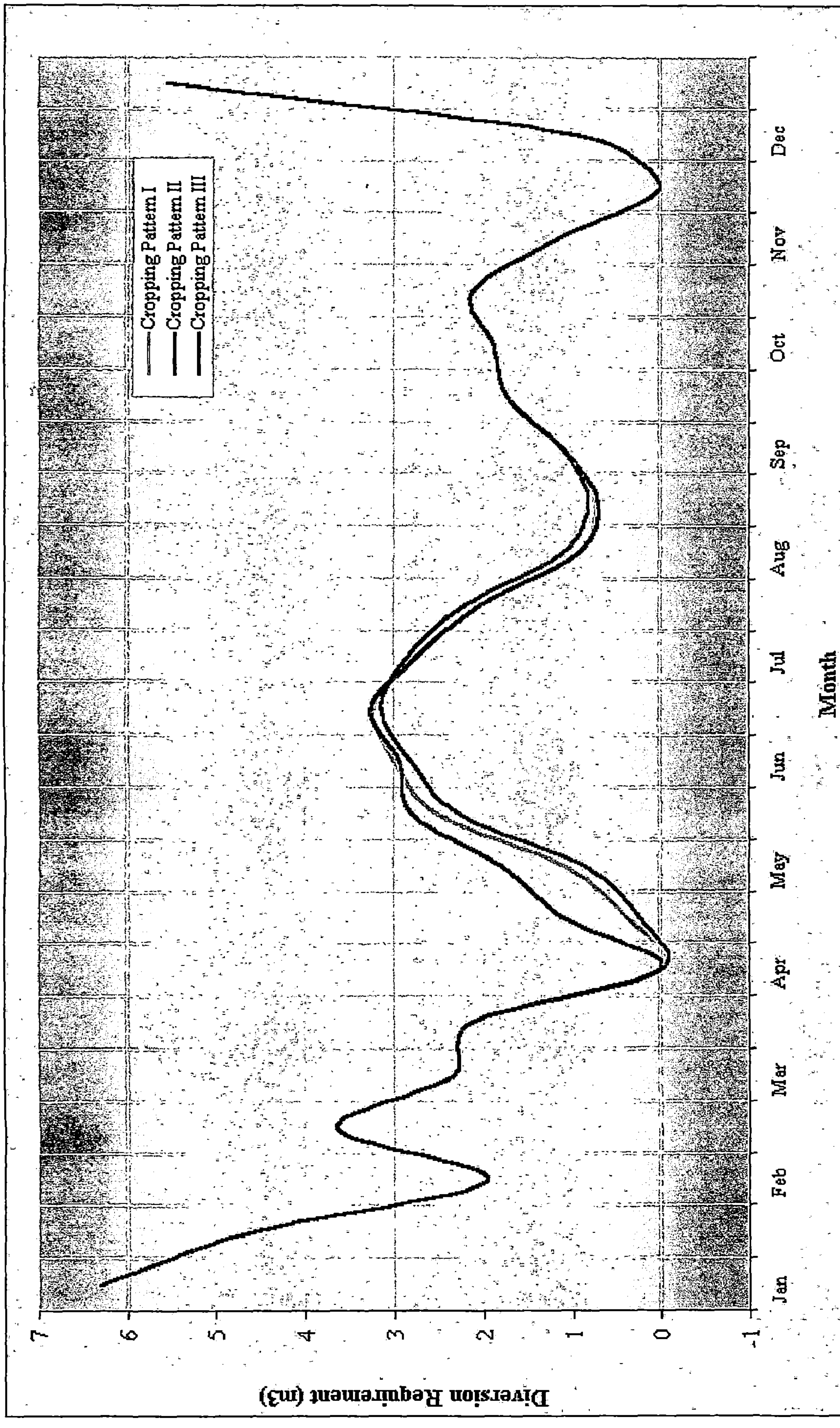


Figure 4.3. Diversion Requirement (Scheme C) Reservoir Capacity 13 MCM, CCA 5550 Ha

CHAPTER 5

Irrigation Scheduling

CHAPTER – 5

IRRIGATION SCHEDULLING

5.1 GENERAL

Irrigation scheduling means timing and depth of irrigation application during growth of crop. Thus it is mainly related to

i. Soil moisture content within the effective root zone of a crop and storage capacity within the root zone
ii. Crop evaporation
iii. Relationship between soil moisture content and stress
iv. Relationship between crop yield and soil moisture stress

Irrigation scheduling is a part of water distribution planning in the command area of an irrigation project. It is an important aspect of irrigation project planning but generally ignored in project preparation stage. While analyzing possible irrigation development scenarios during the life of a project, it is important to consider likely water deficit condition, resulting yield reduction, and plan for irrigation scheduling to manage water deficits at micro and macro level (field level and project level). Therefore irrigation scheduling at field level and water distribution planning for the command area should form part of irrigation planning at project preparation stage itself.

During operation stage, conventional procedure of water distribution planning is to prepare a roster of regulation for canal network specifying discharge and running days for each segment of canal network. It is prepared at the beginning of a crop season and published for the information of farmers. Modification in the roster is made if there is unexpected rain or other reason beyond control.

During project preparation stage irrigation scheduling is accounted for in terms crop type number of watering and depth of irrigation. Thus there is lot of subjectivity in assessment of demand and in the procedure for meeting the spatially distributed irrigation demand. With the availability of software's such as CROPWAT and others, it is possible to carry out irrigation scheduling and water distribution planning in more scientific manner.

5.2. FACTORS INFLUENCING IRRIGATION SCHEDULLING

Irrigation scheduling and hence water distribution planning is influenced by factors such depth of root zone, extraction pattern, relation between moisture content, stress and crop yield. There are briefly explained below.

Development of root Zone

The effective root zone is depth from which the roots of an average plant are capable of extracting soil moisture, which needs to be replaced by irrigation. The rooting depth depends on the nature of the crop, but can be influenced by restricting conditions e.q. shallow soil layer, or high water table. The effective root zone depths of some of the more common crops are given below:

Table 5.1. Effective root zone depths (on full development)

Shallow rooted 60 cms	Moderately deep 90 cms	Deep rooted 120 cms	Very deep rooted 180 cms
Rice	Wheat	Maize	Sugar cane
Potato	Tobacco	Cotton	Citrus
Cauliflower	Groundnut	Soyabean	Apples
Cabbage	Carrots	Sugar beat	Coffee
Onion	Beans	Tomato	Grape vines
	Chillies		Safflower

The rate of development of root zone depth depends on the crop subject to influence of soil-moisture and nutrients. Measurements at the demonstration farm of IIT Roorkee showed the development of effective root zone for wheat by almost 1 cm/day for the first

90 days, and negligible growth afterwards (Bharat Singh 1994). For all crops the general pattern is faster growth of root zone up to the flowsing stage and considerably slower afterwards.

Extraction pattern:

When to irrigate and how much to apply are affected considerably by where and when water is removed from the soil by the plant root zone. Shallow rooted crops will require more frequent irrigation than deep-rooted crops, rooting data from irrigated crops grown in semi humid regions show considerably more water removed from the top 30 cm of soil than from any succeeding depth while data from hot arid regions generally shows less water removed from the first 30 cm than from the next lower 30 cm. For normal irrigated soils the average patterns is given in Fig. 1

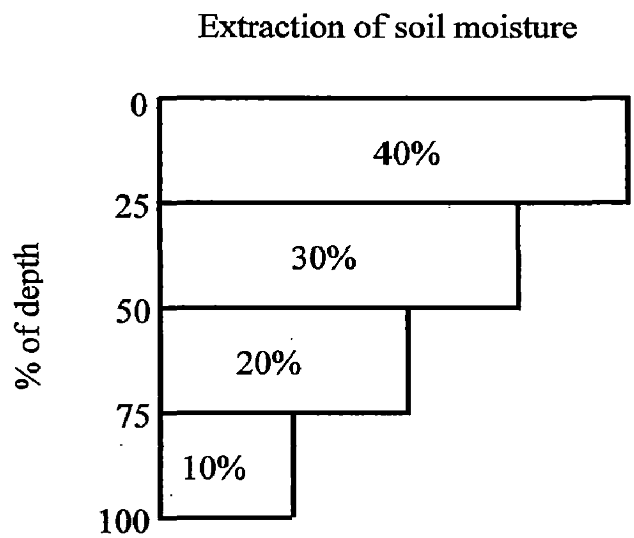


Figure 5.1 Average extraction of soil moisture by plant roots

Influence of stage of growth

Growth of all plants can be divided into three stages with regard to irrigation practice; vegetative; flowering and fruiting. During vegetative stage, consumptive use continues to increase. Flowering occurs near and during the peak of consumptive use. The fruiting stage may be further subdivided into two parts; the wet fruit stage which follows flowering and the dry fruit stage. Dry fruiting is accompanied by a decrease in consumptive use until transpiration ceases and the plant is dead. Different crops are harvested at different stages depending on their utilization e.q. Green fodder-and leafy vegetables at the vegetative stage, cauliflower at the flowering stage, tomatoes, green peas, sugarcane and other fruits at wet fruit stage and cereals, pulses, and cotton at the dry fruit stage. The amount of water applied and the frequency of irrigation must be adjusted to the actual consumptive use of the crop, water holding capacity of the soil and depth of rooting. Since consumptive use is at or near maximum during the flowering stage, care must be exercised to ensure adequate moisture in the root zone. The increased consumptive use is offset by increased depth of root zone, and frequency normally does not need to be increased.

The root system is essentially extended to its maximum depth by the time fruiting occurs and the consumptive use has begun to decrease, reducing the water requirements of the crops and the frequency of irrigation. Adequate supply of phosphorous and potash fertilizers should be present in the soil at this stage. During production of dry fruit, irrigation has essentially ceased, the slight water requirements of the crop are met usually from the stored water in the soil. The last watering should normally be given during the wet fruiting stage.

Relationship between soil moisture content (SMC) and stress.

SMC is related to the soil moisture stress by the soil moisture retention function. A decrease in SMC generally results in an increase in stress. Soil moisture stress can be plotted against moisture content or against available water deficiency. The later mode of plotting is more meaningful. Typical curves for different soils are plotted in fig 2. It can be seen that for the same soil moisture deficiency, the stress is higher in clayey soils and less in sandy soils.

Effect of soil moisture stress on yield

To obtain optimal yield, the soil moisture should be so maintained that the plant is not under stress, particularly at sensitive growth stages. The results in this respect are based on experimental data. Data for a few crops based on work done in U.S.A. by Peri and Skogerboe is given below:

Crop	Maximum Soil section (bars)
Beans	0.75 to 2.0
Sugarcane	0.25 to 0.30
Potatoes	0.30 to 0.50
Oranges	0.20 to 1.00
Tomatoes	0.80 to 1.50

It is generally accepted that up to 50 percent depletion of available capacity, the stress level is such that it does not have appreciable effect on yield. Also up to this much soil moisture depletion the actual ETa is only marginally less than potential Etm. In the dry fruiting stage depletion up to 75 percent is acceptable.

Some work done in India on wheat is given below. It does not give measured stress, but is based on no. of days delay

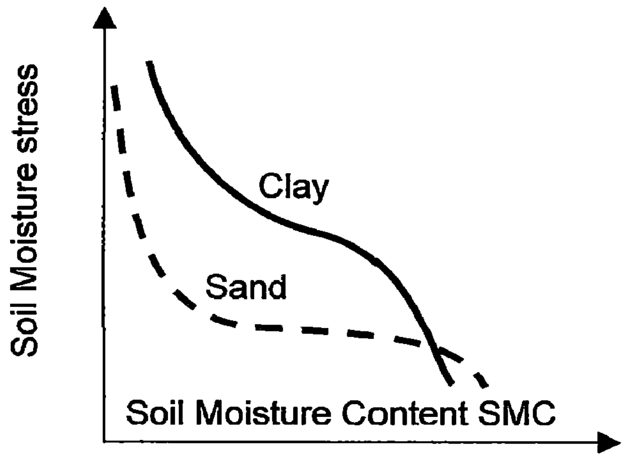


Fig 5.2 Retention curve for various types of soils

Soil-clay loam-crop wheat

Zero stress yield 40 ql/ha

Stage	Crown rooting		Flowering	
Delay (days)	5	8	5	8
Yield (ql/ha)	37.5	31.8	38.5	32.7
% loss of yield	6.25	20.5	3.75	19

Soil Moisture Content

The moisture deficiency Δ at a particular time is given by

$$\Delta = (w_f - w)^* Z * \gamma_{ds} \quad \text{...(1)}$$

Where, Δ is the required water depth

w_f is moisture content at field capacity as proportion of dry soil weight

w is moisture content at the time in question

Z is effective root zone depth and

γds is specify dry unit weight of the soil

If w is the moisture content at wilting point, the deficiency is expressed as a percentage, P as below;

$$\frac{P}{100} = (w_f - w)$$

$$= (w_f - w_p)\left\{1 - \frac{w - w_p}{w_f - w_p}\right\} \quad \text{.....................} (2)$$

Equations. (1) and (2) give the moisture deficiency to be made up by irrigations. Knowing soil properties, w_f, w_p and γ_{ds}, the effective root zone depth Z, and permissible stress or permissible depletion, the depth of irrigation watering can be computed. Slight variations in actual technique are possible as follows:

(a). Continuously monitor soil moisture content or soil moisture stress in the root zone. Irrigate when moisture deficiency or stress reaches the maximum permissible limit.

(b). Time interval to next irrigation, T, is estimated by,

$$T = \frac{\Delta}{ETa}$$

Where ETa is the actual evapo-transpiration per unit of time to be determined from climatologically equation, or pan evaporation measurement and crop factor at the stage of growth. The depth of irrigation again to be determined by equation (1), so that soil moisture measurement at the time of determining T is necessary.

(c). Assuming that last irrigation left the soil moisture at field capacity, daily loss can be computed by daily ETa, and irrigation applied when permissible deficiency is estimated to have been reached by such computation.

Physiological growth stages

Certain stages of plant growth are more sensitive to water requirement than others. As far as possible, there should be no stress as the stages. E.q. for wheat the critical stages and days after showing are as below:

Stage for Wheat	No. of days from sowing	Order of priority
Crown rooting	20 – 25	1
Tillering	40 – 45	4
Jointing	60 – 65	3
Flowering	75 – 85	2
Milking	100 – 105	5
Dough formation	115 - 120	6

Thus optimally six watering are needed. As far as possible watering should be made to coincide with the more important critical growth stages, e.q. Crown rooting and flowering for wheat.

Illustrative Example

Dominant crop wheat

Effective root zone depth	90 cm
Field capacity	30 percent
Wilting point	13 percent
Storage capacity	17 percent
Specify dry weight	1.6

Soil profile is uniform over the root zone depth. Irrigation is needed when the average deficiency in the root zone. Alternatively moisture content can be monitored in all the three horizon and average taken. Watering will be needed when the average moisture deficiency is 50% and effective" depth" to be supplied to the root zone will be

$$\frac{0.17}{2} \times 90 \times 1.6 = 12.24 \text{ cm}$$

If field application efficiency is 80 percent and loss in water course 25 percent, water depth required at outlet will be

$$\frac{12.24}{0.8 \times 0.75} = 20.4 \text{ cm}$$

5.3. CROPWAT PROGRAM FOR IRRIGATION SCHEDULLING

"Cropwat for Windows" is a software developed by Derek Clark, Martin Smith and Khaled El-Askari (Clark D. et al 1998). It uses Penman-Monteith method for calculating reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculates. Results are obtained in graphic and tabular form

The software can deal with multiple crops (up to 30 crops) in a cropping pattern. Complex cropping patterns can be designed with several crops with staggered planting dates. Irrigation schedules can be calculated for individual blocks of each crop. Time base can be daily, weekly, monthly. The program uses monthly climatic data only. The program allows user defined irrigation events and has option to add adjustments to the calculated soil moisture deficit. This provides a flexible fool for managing soil moisture during the growing season. Important drawback is that in the present version it can not calculate crop water requirements for rice so these have to be given as input data.

Table 5.2. Shows the input data and output for estimation of crop water requirement and for irrigation scheduling.

Scheduling Criteria Option

Several options are available for specifying irrigation schedule as stated below.
If no option is given (default option); then optimal irrigation schedule from the first planting date of the crops is automatically adopted by the program. Irrigation is calculated to take place when all the readily available soil moisture has been used so the crop never becomes stressed. The amount of irrigation is calculated to refill the soil moisture store i.e. irrigate to return the soil to field capacity (100% of the readily available moisture is replaced). Scheduling begins from the earlier planting date of each crop

Option for application timing

a) Irrigate at fixed intervals (days)
b) Irrigate when a specified percentage of readily available soil moisture depletion occurs
c) Irrigate when a specified percentage of total soil moisture depletion occurs
d) Irrigate at variable intervals (user defined) (days)

Option for application depths

a) Fixed depths

b) Refill to a specified percentage of readily available soil moisture

c) Variable depths (user specified) (mm)

Once the criteria are defined, the program calculates the irrigation data and amounts. ***Scheduling scenario:*** It is snapshot of the scheduling data for an irrigated area. Once a scenario is saved, it can be reloaded rapidly allowing to store sets of irrigation conditions for different tertiary units. Same set of data files can be read in to carry out calculations for the same area on another days. This allows to store sets of crop, soil and climate data for different irrigated areas. Scenarios file does not store the current scheduling criteria. It has to be set again

Irrigation Scheduling Table: It can appear two ways either Irrigation Schedule or Daily Soil Moisture Balance.

Key to the column heading in the irrigation schedule table:

Date	:	either the date of a rainfall/calculated irrigation event or the date in the season
TAM	:	Total Available Moisturein the soil for the crop at this date (mm). This is calculated as Field Capacity minus the Wilting Point times the current rooting depth of the crop.
RAM	:	Readily Available Moisture in the soil for the crop at this date (mm). It is calculated as RAM = TAM * P where P is the depletion fraction for this crop at the current date as defined in the crop coefficient (Kc) file e.q. MAIZE.CRO.
RAIN	:	rainfall amount calculated for this date (assuming 5 rain events per month)
Efct. RAIN	:	Effective rainfall – the amount of rainfall that enters the soil
ETc	:	Actual crop evapotranspiration
ETc/Etm	:	Ratio of actual crop ET to the maximum crop ET. This useful developing user defined irrigation schedules it should be 100% for an unstressed crop.

SMD : Soil Moisture Deficit on this date (mm)

Irr. Interval : The interval depth applied (mm)

Loss Irrigation : Irrigation water that is not stored in the soil – i.e. either surface runoff or percolation.

User Adjust : Adjustment you make to the SMD

Totals are shown at the bottom of the table (rainfall, evapotranspiration, net irrigation, lost irrigation). The estimated yield reduction due to crop stress (when Etc/Etm falls below 100%) is shown at the top of the table. The reduction is estimated based on the methods described in FAO Irrigation and Drainage paper no 33 "Yield Reduction to Water". The values calculated should be used only as a guide to the likely effect of water shortage on crop yield. You are recommended to develop crop yield data (Ky) based on in field experience.

User Defined Irrigation: by selecting the schedule criteria as "irrigate at variable intervals" and "variable depths" it is possible to model what actually takes place in a growing season. To do so irrigation schedule table should be displayed with the " Daily Soil Moisture Balance" option.

It is important to remember that irrigation-scheduling calculations do not take into account any leaching requirements or ground water contribution to the soil moisture zone.

User adjustment: Following adjustment are possible :

- to apply actual rainfall data
- to allow for capillary rise contributing to the soil moisture
- to apply for deep percolation out of the soil profile
- to assured soil moisture deficit (SMD) to bring it in line into field measurements of soil moisture.

5.4. POTENTIAL USES OF SOFTWARE IN IRRIGATION PLANNING

- ❖ Calculate the potential evapotranspiration (ETo) by Penman Monteith method (which is standard method) and field irrigation requirement.
- ❖ Can be used to study the practice of actual irrigation in field vs the scientific irrigation. This can give the data on water going as wastage and it's effect on yield and salinity due to over irrigation.

- This gives the field water supply (liters/sec/ha) and further can be essential for water distribution planning. Effect of different application efficiencies for different crops can be analyzed.
- Irrigation planning for complete project area
  - i) Different cropping patterns and related irrigation water demand
  - ii) Each crop may be planted in a set of blocks staggered in time for example paddy crop area staggered into four blocks and planted at ten days interval. Its effect on peak irrigation water demand can be analyzed to reduce the peak demand and thus canal capacity can be scientifically fixed.

5.4.1. Illustration of Potential Use of Cropwat Program

Climatic data for the command area of Pandanduri Project has been analyzed in chapter 3. This data has been illustrated as to how irrigation planning can be improved using Cropwat Software.

Crop Water Requirement: The crop selected for illustration is soyabean. Table 5.3 shows crop water requirement, irrigation requirement and field water supply at 10 day interval when field irrigation is 65%.

Effect of field irrigation efficiency

Table 5.3, table 5.4, table 5.5 and table 5.6 are taken as 65%, 70%, 75% and 80% respectively. The result summarized below:

Irrigation efficiciency (%)	Average field water Supply (l/s/ha)	Range (l/s/ha)
65	0.6	0.0 to 0.87
70	0.3	0.0 to 0.55
75	0.28	0.0 to 0.51
80	0.27	0.0 to 0.35

Table 5.2. Input and Output on Irrigation Scheduling using CROPWAT

INPUT	OUTPUT
a. CROP WATER REQUIREMENT DATA ITEM (MONTHLY BASIS) • Climate (temperature, humidity, wind speed, sunshine) • ETo if climate data not available or if ETo is user specified • Rainfall (choice of four effective rainfall models USDA SCS method by default) • Crops, planting dates of crops • Cropping pattern • Crops coefficient data (optional) Software contains typical crop coefficients data	• ETo (penman Monteith method and fixed net/field irr. requirement • Crop area • Crop Kc (Growth stage) • Crop water requirement • Effective rainfall • field irrigation requirement (mm/day, litre/sec/ha) • Climatic graph
b. IRRIGATION SCHEDULLING	
• All data as above in (a) • Soil type info. Otherwise info on a set of typical soil types is available in CROPWAT. • Start of scheduling (planting date by default) • Initial soil moisture • Irrigation scheduling criteria: different options on depth and timing • Specific % of: b. Specific % of Readily available or total soil moisture depleted or specified soil moisture depletion occurs c. Fixed interval or variable interval d. Fixed/variable depth or refill to specified % of RAM e. Application efficiency • By default "optimal/criteria is adopted	• Table/graphs on all above • Crop data, soil data, scheduling criteria • Total available moisture, readily available moisture, soil moisture deficit (SMD) • Irrigation interval • Irrigation depth applied • Water loss as surface runoff /deep percolation • Adjustment made to SMD • % Reduction in yield in different growth stages, Total yield reduction • Daily Soil Moisture Balance

Effect of Staggering Planting Date

Crop water requirement reports for soyabean crop crop when planting date is taken as 1st April, 11th April, 21st April(staggering by 10 days) are given in table 5.3, table 5.7 and 5.8 with other inputs data being same (irrigation efficiency being 65% in each case). Result are summarized below

Option	Planting data	Total Irrigation Requirement (mm)	Average field water supply (l/s/ha)	Range of FWS (l/s/ha)
1	1st April	453.67	0.6	0.0 to 0.87
2	11th April	263.67	0.35	0.0 to 0.60
3	21st April	273.71	0.36	0.0 to 0.60

This analysis shows that changing the planting data from 1st April to 11th April, has significant effect on field water supply requirement where as changing it from 11th April to 21st April, has very little effect on field water supply requirement.

Effect of Irrigation Scheduling Option

Soil: medium,

crop: soyabean

Planting date: 1st April

Initial Soil Moisture Depletion: 0%

Application timing: irrigate when100% of readily soil moisture depletion occurs.

Start of scheduling: 1st April

To illustrate the effect of irrigation scheduling option, application depth option is changed.

Option 1: Refill to 50% of readily available soil moisture

Results are shown in table 5.9

Option 2: Refill to 75% of readily available soil moisture

Results are shown in table 5.10

Option 3: Refill to 100% of readily available soil moisture

Results are shown in table 5.11

Results are summarized below:

When ETc /ETm changes

	Net Irrigation (mm)	Total Yield Reduction (%)	Etc/Etm (%)
Option 1	80.2	46.7	45.1
Option 2	110.0	46.7	45.1
Option 3	139.9	46.7	45.1

As shown in the table it is possible to follow the above mentioned options without any yield reduction provided ETc/Etm is kept at 100% by applying variable irrigations depths during crop growth stage. The computations are shown in table 5.12, table 5.13, table 5.14 for the above options.

	Net Irrigation (mm)	Total Yield Reduction (%)	Etc/Etm (%)
Option 1	356.3	0.0	100
Option 2	412.2	0.0	100
Option 3	347.8	0.0	100

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Table 5.3

Crop Water Requirements Report

Crop 1 : SOYBEAN
Blocks : All blocks
planting date : 1/4
Calculation Time step 10 Day (s)
Irrigation Efficiency : 65%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1/4	43.52	100	0.4	17.41	29.75	24.64	0	0
10/4	44.24	100	0.4	17.7	22.71	20.03	0	0
21/4	44.93	100	0.54	24.16	16.59	15.77	8.39	0.15
1/5	45.56	100	0.79	35.89	11.68	11.68	24.21	0.43
11/5	46.14	100	1.04	47.88	8.15	8.15	39.73	0.71
21/5	46.67	100	1.15	53.67	6.07	6.07	47.6	0.85
31/5	47.13	100	1.15	54.2	5.34	5.34	48.86	0.87
10/6	47.53	100	1.15	54.66	5.73	5.71	48.95	0.87
20/6	47.86	100	1.15	55.03	6.81	6.28	48.76	0.87
30/6	48.1	100	1.15	55.32	7.95	6.85	48.47	0.86
10/7	48.27	100	1.15	55.51	8.3	7	48.51	0.86
20/7	48.35	100	1.01	48.68	6.78	5.85	42.83	0.76
30/7	48.33	100	0.75	36.1	2.17	2.07	34.03	0.61
9/8	24.13	100	0.55	13.32	0	0	13.32	0.47
Total	630.76			569.55	138.03	125.44	453.67	[0.60]

* ETo data is distributed using polinomial curve fitting
* Rainfall data is distributed using polinomial curve fitting

F:\CWR 4-65.TXT

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Table 5.4

Crop Water Requirements Report

Crop 1 : SOYBEAN
Blocks : All blocks
planting date : 1/4
Calculation Time step 10 Day (s)
Irrigation Efficiency : 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1/4	27.08	100.00	0.40	10.83	30.55	24.55	0.00	0.00
10/4	27.27	100.00	0.40	10.91	20.96	18.68	0.00	0.00
21/4	27.48	100.00	0.54	14.77	13.38	13.29	1.49	0.02
1/5	27.69	100.00	0.79	21.81	8.60	8.60	13.21	0.22
11/5	27.91	100.00	1.04	28.96	7.00	7.00	21.95	0.36
21/5	28.12	100.00	1.15	32.34	8.36	8.36	23.98	0.40
31/5	28.33	100.00	1.15	32.57	11.57	10.69	21.89	0.36
10/6	28.52	100.00	1.15	32.80	14.39	11.76	21.04	0.35
20/6	28.70	100.00	1.15	33.00	13.17	10.33	22.67	0.37
30/6	28.85	100.00	1.15	33.18	3.66	3.20	29.99	0.50
10/7	28.99	100.00	1.15	33.33	0.00	0.00	33.33	0.55
20/7	29.09	100.00	1.01	29.29	0.00	0.00	29.29	0.48
30/7	29.15	100.00	0.75	21.78	0.00	0.00	21.78	0.36
9/8	14.59	100.00	0.55	8.05	0.00	0.00	8.05	0.27
Total	381.76			343.63	131.64	116.45	248.67	[0.30]

* ETo data is distributed using polinomial curve fitting
* Rainfall data is distributed using polinomial curve fitting

F:\CWR- 70.TXT

3/18/2004 CropWat 4 Windows Ver 4.3

Table 5.5
Crop Water Requirements Report

Crop 1 : SOYBEAN
Blocks : All blocks
planting date : 1/4
Calculation Time step 10 Day (s)
Irrigation Efficiency : 75%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1/4	27.08	100.00	0.40	10.83	30.55	24.55	0.00	0.00
10/4	27.27	100.00	0.40	10.91	20.96	18.68	0.00	0.00
21/4	27.48	100.00	0.54	14.77	13.38	13.29	1.49	0.02
1/5	27.69	100.00	0.79	21.81	8.60	8.60	13.21	0.20
10/5	27.91	100.00	1.04	28.96	7.00	7.00	21.95	0.34
21/5	28.12	100.00	1.15	32.34	8.36	8.36	23.98	0.37
31/5	28.33	100.00	1.15	32.57	11.57	10.69	21.89	0.34
10/6	28.52	100.00	1.15	32.80	14.39	11.76	21.04	0.32
20/6	28.70	100.00	1.15	33.00	13.17	10.33	22.67	0.35
30/6	28.85	100.00	1.15	33.18	3.66	3.20	29.99	0.46
10/7	28.99	100.00	1.15	33.33	0.00	0.00	33.33	0.51
20/7	29.09	100.00	1.01	29.29	0.00	0.00	29.29	0.45
30/7	29.15	100.00	0.75	21.78	0.00	0.00	21.78	0.34
9/8	14.59	100.00	0.55	8.05	0.00	0.00	8.05	0.25
Total	381.70	6.00		343.63	131.64	116.45	248.67	[0.28]

* ETo data is distributed using polinomial curve fitting
* Rainfall data is distributed using polinomial curve fitting

F:\CWR- 70.TXT

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Table 5.6

Crop Water Requirements Report

Crop 1 : SOYBEAN
Blocks : All blocks
planting date : 1/4
Calculation Time step 10 Day (s)
Irrigation Efficiency : 80%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1/4	27.08	100.00	0.40	10.83	30.55	24.55	0.00	0.00
10/4	27.27	100.00	0.40	10.91	20.96	18.68	0.00	0.00
21/4	27.48	100.00	0.54	14.77	13.38	13.29	1.49	0.02
1/5	27.69	100.00	0.79	21.81	8.60	8.60	13.21	0.19
10/5	27.91	100.00	1.04	28.96	7.00	7.00	21.95	0.32
21/5	28.12	100.00	1.15	32.34	8.36	8.36	23.98	0.35
31/5	28.33	100.00	1.15	32.57	11.57	10.69	21.89	0.32
10/6	28.52	100.00	1.15	32.80	14.39	11.76	21.04	0.30
20/6	28.70	100.00	1.15	33.00	13.17	10.33	22.67	0.33
30/6	28.85	100.00	1.15	33.18	3.66	3.20	29.99	0.43
10/7	28.99	100.00	1.15	33.33	0.00	0.00	33.33	0.48
20/7	29.09	100.00	1.01	29.29	0.00	0.00	29.29	0.42
30/7	29.15	100.00	0.75	21.78	0.00	0.00	21.78	0.32
9/8	14.59	100.00	0.55	8.05	0.00	0.00	8.05	0.23
Total	381.76			343.63	131.64	116.45	248.67	[0.27]

* ETo data is distributed using polinomial curve fitting
* Rainfall data is distributed using polinomial curve fitting

F:\CWR- 80.TXT

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Table 5.7

Crop Water Requirements Report

Crop 1 : SOYBEAN
Blocks : All blocks
planting date : 11/4
Calculation Time step *10 Day (s)*
Irrigation Efficiency : 65%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req.	FWS (l/s/ha)
11/4	27.27	100.00	0.40	10.91	20.96	18.68	0.00	0.00
21/4	27.48	100.00	0.40	10.99	13.38	13.29	0.00	0.00
1/5	27.69	100.00	0.54	14.89	8.60	8.60	6.29	0.11
11/5	27.91	100.00	0.79	21.98	7.00	7.00	14.98	0.27
21/5	28.12	100.00	1.04	29.18	8.36	8.36	20.82	0.37
31/5	28.33	100.00	1.15	32.57	11.57	10.69	21.89	0.39
10/6	28.52	100.00	1.15	32.80	14.39	11.76	21.04	0.37
20/6	28.70	100.00	1.15	33.00	13.17	10.33	22.67	0.40
30/6	28.85	100.00	1.15	33.18	3.66	3.20	29.99	0.53
10/7	28.99	100.00	1.15	33.33	0.00	0.00	33.33	0.59
20/7	29.09	100.00	1.15	33.45	0.00	0.00	33.45	0.60
30/7	29.15	100.00	1.01	29.36	0.00	0.00	29.36	0.52
9/8	29.18	100.00	0.75	21.80	0.00	0.00	21.80	0.39
19/8	14.59	100.00	0.55	8.05	0.00	0.00	8.05	0.29
Total	383.87			345.50	101.09	91.90	263.67	[0.35]

* ETo data is distributed using polinomial curve fitting
* Rainfall data is distributed using polinomial curve fitting

F:\C WR(11).TXT

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Table 5.8

Crop Water Requirements Report

Crop 1	:	SOYBEAN
Blocks	:	All blocks
planting date	:	21/4
CalculatiocuTatimestep		10 Day (s)
Irrigation Efficiency	:	65%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
21/4	27.48	100.00	0.40	10.99	13.38	13.29	0.00	0.00
1/5	27.69	100.00	0.40	11.08	8.60	8.60	2.48	0.04
11/5	27.91	100.00	0.54	15.00	7.00	7.00	8.00	0.14
21/5	28.12	100.00	0.79	22.15	8.36	8.36	13.79	0.25
31/5	28.33	100.00	1.04	29.39	11.57	10.69	18.70	0.33
10/6	28.52	100.00	1.15	32.80	14.39	11.76	21.04	0.37
20/6	28.70	100.00	1.15	33.00	13.17	10.33	22.67	0.40
30/6	28.85	100.00	1.15	33.18	3.66	3.20	29.99	0.53
10/7	28.99	100.00	1.15	33.33	0.00	0.00	33.33	0.59
20/7	29.09	100.00	1.15	33.45	0.00	0.00	33.45	0.60
30/7	29.15	100.00	1.15	33.53	0.00	0.00	33.53	0.60
9/8	29.18	100.00	1.01	29.39	0.00	0.00	29.39	0.52
19/8	29.17	100.00	0.75	21.79	0.83	0.82	20.98	0.37
29/8	14.57	100.00	0.55	8.04	1.68	1.68	6.36	0.23
Total	385.74			347.13	82.64	75.71	273.71	[0.36]

* ETo data is distributed using polinomial curve fitting
* Rainfall data is distributed using polinomial curve fitting

F:CWR(21).TXT

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Table 5.9

Irrigation Schedulling Report

* Crop Data
Crop # 1 : SOYABEAN
Block : 1
Planting Date : 1/4
* Soil Data :
Soil description : Medium
Initial Soil Moisture Depletion : 0%

* Irrigation Scheduling Criteria :
Application Timing :
-Irrigate when 100% of total soil moisture depletion occurs.
- Applications Depths:
- Refill to 50% of readily available soil moisture.
- Start of Scheduling: 1/4

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
1/4	42.00	21.00	16.60	0.00	1.70	100%	1.70				
6/4	51.80	26.40	14.00	8.70	1.70	100%	1.70				
10/4	61.60	32.00	11.60	8.70	1.80	100%	1.80				
16/4	71.40	37.80	9.40	8.80	1.80	100%	1.80				
21/4	81.20	43.80	7.50	7.50	1.90	100%	3.30				
26/4	91.00	50.00	5.90	5.90	2.50	100%	8.60				
1/5	100.80	56.40	4.70	4.70	3.10	100%	18.00				
6/5	110.60	63.00	3.90	3.90	3.60	100%	31.20				
11/5	120.40	69.80	3.50	3.50	4.20	100%	47.70				
16/5	130.20	76.80	3.50	3.50	4.80	100%	67.20				
21/5	140.00	84.00	3.90	3.90	5.30	100%	89.30				
26/5	140.00	84.00	4.50	4.50	3.70	76.4%	105.30				
31/5	140.00	84.00	5.30	5.30	2.70	53.1%	114.20				
5/6	140.00	84.00	6.20	6.20	2.30	40.2%	118.90				
10/6	140.00	84.00	7.00	7.00	2.00	33.6%	121.00				
15/6	140.00	84.00	7.40	7.40	2.00	30.6%	122.00				
20/6	140.00	84.00	7.20	7.20	1.90	29.1%	122.70				
25/6	140.00	84.00	6.00	6.00	1.70	27.5%	124.30				
30/6	140.00	84.00	3.40	3.40	1.40	24.3%	127.60				
5/7	140.00	84.00	0.20	0.20	0.80	18.3%	132.40				
9/8	140.00	119.30	0.00	0.00	0.00	4.5%	139.90	130.00	80.20	0.00	
Total			131.60	106.40	256.00	45.1%			80.20	0.00	0.00

* Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 0.0%
- Estimated yield reduction in growth stage # 3 = 69.1%
- Estimated yield reduction in growth stage # 4 = 35.1%

Estimated Total yield reduction = 46.7%

* These estimates may be used as guidelines and not as actual figures.
* Legend:
TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].
* Notes:
Monthly ETo is distributed using polynomial curve fitting.
Monthly Rainfall is distributed using polynomial curve fitting.
To generate rainfall events, each 5 days of distributed rainfall are accumulated as one storm
Only NET irrigation requirements are given here. No any kind of losses
was taken into account in the calculations.
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Table 5.10
Irrigation Scheduling Report

* Crop Data:
- Crop # 1 : SOYBEAN
- Block # : 1
- Planting date: 1/4

* Soil Data:
Soil description : Medium
Initial soil moisture depletion : 0%

* Irrigation Scheduling Criteria:
- Application Timing:
  Irrigate when 100% of total soil moisture depletion occurs.
- Applications Depths:
  Refill to 75% of readily available soil moisture.
- Start of Scheduling: 1/4

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
1/4	42.00	21.00	16.60	0.00	1.70	100%	1.70				
6/4	51.80	26.40	14.00	8.70	1.70	100%	1.70				
10/4	61.60	32.00	11.60	8.70	1.80	100%	1.80				
16/4	71.40	37.80	9.40	8.80	1.80	100%	1.80				
21/4	81.20	43.80	7.50	7.50	1.90	100%	3.30				
26/4	91.00	50.00	5.90	5.90	2.50	100%	8.60				
1/5	100.80	56.40	4.70	4.70	3.10	100%	18.00				
6/5	110.60	63.00	3.90	3.90	3.60	100%	31.20				
11/5	120.40	69.80	3.50	3.50	4.20	100%	47.70				
16/5	130.20	76.80	3.50	3.50	4.80	100%	67.20				
21/5	140.00	84.00	3.90	3.90	5.30	100%	89.30				
26/5	140.00	84.00	4.50	4.50	3.70	76.4%	105.00	3.00			
31/5	140.00	84.00	5.30	5.30	2.70	53.1%	114.00	2.00			
5/6	140.00	84.00	6.20	6.20	2.30	40.2%	118.00	9.00			
10/6	140.00	84.00	7.00	7.00	2.00	33.6%	121.00	0.00			
15/6	140.00	84.00	7.40	7.40	2.00	30.6%	122.00	0.00			
20/6	140.00	84.00	7.20	7.20	1.90	29.1%	122.00	7.00			
25/6	140.00	84.00	6.00	6.00	1.70	27.5%	124.00	3.00			
30/6	140.00	84.00	3.40	3.40	1.40	24.3%	127.00	6.00			
5/7	140.00	84.00	0.20	0.20	0.80	18.3%	132.00	4.00			
9/8	140.00	119.30	0.00	0.00	0.00	4.5%	139.00	9.13	110.00	0.00	
Total			131.60	106.40	256.60	45.1%			110.00	0.00	0.00

* Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 0.0%
- Estimated yield reduction in growth stage # 3 = 69.1%
- Estimated yield reduction in growth stage # 4 = 35.1%

- Estimated Total yield reduction = 46.7%

* These estimates may be used as guidelines and not as actual figures.

* Legend:
TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].

* Notes:
Monthly ETo is distributed using polynomial curve fitting.
Monthly Rainfall is distributed using polynomial curve fitting.
To generate rainfall events, each 5 days of distributed rainfall are accumulated as one storm.
Only NET irrigation requirements are given here. No any kind of losses was taken into account in the calculations.
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Table 5.11
Irrigation Scheduling Report

* Crop Data:
- Crop # 1 : SOYBEAN
- Block # : 1
- Planting date: 1/4

Soil Data : Medium
Initial Soil moisture depletion : 0%

* Irrigation Scheduling Criteria:
- Application Timing:
  Irrigate when 100% of total soil moisture depletion occurs.
- Applications Depths:
  Refill to 100% of readily available soil moisture.
- Start of Scheduling: 1/4

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv (Days)	. Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
1/4	42.00	21.00	16.60	0.00	1.70	100%	1.70				
6/4	51.80	26.40	14.00	8.70	1.70	100%	1.70				
10/4	61.60	32.00	11.60	8.70	1.80	100%	1.80				
16/4	71.40	37.80	9.40	8.80	1.80	100%	1.80				
21/4	81.20	43.80	7.50	7.50	1.90	100%	3.30				
26/4	91.00	50.00	5.90	5.90	2.50	100%	8.60				
1/5	100.80	56.40	4.70	4.70	3.10	100%	18.00				
6/5	110.60	63.00	3.90	3.90	3.60	100%	31.20				
11/5	120.40	69.80	3.50	3.50	4.20	100%	47.70				
16/5	130.20	76.80	3.50	3.50	4.80	100%	67.20				
21/5	140.00	84.00	3.90	3.90	5.30	100%	89.30				
26/5	140.00	84.00	4.50	4.50	3.70	76.4%	105.30				
31/5	140.00	84.00	5.30	5.30	2.70	53.1%	114.20				
5/6	140.00	84.00	6.20	6.20	2.30	40.2%	118.90				
10/6	140.00	84.00	7.00	7.00	2.00	33.6%	121.00				
15/6	140.00	84.00	7.40	7.40	2.00	30.6%	122.00				
20/6	140.00	84.00	7.20	7.20	1.90	29.1%	122.70				
25/6	140.00	84.00	6.00	6.00	1.70	27.5%	124.30				
30/6	140.00	84.00	3.40	3.40	1.40	24.3%	127.60				
5/7	140.00	84.00	0.20	0.20	0.80	18.3%	132.40				
9/8	140.00	119.30	0.00	0.00	0.00	4.5%	139.90	130.00	139.90	0.00	
Total			131.60	106.40	256.60	45.1%			139.90	0.00	0.00

* Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 0.0%
- Estimated yield reduction in growth stage # 3 = 69.1%
- Estimated yield reduction in growth stage # 4 = 35.1%

Estimated Total yield reduction = 46.7%

* These estimates may be used as guidelines and not as actual figures.
* Legend:
TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].
* Notes:
Monthly ETo is distributed using polynomial curve fitting.
Monthly Rainfall is distributed using polynomial curve fitting.
To generate rainfall events, each 5 days of distributed rainfall are accumulated as one storm.
Only NET irrigation requirements are given here. No any kind of losses was taken into account in the calculations.
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Table 5.12

Irrigation Scheduling Report

* Crop Data:
- Crop # 1 : SOYBEAN
- Block # : 1
- Planting date: 1/4
* Soil Data:
Soil description : Medium
Initial soil moisture depletion : 0%
* Irrigation Scheduling Criteria:
- Application Timing:
  Irrigate when 100% of readily soil moisture depletion occurs.
- Applications Depths:
  Refill to 50% of readily available soil moisture.
- Start of Scheduling: 1/4

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
1/4	42.00	21.00	16.60	0.00	1.70	100%	1.70				
6/4	51.80	26.40	14.00	8.70	1.70	100%	1.70				
11/4	61.60	32.00	11.60	8.70	1.80	100%	1.80				
16/4	71.40	37.80	9.40	8.80	1.80	100%	1.80				
21/4	81.20	43.80	7.50	7.50	1.90	100%	3.30				
26/4	91.00	50.00	5.90	5.90	2.50	100%	8.60				
1/5	100.80	56.40	4.70	4.70	3.10	100%	18.00				
6/5	110.60	63.00	3.90	3.90	3.60	100%	31.20				
11/5	120.40	69.80	3.50	3.50	4.20	100%	47.70				
16/5	130.20	76.80	3.50	3.50	4.80	100%	67.20				
19/5	136.10	81.10	0.00	0.00	5.20	100%	82.50	48.00	42.00	0.00	
21/5	140.00	84.00	3.90	3.90	5.30	100%	47.40				
26/5	140.00	84.00	4.50	4.50	5.40	100%	69.70				
29/5	140.00	84.00	0.00	0.00	5.40	100%	85.80	10.00	43.80	0.00	
31/5	140.00	84.00	5.30	5.30	5.40	100%	47.50				
5/6	140.00	84.00	6.20	6.20	5.40	100%	68.30				
8/6	140.00	84.00	0.00	0.00	5.40	100%	84.60	10.00	42.60	0.00	
10/6	140.00	84.00	7.00	7.00	5.40	100%	45.90				
15/6	140.00	84.00	7.40	7.40	5.50	100%	65.80				
19/6	140.00	84.00	0.00	0.00	5.50	100%	87.70	11.00	45.70	0.00	
20/6	140.00	84.00	7.20	7.20	5.50	100%	40.30				
25/6	140.00	84.00	6.00	6.00	5.50	100%	61.80				
30/6	140.00	84.00	3.40	3.40	5.50	100%	85.90	11.00	43.90	0.00	
5/7	140.00	84.00	0.20	0.20	5.50	100%	69.40				
8/7	140.00	84.00	0.00	0.00	5.50	100%	86.00	8.00	44.00	0.00	
16/7	140.00	84.00	0.00	0.00	5.60	100%	86.40	8.00	44.40	0.00	
27/7	140.00	97.40	0.00	0.00	4.60	100%	98.60	11.00	49.90	0.00	
Total			131.60	106.40	569.50	100%			356.30	0.00	0.00

* Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 0.0%
- Estimated yield reduction in growth stage # 3 = 0.0%
- Estimated yield reduction in growth stage # 4 = 0.0%
- Estimated Total yield reduction = 0%
* These estimates may be used as guidelines and not as actual figures.
* Legend:
TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].
* Notes:
Monthly ETo is distributed using polynomial curve fitting.
Monthly Rainfall is distributed using polynomial curve fitting.
To generate rainfall events, each 5 days of distributed rainfall are accumulated as one storm
Only NET irrigation requirements are given here. No any kind of losses
was taken into account in the calculations.
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Table 5.13

Irrigation Scheduling Report

* Crop Data:
- Crop # 1 : SOYBEAN
- Block # : 1
- Planting date: 1/4

* Soil Data:

Soil description : Medium
Initial soil moisture depletion : 0%

* *Irrigation Scheduling Criteria:*
- Application Timing:
  Irrigate when 100% of readily soil moisture depletion occurs.
- Applications Depths:
  Refill to 75% of readily available soil moisture.
- Start of Scheduling: 1/4

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
1/4	42.00	21.00	16.60	0.00	1.70	100%	1.70				
6/4	51.80	26.40	14.00	8.70	1.70	100%	1.70				
11/4	61.60	32.00	11.60	8.70	1.80	100%	1.80				
16/4	71.40	37.80	9.40	8.80	1.80	100%	1.80				
21/4	81.20	43.80	7.50	7.50	1.90	100%	3.30				
26/4	91.00	50.00	5.90	5.90	2.50	100%	8.60				
1/5	100.80	56.40	4.70	4.70	3.10	100%	18.00				
6/5	110.60	63.00	3.90	3.90	3.60	100%	31.20				
11/5	120.40	69.80	3.50	3.50	4.20	100%	47.70				
16/5	130.20	76.80	3.50	3.50	4.80	100%	67.20				
19/5	136.10	81.10	0.00	0.00	5.20	100%	82.50	48.00	62.20	0.00	
21/5	140.00	84.00	3.90	3.90	5.30	100%	27.10				
26/5	140.00	84.00	4.50	4.50	5.40	100%	49.40				
31/5	140.00	84.00	5.30	5.30	5.40	100%	71.00				
3/6	140.00	84.00	0.00	0.00	5.40	100%	87.20	15.00	66.20	0.00	
5/6	140.00	84.00	6.20	6.20	5.40	100%	25.60				
10/6	140.00	84.00	7.00	7.00	5.40	100%	45.80				
15/6	140.00	84.00	7.40	7.40	5.50	100%	65.70				
19/6	140.00	84.00	0.00	0.00	5.50	100%	87.60	16.00	66.60	0.00	
20/6	140.00	84.00	7.20	7.20	5.50	100%	19.30				
25/6	140.00	84.00	6.00	6.00	5.50	100%	40.80				
30/6	140.00	84.00	3.40	3.40	5.50	100%	64.90				
4/7	140.00	84.00	0.00	0.00	5.50	100%	87.10	15.00	66.10	0.00	
5/7	140.00	84.00	0.20	0.20	5.50	100%	26.30				
16/7	140.00	84.00	0.00	0.00	5.60	100%	87.30	12.00	66.30	0.00	
5/8	140.00	112.60	0.00	0.00	3.40	100%	112.90	20.00	84.80	0.00	
Total			131.60	106.40	569.50	100%			412.20	0.00	0.00

* Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 0.0%
- Estimated yield reduction in growth stage # 3 = 0.0%
- Estimated yield reduction in growth stage # 4 = 0.0%

-Estimated Total yield reduction = 0%

* These estimates may be used as guidelines and not as actual figures.
* Legend:

TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].

* Notes:

Monthly ETo is distributed using polynomial curve fitting.
Monthly Rainfall is distributed using polynomial curve fitting.
To generate rainfall events, each 5 days of distributed rainfall are accumulated as one storm
Only NET irrigation requirements are given here. No any kind of losses
was taken into account in the calculations.
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Table 5.14
Irrigation Scheduling Report

* Crop Data:
- Crop # 1 : SOYBEAN
- Block # : 1
- Planting date: 1/4
* Soil Data:
Soil description : Medium
Initial soil moisture depletion : 0%

* Irrigation Scheduling Criteria:
- Application Timing:
  Irrigate when 100% of readily soil moisture depletion occurs.
- Applications Depths:
  Refill to 100% of readily available soil moisture.
- Start of Scheduling: 1/4

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
1/4	42.00	21.00	16.60	0.00	1.70	100%	1.70				
6/4	51.80	26.40	14.00	8.70	1.70	100%	1.70				
11/4	61.60	32.00	11.60	8.70	1.80	100%	1.80				
16/4	71.40	37.80	9.40	8.80	1.80	100%	1.80				
21/4	81.20	43.80	7.50	7.50	1.90	100%	3.30				
26/4	91.00	50.00	5.90	5.90	2.50	100%	8.60				
1/5	100.80	56.40	4.70	4.70	3.10	100%	18.00				
6/5	110.60	63.00	3.90	3.90	3.60	100%	31.20				
11/5	120.40	69.80	3.50	3.50	4.20	100%	47.70				
16/5	130.20	76.80	3.50	3.50	4.80	100%	67.20				
19/5	136.10	81.10	0.00	0.00	5.20	100%	82.50	48.00	82.50	0.00	
21/5	140.00	84.00	3.90	3.90	5.30	100%	6.80				
26/5	140.00	84.00	4.50	4.50	5.40	100%	29.10				
31/5	140.00	84.00	5.30	5.30	5.40	100%	50.70				
5/6	140.00	84.00	6.20	6.20	5.40	100%	71.50				
8/6	140.00	84.00	0.00	0.00	5.40	100%	87.80	20.00	87.80	0.00	
10/6	140.00	84.00	7.00	5.40	5.40	100%	5.40				
15/6	140.00	84.00	7.40	7.40	5.50	100%	25.30				
20/6	140.00	84.00	7.20	7.20	5.50	100%	45.60				
25/6	140.00	84.00	6.00	6.00	5.50	100%	67.10				
29/6	140.00	84.00	0.00	0.00	5.50	100%	89.10	21.00	89.10	0.00	
30/6	140.00	84.00	3.40	0.00	5.50	100%	5.50				
5/7	140.00	84.00	0.20	0.20	5.50	100%	32.90				
15/7	140.00	84.00	0.00	0.00	5.60	100%	88.40	16.00	88.40	0.00	
Total			131.60	101.40	569.50	100%			347.80	0.00	0.00

* Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 0.0%
- Estimated yield reduction in growth stage # 3 = 0.0%
- Estimated yield reduction in growth stage # 4 = 0.0%

- Estimated Total yield reduction = 0%

* These estimates may be used as guidelines and not as actual figures.
* Legend:
TAM = Total Available Moisture = (FC% - WP%)* Root Depth [mm].
RAM = Readily Available Moisture = TAM * P [mm].
SMD = Soil Moisture Deficit [mm].
* Notes:
Monthly ETo is distributed using polynomial curve fitting.
Monthly Rainfall is distributed using polynomial curve fitting.
To generate rainfall events, each 5 days of distributed rainfall are accumulated as one storm
Only NET irrigation requirements are given here. No any kind of losses
was taken into account in the calculations.
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CHAPTER 6

Summary and Conclusions

CHAPTER – 6

SUMMARY AND CONCLUSIONS

There is empiricalism and gross simplication in the conventional approach followed in planning for irrigation project. Following are the comments:

1. 75% dependability of water supply is the prevalent criteria for irrigation planning. It is more useful to work out relationship between storage, withdrawal and reliability for irrigation on seasonal and annual basis. The prevalent dependability criteria on annual basis does not appear to have sound analytical depth social and economic factors should so also considered in fixing dependability criteria for a project.
2. In conventional simulation study, the elevation-area-capacity curve as anticipated after half of project life is first derived using Area Reduction Method (or any other appropriate method) and assumed to apply uniformly from first year up to end of project life in the simulation study. It is suggested that, elevation-area-capacity relationship be revised at regular interval of 10 years and incorporated in the simulation study.
3. Conventional procedures were evolved considering limitations of data, computational facility and methods of analysis. With availability of computer technology and analytical tools, it is possible to simulate long term behaviour of reservoir under variety of conditions and make the analysis more realistic as well as more useful. Even preliminary design can be made more realistic and informative (storage-yield-reliability relation) for the planner.
4. Planning of river valley project needs to be based on thorough hydrological investigations. It is seen that project feasibility reports are not in conformity with guidelines and procedures prescribed by agencies responsible for technical scrutiny

and financial sponsorship resulting in delay in clearance of project. Some important guidelines on requirement of hydrologic data and for simulation study are reviewed and highlighted.

5. A design-cropping pattern should have a fair chance of being implemented in field. Too ambitious or pessimistic cropping pattern may cause several errors in sizing of project in planning stage and confusion/manipulation in implementation stage. Further, variation in irrigation demand from year to year should also be considered in planning of irrigation project.

6. Major and medium irrigation projects are generally river valley project, type Inadequate river flow data, randomness of flows give rise to problem of unreliability, inadequacy, inequity, etc. In the planning stage itself conjunctive use of surface and ground water in a command area should be considered. Guidelines prescribed by Central water Commission of Government of India (CWC, 1995) should be uniformly followed.

7. In the conventional procedure, storage capacity of an irrigation reservoir is planned to meet annual irrigation demand on 75 % dependable basis. Instead of considering a fixed dependability criteria, which is empirical in nature it is more useful to work out storage capacity requirement for different dependability levels of irrigation water utilization. Further, instead of considering dependability on annual basis only, dependability should be analyzed on crop seasonal basis also. Such analysis between storage capacity, water with-withdrawal and seasonal reliability provides more useful information in fixing size of live storage and irrigation water utilization.

Improvements in Planning of Pandanduri Irrigation Project

Based on literature review and case study of the Pandanduri Irrigation Project, following improvements are possible.

1. ***Variation in Irrigation Demand:*** In the conventional simulation study for irrigation system planning, a design cropping pattern is evolved and it is assumed to be fixed i.e. variation from year to year is not considered. In the present study, different scenarios of irrigation development and different cropping intensities are considered. Irrigation release requirements at the Pandanduri reservoir will therefore vary not only from month to month but also from year to year due to randomness of flow and irrigation demand.

2. ***Consideration of Group System of Irrigation**:* Water distribution is an important component of irrigation system design and implementation. Each irrigation project has its own specific water distribution plan to achieve project target. The water balance simulation study of irrigation has to be done according to the water distribution plan.

   In Indonesia, water distribution plan is based on group system. Concept of *Golongan* (Group) system of irrigation has been introduced in determining irrigation demand in time and space framework. The peak irrigation demand is reduced due to staggering of crop calendar in *Golongans. For example in case of Batutegi project, peak demand could be reduced from 5003 m^3/month/ha (without Golongan system) to 3686 m^3/month/ha by consideration of staggering crop calendar in six golongans.* Thus, the concept of *Golongan is* useful both in irrigation system design and in irrigation system operation. Use of *Golongan* concept in system design results in lower capacities of canal network at head and helps in equitable sharing of deficit water supplies.

3. ***Irrigation scheduling*** is a part of water distribution planning in the command area of an irrigation project. It is an important aspect of irrigation project planning but generally ignored in project preparation stage. While analyzing possible irrigation development scenarios during the life of a project, it is important to consider likely water deficit condition, resulting yield reduction, and plan for irrigation scheduling to manage water deficits at micro and macro level (field level and project level). Therefore irrigation scheduling at field level and water distribution planning for the command area should form part of irrigation planning at project preparation stage itself.

   During project preparation stage irrigation scheduling is accounted for in terms crop type, number of waterings and depth of irrigation. Thus there is lot of subjectivity in assessment of demand and in the procedure for meeting the spatially distributed irrigation demand. With the availability of software's such as CROPWAT and others, it is possible to carry out irrigation scheduling and water distribution planning in more scientific manner.

CONCLUSIONS FROM CASE STUDY OF PANDANDURI PROJECT

Analysis of rainfall variation with elevation shows that different stations at similar elevation have recorded significantly different rainfall. It is therefore necessary that variation in rainfall over the command area should be accounted in irrigation planning.

Evaporation estimates based on solar radiation are found to be on lower side. This may be partly attributable to underestimation of solar radiation due to lack of calibration of the radiometer.

On the other hand estimation of solar radiation from the equation (Rs/Ra = a + b n/m) requires values of a and b. Standard values of a and b given in FAO paper 24 (FAO, 1977)are found to be on higher side (table 3.2 chapter 3) compared to those estimated from observed radiation data. This means evaporation and evapotranspiration estimates following standard 'a' and 'b' coefficient could be on higher side. Figure 3.2 chapter 3 suggests that appropriate values of 'a' and 'b' could be 0.21 and 0.37 respectively.

As per prevalent procedure in Indonesia effective rainfall is defined as 70% the average rainfall. This may not be accurate when rainfall shows large variability from year to year. To determine design releases, it is recommended to set effective rainfall as 70% of average rainfall with extreme high and low values (top two and bottom two) omitted from the calculation of average rainfall as shown in table 3.4 of chapter 3.

The FAO ***Penman-Monteith*** is universally accepted standard method for estimation of crop evapotranspiration requirement and the same has been used in present study. As seen in table 3.3 chapter 3, lower values are obtained using Penman-Monteith method.

Concept of golongan has been applied in estimation of crop coefficient for each fortnight for different crops. Starting dates for a particular crop were staggered by half month to effect ground reality. Peak diversion requirement work out to be 1.41 litres per second per hectare which occurs in 1st fortnight of January.

For the analysis of irrigation development options, three alternate command area size (10197 ha, 8190 ha, 5550 ha) and three cropping patterns with following difference have been considered.

	I	II	III
Wet season			
Rice	100%	100%	100%
Dry season I			
Rice & other crops	←	5% difference	→
Dry season II	←	no difference	→

Diversion requirements for each of the different option have been worked out.

This exercise illustrates procedure to account for possible development scenarios in the planning process and thus makes irrigation planning more realistic.

Sedimentation in reservoir reduces live storage capacity and consequently the availability of water for irrigation and irrigated crop intensity as shown by the study of Pandanduri reservoir. The over all average cropping intensity reduces from 199% in 1st year to 187% in 37th year due to sedimentation of reservoir.

Using a computer software, the effect of field irrigation efficiency (65%,70%,75% and 80%), effect of staggering planting date for soybean crop (1st April, 11th April, 21st April) and effect of irrigation scheduling option on irrigation scheduling have been analyzed. This exercise has been done to illustrate potential use of software such as CropWat in making water distribution planning more scientific and realistic.

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ANNEXURE

ANNEXURE

PENMAN-MONTEITH EQUATION

Calculation procedure

ET_o calculated with different time steps

From the original Penman-Monteith equation and the equations of the aerodynamic and canopy resistance, the FAO Penman-Monteith equation has been derived in

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where

ET_o	:	reference evapotranspiration [mm day^{-1}],
R_n	:	net radiation at the crop surface [MJ m^{-2} day^{-1}],
G	:	soil heat flux density [MJ m^{-2} day^{-1}],
T	:	air temperature at 2 m height [°C],
u_2	:	wind speed at 2 m height [m s^{-1}],
e_s	:	saturation vapour pressure [kPa],
e_a	:	actual vapour pressure [kPa],
$e_s - e_a$	:	saturation vapour pressure deficit [kPa],
D	:	slope vapour pressure curve [kPa $°C^{-1}$],
g	:	psychrometric constant [kPa $°C^{-1}$].

The FAO Penman-Monteith equation determines the evapotranspiration from the hypothetical grass reference surface and provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which the evapotranspiration from other crops can be related.

Calculation procedure

Calculation sheet

ET_o can be estimated by means of the calculation sheet presented in Box 1. The calculation sheet refers to tables available in textbooks for the determination of some of the climatic parameters. Example 1 given at the end illustrates the procedure. The calculation procedure consists of the following steps:

1. Derivation of some climatic parameters from the daily maximum (T_{max}) and minimum (T_{min}) air temperature, altitude (z) and mean wind speed (u_2).
2. Calculation of the vapour pressure deficit (e_s - e_a). The saturation vapour pressure (e_s) is derived from T_{max} and T_{min}, while the actual vapour pressure (e_a) can be derived from the dewpoint temperature (T_{dew}), from maximum (RH_{max}) and minimum (RH_{min}) relative humidity, from the maximum (RH_{max}), or from mean relative humidity (RH_{mean}).
3. Determination of the net radiation (R_n) as the difference between the net shortwave radiation (R_{ns}) and the net longwave radiation (R_{nl}). In the calculation sheet, the effect of soil heat flux (G) is ignored for daily calculations as the magnitude of the flux in this case is relatively small. The net radiation, expressed in MJ m^{-2} day^{-1}, is converted to mm/day (equivalent evaporation) in the FAO Penman-Monteith equation by using 0.408 as the conversion factor within the equation.
4. ET_o is obtained by combining the results of the previous steps.

Computerized calculations

Calculations of the reference crop evapotranspiration ET_o are often computerized. Typical sequences in which the calculations can be executed are given in the calculation sheets. The procedures presented in Box 1 (vapour pressure deficit), 9 (extraterrestrial radiation and daylight hours), 10 (net radiation) and 11 (ET_o) can be used when developing a spreadsheet or computer program to calculate ET_o. Many software packages already use the FAO Penman-Monteith equation to assess the reference evapotranspiration. As an example, the output of CROPWAT, the FAO software for irrigation scheduling, is presented in Table 1.

BOX 1. Calculation sheet for ET_o (FAO Penman-Monteith) using meteorological tables					
Parameters					
T_{max}		°C			
T_{min}		°C	$T_{mean} - (T_{max} + T_{min})/2$		°C
T_{mean}		°C	Δ (Table)		kPa/°C
Altitude		m	γ (Table)		kPa/°C
u_2		m/s	$(1 + 0.34\ u_2)$		
$\Delta/[\Delta+\gamma\ (1 + 0.34\ u_2)]$					
$\Delta/[\Delta+\gamma\ (1 + 0.34\ u_2)]$					
$[900/(T_{mean} + 273)]\ u_2$					
Vapour pressure deficit					
T_{max}		°C	$e°(T_{max})$ (Table)		kPa
T_{min}		°C	$e°(T_{min})$ (Table)		kPa
Saturation vapour pressure $e_s = [(e°(T_{max}) + e°(T_{min})]/2$					kPa
e_a derived from dewpoint temperature:					
T_{dew}		°C	$e_a = e°(T_{dew})$ (Table)		kPa
OR e_a derived from maximum and minimum relative humidity:					
RH_{max}		%	$E°(T_{min})\ RH_{max}/100$		kPa
RH_{min}		%	$E°(T_{max})\ RH_{min}/100$		kPa
			e_a: (average)		kPa
OR e_a derived from maximum relative humidity: (recommended if there are errors in RH_{min})					
RH_{max}		%	$e_a = e°(T_{min})\ RH_{max}/100$		kPa
OR e_a derived from mean relative humidity: (less recommended due to non-linearities)					
RH_{mean}		%	$e_a = e_s\ RH_{mean}/100$		kPa

Vapour pressure deficit (e_s - e_a)					kPa
Radiation					
Latitude		°			
Day			R_a (Table)		MJ m^{-2} d^{-1}
Month			N (Table)		hours
N		hours	n/N		
If no R_s data available: $R_s = (0.25 + 0.50\ n/N)\ R_a$					MJ m^{-2} d^{-1}
$R_{so} = [0.75 + 2\ (Altitude)/100000]\ R_a$					MJ m^{-2} d^{-1}
R_s/R_{so}					
$R_{ns} = 0.77\ R_s$					MJ m^{-2} d^{-1}
T_{max}			$\sigma T_{max}K^4$ (Table)		MJ m^{-2} d^{-1}
T_{min}			$\sigma T_{max}K^4$ (Table)		MJ m^{-2} d^{-1}
$\sigma T_{max}K^4 + \sigma T_{max}K^4$					MJ m^{-2} d^{-1}
e_a		kPa	$(0.34-0.14\ \gamma\ e_a)$		
R_s/R_{so}			$(1.35\ R_s/R_{so} - 0.35)$		
$Rnl = [\sigma T_{max}K^4 + \sigma T_{max}K^4]/2(0.34-0.14 \sqrt{e_a})\ (1.35\ R_s/R_{so} - 0.35)$					
$R_n = R_{ns} - R_{nl}$					
T_{month}		°C	G_{day} (assume)	0	
$T_{month-1}$		°C	$G_{month} = 0.14\ (T_{month} - T_{month-1})$		
$R_n - G$					MJ m^{-2} d^{-1}
$0.408\ (R_n - G)$					mm/day
Grass reference evapotranspiration					
$\left[\frac{\Delta}{\Delta+\gamma(1+0.34u_2)}\right][0.408(R_n-G)]$					mm/day
$\left[\frac{\gamma}{\Delta+\gamma(1+0.34u_2)}\right]\left[\frac{900}{T+273}\right]u_2\ [(e_s-e_a)]$					mm/day
$ET_o = \frac{0.408\Delta(R_n-G)+\gamma\frac{900}{T+273}u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)}$					mm/day

Table 1. ET_0 computed by CROPWAT

MONTHLY REFERENCE EVAPOTRANSPIRATION PENMAN MONTEITH							
Mateostation: CABINDA				Country: Angola			
Altitude: 20 m.				Coordinates: -5.33		South	12.11 East
Month	MinTemp	MaxTemp	Humid.	Wind	Sunshine	Radiation	ETo-PenMon
	°C	°C	%	km/day	Hours	MJ/m²/day	mm/day
January	22.8	29.6	81	78	4.0	15.7	3.4
February	22.7	30.3	82	69	4.6	16.9	3.7
March	23.0	30.6	80	78	5.1	17.4	3.8
April	23.0	30.2	82	69	5.0	16.4	3.5
May	22.0	28.6	84	69	3.8	13.5	2.9
June	19.2	26.5	81	69	3.3	12.2	2.6
July	17.6	25.1	78	78	3.2	12.3	2.6
August	18.6	25.3	78	78	2.6	12.4	2.6
September	20.5	26.5	78	104	2.0	12.4	2.8
October	22.5	28.0	79	130	2.2	12.9	3.1
November	23.0	28.7	80	104	3.2	14.4	3.3
December	23.0	29.1	82	95	3.8	15.2	3.4
Year	21.5	28.2	80	85	3.6	14.3	3.1

CROPWAT 7.0 Climate file: C:\PROF-P~1\CROPWAT\CROPWAT\CLI\CABINDA.PEN 03/07/98

Ten-day or monthly time step

Notwithstanding the non-linearity in the Penman-Monteith equation and some weather parameter methods, mean ten-day or monthly weather data can be used to compute the mean ten-day or monthly values for the reference evapotranspiration. The value of the reference evapotranspiration calculated with mean monthly weather data is indeed very similar to the average of the daily ET_o values calculated with daily average weather data for that month.

The meteorological data consist of:

- Air temperature: ten-day or monthly average daily maximum (T_{max}) and average daily minimum temperature (T_{min}).
- Air humidity: ten-day or monthly average of the daily actual vapour pressure (e_a) derived from psychrometric, dewpoint or relative humidity data.
- Wind speed: ten-day or monthly average of daily wind speed data measured at 2 m height (u_2).
- Radiation: ten-day or monthly average of daily net radiation (R_n) computed from the mean ten-day or monthly measured shortwave radiation or from actual duration of daily sunshine hours (n). The extraterrestrial radiation (R_a) and daylight hours (N) for a specific day of the month can be computed using Equations.

When the soil is warming (spring) or cooling (autumn), the soil heat flux (G) for monthly periods may become significant relative to the mean monthly R_n. In these cases G cannot be ignored and its value should be determined from the mean monthly air temperatures of the previous and next month. Chapter 3 outlines the calculation procedure(Equations).

EXAMPLE 1. Determination of ET_o with mean monthly data

Given the monthly average climatic data of April of Bangkok (Thailand) located at 13°44'N and at an elevation of 2 m:

-	Monthly average daily maximum temperature (T_{max}) =	34.8	°C
-	Monthly average daily minimum temperature (T_{min}) =	25.6	°C
-	Monthly average daily vapour pressure (e_a) =	2.85	kPa
Measured at 2 m	Monthly average daily wind speed (u_2) =	2	m/s
-	Monthly average sunshine duration (n) =	8.5	hours/day
For April	Mean monthly average temperature ($T_{month, i}$) =	30.2	°C
For March	Mean monthly average temperature ($T_{month, i-1}$) =	29.2	°C

Determination according to outline of Box 11 (calculation sheet ET_o)			
Parameters			
-	$T_{mean} = [(T_{max} = 34.8) + (T_{min} = 25.6)]/2 =$	30.2	°C
From Table or Eq.	$\Delta =$	0.246	kPa/°C
From Table and or Eq.	Altitude =	2	m
	P=	101.3	kPa
	$\gamma =$	0.0674	kPa/°C
-	$(1 + 0.34\ u_2) =$	1.68	-
-	$\Delta /[\Delta + \gamma\ (1 + 0.34u_2)] = 0.246/[(0.246 + 0.0674\ (1.68)] =$	0.685	-
-	$\Delta /[\Delta + \gamma\ (1 + 0.34u_2)] = 0.0667/[0.246 + 0.0674\ (1.68)] =$	0.188	-
-	$900/(T_{mean} + 273)\ u_2 =$	5.94	-
Vapour pressure deficit			
From Table	$T_{max} =$	34.8	°C
Eq.	$e°(T_{max}) =$	5.56	kPa
From Table or	$T_{min} =$	25.6	°C
Eq.	$e°(T_{min}) =$	3.28	kPa
-	$e_s = (5.56 + 3.28)/2 =$	4.42	kPa
Given	$e_a =$	2.85	kPa
-	Vapour pressure deficit $(e_s - e_a) = (4.42 - 2.85) =$	1.57	kPa
Radiation (for month = April)			
From Table or Eq.	J = (for 15 April)	105	-
	Latitude = 13°44'N = (13 + 44/60) =	13.73	°N
	$R_a =$	38.06	MJ m^{-2} day^{-1}
N (Table or Eq.)	Daylength N =	12.31	hours
-	n/N = (8.5/12.31) =	0.69	-

-	R_s = [0.25 + 0.50 (0.69)] 38.06 =	22.65	MJ m^{-2} day^{-1}
-	R_{so} = (0.75 + 2 (2)/100000) 38.06 =	28.54	MJ m^{-2} day^{-1}
-	R_s/R_{so} = (22.65/28.54) =	0.79	-
-	R_{ns} = 0.77 (22.65) =	17.44	MJ m^{-2} day^{-1}
From Table	T_{max} =	34.8	°C
	$\sigma T_{max,K^4}$ =	44.10	MJ m^{-2} day^{-1}
From Table	T_{min} =	25.6	°C
	$\sigma T_{min,K^4}$ =	39.06	MJ m^{-2} day^{-1}
-	$(\sigma T_{max,K^4} + \sigma T_{min,K^4})/2 = (44.10 + 39.06)/2$ =	41.58	MJ m^{-2} day^{-1}
For:	e_a =	2.85	kPa
Then:	$(0.34 - 0.14\sqrt{e_a})$ =	0.10	-
For:	R_s/R_{so} =	0.79	-
Then:	$(1.35\ R_s/R_{so} - 0.35)$ =	0.72	-
-	R_{nl} = 41.58 (0.10)0.72 =	3.11	MJ m^{-2} day^{-1}
-	R_n = (17.44-3.11) =	14.33	MJ m^{-2} day^{-1}
-	G =0.14 (30.2-29.2) =	0.14	MJ m^{-2} day^{-1}
-	$(R_n - G)$ = (14.33-0.14) =	14.19	MJ m^{-2} day^{-1}
-	0.408 $(R_n - G)$ =	5.79	mm/day
Grass reference evapotranspiration			
-	0.408 $(R_n - G)\ \Delta / [\Delta + \gamma (1 + 0.34\ u_2)]$ =		
-	(5.79) 0.685 =	3.97	mm/day
-	900 $u_2/(T + 273)\ (e_s - e_a)\ \gamma / [\Delta + \gamma (1 + 0.34\ u_2)]$ = 5.94(1.57)0.188 =	1.75	mm/day
-	ET_o = (3.97+1.75) =	5.72	mm/day
The grass reference evapotranspiration is 5.7 mm/day.			