WATER RESOURCES MANAGEMENT
FOR
AN IRRIGATION PROJECT USING A DSS

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
HYDROLOGY

By

PRATAP CHANDRA CHAUDHURY

DEPARTMENT OF HYDROLOGY
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE -247 667 (INDIA)
JUNE, 2008

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled **"WATER RESOURCES MANAGEMENT FOR AN IRRIGATION PROJECT USING A DSS"** in partial fulfilment of the requirements for the award of the degree of **Master of Technology in Hydrology**, submitted in the Department of Hydrology,Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from July 2007 to June 2008 under the supervision and guidance of **Dr.D.K.Srivastava,Professor** and **Dr.D.S.Arya,Assistant Professor**, Department of Hydrology, Indian Institute Of Technology, Roorkee.

The matter presented in this dissertation has not been submitted by me for award of any other degree.

Roorkee

June, 2008

PRATAP CHANDRA CHAUDHURY

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

Dr.D.K.SRIVASTAVA
Professor,
Department of Hydrology,
Indian Institute of Technology,
Roorkee(India)

Dr.D.S.ARYA
Assistant Professor,
Department of Hydrology,
Indian Institute of Technology,
Roorkee(India)

ACKNOWLEDGEMENT

I offer my heartfelt gratitude and sincere thanks to my esteemed guides for their excellent guidance, constant encouragement, valuable instruction and keen interest throughout the preparation of this dissertation. In spite of their very busy schedule, they have spared a lot of time for me and gave invaluable suggestions whenever I approached. I feel gifted to be their student.

I am also highly thankful and immensely grateful to Dr.B.S.Mathur, Professor, Dr.D.C.Singhal, Professor, Dr.N.K.Goel, Professor, Dr.H.Joshi, Professor, Dr.M.Perumal, Associate Professor and Dr.M.K. Jain, Assistant Professor, Department of Hydrology, Indian Institute of Technology, Roorkee for their well wishes, useful cooperation and suggestions during the preparation of this dissertation.

I would like to acknowledge the help and support extended by Mr.G.C.Padhi, Trainee Officer, Mr.A.Kar, Trainee Officer, Mr.M.M.Mishra, Trainee Officer, Mr.H.Mohanty, Research Scholar, Mr.C.S.Padhi, Research Scholar, Mr.S.Ch.Das, Asst. Engineer, Mr. S. Gupta, Asst. Engineer and Mr.B.Sethi, during the preparation of this dissertation. I would like to acknowledge the timely help rendered by Mr.D.Satiskumar, Research Scholar during the preparation and final shaping of DSS.

I am deeply indebted to Government of Orissa, Department of Water Resources, Bhubaneswar, for sponsoring me to this course.

I am thankful to Er H.Behara, Engineer-in-chief, Department of Water Resources, Bhubaneswar, for recommending me to this course.

I express my humble thanks to all my friends and colleagues and to all those directly and indirectly encouraged me and put a helping hand in every step of this study.

The continuous loving care and emotional support by my family members, in spite of many family difficulties are my profound lasting memories. I shall remain obliged to the almighty Lord Jagannath for being with me during all the difficult times in my life.

PRATAP CHANDRA CHAUDHURY

ABSTRACT

The operation of canal irrigation systems is a complex task with spatially variable soils, crops and weather conditions. The releases for the irrigation, reach the fields through a hierarchical network of main canals, branch canals (secondary canals) and distributaries (tertiary canals).

The proposed study area, Harbhangi irrigation project is constructed to serve two major purposes such as (a) Providing irrigation facility to its own command area and (b) Transferring water from Vansadhara basin (project basin) to adjacent Rushikulya basin which is water scarcity basin through a natural carrier, river Padma . Hence, the accurate estimates of reference crop evapotranspiration(ET_0), crop coefficients for the different stages of various crops, crop water requirement (CWR) of the project and preparation of irrigation scheduling for the canal network envisage the optimal use of the storage water of reservoir and also preventing the ayacut area from the negative effects, i.e., leaching, water logging and subsequently ground water pollution.

Steps are taken to calculate daily ET_0 by Penman-Monteith method. Crop water requirement of the project with single coefficient method is estimated. Determination of optimal yield from the reservoir with several failure fraction conditions at different annual reliability and indicating dependability of the project to sustain the future food requirement of the project command area is carried out. Also, irrigation scheduling for the different crops of the project is prepared individually and periodical release for all the distributaries of the project for better management of the irrigation system.

For real time management of the irrigation system, A DSS is developed with Visual Basic-6 in four major modules, i.e., (a) to calculate ET_0 after running the Fortran program in back end with **ET_0 module,** (b) to estimate CWR of the project with **CWR module,** (c) to

determine reservoir annual dependable yield after running the developed Fortran program at back end with **yield module** and (d) to prepare the gate operation for all the distributaries after preparing the irrigation scheduling for all the crops of the command area with **scheduling module**.

CWR of the project is 16.37 Tham against project value of 18.67 Tham for the scheduled cropping pattern. After incorporating soil coefficient (K_s) to the K_c value, CWR of the project is reduced by 5%. The maximum annual firm yield with 100% project dependability is 12.8 Tham. Maximum annual total yield is 22.23 Tham on an annual project dependability of 75% with normal flow condition.

List of Contents

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Role of water for survival of flora and fauna needs no elaboration. It is one of the most important resources for mankind. It has come under tremendous pressure both qualitatively and quantitatively due to continuous rise in its demand and socio-economic elevation. So the need of the hour is to plan and manage available water resources for sustainable development. This requires a clear vision on the planning horizon focusing on the imperative strategies.

In the post independence era in India, wide networks of irrigation system infrastructure have been created through Five Year plans, better known as Green Revolution, to meet the food sufficiency. Since the population of India is still has a rising trend and is expected to stabilize by 2045 AD (Press Information Bureau, India, http://bpib.nic.in, released on eve of Independence Day, 2002, 10/10/2007), the Govt. of India has intended to undertake steps for second Green Revolution to meet the requirement. Because the available water resources are limited, the next alternative is to use the resources efficiently in a sustainable manner. The review of literature clearly indicates that the water utilization efficiency of irrigation in India is far poor compared to the developed nations (Energy Dept. of India, http://www.renewingindia.org/eefagri.html).This is because of release of irrigation water is supply based rather demand based, superstition among the farmers, lack of education among the farming communities, absence of mobilization and effective training at the grassroots level, gaps between the irrigation water managers and the farmers and dearth of technology application.

Irrigation potential of India has increased to 98.84 m ha (1997-98) from 22.6m ha during 1950-51(during pre-plan time) (http//India.gov.in/ sectors/ water_resources/ irrigation). Presently, the operation and management of the irrigation are being criticized for the significant gap between

- irrigation potential created and actual irrigation potential achieved, and
- lack of equitable distribution of water among the beneficiaries within the ayacut area and adaptation of useful cropping pattern which results in an alarming water use efficiency, i.e., up to 30-35%.

The principal challenge to the State Water Policy of Orissa is to manage the water resources and cultivable land more effectively to meet the growing needs of the population, which is putting enormous pressure on agricultural production and on the non-renewable and limited natural resources. Thus a balance has to be achieved between the needs of a progressing economy and the protection of natural resources, while addressing the impact of current environmental problems. Hence, there is an urgent need in all the major irrigation projects for improving efficiencies in the of irrigation water management through the development and adaptation of advance water management technique that take care of the rainfall distribution, cropping pattern variation, crop water demand for short duration draught situation and also to avoid excess supply of irrigation water which causes water logging.

Decision Support System (DSS) is a computer based interactive system which provides modeling and simulation facilities. It may help in integrated water resources project development to meet the irrigation requirement. The system helps in generating what-if scenarios to aid irrigation officers in implementing the water management policies efficiently. The study aims at designing and developing such a decision support system for Harbhangi Irrigation project, Department of Water resources (DOWR), Orissa. The study intended to provide the techno-scientific capability to assess and evaluate possible alternatives for irrigation in a systematic way to assist decision makers about the availability of water resources at specific locations inside the ayacut area at a given time. Rather than adding a bit of knowledge 'vertically' and getting more insight on some particular aspect, the idea is to broaden the understanding of the total irrigation system management 'horizontally', by integrating the knowledge and tools already available through an innovative cross-sector and multidisciplinary view.

1.2 AN OVERVIEW OF THE STUDY AREA

The study area covers the Harbhangi Irrigation Project, an inter-basin irrigation project in Orissa state, where water from river Harbhangi, a tributary of river Vanshadhara in Vanshadhara basin (an interstate basin between Orissa and Andhra Pradesh) is transferred to Rushikulya basin (a basin in Orissa state). The river Padma, a tributary of river Rushikulya is used as a carrier for transferring water to Harbhangi irrigation project. The ayacut area of the project is 9650 ha in Rushikulya Basin where the imported water is used. Inflow to river Padma from its original catchment area will not be utilized within the ayacut area of the Harbhangi Irrigation Project.

Subsequently, it is proposed to construct a cascade type powerhouse to utilize the geophysical advantage of the project location and accommodate a natural gross head of 230m with an installed capacity of 24.75MW. However, the powerhouse operation is yet to be commissioned.

1.3 OBJECTIVES OF STUDY

In this study it is proposed to develop a demand based irrigation strategy for Harbhangi project on ten daily basis by designing and developing a Decision Support System based on the following approaches and methodology:

i. Estimation of runoff and inflow into the reservoir using a suitable rainfall-runoff model.

ii. Calculation of ET_c (crop evapotranspiration) from ET_o (reference evapotranspiration) using Penman-Monteith Method to estimate the gross water requirement of the crops.

iii. Application of Linear Programming based reservoir yield model to ensure the reliability of water release from the reservoir for irrigation purpose.

iv. Development of irrigation scheduling and management scheme for canals (reach wise) to minimize the deficit between the canal water supply and the crop water requirement. 82

1.4 METHODOLOGY AND APPROACHES

A DSS will be developed as an active decision support system to allow the user to adopt the decision directly. The methodology and approach for the development of the software of DSS are described below:

The methodologies to be used for the purpose:-

i. SCS-CN method shall be used for estimation of inflow to the reservoir.

ii. ET_o shall be calculated by Penman-Monteith method and the result shall be compared with CROPWAT72 software developed by FAO.

iii. Yield model developed and used by Dahe and Srivastava (2000), Panigrahi and Srivastava (2005) and Sethi and Srivastava (2007) shall be used to get the annual reservoir yield with 75% dependability. Available FORTRAN program for LP solution shall be used with input data matrix and data matrix required for LP model will be generated by developing a computer program.

iv. Using existing/optimal cropping pattern, the optimal utilization of water shall be decided with appropriate irrigation scheduling by 'Field Water Balance' model.

v. All the above approaches will be programmed in FORTRAN and dynamic link libraries (DLLs) shall be developed for each method to integrate in a DSS software.

vi. DSS container software shall be developed using Microsoft Visual Basic (VB). The rich content of graphical user interface available in VB shall be used to design easy to use interface of DSS. All the DLLs developed in (v) will be integrating as back-end tools in the front-end container software.

CHAPTER 2

AN OVERVIEW OF HARBHANGI IRRIGATION PROJECT

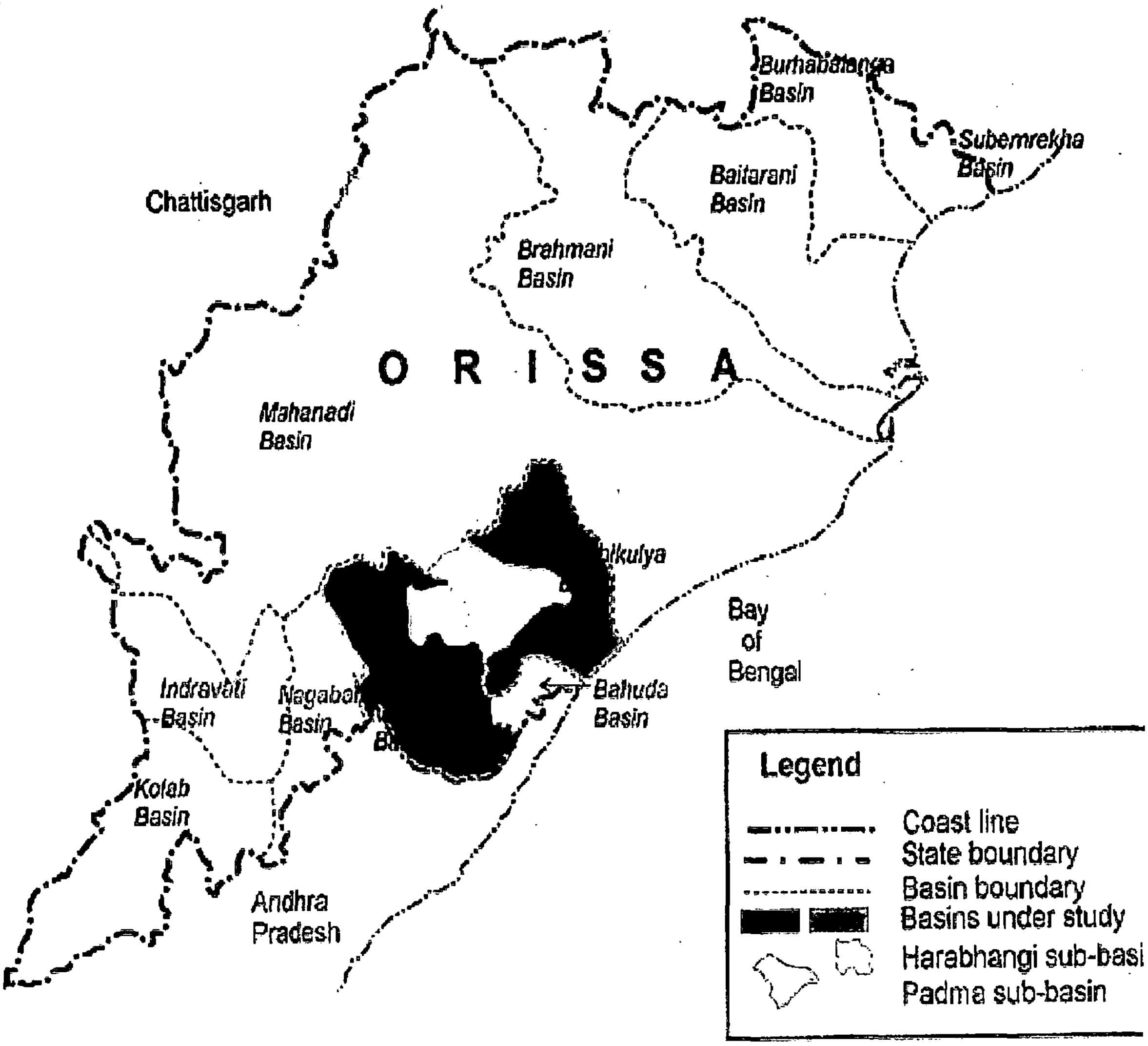
2.1 GENERAL

Harbhangi Irrigation Project is an inter-basin irrigation project in Orissa state, constructed across river Harbhangi. The Harbhangi river is a major tributary at uppermost part of river Vansadhara. Vansadhara river originates from Mahendratanaya hills located at the southern part of Orissa. Its basin is an interstate basin between Orissa and Andhra Pradesh. The catchment area of the Vansadhara basin belongs to hilly terrain and undulated topography.

The command area of the Harbhangi irrigation project lay under the sub-basins of river Padma and Joro, the two upper most tributaries of river Rushikulya. The Padma river originates from Kuduma hill ranges at latitude 19^0- $38'$ North and Longitude 84^0- $15'$ East at an elevation of 500m. The Padma river has a drainage area of 663sq.km and it joins river Rushikulya on its right. Harbhangi river transfers water of Vansadhara basin to Rusikulya basin through exit channel connecting to Padma river. River basin position along with other near by basin and the overall project layout is given in Fig.-2.1 and Fig.-2.2.

2.2 HISTORICAL DEVELOPMENT OF THE PROJECT

The irrigation authority planned to develop command area in the upper zone of Rushikulya basin (Padma valley) which is prominently a draught prone area. The water resources of river Padma, which were being utilized for the downstream projects i.e. in lower area of the rushikulya basin, was not available for this purpose. Hence the water resources of Harbhangi river in the adjacent Vansadhara basin were chosen for transferring water to the proposed command area of the Padma valley



Orissa and its river basins (Jena, 2002)

Fig.-2.1 Basins and Sub-basins of Harbhangi Irrigation Project

. Accordingly, the conceptual planning of the project was started by Govt. of Orissa around 1962. Construction work of the reservoir site as well as canal system was completed by 1994 and since then, the project is functioning quite satisfactorily.

The river Harabhangi is the upper most and major potential tributary of river Vansadhara. It originates from Ramgiri hills of southern Orissa at the general elevation around 1100m.The main dam that intercepts a catchment area of 503.8 km^2 is located at about 90Km of downstream of its origin.

The stored water is being utilized for inter-basin transfer cutting across the dividing line through a lined D-shaped tunnel of 3m diameter and 2.2km length. At the exit end the water emerges out at a RL367.00m and flows into the river Padma. A pickup weir has been constructed over river Padma at Gokulpur named Gokulpur Barrage keeping pond level of the barrage kept at 137.2 m above the MSL at about 33 Km downstream of the tunnel exit. A new pick up weir is located at 7.6km upstream of the old Padma weir.The discharge of the river Padma is being diverted to the renovated Sorada reservoir through a new link channel and the Sorada reservoir functions as a balancing reservoir for the Rushikulya irrigation project at the downstream.

Thus the river Padma from the diversion tunnel exit to the Gokulpur barrage used as a carrier or natural conductor system for Harbhangi irrigation system only, because practically the water of the river Padma is not being utilized by the Harbhangi irrigation project.

The proposed hydropower plant to utilize the potential head of 230m available along the course of the Padma River to generate 12.4MW hydroelectricity is under construction.

2.3 PHYSICAL CHARACTERISTICS OF THE PROJECT AREA

2.3.1 Location

The project is located in Ganjam and Gajapati districts. The dam is located at about longitude 84^0 80' East and latitude 18^0 30' North with MWL of the reservoir at 387.5m above the sea level. Where as the elevation of the command area of the project, under Soroda and Badagada block vary from 130m to 90m above MSL.

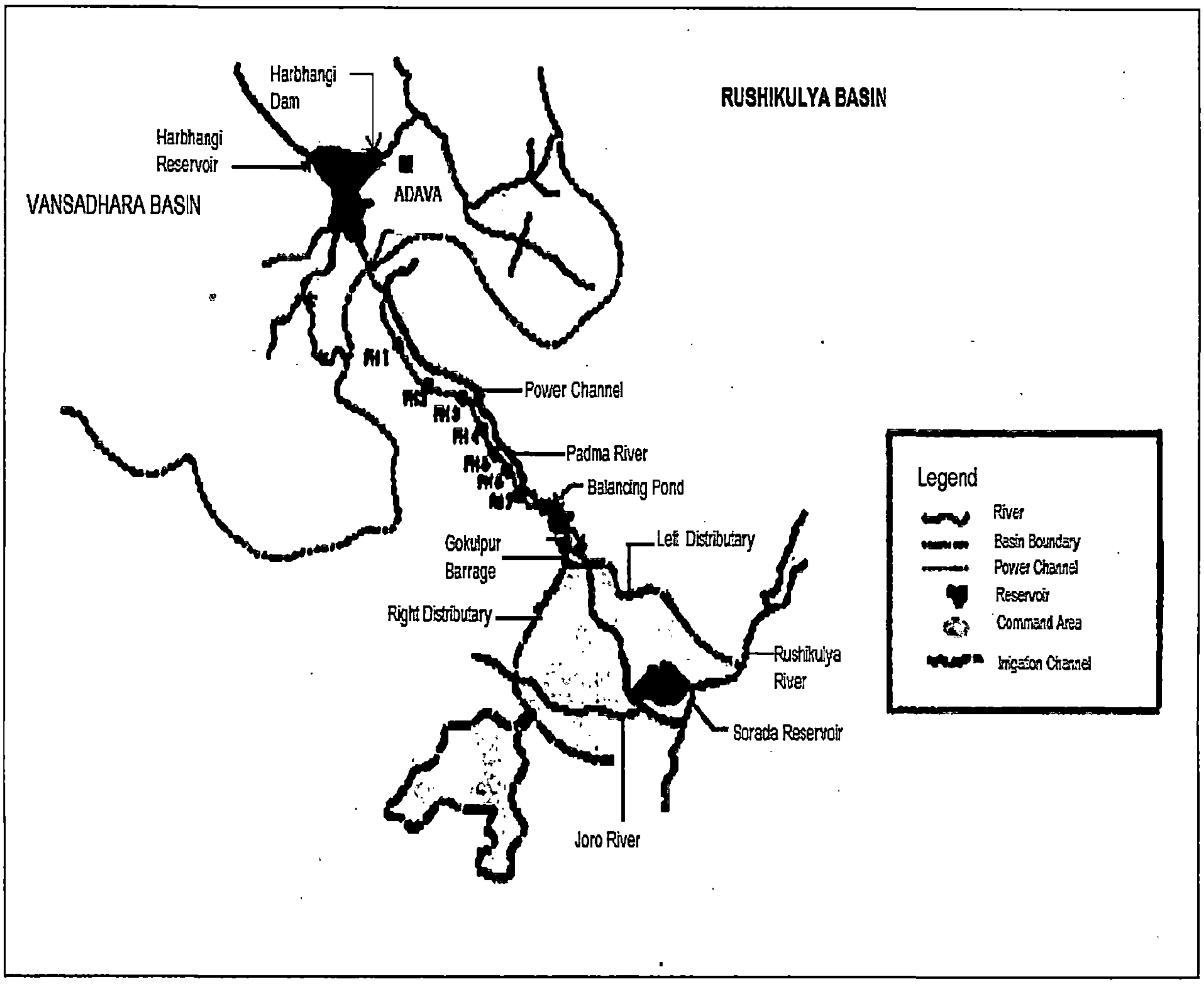


Fig.-2.2 Layout Plan of Harbhangi Irrigation Project (Jena, 2002)

2.3.2 Climate

The climate of the entire project area is of tropical monsoon type. There are four well-defined seasons i.e. summer (March to May), monsoon (June to September), post monsoon (October to November) and winter (December to February). Thunderstorms are quite frequently encountered during the monsoon periods. The hydrometeorological data of Dhaugaon hydrometeorological station of CWC which is situated within command area are used for the analysis. The average maximum and minimum temperature varies from 45^0C to 27^0C during summer and minimum temperature varies from 9.6^0C to 15.3^0C during winter. The relative humidity varies from 88% to 93% during July to September. The area is visited by tropical monsoon climate of pronounced wet season from June to October with average annual precipitation of 1350 mm and annual pan evaporation is 1496mm. Monthly average of hydrometeorological data of the Dhaugaon station is furnished in table-2.1.

Table-2.1 Monthly hydrometeorological data of Dhaugaon station

Sl.No.	Month	Mean Max Temp in 0C	Mean Min Temp in 0C	Mean Air humidity in %	Mean Wind speed in km/day	Mean Daily Sunshine in hr	Monthly Pan Evaporation in mm
1	January	29.5	16.3	87.7	40.5	7.1	93.9
2	February	33.1	19.1	88.4	49.2	8.4	123.6
3	March	35.5	23.2	89	55.2	8.1	155.3
4	April	38.6	25.4	80.6	61.9	8.4	188.9
5	May	40.3	27.5	80.3	69.5	8.3	227.8
6	June	36.6	27.4	80.4	35.8	5.1	141.4
7	July	33.9	26.8	86.5	26.4	3.5	118.3
8	August	31.9	26.1	88.7	22.8	3.1	98
9	September	33.1	25.8	89.6	22.1	4.2	96.2
10	October	31.8	24.5	89.4	29.4	6.4	91.8
11	November	30.1	19.6	87.1	29.5	6.1	81.5
12	December	29.8	15.9	84.6	29.3	5.1	79.8

2.3.3 Soil Characteristics

The geographical formation of the study area is Alluvial, brown land Laterites, Gondowanas, Newer Dolerites and Archon comprising igneous and metamorphic rocks. Based on the soil survey, five soil series were recognized in the command area. Soil texture varies from loamy sand to clayey loam.

Depending on the topography, soil type and drainage characteristics, the command are was classified into land suitability for irrigation. Out of the total CCA of 9650 ha, 6500 ha (71%) is assessed under classes-I and II, i.e. moderately suitable for irrigation, and 3100 ha (29%) under class-III i.e., fairly suitable but severe limitation for the sustained use for irrigation.

2.3.4 Agriculture

The present land use and cropping pattern is proposed for a total cropping area of 17650ha through out the year. The rice is the major crop in the area about 7100 ha being grown on medium and low lands and 1850 ha in high lands. Other crops grown in the command area are raggi, pulses, groundnuts, vegetables and sugarcane also grown on small areas.

After irrigation facility provided, the farmers have adopted complex cropping pattern involving mixed relay cropping, but two basic patterns recognized are as follows:

(a) On medium low land, rice folloed by a pulse crop, and

(b) On high land, raggi also followed by a pulse crop.

In both the cases, the first crop is most important.

2.4 WATER RESOURCES

The mean annual inflow at the dam site was estimated as 273mcm per year (8.7cumecs), which is correspond to 540mm of runoff. An inter-state agreement is in force with Andhra Pradesh to use Vasnadhara basin water at Gotta reservoir on 50%-50% share. But, diversion of Harbhangi reservoir water to the Rushikulya bain cast a share of around 18% of the Orissa share. Hence, the water share of Orissa at Gotta reservoir is revised.

The monthly yield series for a period of 40 years at dam site have been presented in table 2.2.

Table-2.2 Yield series of the Harbhangi reservoir at dam site

		Monsson months						Non-monsoon Months										
Sl. No.	Year	Jun	Jul	Aug	Sep	Oct	Sub-total	Nov	Dec	Jan	Feb	Mar	Apr	May	Sub-total	Total Yearly Yield	Annual Yield in descending order	Probability of Excedence
1	1950	5187	6329	7227	4629	3227	26599	411	97	56	38	47	60	62	771	27370	101655	2.33
2	1951	1789	6474	14353	7387	4453	34456	411	97	56	38	47	60	62	771	35227	44108	4.65
3	1952	1430	10525	4683	16895	9804	43337	411	97	56	38	47	60	62	771	44108	36954	6.98
4	1953	3592	4777	10398	9766	3565	32098	411	97	56	38	47	60	62	771	32869	35550	9.30
5	1954	2265	3079	12577	9782	8480	36183	411	97	56	38	47	60	62	771	36954	35227	11.63
6	1955	2862	3807	9029	9274	1517	26489	411	97	56	38	47	60	62	771	27260	33172	13.95
7	1956	4098	7979	7475	8022	1233	28807	411	97	56	38	47	60	62	771	29578	32869	16.28
8	1957	3825	2031	7538	1813	1148	16355	411	97	56	38	47	60	62	771	17126	32474	18.60
9	1958	1549	5480	8532	12758	1672	29991	411	97	56	38	47	60	62	771	30762	31501	20.93
10	1959	4249	6184	7476	4665	9129	31703	411	97	56	38	47	60	62	771	32474	31031	23.26
11	1960	2334	4219	7538	7859	8310	30260	411	97	56	38	47	60	62	771	31031	30877	25.58
12	1961	3688	8974	8353	9710	1676	32401	411	97	56	38	47	60	62	771	33172	30762	27.91
13	1962	2889	3953	12110	3177	6542	28671	411	97	56	38	47	60	62	771	29442	29789	30.23
14	1963	3015	4280	10253	2985	7257	27790	1294	268	103	64	104	105	61	1999	29789	29578	32.56
15	1964	1695	4800	9566	6286	6285	28632	2157	205	104	72	38	97	196	2869	31501	29442	34.88
16	1965	497	5737	5246	5686	4590	21756	182	82	106	64	126	52	52	664	22420	29291	37.21
17	1966	2158	4175	5649	5130	1197	18309	1530	251	108	31	22	146	158	2246	20555	27370	39.53
18	1967	3427	4569	6583	1269	1655	17503	190	117	126	36	507	48	62	1086	18589	27260	41.86
19	1968	958	2107	2355	1160	825	7405	441	330	56	39	40	60	61	1027	8432	27179	44.19
20	1969	3115	9565	4959	8658	426	26723	1365	517	360	107	97	60	62	2568	29291	26224	46.51
21	1970	2085	3756	5988	2159	2787	16775	411	371	368	259	391	157	224	2181	18956	26197	48.84
22	1971	1652	1116	9258	5828	6590	24444	483	397	200	152	58	271	192	1753	26197	25146	51.16
23	1972	3562	1043	4230	4964	7370	21169	411	97	56	38	47	600	62	1311	22480	24827	53.49
24	1973	387	3896	4159	4892	2988	16322	411	97	56	38	47	60	62	771	17093	24450	55.81
25	1974	789	760	1198	3862	8655	15264	181	97	103	49	131	135	131	827	16091	23761	58.14
26	1975	3175	3326	5149	9217	4816	25683	771	169	55	65	125	107	204	1496	27179	23299	60.47
27	1976	192	6184	11486	2896	2286	23044	216	53	109	64	47	95	133	717	23761	23072	62.79
28	1977	127	1255	4613	5645	272	11912	1811	216	26	15	61	51	72	2252	14164	22731	65.12
29	1978	2757	8155	7126	4671	886	23595	732	36	38	37	184	215	309	1551	25146	22480	67.44
30	1979	2438	3049	7168	2798	6812	22265	2516	69	38	37	184	215	900	3959	26224	22420	69.77

Table-2.2 Yield series of the Harbhangi reservoir at dam site

		Monsson months						Non-monsoon Months										
Sl. No.	Year	Jun	Jul	Aug	Sep	Oct	Sub-total	Nov	Dec	Jan	Feb	Mar	Apr	May	Sub-total	Total Yearly Yield	Annual Yield in descending order	Probability of Excedence
31	1980	2832	1064	5671	15284	5115	29966	1069	1697	322	243	717	778	758	5584	35550	22351	72.09
32	1981	3116	4533	6248	6066	1101	21064	309	286	350	261	644	778	758	3386	24450	21576	74.42
33	1982	2873	1419	1510	1832	1593	9227	352	267	161	235	586	866	965	3432	12659	20555	76.74
34	1983	2413	1983	3089	3987	7679	19151	351	287	257	279	717	797	892	3580	22731	18956	79.07
35	1984	2430	1202	4376	1076	4053	13137	307	218	316	243	645	679	965	3373	16510	18589	81.40
36	1985	1627	3543	5039	2426	5034	17669	251	238	322	311	717	963	1105	3907	21576	17126	83.72
37	1986	1833	2432	7004	2565	5828	19662	351	289	160	261	733	882	961	3637	23299	17093	86.05
38	1987	1993	4520	2390	3824	3037	15764	3900	908	146	323	551	721	759	7308	23072	16510	88.37
39	1988	756	1419	1094	9399	4329	16997	561	169	425	341	162	3081	615	5354	22351	16091	90.70
40	1989	4031	4843	4581	2686	981	17122	981	853	267	281	594	799	3930	7705	24827	14164	93.02
41	1990	2758	1634	12394	7262	17523	41571	39013	1942	784	227	257	230	17631	60084	101655	12659	95.35
42	1991	1102	8924	784	8502	5308	24620	1705	555	1473	644	964	580	336	6257	30877	8432	97.67
Avg.		2370.2	4264.3	6582.3	5922.7	4477.0	23616.5	1657.0	293.9	183.9	126.4	240.6	343.0	795.8	3640.6	27257.1	50873.5	
βt (75%)		0.075	0.164	0.234	0.112	0.233	0.819	0.012	0.011	0.015	0.014	0.033	0.045	0.051	0.181	1.000	75% of Excedence	
βt (90%)		0.049	0.047	0.074	0.240	0.538	0.949	0.011	0.006	0.006	0.003	0.008	0.008	0.008	0.051	1.000	90% of Excedence	
βt (98%)		0.114	0.250	0.279	0.138	0.098	0.878	0.052	0.039	0.007	0.005	0.005	0.007	0.007	0.122	1.000		
βt (Average)		0.087	0.156	0.241	0.217	0.164	0.866	0.061	0.011	0.007	0.005	0.009	0.013	0.029	0.134	1.000		

N.B.:- βt values will be used for yield model analysis.

2.5 CANAL NETWORK

The canal network of the project is originated from the Gokulpur barrage. Total ayacut area of 9650 ha [of the project] is spread over Sorada and Badagada Blocks.Main canal starts from the Gokulpur barrage to a length of 2.515 km. Then the canal is bifurcated to two distributary i.e. Left distributaries and Right distributary. Total ayacut area of the Left distributary is coming under the Sorada block is 2300ha. Similarly, the ayacut area of the Right distributary is 7350 ha. The canal length, off-taking reduced distance (RD), system ayacut area and self ayacut area of each canal is furnished in Table-2.3. Canal layout with the major canals is given in Fig.-2.3

2.6 SALIENT FEATURES OF THE PROJECT

Item	Feature
Name of the project	Harbhangi Irrigation Project
Name of the Basin	Rushikulya and Vansadhara
Location	Longitude 84030' East
	Latitude 18030' North
State	Orissa
District	Gajpati and Ganjam
Hydrology	
Catchment area	503.8 sqkm
Maximum annual rainfall	3249 mm
Minimum annual rainfall	414 mm
Average annual rainfall	1235 mm
75% year's dependable inflow	21.576 Tham
Reservoir	
Type of Dam	Earth dam
Crest level of Dam	RL 390.500 m
Spillway discharge capacity	4608.000 cumecs
Live storage capacity	10.025 Tham
FRL/MWL	RL 387.500 m
DSL	RL 375.000 m
FRA	RL 1215.000 ha

Item	Feature		
DSA	RL	535.000	ha
FRC	RL	14125.000	ham
DSC	RL	4100.000	ham
Diversion Tunnel			
Shape	D- shaped		
Diameter		2.8000	m
Length		2.200	Km
Barrage			
Catchment area		200.98	sqkm
FRL/MWL	RL	137.200	m
MFD		1252.000	cumecs
HFL	RL	140.640	m
Irrigation			
CCA		9650.00	ha
Gross annual irrigation requirements		16.370	Tham

N.B.:-Area-elevation-capacity data of the reservoir is furnished in the Table-2.4 which will be used for the reservoir yield analysis.

Table-2.3 Canal details of Harabhangi irrigation project

Name of the Canal	Name of the Parent Canal	Off-taking at RD in Km.	Ayacut Area in ha	Self Ayacut area in ha	Bed Width in m	FSD in m	Velocity in m/s	free board in m	Group Ayacut Area in ha	Length in Km.	Design Discharge in m3/s	Irrigation Zone
Main Canal	-		9650		10.25	1.85	0.72	0.9	9650	2.515	13.34	
Left Distributary	***Main Canal***	*2.515*	*2300*	*618.58*	*4.90*	*1.05*	*0.5353*	*0.9*	*2300*	*15.864*	*3.05*	
Baroda s/m	Left Distributary	0.16	78.98	78.98							0.0817	A
Gadachikili s/m	Left Distributary	1.678	134.85	134.85							0.1852	A
Latapali s/m	Left Distributary	5.19	255.06	255.06							0.3483	A
Buguda minor	Left Distributary	7.34	557.49	557.49							0.6579	A
												A
Renti s/m	Left Distributary	8.79	52.83	52.83							0.0594	A
Borosingi s/m	Left Distributary	9.99	172.47	172.47							0.2224	A
Baghalingi s/m	Left Distributary	10.71	49.19	49.19							0.054	A
Gundabira s/m	Left Distributary	11.805	51.15	51.15							0.0812	A
Hukuma s/m	Left Distributary	13.47	85.02	85.02							0.1164	A
Chencharapalli s/m	Left Distributary	14.37	81.37	81.37							0.0984	A
Bijoy Gopalpur s/m	Left Distributary	15.114	46.76	46.76							0.0521	A
K.Kotibadi s/m	Left Distributary	15.864	116.25	116.25							0.2694	A
	Left Distributary	**Sub Total**	**1681.42**									
Right Distributary	**Main Canal**	**2.515**	**7350**	**821.54**	**8.03**	**1.64**	**0.7254**	**0.9**		**21.47**	**10.193**	
Right Distributary	**RD 0.0Km-5.4Km**			**220.2**	**8.03**	**1.64**	**0.7254**	**0.9**	**1720**		**10.193**	B
Kaithapali s/m	Right Distributary	1.465	155.5	155.5					1723.02		0.1672	B
Takarda Distributary	Right Distributary	3.654	731.57	379.28	3.00	0.7	0.4684	0.6		**6.398**	1.098	B
Lokhari s/m no-I	Takarda Distributary	1.07	66	66.00							0.0737	B
Lokamari s/m no-II	Takarda Distributary	2.56	30.36	30.36							0.0327	B
Saranauti s/m	Takarda Distributary	4.21	30.67	30.67							0.0335	B
Chaulakhai s/m	Takarda Distributary	4.994	76.12	76.12							0.0821	B
Takarada s/m	Takarda Distributary	5.891	111.3	111.3							0.0576	B
Rajapur s/m	Takarda Distributary	7.927	37.84	37.84							0.0586	B
	Takarda Distributary	**Sub Total**	**352.29**									B
Raibandha minor	Right Distributary	4.717	615.75	244.53	2.8	0.73		0.6			0.7336	B
Ekalpur s/m	Raibandha minor	0.28	176.32	176.32							0.2291	B
Kusumgadia s/m	Raibandha minor	1.68	148.35	148.35							0.1927	B
Raibandha s/m	Raibandha minor	2.032	46.55	46.55							0.0738	B
	Raibandha minor	**Sub Total**	**371.22**								0.0292	

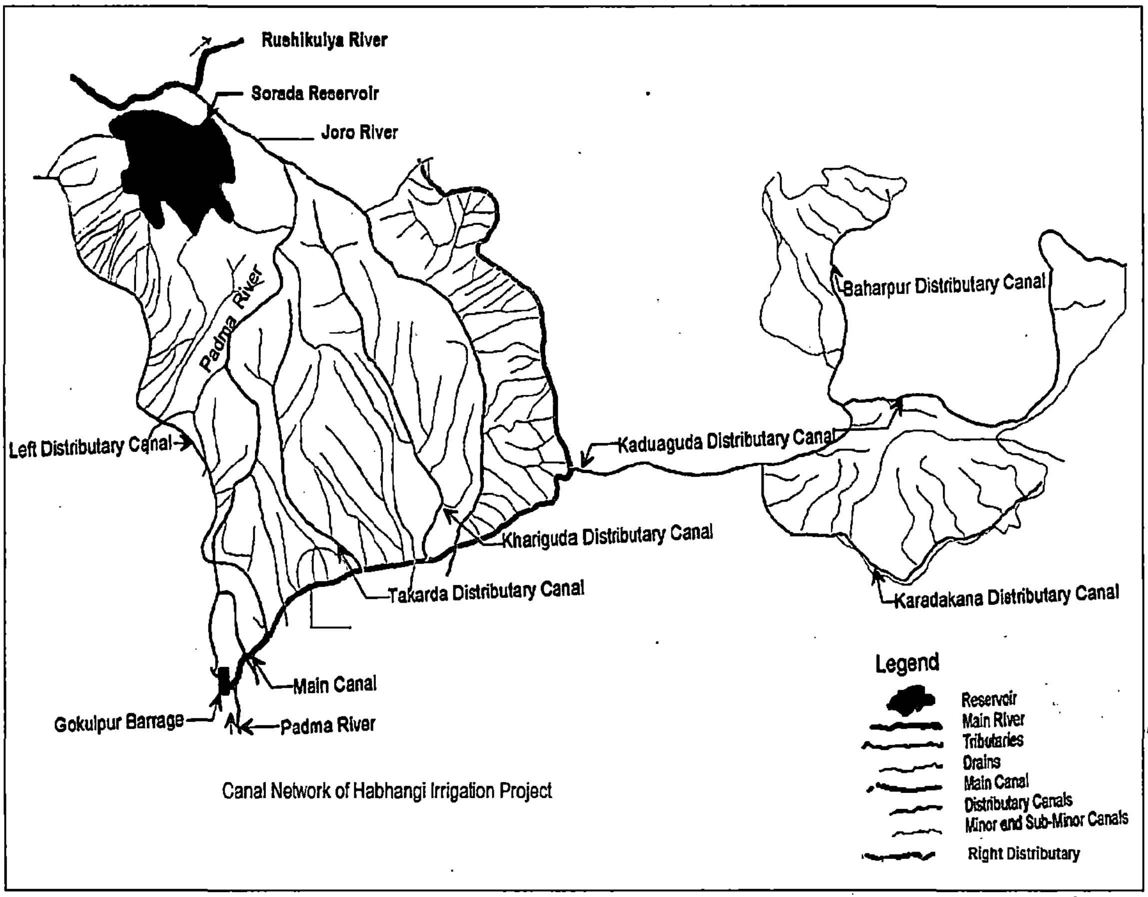
Table-2.3 cont

Table-2.3 Canal details of Harabhangi irrigation project

Name of the Canal	Name of the Parent Canal	Off-taking at RD in Km.	Ayacut Area in ha	Self Ayacut area in ha	Bed Width in m	FSD in m	Velocity in m/s	free board in m	Group Ayacut Area in ha	Length in Km.	Design Discharge in m3/s	Irrigation Zone
Right Distributary	**RD 5.4Km-11.4Km**			**172.43**					**1990**			
Khariaguda Disrtibutary	Right Distributary	5.763	1718.53	356.05	4.00	1.00	0.53	0.60	1985.05	**10.26**	2.3866	C
Padmapur minor	Khariaguda Disrtibutary	1.5	150	150							0.1646	C
Sidhapur minor	Khariaguda Disrtibutary	2.22	313.65	313.65							0.3975	C
Sidhapur s/m-I	Sidhapur minor	0.18	54.56	54.56							0.0601	C
Sidhapur s/m-II	Sidhapur minor	0.81	72.36	72.36							0.0869	C
Tail cluster	Sidhapur minor	5.555	33.25	33.25							0.0208	C
Sandhikendu monor	Khariaguda Disrtibutary	2.59	252	252							0.286	C
Sandhikendu s/m	Sandhikendu monor											C
Surekhadeipur s/m	Khariaguda Disrtibutary	3.225	120	120							0.1333	C
Tentulikhunti s/m	Khariaguda Disrtibutary	4.32	45.68	45.68							0.0492	C
Sarabadi minor	Khariaguda Disrtibutary	5.31	141.15	141.15							0.17	C
Patrapur s/m	Khariaguda Disrtibutary	6.39	86.21	86.21							0.0892	C
Chakunda s/m	Khariaguda Disrtibutary	7.5	74.4	74.4							0.0795	C
Khariaguda minor	Khariaguda Disrtibutary	8.565	132	132							0.1717	C
Khariaguda s/m	Khariaguda Disrtibutary	8.67	47.39	47.39							0.0498	C
	Khariaguda Disrtibutary	**Sub Total**	**1362.48**								0.025	
Batasana s/m	Right Distributary	9.645	94.09	94.09							0.1023	
Kadaguda Disrtibutary	**Right Distributary**	**11.58**	**2580**	**359.87**	**5.6**	**1.1**	**0.625**	**0.6**	**2580**	**16.8**	**3.8066**	
Karadakana Distributary	Kadaguda Disrtibutary	6.428	924.9	302.97	3.25	0.75	0.473	0.6		**9.955**	1.2576	C
Dhaupada s/m	Karadakana Distributary	0.555	34.81	34.81							0.0382	C
Lengama s/m	Karadakana Distributary	1.585	32.6	32.6							0.0358	C
Manikpur s/m-I	Karadakana Distributary	3.1	76.2	76.2							0.0822	C
Maradi s/m	Karadakana Distributary	3.33	43.28	43.28							0.0993	C
Manikpur s/m-II	Karadakana Distributary	4.5	250.7	250.7							0.271	C
Badapur s/m	Karadakana Distributary	5.71	40.23	40.23							0.0449	C
Belapada s/m	Karadakana Distributary	6.95	77.25	77.25							0.083	C
Abhaypur s/m no-I	Karadakana Distributary	8.88	35.64	35.64							0.0476	C
Abhaypur s/m no-II	Karadakana Distributary	9.42	31.22	31.22							0.034	C
	Karadakana Distributary	**Sub Total**	**621.93**								0.0173	

Table-2.3 Canal details of Harabhangi irrigation project

Name of the Canal	Name of the Parent Canal	Off-taking at RD in Km.	Ayacut Area in ha	Self Ayacut area in ha	Bed Width in m	FSD in m	Velocity in m/s	free board in m	Group Ayacut Area in ha	Length in Km.	Design Discharge in m3/s	Irrigation Zone
Dhaupada s/m	Kadaguda Disrtibutary	7.27	62.48	62.48							0.0327	C
Durgamadhabpur s/m.	*Kadaguda Disrtibutary*	7.83	48.75	48.75							0.0504	C
Bharapur Distributary	Kadaguda Disrtibutary	8.215	1184	183.36	3.25	0.8	0.527	0.6		**6.54**	1.498	C
Bakhrakota minor	Bharapur Distributary	1.97	647.9	412.2							0.8028	C
Rugma s/m	Bakhrakota minor	1.3	235.7	235.7							0.0601	C
K.Kotibadi s/m	Bharapur Distributary	3.57	49.92	49.92							0.0687	C
Ulama s/m no-I	Bharapur Distributary	4.44	54.48	54.48							0.0587	C
Ulama s/m no-II	Bharapur Distributary	4.63	112.86	112.86							0.1234	C
Bakhrakota s/m no-I	Bharapur Distributary	4.83	37.13	37.13							0.07	C
Bakhrakota s/m no-II	Bharapur Distributary	5.34	62.4	62.4							0.067	C
Bakhrakota s/m no-III	Bharapur Distributary	6.09	35.95	35.95							0.0605	C
	Bharapur Distributary	**Sub Total**	**1000.64**								0.0417	
Harapriyapur s/m	Kaduaguda Disrtibutary	8.89	41.4	41.4					Not Developed		0.0496	
Sikuliapalli s/m	Kaduaguda Disrtibutary	9.69	144.09	144.09					Not Developed		0.2364	
Paniapalli s/m	Kaduaguda Disrtibutary	14.31	49.36	49.36					Not Developed		0.0607	
Chasamahuli minor	Kaduaguda Disrtibutary	16.8	367.8	367.8					Not Developed		0.4917	
	Kaduaguda Disrtibutary	**Sub Total**	**2220.13**									
Right Distributary	**RD11.58Km-21.47Km(Tail)**			**275**	**3.6**	**0.8**	**0.4695**	**0.6**	**1060**		**1.5887**	E
Gangapur s/m no-I	Right Distributary	12.54	78	78					1063.52		0.088	E
Gangapur s/m no-II	Right Distributary	13.82	84.3	84.3							0.0893	E
Sidhapur s/m	Right Distributary	14.4	110.82	110.82							0.1171	E
Kalakhadi s/m	Right Distributary	15.33	140.39	140.39							0.2005	E
Goberlundi s/m no-I	Right Distributary	16.485	40.5	40.5							0.0661	E
Goberlundi s/m no-II	Right Distributary	16.965	62.6	62.6							0.043	E
Lembakumpa s/m	Right Distributary	17.415	62.4	62.4							0.0678	E
Sarabadi minor(tail)	Right Distributary	21.47	209.51	209.51							0.3101	E
		Sub Total	788.52									



(Jena, 2002)

Fig.-2.3 Layout Plan of Canal Network of Harbhangi Irrigation Project

Table-2.4 Elevation-Area-Capacity of Harbhangi reservoir

Sl. No.	Elevation in m	Area in Ha	Capacity in ham	Sl. No.	Elevation in m	Area in Ha	Capacity in ham
1	370.00	330	2100	11	380.00	758	7300
2	371.00	370	2425	12	381.00	810	8100
3	372.00	420	2750	13	382.00	870	8925
4	373.00	440	3200	14	383.00	927	9700
5	374.00	490	3600	15	384.00	985	10525
6	375.00	535	4100	16	385.00	1045	11400
7	376.00	575	4625	17	386.00	1100	12350
8	377.00	620	5200	18	387.00	1157	13500
9	378.00	665	5500	19	387.50	1215	14125
10	379.00	710	6550				

CHAPTER-3

REVIEW OF LITERATURE

3.1 GENERAL

Model is the representation of the behavior of the system. It may be physical, mathematical, analytical or analogous. However, adoption of a particular type is based on scale, logistics, availability of time, funds, data, computational facility, required accuracy. The following papers are reviewed before take up the project work.

3.2 RAINFALL-RUNOFF MODELING

The National Engineering Handbook (NEH-4) Soil Conservation Service-Curve Number (SCS-CN) method (SCS 1956, 1964, 1971, 1985, 1993) is one of the most popular methods for computing the volume of direct surface runoff for a given rainfall event. A significant research dealing with several issues (Mishra and Singh 2003a) related with the SCS-CN method's capabilities, limitations, uses, and possible advancements have been published in the recent past.

Mishra and Singh (1999a, b; 2002a; 2003a, b) provided analytical treatments of the SCS-CN methodology. Jain et al. (2006a) incorporated the storm duration and a nonlinear relation for initial abstraction (Ia), to enhance the SCSCN- based Mishra and Singh (2003a) model.

Using the volumetric concept of soil–water–air, Mishra et al. (2004a) described CN as the percent degree of saturation of the watershed at 10 in. of rainfall and its efficacy to distinguish the hydrological activeness of watersheds. This concept is consistent with the work of Neitsch et al. (2002) relating the curve number with the available soil water content, wilting point, and field capacity. Mishra and Singh (2003a, c) further extended the physical description of CN using dynamical concept of infiltration and attributed its dependence on soil sporitivity and hydraulic conductivity besides others. A criterion is developed for determining the validity of the Soil Conservation Service curve number (SCS-CN) method. According to this criterion, the existing SCS-CN method is found to be applicable when the potential maximum retention, S, is less than or equal to twice the total rainfall amount. Mishra and Singh(2004). A new lumped conceptual model based on the Soil Conservation Service Curve Number (SCS-CN) concept has been proposed in this paper for long-term hydrologic simulation (K. Geetha et. al.-2007) and modified SCS-CN method (Mishra et. al.), will be discussed later in the chapter-4.

3.3 YIELD MODEL

The yield model was developed by Loucks et al.(1981) according to whom it is a general purpose implicitly stochastic LP model that incorporates several approximations to reduce the size of the constraints set needed to enunciate reservoir system planning and operation and to achieve the target releases with desired reliability. Dandy et al. (1997) made a comparison of simulation, network linear programming, full optimization LP model and the LP yield model for estimating the safe yield of the Canberra water supply system consisting of four reservoirs. They however pointed out that, if the system yield with a specified reliability needs to be determined; there is considerably more difficulty in using the optimization and yield models. Sinha et al. (1999b) presented a yield model for selecting and sizing potential reservoirs and hydro plants on a river basin and a linked simulation-optimization framework is used for formulation. However, Dahe and Srivastava (2000) have demonstrated the use of yield model for assessment of annual yield from a system of eight reservoirs in the upper basin of the Narmada river with specified reliability and the extent of availability of irrigation supply during failure years. Such an assessment can assist the planners to decide upon the irrigation policies regarding the area to be brought under irrigation with sustainable cropping pattern and to reduce the damages due to likely shortages in supply during failure years. Also, a FORTRAN program is developed for the sequential creation of LP matrix for LP solution to be used in yield model analysis (Dahe-2001). Panigrahi and Srivastava (2005) presented integrated yield model (IYM) for river basin development to assess optimal annual yields from reservoirs based on pre-specified annual release reliabilities with site specific yield failure years fraction factors and also simultaneously optimizing the cropping pattern. Other studies are Jena (2005) and Awchi (2005). Work needs to be done to estimate reservoir yield for a shorter time period to help management of demand based weekly irrigation water releases in a multi purpose project.

3.4 IRRIGATION SCHEDULING

Optimal distribution of water to irrigation canals was studied by Muspratt (1971). In these study systems optimization based on mathematical programming is described for water assignment to irrigation canal network with capacity constraint. Flynn and Marino (1987) presented the methods for determining the optimal design capacities and distribution management of water delivery system in the presence of probabilistic supplies and known transportation losses. The above problem is presented with a discrete distance model of conveyance system and is solved using dynamic programming. In this method's development, important economic interactions are detailed. Lohani and Fontane (1988) have studied the analysis of main and lateral canal designs (allocation of discharges only) for optimal allocation of water that will maximize the economic benefits using dynamic programming (DP) techniques

An integrated canal-scheduling model was reported by Rajput and Michael (1989). The model was used to determine the irrigation schedule of the Sansad distributary of MRBC, Gujarat on the basis of soil moisture status of different parts of the command area. The model was one of the first efforts to match the canal supplies with actual water needs (Rajput and Michael, 1990). The model was further improved and was made to determine optimal canal operation policies under different levels of rotation (Rajput, 1992).

A detail study over the soil water monitoring and measurement by Thomas et al. considering various methods gave a good idea regarding root depth behavior towards available soil moisture. Akhand et al. (1995) developed a water allocation model to recommend allocation of irrigation water to different crop fields in a canal based irrigation project. Model components were an irrigation-scheduling program to predict irrigation water demands, crop response losses. Mujumdar et al. (1998) developed an integrated model for short-term yearly reservoir operation for irrigation of multiple crops. Ghahraman and Sepaskhah (2002) developed a model for optimal allocation of water from a single purpose reservoir to irrigation projects with the pre-determined multiple cropping patterns.

Water conservation fact sheet published by the ministry of Food, Agriculture and fisheries (2002) provide detail calculation for available water for different types of soil basing on soil type and root depth of the crop for preparing the scheduling of the individual crop. Jena and Srivastava (2,005) and Deepti Rani (2005) dealt with the real life problems of optimal allocation of available water through canal networks using DP.

Scheduling of irrigation using daily water balance approach for wheat considering actual K_c values, site specific soil type, climatic, meteorological and crop growth conditions, soil coefficient for various allowable depletion limits, daily rainfall and ET_o in a semi-humid tropical canal command using water balance approach (Parhi, P.-2008). The crop water requirement computed comes out to be 4 % less than those estimated using conventional crop coefficient approach.

3.5 DEVELOPMENT OF DSS

Decision support system is an integrated approach for helping people to make better decisions. One of the early expert system for canal water scheduling was suggested by Hershauer et al. (1989). The system was proposed to schedule the distribution of canal water according to the physical changes of the environment. Chang et al. (1993) described the decision support system for the management of the irrigation schedule (DMIS) at field level of medium to large scale irrigation schemes. It was reported that DMIS is an effective tool suitable for the management of the parcel-based irrigation schedule of medium to large-scale irrigation schemes. Jacucci et al. (1994) developed the software HYDRA, a decision support system to improve irrigation water use efficiency in Mediterranean agriculture at various levels. An integrated decision support system was developed by Rao (1995) which integrates simulation models; databases and expert system based knowledge-bases. This was used for estimation of ground water recharge, simulation of ground water system and to develop alternative conjunctive water use plans. Kaca et al. (1996) developed an irrigation decision support system within the framework of the Notec River Water Management System, Poland which provided real time control of water distribution and irrigation. An integrated decision support system was developed by Arumugam and Mohan (1997) to assess the decision making using five years data. It was reported that shortages in irrigation water supplies simulated from the decision support system were less than those occurring in actual operation practiced by water authorities. Hasan et al. (2000) reported the application of a DSS in Jordan, specifically to manage and operate the irrigation water demand and supply of the main water carrier the King Abdallah canal in the Jordan valley. Scheme irrigation management information system (SIMIS), the decision support used by FAO for managing irrigation schemes was developed by Mateos et. al. (2002). It is based on simple water balance models with capacity constraints. Rotational irrigation scheduling system (RISS) for supporting both water supply scheduling and on–off control works for automated irrigation with reservoir ORC (operation rule curve) by Kim et. al. (2003).

GIS-based decision support system for real time water demand estimation in canal irrigation systems for Sone irrigation system of Bihar state was prepared by Rao et. al. (2004). Real time water demand from different points of the canal system is integrated to decide the release of irrigation water. Pesco river decision support system (PRDSS) is developed by Mexico state engineers which simulates major components of the groundwater and surface water hydrology and water operations associated with the Pecos River (2006). Online decision support for irrigation was modified by Thysen, Ivar (2006) for Denmark farmers to manage the irrigation supply to different crops ascertaining the moisture position at field. This is calculated on moisture balancing method after acquiring the necessary field data from farmers over internet.

CHAPTER-4

LONG-TERM SIMULATION OF RESERVOIR INFLOW BASED ON SCS-CN METHOD

4.1 GENERAL

The simulation of rainfall-generated runoff is very important in various activities of water resources development and management such as flood control and its management, irrigation scheduling, design of irrigation and drainage works, design of hydraulic structures, and hydro-power generation etc. Ironically, determining a robust relationship between rainfall and runoff for a watershed has been one of the most important problems for hydrologists, engineers, and agriculturists since its first documentation by P. Perrault

(In: Mishra and Singh 2003) about 325 years ago. The process of transformation of rainfall to runoff is highly complex, dynamic, non-linear, and exhibits temporal and spatial variability, further affected by many and often interrelated physical factors. However an understanding of various hydrologic variations (spatial and temporal) over long periods is necessary for identification of these complex and heterogeneous watershed characteristics. Also,the long-term hydrologic simulation plays an important role in watershed management practices. It is also used for augmentation of hydrologic data beneficial for water resources planning and management (Mishra and Singh 2004).

The available models for simulation are vary in description of the components of the hydrologic cycle,degree of complexity of inputs, number of parameters to be determined, time interval used, and output generated. Some event-based simulation models like Hydrologic Simulation Package Fortan(HSPF), System Hydrologique Europeen(SHE)

USDAHL(Holtan and Lopez, 1971), Hydrologic Modeling System(HMS), HEC-I Flood (1985).Despite their comprehensive structure, many of these models have not yet become standard tools in hydrologic practice in developing countries, such as India, Pakisthan, Nepal and other Asian countries. The reason is (a)most basins in these countries are ungauged or if gauged at all, then measurement is taken only daily basis and there is little hydrological data available, (b)these models contains too many parameters which are difficult to estimate in practice and vary from basin to basin. Furthermore, when these models are compared on the same basin, they are found widely varying in their performance (Woodward and Gburek, 1972). Hence, the infiltration loss based SCS-CN model is suitable for the simulation.

4.2 HISTORICAL BACKGROUND OF THE SCS-CN METHOD

The origin of the SCS-CN method can be traced to the proposal of Sherman (1942,1949) on plotting direct runoff versus storm rainfall, and the subsequent work of Mockus (1949) on estimating surface runoff for ungauged watersheds using information on soil, land use, antecedent rainfall, storm duration, and average annual temperature. Andrews (1954) developed a graphical procedure for estimating runoff from rainfall for combinations of soil texture and type, the amount of vegetative cover, and conservation practices. All of these are combined into what is referred to as the soil-cover complex or soil-vegetation-land use complex (Miller and Cronshey 1989). Thus, the empirical rainfall-runoff relation of Mockus (1949) and the soil-vegetation-land complex of Andrews (1954) constituted the building blocks of the SCS-CN method described in the Soil Conservation Service (SCS) National Engineering Handbook Section 4 (''Hydrology'' 1985). Rallison and Miller (1982) succinctly described the SCS-CN method as a graphical transformation and generalization of the works of Andrews (1954) and Mockus (1949). The SCS-CN method is also used in popular continuous simulation models such as CREAMS Knisel(1980) and SPUR Wight and Skiles (1987). It has been adapted for urban catchments by the Soil Conservation Service and was discussed for this application by Aron (1982) and Kibbler(1982). Besides being fairly accurate in runoff predictions, the versatility of the SCS-CN method lies in the fact that it is simple, easy to understand and apply, stable, and capable of accounting for several watershed runoff producing characteristics, such as soil type, land cover and practice, hydrologic condition, and antecedent moisture condition (AMC), Ponce and Hawkins (1996); Mishra and Singh (2003b). The original SCS-CN method computes the direct runoff by considering only the available rainfall on the current day without taking care of the effect of the moisture available prior to the storm. On the other hand, the curve numbers are sensitive to antecedent conditions (Ponce 1989).

Several others have reviewed the SCS-CN method for its limitations such as unaccounted rainfall intensity which is an important source of variability in the methodology, consideration of time factor, lack of clear guidance as to how to vary antecedent moisture condition (AMC), the discrete unrealistic relation between CN and AMC, and the fixing of the initial abstraction ratio at 0.2.

4.3 ORIGINAL SCS-CN METHOD

The Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956), an event-based, lumped rainfall-runoff model, is based on the water balance equation and two fundamental hypotheses. The first hypothesis is the ratio of the actual amount of direct surface runoff (Q) to the maximum potential surface runoff) is equal to the ratio of amount of actual infiltration (F) to the amount of the potential maximum retention (S).

The second hypothesis relates the initial abstraction (I_a) to the potential maximum retention. Water balance equation: $P = I_a + F + Q$ (4.1)

(a) first hypothesis

$$\frac{F}{S} = \frac{Q}{P - I_a} \quad (4.2)$$

(b) second hypothesis

$$Ia = \lambda S \quad (4.3)$$

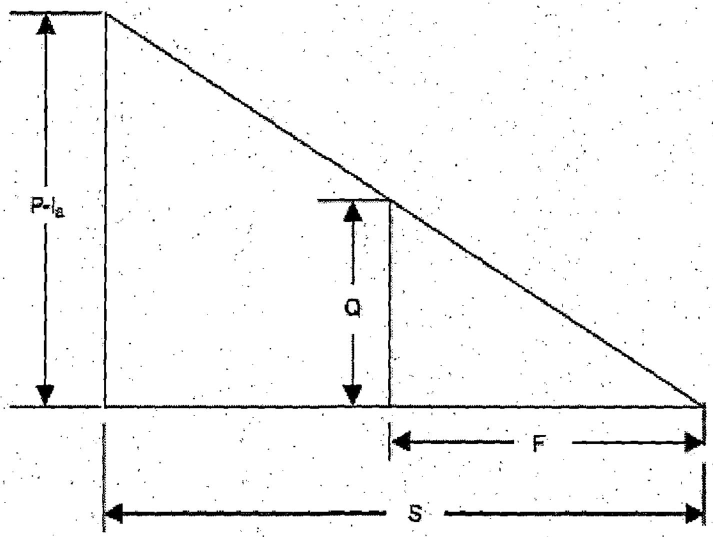


Fig. 4.1-Proportionality Concept

where, P = total precipitation, I_a = initial abstraction, F = cumulative infiltration after time to ponding, Q = direct runoff, S = potential maximum retention and λ = initial abstraction coefficient. λ = 0.2 (a standard value). Equation (1.2) combined with Equation (4.1) leads to

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad (4.4)$$

valid for $P \geq I_a$; Q = 0, otherwise. Coupling of Equation (4) with Equation (3) enables a determination of S/P as (Mishra and Singh, 1999a, b):

$$\frac{S}{P} = \frac{[2\lambda + C(1-\lambda)] - \sqrt{C[C(1-\lambda)^2 + 4\lambda]}}{2\lambda^2} \quad (4.5)$$

or alternatively (Hawkins, 1993),

$$S = 5[(P+2Q] - \sqrt{Q(4Q+5P)}] \quad (4.6)$$

for λ = 0.2. Here, C = Q/P = runoff factor. In practice, S is derived from a mapping equation:

$$S = \frac{1000}{CN} - 10 \quad \text{or } S = \frac{2540}{CN} - 2.54 \quad (4.7)$$

where S is in inch or cm, and CN is the curve number varying from 0 to 100.

The curve number CN is derived from the tables given in the National Engineering Handbook (Section 4) (NEH-4). Parameter S of for any catchment depends on soil type, land use, hydrologic condition and antecedent moisture condition. Parameter λ is frequently viewed as a regional parameter dependent on geological and climatic factors.

4.4 DERIVATION OF THE MODIFIED SCS-CN METHOD

The modified SCS-CN method is based in the SCS-CN method and was formulated by Mishra and singh (2002a) and Mishra et al. (2004).

4.4.1 Total Infiltration Concept

The existing SCS-CN method consists of initial abstraction that excludes the static infiltration and valid for the time past ponding. Hence the total infiltration is the dynamic infiltration and static infiltration. Whereas the dynamic infiltration is retained in the soil and is absorbed in the potential volumetric space i.e. S, the static portion actually contributes to percolation to meet the ground water table and finally appear as delayed flow or baseflow at the outlet of the basin.

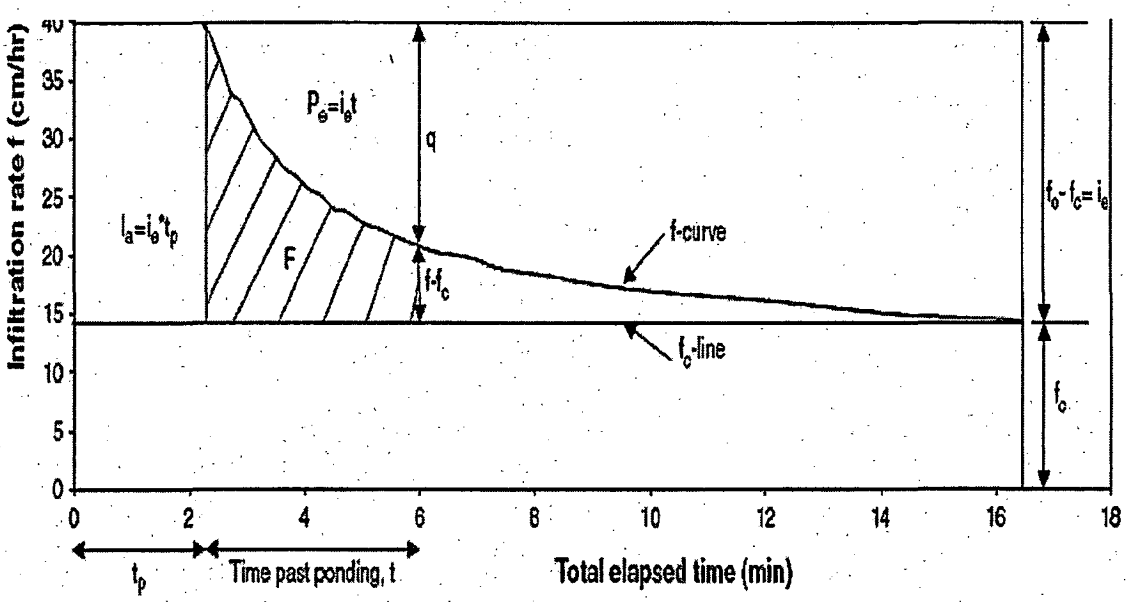


Fig. 4.2 A descriptive infiltration curve of Columbia sandy loam.

4.4.2 Rainfall-excess equation

The modified SCS-CN method considers both these parameters as well as AMC of the soil in the model. Fc can be deducted directly from the cumulative rainfall amount and applied to the proportional equality hypothesis of SCS-CN method can be written as shown in Fig.4.2 So the proportional equality hypothesis of SCS-CN method can be written as

$$\frac{Q}{P - I_a - F_c} = \frac{F_d}{S} \tag{4.8}$$

Where F_c=static infiltration and F_d is the dynamic infiltration.

And $F=F_c + F_d$ (4.9)

Thus the water balance equation can be expressed as

$$P=Ia+ F_c + F_d +Q \tag{4.10}$$

A useful form of the model can be derived from above equation (4.8) and (4.10) as

$$Q = \frac{(P - I_a - F_c)^2}{P - I_a - F_c + S} \tag{4.11}$$

The effect of Fc on Q is similar to that of Ia i.e. greater the value of Fc, lesser will be value of Q and vice-versa. Introducing M (antecedent soil moisture) on similar lines leads to the general form of the SCS-CN equation as follows.

$$Q = \frac{(P - I_a - F_c)\ (P - I_a - F + M)}{P - I_a - F_c + M + S} \qquad (4.12)$$

4.5 SIMULATION MODEL USING THE MODIFIED SCS-CN METHOD

Mishra and Singh (2004) developed a more versatile model based on the modified SCS-CN method for daily flow simulation.

4.5.1 Rainfall-Excess Computation

The modified SCS-CN model can be written for time t as

$$RO_{(t,t+\Delta t)} = \frac{(P_{(t,t+\Delta t)} - I_{a(t)} - F_{c(t,t+\Delta t)})(P_{(t,t+\Delta t)} - I_{a(t)} - F_{c(t,t+\Delta t)} + M_t)}{P_{(t,t+\Delta t)} - I_{a(t)} - F_{c(t,t+\Delta t)} + M_t + S_t} \qquad (4.13)$$

where RO(t+Δt)=rainfall excess during a time period, P(t+Δt)= rainfall occurring in Δt period,Ia(t)=initial abstraction, Fc(t+Δt)= static infiltration in Δt period, M_t = antecedent moisture amount,prior to the beginning of the storm and St the potential retention. This equation (1.8) is valid for $P_{(t,t+\Delta t)}$>=($Ia_{(t)}$+$Fc_{(t,t+\Delta t)}$, $RO_{(t,t+\Delta t)}$=0 otherwise. If $P_{(t,t+\Delta t)}$<=$Ia_{(t)}$,then $Fc_{(t,t+\Delta t)}$=0. If $P_{(t,t+\Delta t)}$<=($Ia_{(t)}$+$Fc_{(t,t+\Delta t)}$),then $Fc_{(t,t+\Delta t)}$=($P_{(t,t+\Delta t)}$-$Ia_{(t)}$).

Here $Ia_{(t)}=\lambda S_t$ (4.14)

4.5.2 Soil Moisture Budgeting

The dynamic infiltration component of infiltration (Fd) that occurred during the Δt period can be computed from the water balance equation as

$$Fd_{(t,t+\Delta t)}=P_{(t,t+\Delta t)}-I_a-Fc_{(t,t+\Delta t)}-RO_{(t,t+\Delta t)} \qquad (4.15)$$

which is valid for $RO_{(t,t+\Delta t)}>=0$, $Fd_{(t,t+\Delta t)}=0$ otherwise. The term $Fd_{(t,t+\Delta t)}$ also represents an increase in the amount of soil moisturwe in the soil profile during Δt period, which when added to its antecedent moisture Mt leads to the antecedent moisture amount for the next storm as:

$$M_{(t,t+\Delta t)}=Fd_{(t,t+\Delta t)}+M_t-ET_{(t,t+\Delta t)} \quad (4.16)$$

where $M_{(t,t+\Delta t)}$ varies from 0 to S_{abs}. St can be modified for the next storm by balancing the soil moisture as

$$S_{(t,t+\Delta t)}=S_t-Fd_{(t,t+\Delta t)}+ET_{(t,t+\Delta t)} \quad (4.17)$$

It is noted that the sum of S_t+M_t for a watershed represents the absolute potential maximum retention, S_{abs} which corresponds to the completely dry condition of the soil. Therefore, it represents the upper bound of S-variation. The minimum value of S is, however, equal to 0.

4.5.3 Computation of Evapotranspiration

The potential evapotranspiration (PET) can be computed using the pan evaporation as

$$PET_{(t,t+\Delta t)}=PANC*E_{(t,t+\Delta t)} \quad (4.18)$$

where PANC is the pan coefficient and $E_{(t,t+\Delta t)}$ is the pan evaporation during Δt period. PANC depends on the vegetative cover and season, and thus, is a function of the time of the year.

$$PET_{(t,t+\Delta t)}=\frac{S_t}{S_{abs}}E_{(t+\Delta t)} \quad (4.19)$$

From equation (13) and (14) it can be written as

$$PANC=\frac{S_t}{S_{abs}} \quad (4.20)$$

Thus, PANC is defined as the ratio of the potential maximum retention at a time to the absolute potential maximum retention. Following Schaakel et al. (1996) further with the assumption that the ratio of moisture deficits for both the upper and lower layers is equal to each other leads to a description of the total amount of evapotranspiration(ET) as

$$ET_{(t,t+\Delta t)} = E_{(t,t+\Delta t)}[1-(\frac{S_t}{S_{abs}})^2] \quad (4.21)$$

or

$$ET_{(t,t+\Delta t)} = E_{(t,t+\Delta t)}[1-(PANC)^2] \quad (4.22)$$

The initial abstraction coefficient λ, is taken equal to PANC, which varies from 0 to 1.

4.5.4 Catchment Storage Routing

The daily rainfall-excess rates computed previously are routed through the watershed using the single linear reservoir technique and the total watershed assumed as single reservoir for the simplicity.

Continuity Equation: RO-DO= ΔV/ Δt (4.23)

Storage Equation =K (DO) (4.24)

where V is the reservoir storage or the rainfall-excess detention storage, K is the storage coefficient, Δt is the time interval, RO is the rainfall –excess rate, and DO is the runoff rate at the outlet of the watershed. Using finite difference scheme, DO at different time steps can be computed as:

$$DO_{(t,t+\Delta t)} = d_0 Ro_t + d_1 Ro_t + d_2 Do_t \quad (4.25)$$

where d_0,d_1,d_2 are routing coefficients.

$$d_0 = \frac{(\Delta t/K)}{2+(\Delta t/K)} \text{ and } d_1 = d_0 \quad (4.26\ a\&b)$$

$$d_2 = \frac{(2-\Delta t/K)}{(2+\Delta t/K)} \quad (4.26\ c)$$

4.5.5 Baseflow Computation

It is known that infiltration depends on rainfall. Therefore, if $P\text{-}I_a$ is less than F_c on a given day, then $F_c = P\text{-}I_a$. It is simply concluded that $Ro_t=0$ or $F_{d(t)}=0$. It implies that F_c exists even prior to the satisfaction of the capillary demands, which is in contrast with reality. This is because of the assumed equivalence between f_c and the minimum infiltration rate at a time approaching infinity. Considering that infiltrated water beyond the saturation is percolated down to meet the water table and finally appears at the outlet of the basin. It further assumes that the basin boundary coincides with the aquifer boundary and no lateral flow contributes to the water table beyond watershed boundary.

Hence total infiltrated water can be routed assuming a single linear reservoir as above. The baseflow (Q_b) can be computed as

$$Q_{b(t,t+\Delta t)} = g_0 F_{c(t)} + g_1 F_{c(t)} + g_2 Q_{b(t)} \tag{4.27}$$

where

$$g_0 = \frac{(\Delta t/K_b)}{2+(\Delta t/K_b)} \quad \text{and } g_1 = g_0 \tag{4.28 a\&b}$$

$$g_2 = \frac{(2-\Delta t/K_b)}{(2+\Delta t/K_b)} \tag{4.28c}$$

where K_b is the baseflow storage coefficient [T].

Thus, the total runoff hydrograph, RO, appearing at the outlet of the catchment is computed as the sum of the routed rainfall-excess, DO, and the baseflow, Q_b.

$$RO = DO_t + Q_{b(t)} \tag{4.29}$$

where RO: the computed runoff and g_0, g_1, g_2 are baseflow routing coefficients.

4.6 DEVELOPMENT OF CONTINUOUS SIMULATION MODEL FOR MODIFIED SCS-CN METHOD

4.6.1 Parameter Estimation

The model parameters, S_o[L],F_c[L],K[T],and K_b[T] involved in the model are determined using non-linear Marquardt algorithm of constrained least squares (In: Mishra and Singh 2003), coupled with trial and error, utilizing the objective function of minimizing errors between the computed and observed data or maximizing model efficiency (Nash and Sutcliffe 1970) for calibration.

where S_o = absolute potential of maximum retention,

F_c = Minimum daily infiltration,

K = runoff storage coefficient and

K_b = base flow storage routing coefficient

4.6.2 Model calibration and Validation

Under the model calibration, some initial values of the input parameters (S_o, F_c, K and K_b) describing the range of variation for each parameter are given as input into the model. The values of the input parameters are changed in an attempt to get higher efficiencies that indicate performance of the model. These calibrated parameter values are then used for validation for validation to check the efficiencies of the model whether the calibrated model performs consistently beyond the calibrated period. If the satisfactory results are obtained under both the condition then these parameters used for generating the runoff from the available rainfall for that watershed.

4.7 APPLICATION OF THE SIMULATION MODEL

Above model is applied to the watershed of Harbhangi Irrigation Project for rainfall- runoff simulation . Rainfall data of RG station at Mohana for five years (1997-2002) and inflow data of the same period at dam site gauging station are taken for the analysis. For calibration three years' data and for validation two years data is considered with two different combination.

4.8 RESULTS AND DISCUSSION

The estimated values of the parameters S_o, F_c, K and K_b under calibration for the flow record of first three years (1997-2000) and then parameters are validated on remaining two years data (Case-I). Then, to check the consistency of the model, last three years data is taken for the calibration and first two years data is used for validation (Case-II).

Four parameters determined by running a previously available FORTRAN program. The parameters obtained for both the cases are used for the validation and results are tabulated:

Case (I)	(II)
S_o[L]= 12.5 mm	11.72 mm
F_c[L]= 24.4 mm	19.22 mm
K[T]= 2.88 days	2.96 days
K_b[T]=26.66 days	15.41 days

Case-I

Efficiency of the model is 78.6% in calibration and when applied for the validation the efficiency comes out to be 70.35 %.The Root mean square error(RMSE) and relative error for the calibration and validation are 0.81mm & 5.5 % and 1.52mm & 10.9 % respectively.

Case-II

Efficiency of the model is 75.56% in calibration and when applied for the validation the efficiency comes out to be 74.88%.The Root mean square error(RMSE) and relative error for the calibration and validation are 1.16mm & -1.91 % and 0.99mm & -1.63 % respectively.

Graphs are plotted between daily rainfall vs. runoffs (computed and observed) for the calibration and validation periods in fig.-4.3(a) & 4.3(b) and fig-4.4(a) & 4.4(b) respectively.

From the above results for the two cases, it is observed that though the calibration efficiency for the case-I is higher, parameters for the case-II is more consistence and giving very low relative error. Thus the parameters for the case-II are taken as the watershed runoff parameters for reservoir inflow. However, the output result of both the cases for calibration is attached in appendix-a and appendix-b.

Since the Inflow measurement facility is available in the Harabhangi irrigation project, this model is not used in the DSS.

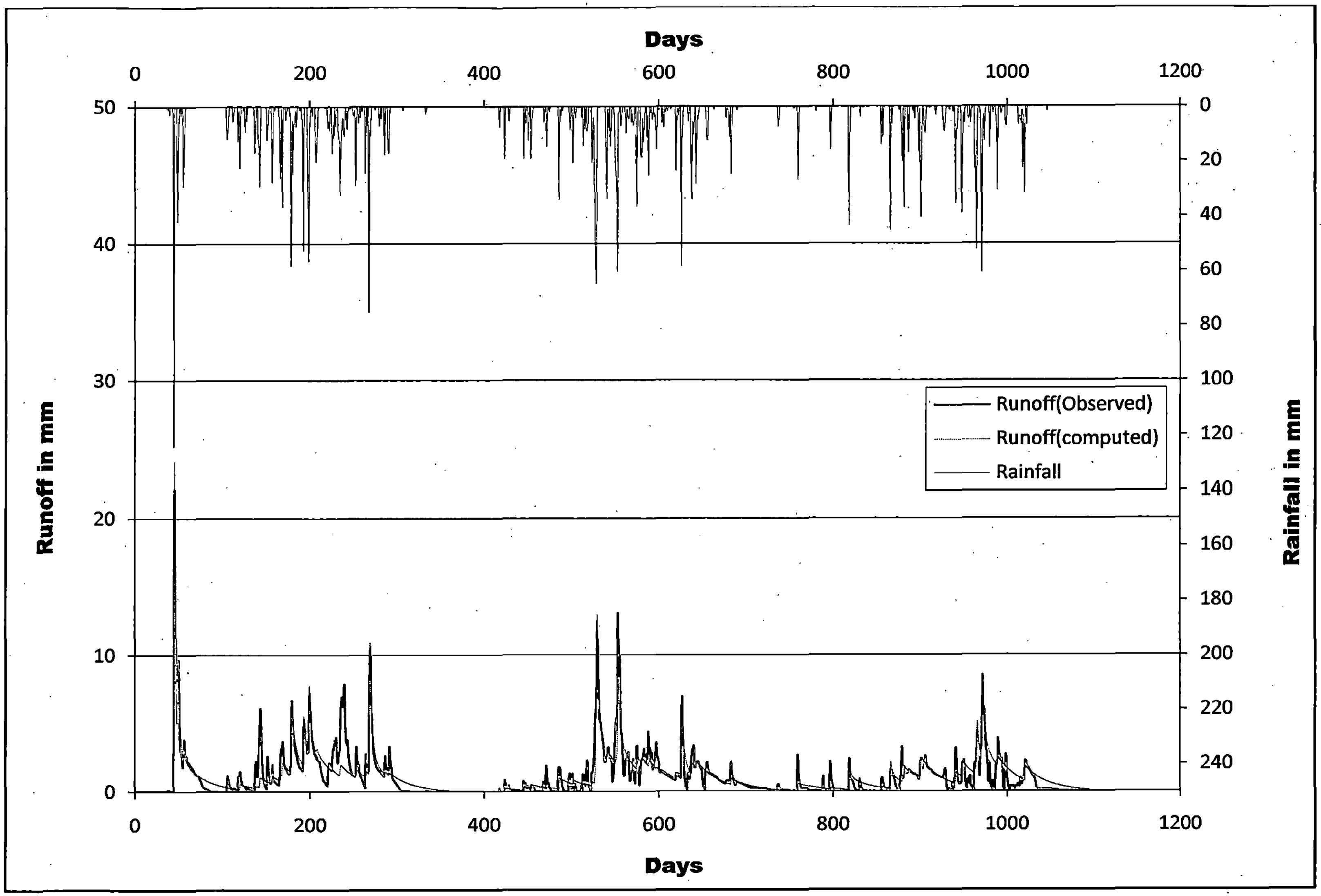


Fig.4.3(a)-Rainfall-Runoff Simulation by Modified SCS-CN Method (Calibration-Case I)

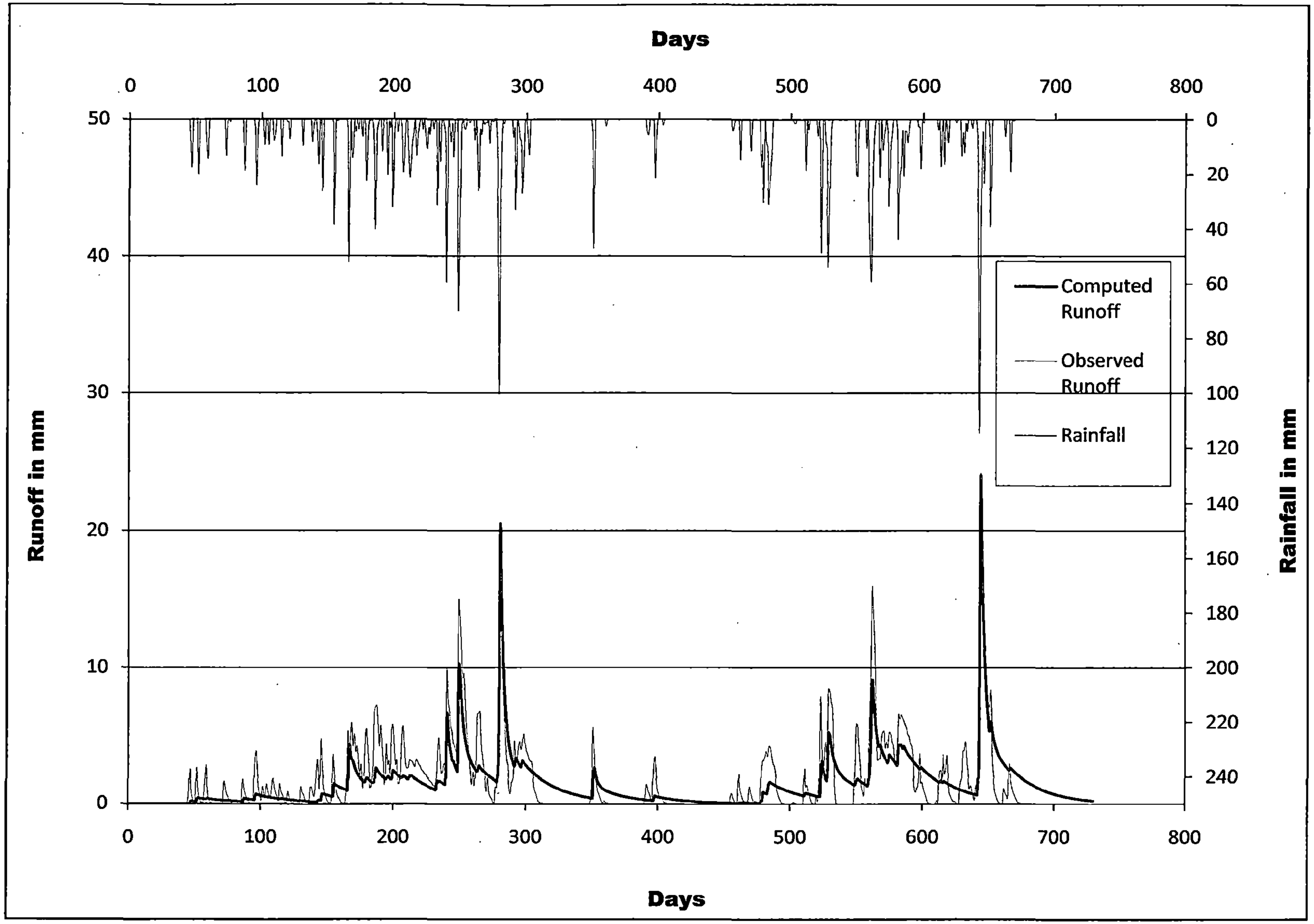


Fig.4.3(b)-Rainfall-Runoff Simulation by Modified SCS-CN Method (Validation-Case I)

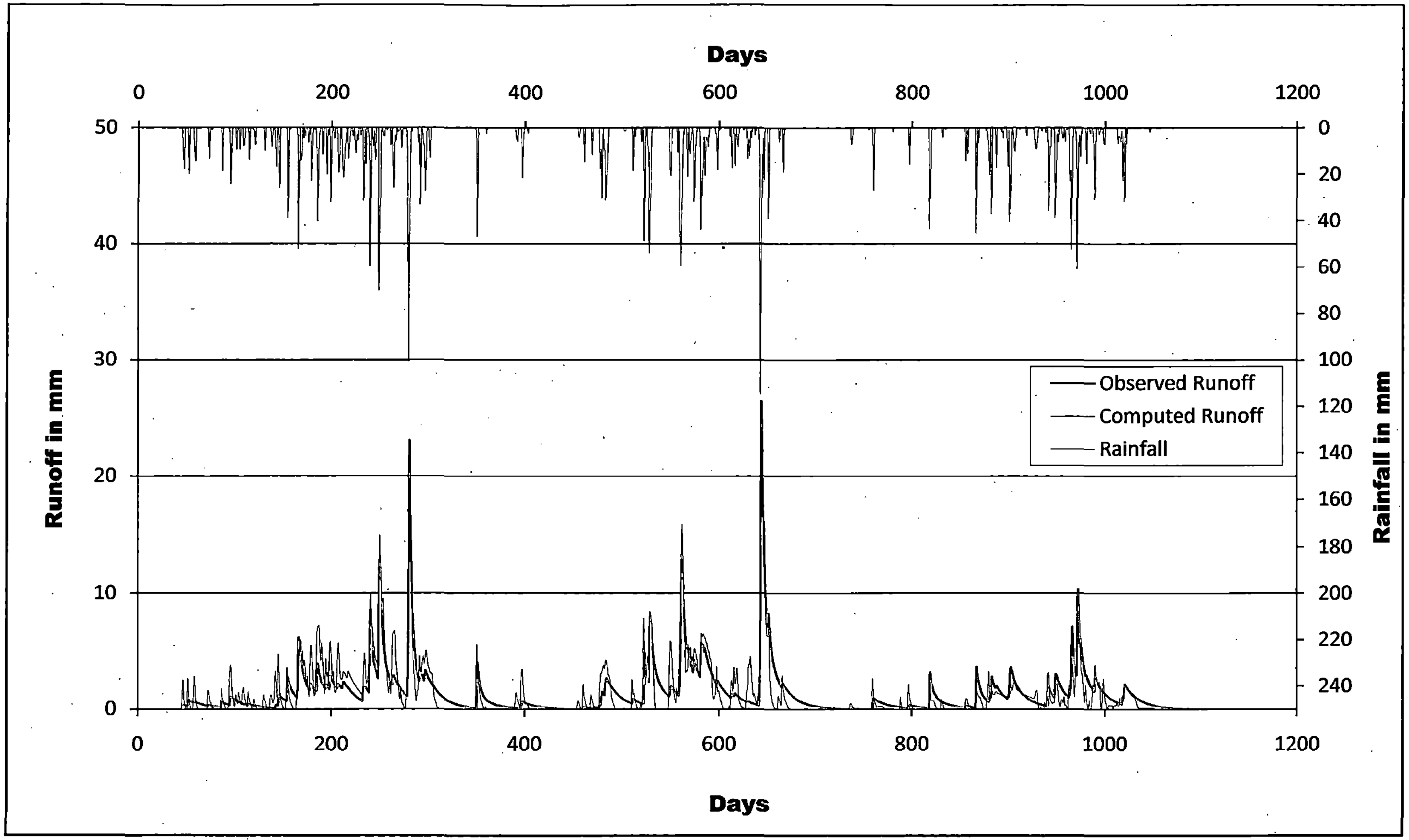


Fig.4.4 (a)-Rainfall-Runoff Simulation by Modified SCS-CN Method (Calibration-Case II)

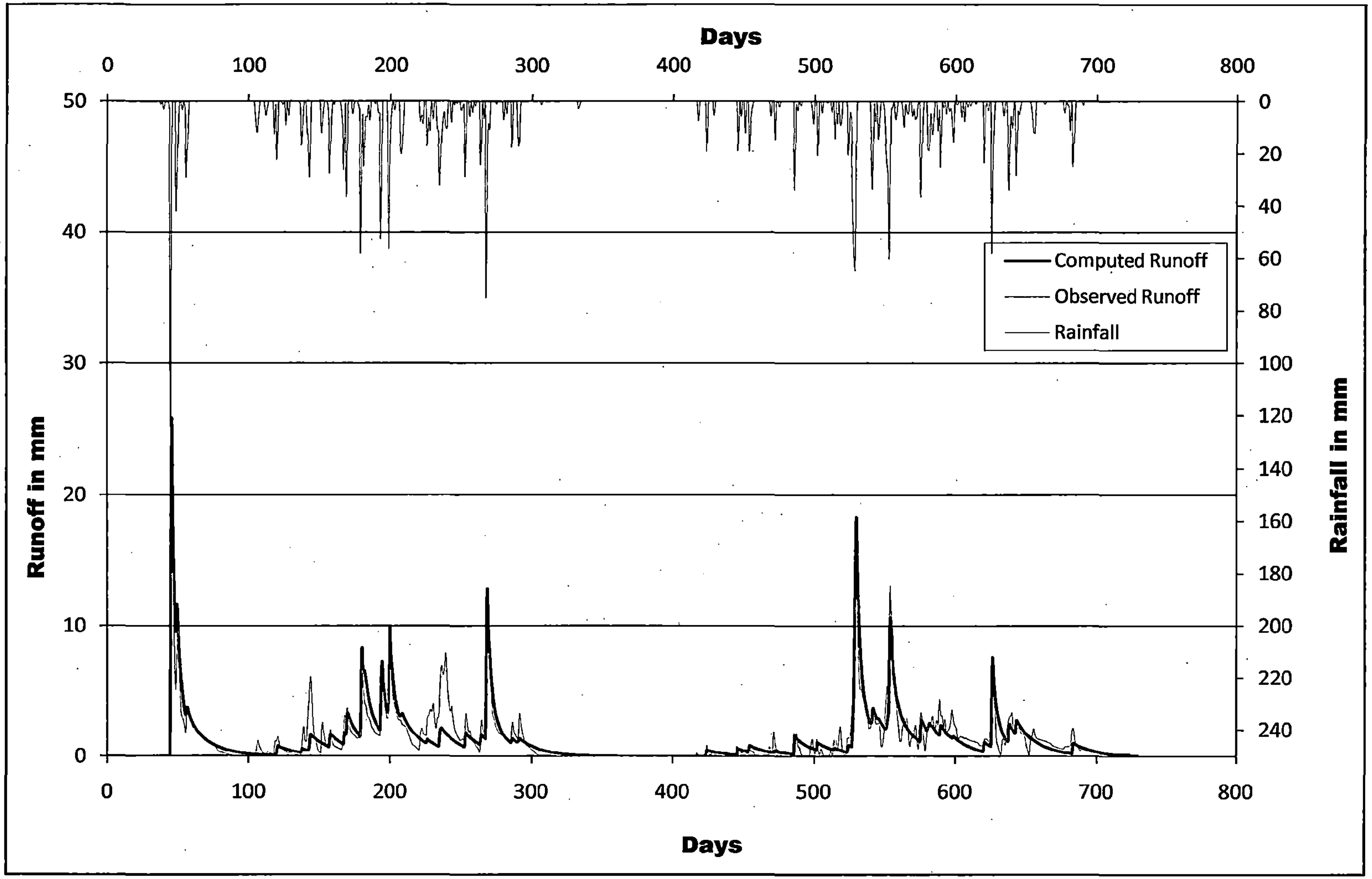


Fig.4.4(b)-Rainfall-Runoff Simulation by Modified SCS-CN Method (Validation-Case II)

4.9 CONTINUOUS SIMULATION MODEL FOR HYDROLOGIC FORECASTING (K. Geetha et.al.)

This model differs from the original model, as in daily flow simulation, the original SCS-CN method is used to compute the direct surface runoff considering the rainfall of the current day utilizing the CN-values corresponding to antecedent 5-days AMC, allowing unrealistic sudden quantum jumps in CN-variation. Secondly, the value of initial abstraction coefficient is fixed as 0.2, which has shown to be varying in literature (For example, Mishra and Singh 2003). The proposed long term hydrologic model obviates these limitations and is capable of simulating, other than direct surface runoff, the total streamflow and its components such as surface runoff, throughflow, and base flow which is conceptualized to have two different moisture stores, i.e. soil moisture store and ground water store. This continuous simulation model considers a daily time step interval for analysis. Thus, the present version is a significant enhancement over the previous ones utilizing original SCS-CN method.

The present model formulation incorporates the SCS-CN concept revised for rainfall dependent initial abstraction and quantification of flows adopting various flow paths in stream flow generation, such as (1) Surface runoff, (2) Through flow and (3) Base flow. This algorithm operates on daily time basis and, therefore, requires daily data of rainfall and evaporation as input to explain the physical behavior of the catchment. The observed runoff is used for model evaluation. A complete description of individual components of the proposed model as given fig.-4.5.

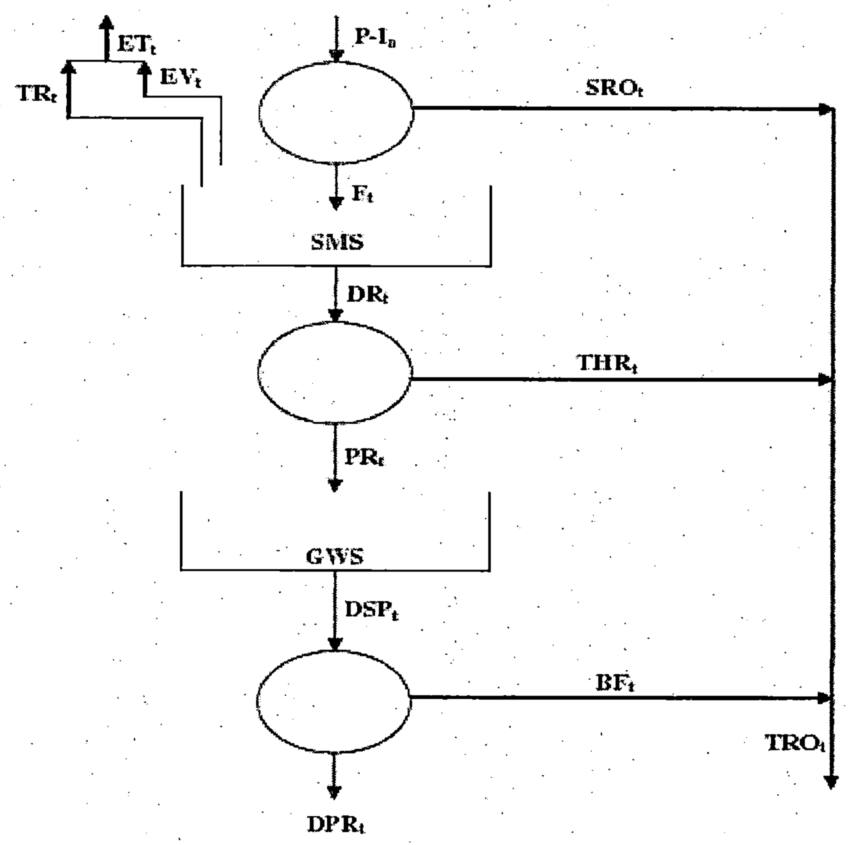


Fig. 4.5 Schematic diagram of SCS-CN-based lumped conceptual rainfall-runoff model

4.9.1 Initial Abstraction

Initial abstraction is considered as a short term loss before ponding such as interception, infiltration, surface storage (Ponce and Hawkins 1996; Mishra and Singh 2003). Here it is assumed that this loss is a fraction of the possible retention in the soil and is computed as:

$$I_{at} = \lambda S_t \quad \text{For t < 5 days} \tag{4.30}$$

here, λ is taken as 0.2. Physically this means that for a given storm, 20% of the potential maximum water retention is the initial abstraction before runoff begins (Singh 1992).

Otherwise

$$I_{a(t)} = \lambda S_t \left[\frac{P_t}{P_t + S_t} \right]^{\alpha} \tag{4.31}$$

where λ_t and α are the coefficient and exponent of the initial abstraction which are to be optimized.

4.9.2 Antecedent Rainfall

In literature, the term antecedent varies from previous 5 to 30 days (SCS 1971; Singh 1992; Mishra and Singh 2003). However no explicit guideline is available to vary the soil moisture with the antecedent rainfall of certain duration. Since the NEH-4 (SCS 1971) uses 5-day rainfall based on the exhaustive field investigations, this duration of 5 days was retained. In this model, for the first 5 days beginning from the starting day of simulation (June 1–June 5, in this study), curve number CN is taken as CN0 and as the day advances, CN varies with respect to antecedent moisture amount, AM, based on the antecedent rainfall

(ANTRF) as: $ANTRF_t = P_{(t-1)} + P_{(t-2)} + P_{(t-3)} + P_{(t-4)} + P_{(t-5)}$ (4.32)

where t is the day under consideration and P is the rainfall of the respective day.

4.9.3 Antecedent Moisture

The initial moisture available in the soil prior to storm plays a vital role in the estimation of runoff (Mishra and Singh 2002a) as curve number CN variability is primarily attributed to antecedent moisture amount rather than the antecedent moisture conditions (SCS 1971;Mishra and Singh 2003) which may lead to sudden jumps in daily curve number values. This model assumes that the current space available for water retention S_t is constant for first 5 days of simulation and hence CN_t=CN_0. S_t can be computed from curve number CN_0 of the first day which is determined by optimization. When the number of days exceeds 5, the antecedent moisture, representing the initial moisture available in the watershed on the day under consideration (AM_t), can be computed as follows:

$$AM_t = \beta\sqrt{ANTRF_t} \tag{4.33}$$

here, β_t is the coefficient of antecedent moisture to be determined by optimization. Then,

St is modified as: $S_t = \dfrac{(S_t)^2}{(AM_t + S_t)}$ (4.34)

here in this model, it is considered that daily antecedent moisture amount AM_t varies with respect to antecedent rainfall (Eq. 4.33) and hence the daily possible water retention of the soil is computed using Eq. 4.34.

4.9.4 Rainfall Excess

The amount of rainfall (P) reaching on the ground after the initial losses (Ia) is termed as effective rainfall (Pe) and this is available for initiating various other processes in the hydrologic cycle. The effective rainfall (Pe) is assumed to be partitioned as surface runoff or rainfall excess (RO) and infiltration (F) as stated in Eq. 1. Using the daily effective rainfall (Pet), the daily rainfall excess ROt can be computed by using Eq. 4 for the first 5-days of simulation, only if rainfall P exceeds initial abstraction (Ia), it is zero otherwise.

4.9.5 Routing of Rainfall Excess

When the number of days exceeds 5, to transform the surface runoff that is produced at the outlet of the basin, the rainfall excess ROt (Eq. 4) is routed using a single linear reservoir concept, as follows (Nash 1957; Mishra and Singh 2003):

$$SROt = C0 \text{ X } Rot + C1 \text{ X } RO_{(t-1)} + C2 \text{ X } SRO_{(t-1)} \tag{4.35}$$

where $C0 = \dfrac{(1/K)}{2+(1/K)}$ and C0=C1 (4.36 a & b)

$$C0 = \frac{2-(1/K)}{2+(1/K)} \quad (4.36\ c)$$

where K is the storage coefficient.

4.9.6 Infiltration

The amount of water reaching the ground after initial abstraction and not produced as direct surface runoff is assumed to infiltrate into the upper soil. It is modelled as:

$$F_t = P_t - I_{a(t)} - RO_{(t)} \quad (4.37)$$

4.9.7 Evapotranspiration

The amount of water goes back or lost to the atmosphere is in the form of evapotranspiration ET_t and can be obtained by the summation of daily evaporation from the water bodies and transpiration from the soil zone in the watershed.

(a) Evaporation

The daily evaporation EV_t is computed as follows:

$$EV_t = PANC X EVP_t \quad (4.38)$$

where EVP_t is the potential evaporation based on the field data and PANC is the pan coefficient.

(b) Transpiration

Transpiration from the soil zone is considered as a function of water content available in the soil store above the wilting point of the soil (Putty and Prasad 1994, 2000; Mishra et al.2005). The transpiration is computed as

$$TR_t = C_1 X (S_{abs} - S_t - \theta_w) \quad (4.39)$$

where C_1=coefficient of transpiration from soil zone, θ_w=wilting point of the soil, S_{abs}=the maximum possible water retention, and St=possible water retention on tth day. The total actual evapotranspiration is taken as the sum of evaporation and transpiration as follows:

$$ET_t = EV_t + TR_t \tag{4.40}$$

4.9.8 Drainage

The term drainage is used as the outflow from a linear reservoir (Nash 1957) only when the moisture content in the soil zone increases and exceeds the field capacity θf (Putty and Prasad 2000; Mishra et al. 2005) as:

$$DR_t = C_2 X (S_{abs} - S_t - \theta_f) \tag{4.41}$$

where C_2= subsoil drainage coefficient, S_{abs}=maximum potential water retention, S_t= possible water retention on tth day, DR_t=drainage rate at time't', and θ_f=field capacity of the soil.

4.9.9 Throughflow or Interflow

The outflow from the unsaturated soil store is partitioned into two components: (a) Subsurface flow in lateral direction and (b) vertical percolation into ground water zone. The former component representing the through flow is taken as a fraction of the above drainage rate (Putty and Prasad 1994, 2000):

$$THR_t = C_3 X DR_t \tag{4.42}$$

where THR_t=throughflow at time 't' and C_3=unsaturated soil zone runoff coefficient.

4.9.10 Percolation

The outflow in the vertical direction from the unsaturated zone meets the ground water store due to the permeability of the soil. This percolated amount of water is considered as a part of drainage, and it is estimated as (Putty and Prasad 1994, 2000; Mishra et al. 2005):

$$PR_t = (1 - C_3) X DR_t \tag{4.43}$$

where PR_t=percolation at time 't'.

4.9.11 Deep Seepage

The saturated store is considered as a non-linear reservoir and from this saturated store, outflow occurs at an exponential rate in the form of deep seepage. As the saturated store is considered as a non-linear store, the formulation for the deep seepage is made as an exponential function of the percolation. This is modeled as follows:

$$DSP_t = (PR_t)^E \qquad (4.44)$$

where DSPt=deep seepage at any time 't' and E=exponent of ground water zone. Deep seepage can travel in lateral direction as well as vertical direction through the saturated store. This seepage is again bifurcated into two components: (1) active ground water flow (base flow) and (2) inactive ground water flow (deep percolation) into the aquifers.

4.9.12 Base Flow

The base flow of a watershed is the ground water release from a catchment in a stream. This active ground water flow which is also known as delayed flow can be modeled as outflow from a non-linear storage in the form of base flow (BFt) as follows:

$$BF_t=BCOEF X DSP_t \qquad (4.45)$$

where BCOEF=ground water zone runoff coefficient

4.9.13 Deep Percolation

The inactive ground water flow into aquifers is termed as deep percolation, occurs from the saturated ground water zone in vertical direction, and is considered as a loss from the saturated store which is modeled as:

$$DPR_t=(1-BCOEF) X DSP_t \qquad (4.46)$$

where DPRt=deep percolation at any 't' and BCOEF=ground water zone runoff coefficient. Here, it is worth emphasizing that the proposed model considers deep seepage which is partitioned into two components, base flow and deep percolation. On the other hand, both the Putty and Prasad (1994, 2000) and Kentucky (James 1972; Singh 1989) models do not account for deep seepage and deep percolation.

4.9.14 Total Stream Flow

The total stream flow (TROt) on a day t, is obtained as the sum of the above three components, surface runoff, throughflow, and base flow .

$$TROt = ROt + THRt + BFt \qquad \text{if } t \_ 5 \text{ days} \tag{4.47}$$

$$TROt = SROt + THRt + BFt \qquad \text{if } t > 5 \text{ days} \tag{4.48}$$

4.9.15 Water Retention Budgeting

The computation of daily water retention storage or soil moisture budgeting is essential in a daily hydrologic simulation. This SCS-CN-based model represents a soil-water balance model. The current space available for retention of water St is again modified by taking into account the evapotranspiration loss, drainage from the soil moisture zone, and daily infiltration to the unsaturated store as:

$$S_t = S_{(t-1)} - F_{(t-1)} + ET_{(t-1)} + DR_{(t-1)} \tag{4.49}$$

where $S_{(t-1)}$ is the previous day potential maximum retention (mm); $ET_{(t-1)}$ is the previous day evapotranspiration (mm); $DR_{(t-1)}$ is the drainage on the previous day; $F_{(t-1)}$ is the previous day infiltration (mm), computed using water balance equation:

$$F_{(t-1)} = P_{(t-1)} - I_{a(t-1)} - RO_{(t-1)} \tag{4.50}$$

here, if $P_{e(t)} \geq 0$, $F \geq 0$.

4.10 DEVELOPMENT OF CONTINUOUS SIMULATION MODEL

The proposed long-term hydrologic simulation model (Fig. 4.5) is developed for describing watershed hydrology by considering temporal and spatial variations of various processes involved in the runoff generation mechanism and also by incorporating modified soil conservation service curve number (SCS-CN) technique as well as storage concepts to represent the catchment response in a better way.

This modified SCS-CN based lumped model that captures the relevant catchment features requires 13 parameters, viz., CN0, I1, a, b, K, C1, C2, C3, Sabs, θf, θw, BCOEF, and E to derive an acceptable model output. Commonly, a close fit between calculated and observed variables is possible for models with a high number of parameters even if the model assumptions are false (Grayson et al. 1992; Beven 1997). In contrast to the studies showing less number of parameters is needed to establish rainfall–runoff relationship (Jakeman and Hornberger 1993), here the number of parameters involved in the model is comparatively large, but it is at the gain of significant higher efficiency and it generates not only streamflow but also its components, a distinctive feature. It is notable that the presented model requires easily available rainfall and evaporation in order to generate streamflow and its components. Here the parameters involved in the model are determined by trial and error method.

4.11 RESULTS AND DISCUSSION

All the parameters are optimized manually in excel sheet for one year (1997) rainfall-runoff record and the efficiency,RMSE and relative error for the calibration is achieved 69.82%, 1.22mm and 0.7% respectively. These parameters are applied for validation next year (1998) flow record and found to be the efficiency,RMSE and relative error for the ~~calibration~~ validation. is achieved 64.07 % ,1.02mm and -5.02 %. The results have been plotted in Fig.4.6 (a) and 4.6(b). The manually optimized parameter with sample calculation is furnished for calibration is furnished in appendix-c and sample calculation with those parameters is furnished in appendix-d.

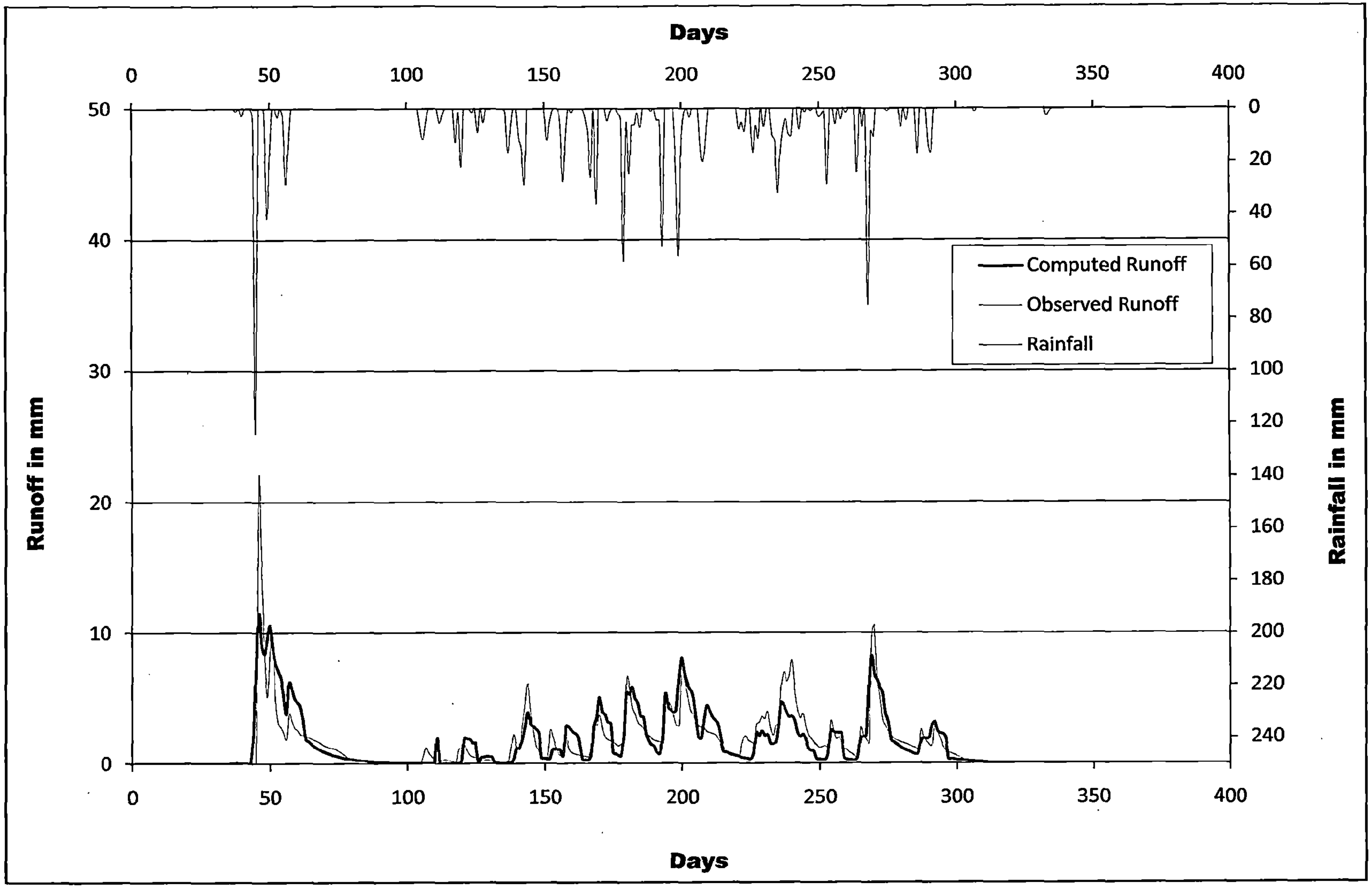


Fig.-4.6(a) Rainfall-runoff Simulation By Continuous Simulation Model (Calibration)

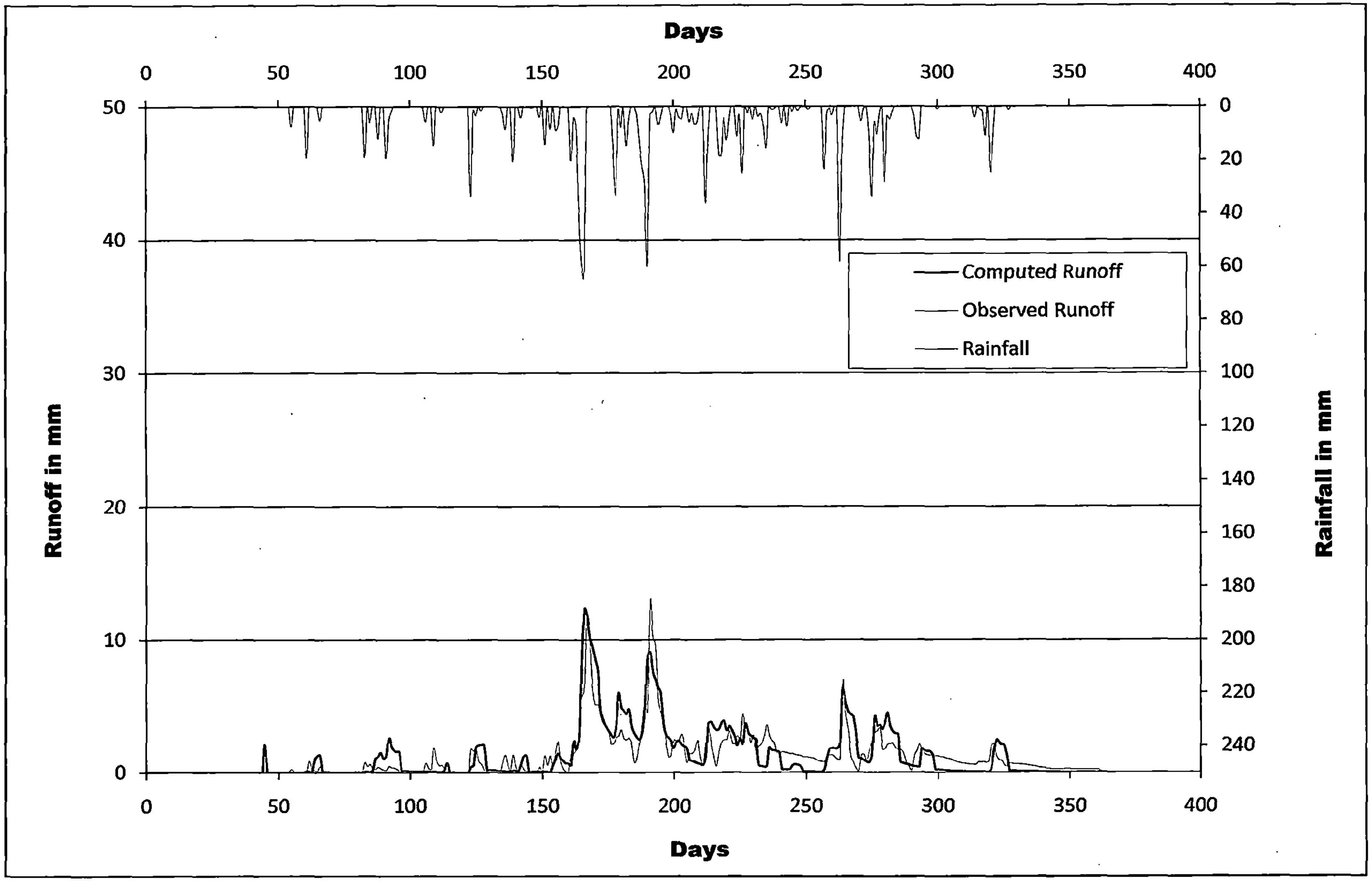


Fig.-4.6(b) Rainfall-runoff Simulation By Continuous Simulation Model (Validation)

CHAPTER-5

CROP WATER REQUIREMENT

5.1 GENERAL

Reasonable estimation of crop water requirement (CWR) of the project is very much essential for optimal management of the water resources for an irrigation project. In this irrigation project, the CWR is many fold of the water demand from the reservoir for other purposes; hence CWR is only estimated for the further analysis. It is very much essential to asses the present as well as future demand of CWR for various options such as CWR for project stipulated cropping pattern and cropping pattern required for the minimum food requirement for the total population of the basin/sub-basin. Hence, it is essential to predict the year of population stabilization and future human population to estimate the future requirement of crop produce. For this purpose, the population projection has been made for the Harbhangi sub-basin, corresponding to year 2041 AD by which the population is likely to be stabilized.

5.2 CALCULATION OF REFERENCE CROP EVAPOTRANSPIRATION (ET_o)

The indirect ETo estimation methods based on climatological data vary from empirical relationships to complex combination methods based on physical processes. Out of all the methods of estimation, the Penman-Monteith method is recommended as a standard method (FAO-1998), i.e.,

$$ET_0 = \frac{.408\Delta(Rn - G) + \gamma \dfrac{900}{T + 273} U2(ea - ed)}{\Delta + \gamma(1 + 0.34U2)} \qquad (5.1)$$

where ETo= reference crop evapotranspiration (mm/day),R_n= soil heat flux (MJ/m^2/day), G= soil heat flux (MJ/m^2/day), T= average temperature (^{0}C) , U_2= wind speed measured at 2m height(m/s),(e_a-e_d)= vapour pressure deficit (KP_a), Δ= slope vapour pressure curve ($KP_a/^0C$) and γ =psychometric constant ($KP_a/^0C$).

For the study area daily hydro-meteorological data of three years from year 2001-2004 at Dhaugaon station is taken and daily average is calculated. Monthly average for the hydro-meteorological data is calculated from the daily average and used for calculating reference ET_0 with CROPWAT-4 software (FAO-1999), furnished in Table-5.1(A) . The annual ET_0 comes out to be 1365mm. A FORTRAN program is developed for estimating daily ET_0 for calculation of crop water requirement and preparation of irrigation scheduling. The annual value of ETo estimated on daily basis is found to be 1270mm is given in Table-5.1(B). The program is able to calculate the ETo for any time period as per availability of hydro-meteorological data and also from daily hydro-meteorological data of a year, the same may be calculate for different time intervals i.e. monthly, five daily weekly, ten daily or fortnightly interval other than daily ET_0. In our study, ten daily ET_0 is used for further analysis.

Table-5.1(A) Calculated ETo (grass) (CROPWAT)

Month	ETo (mm/day)
January	2.8
February	3.79
March	4.53
April	5.3
May	5.61
June	4.15
July	3.47
August	3.2
September	3.4
October	3.53
November	2.78
December	2.31
Average	3.74

Annual evaporation =3.74* 365 = **1365.3 mm**; Windows Ver. 4.3 (FAO-1999)

Table-5.1(B) ET_o on 10 daily (month wise) basis calculated from daily ET_o value

Month	Start Period	End Period	Block No.	ETo (mm)	Month	Start Period	End Period	Block No.	ETo (mm)
Jan	1	10	1	23.17	Jul	1	10	19	36.68
	11	20	2	27.07		11	20	20	31.3
	21	31	3	31.74		21	31	21	31.01
Feb	1	10	4	33.21	Aug	1	10	22	28.33
	11	20	5	34.78		11	20	23	30.13
	1	28	6	31.14		21	31	24	31.35
Mar	1	10	7	38.67	Sep	1	10	25	27.33
	11	20	8	41.55		11	20	26	32.36
	21	31	9	48.73		1	30	27	31.98
Apr	1	10	10	47.42	Oct	1	10	28	32.81
	11	20	11	47.35		11	20	29	31.48
	1	30	12	52.65		21	31	30	36.43
May	1	10	13	55.17	Nov	1	10	31	29.23
	11	20	14	49.92		11	20	32	27.1
	21	31	15	56.19		1	30	33	23.76
Jun	1	10	16	46.33	Dec	1	10	34	24.02
	11	20	17	40.83		11	20	35	22.96
	1	30	18	31.07		21	31	36	24.71
								Annual	**1269.96**

5.3 CROP WATER REQUIREMENT (CWR)

The crop evapotranspiration, ET_c differs distinctly from the reference evapotranspiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish crops from grass are integrated into the crop coefficient (K_c). ET_c is determined by two approaches, the single and the dual crop coefficient approach. In the single crop coefficient approach, the difference in evapotranspiration between the cropped and reference grass is combined into one single coefficient. In the dual crop coefficient approach, the crop coefficient is split into two factors describing separately the differences in evaporation and transpiration between the crop and reference surface. However, the single crop coefficient approach is followed here.

5.3.1 Single Crop Coefficient Approach

In this approach the crop evapotranspiration, i.e., Etc is calculated as below.

$$ETc = Kc * ETo \quad (5.2)$$

where ETc [mm d-1], Kc [dimensionless] and ETo [mm d-1].

5.3.1.1 Kc values for Crop growth stages

As the crop develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the Kc for a given crop will vary over the growing period. The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late-season. Kc values for the crops are taken from FAO-56, Irrigation and Drainage (1998) for all the stages. Kc value for the initial stage is not corrected due to non availability of infiltration data and other crop data and taken original value. Kc values for the mid stage and late stage are corrected for the prevailing relative humidity and wind velocity as mentioned below.

(a) Determination of Kc mid

For specific adjustment in climates where RH_{min} differs from 45% or where U_2 is larger or smaller than 2.0 m/s, the Kc mid values from Table 12 of FAO-56 bulletin are corrected, i.e.,

$$K_{c(mid)} = K_{c(mid\ from\ table)} + [.04(U_2-2) - .004(RH_{min}-45)]\ (h/3)^{0.3} \quad (5.3)$$

where h=prevailing average crop height of the locality, RH_{min}= minimum relative humidity and U_2 =wind velocity at 2m height form ground level.

(b) Determination of Kc late

The Kc late values in Table 12 of FAO-56 are typical values expected for average Kc end under the standard climatic conditions. For specific adjustment in climates where RH_{min} differs from 45% or where u2 is larger or smaller than 2.0 m/s, Kc end value can be corrected , i.e.,

$$K_{c(late)} = K_{c(late\ from\ table)} + [.04(U_2-2) - .004(RH_{min}-45)]\ (h/3)^{0.3} \quad (5.4)$$

$K_{c(mid)}$ and $K_{c(late)}$ values of each crop is given in Table-5.2. and total crop period, final K_c and crop duration in each stage for all the crops are furnished in the table-5.3.

Table-5.2 Corrected K_c values of $K_{c\ mid}$ and $K_{c\ late}$

Sl. No.	Crop Name	Crop Height (m)	Mid Period	Kc for Mid-stage			Late Period	Kc for Late-stage		
				As per FAO-56	Esti-mated	% Change		As per FAO-56	Esti-mated	% Change
1	Early Paddy	1.00	Aug11-Sept20	1.2	1.03	14.52	Sep11-Sep30	1.05	0.87	16.80
2	Mid Paddy	1.00	Aug21-Oct10	1.2	1.02	14.77	Sep26-Oct20	1.05	0.87	16.79
3	Late Paddy	1.00	Sept01-Oct20	1.2	1.02	14.72	Oct25-Nov25	1.05	0.88	16.46
4	Raggi	0.50	Aug11-Sept10	0.9	0.83	7.78	Sep11-Sep25	0.9	0.64	28.89
5	Groundnut	0.40	Oct11-Nov10	1.15	1.02	11.37	Nov16-Nov30	0.8	0.75	6.82
6	Maize	2.00	Sept11-Oct10	1.2	0.99	17.66	Nov 6-Nov30	0.75	0.67	10.80
7	Sugarcane	3.00	May21-Nov20	1.25	1.01	18.80	Nov27-Jan25	0.8	0.77	4.10
8	Dalua Paddy	1.40	Feb21-Apr10	1.2	1.03	14.48	Apr18-May15	1.05	0.89	15.53
9	Pulses	1.30	Jan01-Jan31	1.15	0.98	15.22	Jan01-Jan15	0.75	0.66	11.67
10	Groundnut (Rabi)	0.40	Mar11-Apr10	1.15	1.03	10.08	Apr21-May15	0.8	0.76	4.41
11	Vegetable up	0.30	Dec21-Jan31	1.05	0.93	11.07	Jan25-Feb15	0.95	0.88	6.96
12	Vegetable low	0.50	Feb11-Mar20	1.05	0.92	12.84	Apr01-Apr30	0.95	0.88	7.79
13	Patato	0.60	Jan01-Jan31	1.15	1.01	12.45	Jan29-Feb25	0.9	0.81	10.31
14	Mustard	1.00	Jan01-Feb10	1.15	0.98	14.44	Feb09-Feb28	0.75	0.67	11.07

5.4 EFFECTIVE RAINFALL

Effective rainfall is calculated by different methods as per the FAO (Training Manual-3, 1986) and USDA-SCS, and the later one is used as it gives reasonable values for the basin. For Padagaon Detail calculation is furnished in Table-5.4

1. **Probable rainfall % interactively defined by user.**

   Normally 80% of the total rainfall is taken as effective rainfall.

2. **FAO/AGLW formula:**

   Peff = 0.6 * Pmon - 10 for Pmon <= 75 mm (5.4a)

   Peff = 0.8 * Pmon - 25 for Pmon > 75 mm (5.4b)

Table-5.3 Kc values and crop duration of each stage for all the crops

Stages	Total Crop Period	Total Days	Initial Stage			Development Stage			Mid Stage			Late Stage		
Name of crop			Period	Days*	Kcinitial	Period	Days*	Kcdev*	Period	Days*	Kcmid	Period	Days*	Kclate#
Early Paddy	Jun21-Oct15	115	Jun21-Jul10	20	1.05	Jul11-Aug10	30	1.04		40	1.03	Sept21-Oct15	25	0.87
Mid Paddy	Jul01-Nov05	125	Jul01-Jul20	20	1.05	Jul21-Aug21	30	1.04	Aug21-Oct10	50	1.02	Oct11-Nov05	25	0.87
Late Paddy	Jul01-Nov25	145	Jul01-Jul31	30	1.05	Aug01-Aug31	30	1.04	Sept01-Oct20	50	1.02	Oct20-Nov25	35	0.88
Raggi	Jul01-Oct10	100	Jul01-Jul20	20	0.35	Jul21-Aug10	20	0.59	Aug11-Sept10	30	0.83	Sept11-Oct10	30	0.64
Groundnut	Sept01-Nov30	90	Sept01-Sept10	10	0.4	Sept11-Oct10	30	0.71	Oct11-Nov10	30	1.02	Nov11-Nov30	20	0.75
Maize	July21-Oct31	100	July21-Aug10	20	0.5	Aug11-Sept10	30	0.74	Sept11-Oct10	30	0.99	Oct11-Oct31	20	0.67
Sugarcane	Mar01-Jan10	310	Mar01-Mar31	30	0.4	Apr01-May20	50	0.71	May21-Nov20	180	1.01	Nov21-Jan10	50	0.77
Dalua Paddy	Jan01-May05	125	Jan01-Jan20	20	1.05	Jan21-Feb20	30	1.04	Feb21-Apr10	50	1.03	Apr11-May05	25	0.89
Pulses	Nov21-Feb20	90	Nov21-Nov30	10	0.4	Dec01-Dec31	30	0.69	Jan01-Jan31	30	0.98	Feb01-Feb20	20	0.66
Groundnut (Rabi)	Jan21-Apr30	100	Jan21-Feb10	20	0.4	Feb11-Mar10	30	0.72	Mar11-Apr10	30	1.03	Apr11-Apr30	20	0.76
Vegetable (up)	Nov01-Feb20	110	Nov01-Nov20	20	0.7	Nov21-Dec20	30	0.82	Dec21-Jan31	40	0.93	Feb01-Feb20	20	0.88
Vegetable (low)	Dec11-Apr10	120	Dec11-Jan10	30	0.7	Jan11-Feb10	30	0.81	Feb11-Mar20	40	0.92	Mar21-Apr10	20	0.88
Patato	Nov11-Feb30	100	Nov11-Nov30	20	0.5	Dec01-Dec31	30	0.75	Jan01-Jan31	30	1.01	Feb01-Feb20	20	0.81
Mustard	Nov21-Feb28	100	Nov21-Dec10	20	0.4	Dec11-Dec31	20	0.69	Jan01-Feb10	40	0.98	Feb11-Feb28	20	0.67

Note:-

Days* : Days are rounded as per FAO-56

Kclate#: Average Kclate initial value and Kclate end value is used for total late stage

Kcdev*: Average of the Kcinitial and Kcmid

3. **USDA –SCS method**

Peff = (Pmon*(125-0.2*Pmon))/125 for Pmon <= 250 mm (5.5a)

Peff= 125+0.1*Pmon for Pmon>250 mm (5.5b)

Table-5.4 Effective rainfall at Padagaon

Sl. No.	Month	Monthly Rainfall in mm	Effective Rainfall in mm		
			80 % Probable Rainfall (mm)	FAO/AGLW Formula	USDA-SCS Method
1	2	3	4	5	6
1	Jan	11.3	5.8	0.0	11.1
2	Feb	22.6	1.5	3.6	21.8
3	Mar	36.6	0.9	12.0	34.5
4	Apr	66.6	1.1	30.0	59.5
5	May	93.1	2.7	49.5	79.2
6	Jun	179.2	136.5	118.4	127.8
7	Jul	239.7	385.8	166.7	147.8
8	Aug	245.5	347.2	171.4	149.1
9	Sep	205.9	158.3	139.7	138.1
10	Oct	132.6	1.1	81.1	104.5
11	Nov	57.8	0.7	24.7	52.5
12	Dec	8.9	1.0	0.0	8.8
	Annual	1300.0	1042.6	797.1	934.6

5.5 IRRIGATION WATER REQUIREMENT

The irrigation water requirement basically represents the difference between the crop water requirement and effective rainfall. The irrigation water requirement also includes additional water requirement, transplantation and percolation loss. Net Irrigation Requirement (NIR) is given by:

NIR = {(Et_c+ Percolation loss+ Transplantation water requirement, if any) –

(Effective rainfall)} (5.6)

Gross irrigation requirement (GIR): GIR = NIR/ (ζ_c* ζ_f) (5.7)

where ζ_c = conveyance efficiency and ζ_f = field application efficiency.

For this project, field application efficiency and conveyance efficiency for the paddy crop is 70% and 80% and for the other crops it is 52.5% and 80% respectively. Thus, the combined efficiency for the paddy crop is 56% and for the other crops it is 42%. For the paddy crop the percolation loss in the field is taken as 6mm/day (FAO-56) and 200mm depth of water is applied during previous month for the land preparation. It is observed that irrigation requirement for the crops of the project is around 15 % less as compared to the calculated on the basis of monthly ETo by CROPWAT-4 and Kc values are taken as per FAO-24. A sample calculation of one crop (late paddy) is given in the Table-5.5 and total project water requirement comes out to 16370ham which is furnished in the Table-5.6.

5.6 IRRIGATION WATER REQUIREMENT FOR MINIMUM FOOD REQUIREMENT

5.6.1 Population Projection

Population of the project command area is projected using the state population data from year 1971-2001 and growth trend fixed by the Census India (2001) for the state up to year 2026. It is found that the stabilized project basin population will be 99552 by 2041A.D (Figure-5.1 and Table5.7).

Table-5.7 Population projection up to year 2041

Base year	Projected Year	Growth in 5 years	Population	Remarks
1991	-	-	67458	Assumed rate of growth is decreasing as per the trend projected by Census India for the state population (Orissaa)
1991	2001	1.515	78404	
2001	2006	1.107	82841	
2006	2011	0.950	86851	
2011	2016	0.835	90538	
2016	2021	0.737	93924	
2021	2026	0.565	96608	
2026	2031	0.391	98510	
2031	2036	0.202	99509	
2036	2041	0.009	99552	
2041	2046	0.000	99552	

Table-5.5 Estimation of CWR for late paddy (sample crop) Crop Area 1850

Months	June			July			Aug			Sept			Oct			Nov			Total	Remarks
ETo (mm/10 daily)	46.3	40.8	31.1	36.7	31.3	31.0	28.3	30.1	31.3	27.3	32.4	32.0	32.8	31.5	36.4	29.2	27.1	23.8	1269.9	CROPWAT
Growth stages	Land Prep.			Initial Stage			Crop.Dev.Stg			Mid.S.Stg						Late.S.Stg				
Growth stage	Jun01-Jun30			Jul01-Jul31			Aug01-Aug31			Sept01-Oct20						Oct20-Nov25				
Kc				1.05			1.04			1.03						0.88				FAO - 56
ETc (mm/10 daily)				38.5	32.9	32.6	29.4	31.3	32.6	28.1	33.4	33.0	33.8	32.4	32.0	25.7				
Saturation, SAT (mm)	70.0	70.0	70.0																	
Deep Percolation, PERC (mm/month)				60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0				FAO-IWM_Training Manual No. 3 (200mm)
Transplanting water				35.00	35.00	35.00														
Total CropWater ETc+SAT+PERC+WL (mm/10daily)	70.0	70.0	70.0	133.5	127.9	127.6	89.4	91.3	92.6	88.1	93.4	93.0	93.8	92.4	92.0	85.7			1510.70	
Effective Rainfall, Pe (mm/month)	42.6	42.6	42.6	49.3	49.3	49.3	49.7	49.7	49.7	46.0	46.0	46.0	34.8	34.8	34.8	17.5	17.5	17.5	934.50	USDA method
Net Irrigation Requirement, NIR (mm/10daily)	27.4	27.4	27.4	84.2	78.6	78.3	39.7	41.6	42.9	42.1	47.4	47.0	59.0	57.6	57.2	68.2			826.00	
Net Irrigation Requirement, NIR (mm/month)	82.20			241.10			124.20			136.50			173.80			68.20			826.00	
Field Irrigation Efficiency	0.70			0.70			0.70			0.70			0.70			0.70				PDSP:M3-page 38
Field Irrigation Requirement, FIR (mm/month)	117.43			344.43			177.43			195.00			248.29			97.43			1180.00	
Conveyance Efficiency	0.80			0.80			0.80			0.80			0.80			0.8				FAO-IWM_Training Manual No. 3
Diversion Water Requirement (mm/month)	146.79			430.54			221.79			243.75			310.36			121.79			1475	
Diversion Water Requirement (Ham)	271.55			796.49			410.30			450.94			574.16			225.30			2728.75	

Table-5.6 Estimation of project CWR

Serial No.	Description of Crops	Cropping Area in ha	Crop Period	Monthlyl Water Diversion Required at the Head race in Ham													Non-Monsoon	Total
				Jun	Jul	Aug	Sept	Oct	Monsoon	Nov	Dec	Jan	Feb	March	Apr	May		
1	Early Paddy	2500	Jun21-Oct15	691.5	827.7	551.3	586.2	0.0	2656.7	0.0	0.0	0.0	0.0	0.0	0.0	194.6	194.64	2851.3
2	Mid Paddy	3100	Jul01-Nov05	455.0	1307.0	689.2	758.9	617.8	3827.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	3827.9
3	Late Paddy	1850	Jul01-Nov25	271.6	796.5	410.3	450.9	574.2	2503.4	225.3	0.0	0.0	0.0	0.0	0.0	0.0	225.30	2728.8
4	Raggi	440	Jul01-Oct10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
5	Groundnut	750	Sept01-Nov30	0.0			0.0	4.1	4.1	27.4	0.0	0.0	0.0	0.0	0.0	0.0	27.42	31.5
6	Maize	150	July21-Oct31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
7	Sugarcane	360	Mar01-Jan10	3.5	0.0	0.0	0.0	1.7	5.2	19.3	39.5	12.1	0.0	14.7	38.7	44.7	169.01	174.2
8	Dalua Paddy	1500	Jan11-May05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	712.1	1266.7	0.0	994.2	708.3	0.0	3681.38	3681.4
9	Pulses	1050	Nov21-Feb20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	101.0	173.2	76.2	0.0	0.0	0.0	350.33	350.3
10	Groundnut (Rabi)	2050	Jan21-Apr30	0.0	0.0	0.0	0.0	0.0	0.0			43.8	189.9	421.6	333.6	0.0	988.86	988.9
11	Vegetable (up)	1400	Nov01-Feb20	0.0	0.0	0.0	0.0	0.0	0.0	21.2	174.4	217.2	66.4	0.0	0.0	0.0	479.18	479.2
12	Vegetable (low)	1400	Dec10-Apr10	0.0	0.0	0.0	0.0	0.0	0.0		91.1	175.9	219.0	274.1	73.0		833.18	833.2
13	Patato	400	Nov11-Feb30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.9	68.3	38.6	0.0	0.0	0.0	149.79	149.8
14	Mustard	700	Nov21-Feb28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.3	116.0	90.8	0.0	0.0	0.0	274.08	274.1
	Total	17650	Monthly Diversion	1421.6	2931.2	1650.8	1796.0	1197.7	8997.4	293.2	1228.3	2073.2	680.8	1704.5	1153.7	239.4	7373.2	16370.5

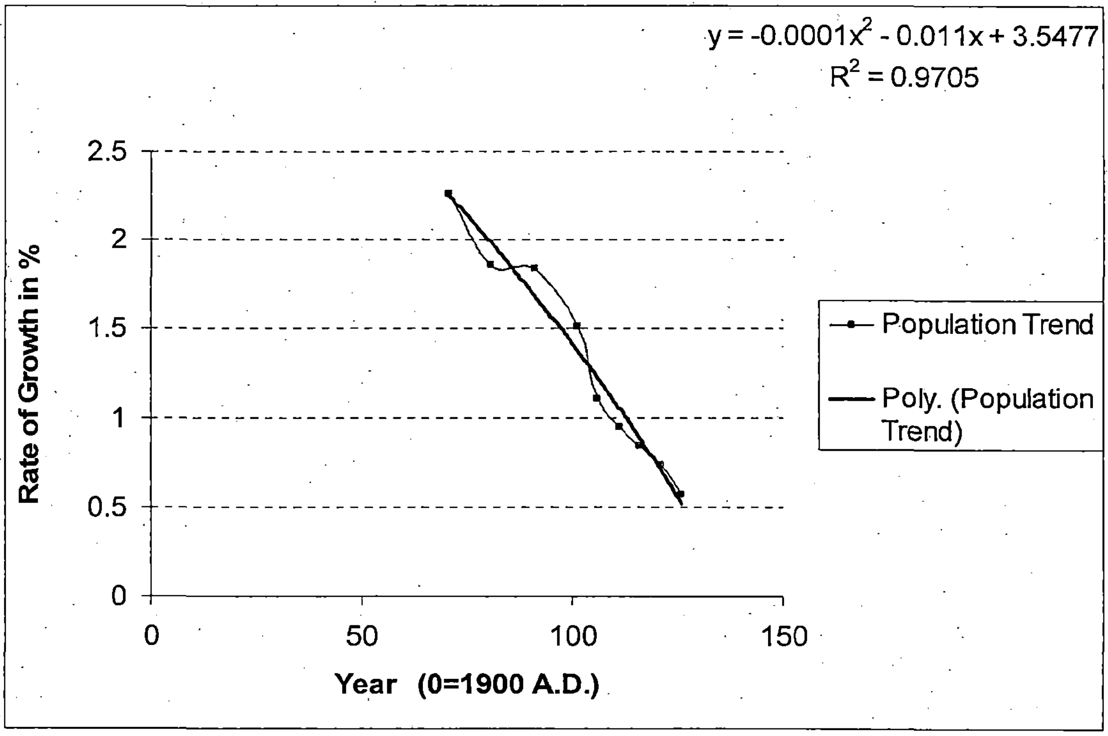


Fig.-5.1 Projected Population from Year 1971

5.6.2 Requirement of Minimum Crop Produce

Standard nutritional parameters i.e.protein requirement and calories requirement for a normal person are taken from Jena (2003) to calculate minimum crop produce required to sustain the stabilized population of the project area. According to the crop yield per hectare for different crops are taken for Dept. of Agriculture,Orissa and crop produce required, the crop area of different crops are fixed in proportion to scheduled cropping area of the project to calculate the CWR_{min} for minimum food requirement. CWR_{min} is used for the analysis of low flow year yield. Details of crop produce requirement calculation are furnished in Table-5.8(a,b,c) (Jena-2002). Crop area of different crops and total CWR_{min} is furnished in Table-5.9. The area of different crops is taken in proportionate to the scheduled cropping pattern. Minimum crop water requirement of the project is 12000ham.

Table-5.8a Age Group-wise Male-Female Population Percentage

Age Group	Male (%)	Female (%)
0-9 years	21.42	21.44
10-19 years	20.23	20.2
20-39 years	33.16	32.51
40-59 years	17.69	18.48
Above 60 years	7.5	7.37
Total	100	100
On total Population	49.24	50.76

Table-5.8b Daily Dietary Allowances

Age Group	Male		Female	
	Proteins (Grams/Kg)	Calories (Units/Kg)	Proteins (Grams/Kg)	Calories (Units/Kg)
1	2	3	4	5
0 to 9 years	42.00	1500.00	42.00	1500.00
10 to 19 years	83.33	2600.00	73.33	2133.00
20 to 39 years	65.00	3000.00	60.00	2200.00
40 to 59 years	65.00	2800.00	60.00	2100.00
Above 60 years	65.00	2500.00	60.00	2100.00
Weighted Average	63.78	2524.90	58.83	2523.79
Weighted Average on rotal population	Proteins=61.27 grams/person		Calories=2524 units/person	

Table-5.8c Total annual crop produce required for minimum nutritional requirements

Crop	Crop Produce Required (Per Capita/Day)	Content of Crops		Available per Capita		Revise Crop Produce Required (Per Capita/Day) as per Calories Required	Calories Available per Capita (Units/day)	Total Crop Produce Required for Total Population (tonne/year)
		Protein (Grams/Kg)	Calorie (Units/Kg)	Protein (Grams/day)	Calories (Units/day)			
1	2	3	4	5	6	7	8	9
Paddy	0.35	75	3460	26.25	1211	0.42	1453.2	15261.3
Pulses	0.025	240	3350	6	83.75	0.025	83.75	908.4
Raggi	0.01	104	3490	1.04	34.9	0.01	34.9	363.4
Potato	0.13	50	2450	6.5	318.5	0.13	318.5	4723.7
Ground nut	0.07	315	5610	22.05	392.7	0.07	392.7	2543.6
Vegetable	0.3	40	800	12	240	0.3	240	10900.9
			Total	78.84	2286.85		2531.05	34701.3

Note: Minimum crop produce revised satisfying all requirements

Table-5.9 Minimum CWR of the project (food requirement for the projected population)

Project: Harbhangi Irrigation Project

Irrigation intensity= 134 %

CCA = 9650 ha

Crop No.	Description of Crops	Crop Coverage in %	Cropping Area in ha	Monthlyl Water Diversion Required at the Head race in Ham													Non-Monsoon	Total in ham
				June	July	Aug	Sept	Oct	Monsoon	Nov	Dec	Jan	Feb	March	Apr	May		
1	Early Paddy	18.96	1830	506.2	605.9	403.6	429.1	0.0	1944.7	0.0	0.0	0.0	0.0	0.0	0.0	142.5	142.48	2087.2
2	Mid Paddy	23.52	2270	333.2	957.0	504.7	555.7	452.4	2803.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	2803.0
3	Late Paddy	14.09	1360	199.6	585.5	301.6	331.5	422.1	1840.4	165.6	0.0	0.0	0.0	0.0	0.0	0.0	165.63	2006.0
4	Raggi	3.32	320	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
5	Groundnut	5.70	550	0.0			0.0	3.0	3.0	20.1	0.0	0.0	0.0	0.0	0.0	0.0	20.11	23.1
6	Maize	1.14	110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
7	Sugarcane	2.69	260	2.6	0.0	0.0	0.0	1.2	3.8	13.9	28.5	8.8	0.0	10.6	28.0	32.3	122.06	125.8
8	Dalua Paddy	11.40	1100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	522.2	928.9	0.0	729.1	519.4	0.0	2699.68	2699.7
9	Pulses	7.98	770	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.0	127.0	55.9	0.0	0.0	0.0	256.91	256.9
10	Groundnut (Rabi)	15.54	1500	0.0	0.0	0.0	0.0	0.0	0.0			32.1	138.9	308.5	244.1	0.0	723.56	723.6
11	Vegetable up	10.67	1030	0.0	0.0	0.0	0.0	0.0	0.0	15.6	128.3	159.8	48.8	0.0	0.0	0.0	352.54	352.5
12	Vegetable low	10.67	1030	0.0	0.0	0.0	0.0	0.0	0.0		67.0	129.4	161.2	201.7	53.7		612.98	613.0
13	Patato	3.01	290	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.1	49.5	28.0	0.0	0.0	0.0	108.59	108.6
14	Mustard	5.28	510	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.0	84.5	66.1	0.0	0.0	0.0	199.68	199.7
	Total	133.99	12930	1041.6	2148.4	1209.9	1316.3	878.7	6594.9	215.3	900.3	1520.0	498.9	1249.8	845.2	174.8	5404.2	11999.1

CHAPTER 6

RESERVOIR YIELD MODEL

6.1 GENERAL

In reservoir studies, modeling attempts to study the behavior of the river and reservoir based on the observed river flows to predict the future yield with the input of various natural data such as annual pan evaporation, temporal distribution of the inflow to the reservoir, historical inflow record and estimated project crop water requirement based on the cropping pattern fixed by the authority. On the basis of characteristics, there are predominantly two approaches in reservoir yield studies:-deterministic and stochastic. Given the uncertainties inherent in the prediction of hydrologic process, that affect the performance of water resources systems, deterministic planning models are often inadequate for preliminary plan formulation and evaluation. Because of the aforesaid limitations stochastic planning models has got advantage over the deterministic models.

6.2 STOCHASTIC MODELLING

Incorporation of stochastic parameters in the modeling of river basin studies brings the system behavior closer to the natural one for it cares the uncertainties in hydro-meteorological factors, which influence the input parameters to the system. Broadly, three types of stochastic reservoir planning models, that incorporate hydrologic variability and uncertainty and are structured for solution either by linear or dynamic programming techniques, are: (i) The first one is explicitly stochastic models that define a number of possible discrete stream flows and storage volumes and their probabilities, in each time interval and at each site; (ii) The second one is implicitly stochastic model. Implicitly stochastic in the sense that, when it optimize over a long continuous series of historical or synthetically generated unregulated inflow time series, most of the stochastic aspects of the problem, including spatial and temporal correlations are implicitly included in the model itself that identify annual firm water yield, its within-year distributions, and its reliability; and (iii) third one is chance-constrained models which have rules that express the unknown reservoir storage volume and release probability distributions as linear functions of the unknown unregulated stream flows (Loucks et al. 1981).

Stochastic design models are large in size, especially for river basin planning. Also, they are not very helpful in defining reservoir operating policies. The chance-constrained models are small but their structure tends to lead to conservative estimates of design variables. Compared to above two, implicit stochastic models, although larger than chance-constrained models, are much smaller than the stochastic design models. They have resulted in relatively good estimates of both design and operating policy variables. Yield model comes under this category and considering its advantages in dealing with large scale problems it is selected for use in the present study.

6.3 PHILOSOPHICAL BACK GROUND OF THE RESERVOIR YIELD MODEL

Reservoir yield is the quantity of water, which is dependent on active storage capacity, the distribution of inflows, and the reservoir operating policy; released/made available from a reservoir for some specific use(s). Water resources managers and planners are trying their best for getting better options and one amongst those is the determination of the guaranteed yield from the reservoir. In connection with any water resources planning and management is the determination of the system yield and reliability that is in the sharp focus of the water resources experts. Hence, safe or firm yield can also be defined as that annual demand which can be met without the reservoir falling to its dead storage level at any point of time. So the philosophical backdrop of the reservoir yield model is founded on this conceptual base of determination of reservoir firm yield.

6.4 CONCEPT OF YIELD MODEL

The yield model based on linear programming developed in Loucks et al. (1981, pp. 339-353, 368-371) was subsequently improved by Dahe and Srivastava (2002). It is a general purpose, implicitly stochastic linear programming screening model that incorporates several approximations to reduce the size of the constraint set needed to describe reservoir system operation and to capture the desired reliability of target releases considering the entire length of historical or synthetically generated unregulated inflow time series (Stedinger et al. 1983). The yield model estimates over-year and within-year reservoir capacity requirements separately to meet the specified release reliability targets.

Unlike complete optimization model in which continuity equation is formulated for each within-year time periods, the yield model consists of a set of constraints at annual time step and an additional set of constraint for within-year time periods based on a critical year (Dandy et al. 1997). Set of constraints at annual time step is applied to model the behavior of over-year storage. Set of constraints for within time period models the within-year storage behavior. Thus, each reservoir consists of two storages; one for "over-year" periods and one for "within-year" periods. This approximate yield model has a specific relation between over year storage and within year storage.

In case of a complete model, the model provides the storage at each time step for the entire length of historical record and the maximum of these storage volumes is the active reservoir storage capacity. Hence, there is no scope to know the over-year and within-year storage capacities separately in a complete model. Whereas, the over-year continuity constraints of the yield model gives the storage at the end of each year known as over-year storage. The maximum of all over-year storage volumes is the over-year storage capacity. Similarly, within-year continuity constraints give the storages of all within-year time periods in a critical year. The maximum of all such within-year storage volumes is the within-year storage capacity. Active reservoir storage capacity is simply the sum of the over-year and within-year storage capacities. Hence, it is proposed to use the approximate yield model for this study.

6.4.1 Over-year and Within-year Storage Capacities

The over-year storage capacity is governed by distribution of annual stream flows and the annual reservoir yield to be provided. Besides that, additional storage is required if the distribution of stream flows within the year does not coincide with the desired within-year distribution of annual reservoir yield. As such, the within-year constraint is designed so as to ensure that the demand within-the-year can always be satisfied for a specified reliability in the yield.

Without the introduction of within-year continuity constraint in the model, there is every possibility that the reservoir may fail to meet the target demand during low flow periods particularly in summer months, even though the demand on annual basis is well satisfied. Hence, safe or firm yield can also be defined as that annual demand which can be met without the reservoir falling to its dead storage level at any point of time. An illustration of such a situation depicted through Figure 5.1 is by ignoring the within-year continuity constraint.

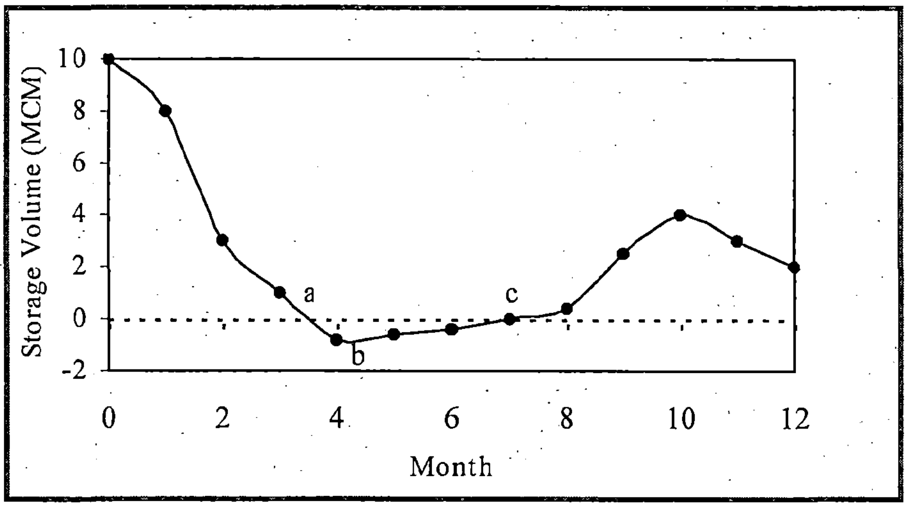


Fig.- 6.1 Within-year storage volume versus time during a dry year

The figure shows the monthly fluctuations in storage volume of a reservoir during a dry year. The starting and end of the year storage values are 10 MCM and 2 MCM, respectively, and therefore give the appearance that the system can satisfy a particular demand in question. However, the area *abc* in Figure 5.1 shows that the reservoir storage will fall below dead storage during the months 4 to 7. Clearly in this case, the safe yield needs to be reduced because of the within-year constraints.

6.4.2 Reliability of Annual Yields

Each historical inflow is associated with a probability to result a yield that can be provided in any future year by a given size of reservoir with a particular operating policy. These probabilities are usually estimated from the unregulated historical flows. So, reliability of any annual yield is the probability that the stream flow in any year is greater than or equal to the value of that yield.

Various methods are employed to estimate the probability that any given stream flow will be exceeded. The commonly employed method is the Weibull plotting position method, which involves the prediction of the mean number of random events that can occur in future. The flow discharge data is arrayed in descending order. Each year's flow so arrayed is assigned the serial number from the top and if M be the serial number of the flow in any year, the percentage dependability for the flow of that year is calculated by applying the formula M*100/(N+1)." The probability associated with such a number is termed as mean probability. The mean probability of any particular stream flow being equaled or exceeded is based on the assumption that any future flow has an equal probability of falling within any interval defined by a sequence of historical and/or synthetically generated stream flows. Having an estimate of the mean probability of a given unregulated stream flow makes it possible to define the mean probability of any particular reservoir yield.

For a known reservoir capacity, in a multiple yield system the maximum possible reliability, *p*, known as *firm annual reservoir yield* is defined, all other yields with reliability less than *p* are *incremental secondary/ annual reservoir yields*. Summation of firm and incremental secondary annual yields is the *total annual reservoir yield*. These yields hereafter in this study shall be referred to as *firm annual yield, secondary annual yield and total annual yield*. Firm annual yield with probability of exceedence *p* will be denoted as Oy^{fp}. Similarly, secondary annual yield with probability of exceedence *p2*, which is less than *p* is denoted by Oy^{sp2}.

6.5 THE APPROXIMATE YIELD MODEL

As discussed in the foregoing section, the model which reduces the size drastically by considering over-year continuity constraint for each year along with an additional set of within-year continuity constraint for the critical period only and capable of producing reasonably accurate results is termed as approximate yield model.

Identification of the critical year and its within-year distribution of inflows is an important as well as a sensitive aspect in particular reference to the within-year continuity constraints and formulation of the approximate yield model. The critical year depends in part on the values of the annual and within-year yields, and it is not possible to identify the same beforehand at the time of model application. In view of the aforesaid difficulties, an approach suggested by Loucks et al. (1981), i.e., by letting some appropriate fraction, β_t, of the total annual yield (outflow) to be the inflow in each period t within the critical year generally gives better result. Hence, $\sum_t \beta_t = 1$. A good choice for β_t is the ratio of inflow in period t of the driest year of record to the total inflow of that year. Each β_t thus reflects the relative proportion of the critical year's inflow that is likely to occur in period t.

The within-year continuity constraints for a single yield can be written as:

$$S_{t-1}^{w} + \beta_t Oy^{fp} - Oy_t^{fp} = S_t^{w} \qquad \forall_t \qquad (6.1)$$

where w = superscript to indicate within-year storage; S_{t-1}^{w} = storage at the beginning of the within-year period t; S_t^{w} = storage at the end of the within-year period t; and Oy_t^{fp} = firm within-year reservoir yield in period t.

Since summation of all β_t equals to one, these constraints ensure that $\sum_t Oy_t^{fp}$ equals the annual reservoir yield Oy^{fp}.

In the equation 4.7, the inflows and required releases are just in balance, so that the reservoir neither fills nor empties during the modeled critical year. This is similar to what would be expected in a critical year that generally occurs at the end of a drawdown period. The within-year capacity Y^{w} is the maximum of all within-year storage volumes, i.e.,

$$S^{w}_{t-1} \leq Y^{w} \qquad \forall_t \qquad (6.2)$$

The total active storage capacity is simply the sum of the over-year storage and within-year storage capacities, i.e.,

$$Y_a = Y^{o} + Y^{w} \qquad (6.3)$$

Combining equation 4.8 and 4.9,

$$Y^{o} + S^{w}_{t-1} \leq Y_a \qquad \forall_t \qquad (6.4)$$

The approximate yield model hereafter in this study shall be referred to as the "*The Yield Model*". This can be applied either to determine the optimal yield for a known reservoir capacity by maximizing the sum of firm and incremental secondary within-year reservoir yields or to obtain the required capacity for desired yields by minimizing the active reservoir capacity.

6.6 THE YIELD MODEL

6.6.1 Single Reservoir Single Yield Model

6.6.1.1 Formulation for firm reservoir yield with maximum reliability (*p*)

The single reservoir yield model to determine the safe or firm reservoir yield with maximum reliability for a known reservoir capacity can be written as:

$$\text{Maximize} \quad Oy^{fp} \qquad (6.5)$$

Subject to the following constraints:

1. Over year storage continuity (equation 5.2), i.e.,

$$S^{o}_{j-1} + I_j - Oy^{fp} - Sp_j = S^{o}_j \qquad \forall_j \qquad (6.6)$$

2. Over-year active storage volume capacity (equation 5.3), i.e.,

$$S^{o}_{j-1} \leq Y^{o} \qquad \forall_j \qquad (6.7)$$

3. Within-year storage continuity (equation 5.7), i.e.,

$$S_{t-1}^{w} + \beta_t Oy^{fp} - Oy_t^{fp} = S_t^{w} \qquad \forall_t \qquad (6.8)$$

4. Active reservoir storage capacity (equation 5.10), i.e.,

$$Y^{o} + S_{t-1}^{w} \leq Y_a \qquad \forall_t \qquad (6.9)$$

5. Proportioning of annual yield in within-year time periods t, i.e.,

$$Oy_t^{fp} = \xi_t (Oy^{fp}) \qquad \forall_t \qquad (6.10)$$

where ξ_t defines a predefined fraction of annual reservoir yield for the within-year yield in period t.

6.6.1.2 Formulation for firm reservoir yield with reliability ($p1$) less than the maximum reliability (p)

The yield model can be used to find out reservoir yields having reliability less than the maximum estimated probability of exceedence p. This also can be called as firm annual yield, although not as firm as the yield corresponding to maximum estimated probability of exceedence p. These are treated as firm so far as the reliability of the purpose for which it is to be used. In these cases a reservoir yield failure is permitted. Reliability of these firm yields are denoted by $p1$.The number of years of reservoir yield failure determines the estimated reliability of each reservoir yield. An annual reservoir yield that fails in n_f years has an estimated probability $[(n - n_f) / (n + 1)]$ of being equaled or exceeded in any future year. Once the desired reliability of a firm annual reservoir yield is known, the problem is to select the appropriate number and the occurrence of failure years (n_f).

The over-year storage continuity constraints can now be written in a form appropriate for identifying a single firm annual reservoir yield with an exceedence probability $p1$ less than the maximum reliability p by incorporating a factor θ_j^{p1}, i. e.,

$$S_{j-1}^{o} + I_j - \theta_j^{p1} Oy^{fp1} - Sp_j = S_j^{o} \qquad \forall_j \qquad (6.11)$$

where θ_j^{p1} = factor to identify a successful or a failure year in case of a single firm yield model with complete failure year and its value will be as follows:

$$\theta_j^{p1} = \begin{cases} 1 & \text{if the annual firm reservoir yield is to be provided in year } j \text{ (successful year)} \\ 0 & \text{if the annual firm reservoir yield is not to be provided in year } j \text{ (failure year)} \end{cases} \qquad (6.12)$$

While writing equation 6.11, the failure year(s) should be selected from among those year(s) in which permitting a failure decreases the required reservoir capacity for a desired reservoir yield, or increases the reservoir yield for a given reservoir capacity. If a failure is selected in which excess release (spill) would be made anyway, no reduction in the required active storage capacity will result, and the reliability of the reservoir yield may be higher than intended.

The failure years, if any, must be selected from within the critical drought periods for the desired reservoir yield. The critical year(s) that determine the required active storage volume capacity may be dependent on the reservoir yield itself. When the magnitude of the reservoir yield is unknown, some trial and error procedures may be necessary to ensure that any failure years are within the critical period of years for the associated reservoir yield. To ensure a wider range of applicable reservoir yield magnitudes, the years having the lowest flow within the critical period should be selected as the failure year if only one failure year is selected.

6.6.2 Single Reservoir Multiple Yield Model

This yield model defines two reservoir yield, i.e., firm or safe yield with given reliabilities p and an incremental secondary annual reservoir yield having a reliability $p2$ less than the firm yield can also be incorporated in the model. For example, let us assume that two annual reservoir yields are desired from 99 years of historical stream flow record, one with 99% reliability [$p = 99 / (99 + 1)$] and the other with 75% reliability [$p2 = 75 / (99 + 1)$]. Let, Oy^{fp} and Oy^{sp2} represent these annual yields having reliabilities of 0.99 and 0.75, respectively. The incremental secondary annual yield Oy^{sp2} represents the amount in addition to Oy^{fp} and is only 75% reliable. Aforesaid statement implies that, no failure year is allowed in firm annual yield where as 24 failure years are allowed in case of incremental secondary annual yield. In case of the 75% reliable incremental secondary yield, the factor θ_j^{p2} shall be 1 for seventy five successful years and zero for 24 selected failure years.

Thus the over-year storage continuity constraint (equation 6.11) can now be written as:

$$S_{j-1}^{o} + I_j - Oy^{fp} - \theta_j^{p2} Oy^{sp2} - Sp_j = S_j^{o} \qquad \forall_j \qquad (6.13)$$

where $\theta_j^{p2} = \begin{cases} 1 & \text{in successful years} \\ 0 & \text{in failure years} \end{cases}$

In multiple yield problems, the factor θ_j^{p2} for secondary reservoir yields are zero in failure years; otherwise, the firm yield is essentially increased by $\theta_j^{p2} Oy^{sp2}$.

6.6.2.1 Incorporation of evaporation losses

Evaporation is an important aspect in reservoir system. Substantial part of the stored water in the reservoir is lost through evaporation. Therefore, it is essential to account for reservoir evaporation losses into the model to achieve secured planning. Since the approximate yield model discussed in the foregoing sections does not directly identify the exact storage volumes at the beginning of each period in each year, evaporation losses must be based on an expected storage volume in each period and year. The approximate expected storage volume in any period t in year j can be defined as the initial over year volume S^o_{j-1}, plus the estimated average within-year volume $[(S^w_{t-1} + S^w_t)/2]$. The annual evaporation volume loss Ev_j in each year j can be based on these estimated average storage volumes. The storage area relationship and approximation of surface area per unit active storage volume is shown in Figure 4.1.

$Ev^a = A_a \times$ Average annual depth of evaporation

and $Ev^0 = A_0 \times$ Average annual depth of evaporation.

Where Ev^a = average annual evaporation volume loss rate per unit of active storage volume, Ev^0 = average annual fixed evaporation volume loss from the dead storage, A_a = water surface area per unit active storage volume beyond dead storage level and A_0 = water surface area at dead storage level.

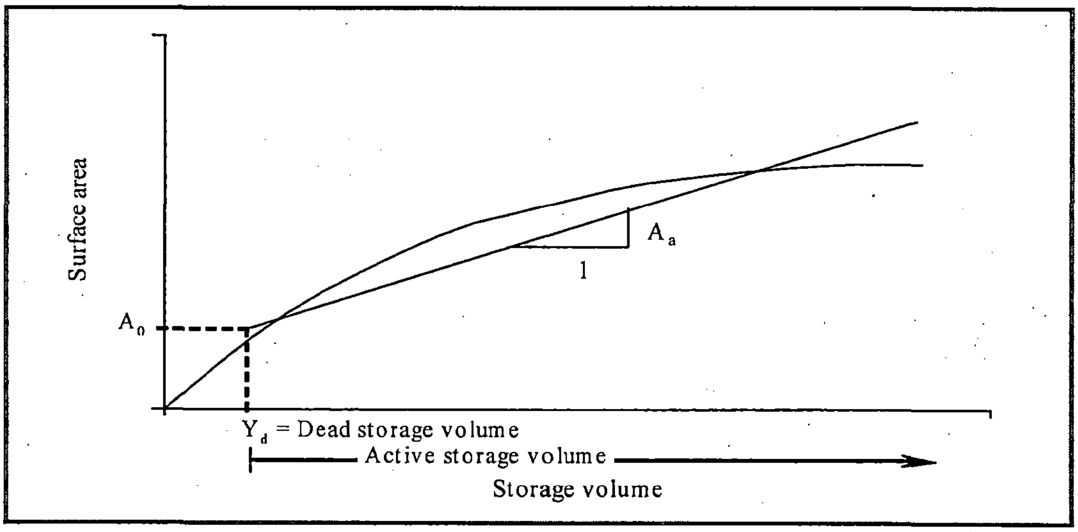


Fig.-6.2 Storage Area Relationship and Approximation of Surface Area per Unit Active Storage Volume

The evaporation loss will be approximately equal to the average annual fixed loss Ev^0 from the dead storage, plus the sum of each period's volume loss per unit of active storage volume times the expected storage volume in the period. Let γ_t be the fraction of the annual evaporation loss that occurs in period *t*. The evaporation equations are already given in previous section (Eq.4.14, Eq.4.15)

$$Ev_j = \sum_t \left[\gamma_t Ev^0 + \left(S^o_{j-1} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t Ev^a \right] \qquad \forall_j \qquad (6.14)$$

Since the sum of all fractions γ_t equals 1, equation 5.21 can be simplified to

$$Ev_j = Ev^0 + \left[S^o_{j-1} + \sum_t \left(\frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t \right] Ev^a \qquad \forall_j \qquad (6.15)$$

The within-year evaporation loss in each period t of the critical year is approximately

$$Ev_t = \gamma_t Ev^0 + \left(S_{cr}^o + \frac{S_{t-1}^w + S_t^w}{2} \right) \gamma_t Ev^a \qquad \forall_t \qquad (6.16)$$

Where S_{cr}^o = initial over-year storage volume in the critical year.

6.6.2.2 Mathematical statement of single reservoir multiple yield model

The single reservoir multiple yield model now can be written to derive two types of reservoir yields of the desired reliabilities by incorporating constraints to take into account the evaporation losses. This can be applied either to determine the optimal yield for a known reservoir capacity by maximizing the sum of firm and secondary within-year reservoir yields or to obtain the required capacity for desired yields by minimizing the active reservoir capacity.

Objective function: Maximize $\sum_t \left(Oy_t^{fp} + Oy_t^{sp2} \right)$ (6.17)

Or Minimize Ya (6.18)

Subject to the following constraints:

1. Over-year storage continuity

$$S_{j-1}^o + I_j - Oy^{fp} - \theta_j^{p2} Oy^{sp2} - EV_j - Sp_j = S_j^o \qquad \forall_j \qquad (6.19)$$

$$\theta_j^{p2} = \begin{cases} 1 & \text{in successful years} \\ 0 & \text{in failure years} \end{cases}$$

2. Over-year active storage volume capacity

$$S_{j-1}^o \le Y^o \qquad \forall_j \qquad (6.20)$$

3. Within-year storage continuity

$$S_{t-1}^w + \beta_t \left[(Oy^{fp} + Oy^{sp2}) + \sum_t Ev_t \right] - (Oy_t^{fp} + Oy_t^{sp2}) - Ev_t = S_t^w \qquad \forall_t \qquad (6.21)$$

4. Estimated annual evaporation losses

$$EV_j = EV^o + [S^o_{j-1} + \sum_t (\frac{S^w_{t-1} + S^w_t}{2})\gamma_t]EV^a \qquad \forall_j \qquad (6.22)$$

5. Estimated evaporation losses in each within-year period t of the critical year

$$Ev_t = \gamma_t EV^o + [S^o_{cr} + \frac{S^w_{t-1} + S^w_t}{2}]\gamma_t EV^a \qquad \forall_t \qquad (6.23)$$

The initial over year storage volume in the critical year, i.e., S^o_{cr} is assumed to be zero.

6. Total reservoir storage capacity

$$Y^o + S^w_{t-1} \leq Ya \qquad \forall_t \qquad (6.24)$$

7. Within-year yield

$$Oy^{fp} = \sum_t Oy^{fp}_t \qquad (6.25)$$

$$Oy^{sp^2} = \sum_t Oy^{sp^2}_t \qquad (6.26)$$

8. Irrigation target

$$Oy^{fp} + Oy^{sp^2} \geq K_t * Ir \qquad \forall_t \qquad (6.27)$$

6.6.2.3 Proportion of total annual yield in failure years (Ǿ)

The model presented in the preceding section did not consider an allowable deficit criterion as the incremental secondary annual yield is made zero during the failure years by setting the value of factor θ^{p2}_j equal to zero. Thus, while maximizing annual yield, the model in the above stated form may not produce desired proportion of the total annual yield during failure years. To over come this other additional constraint is applied. So, in order to obtain the identical results as that of in the single yield model with allowable deficit in the failure years, a relation, i.e., firm annual reservoir yield equals **failure fraction** times the total annual reservoir yield is represented in the following form, i.e.,

$$Oy^{fp} = \frac{\phi}{1-\phi} Oy^{sp^2} \tag{6.28}$$

where $\acute{\phi}$ =fraction of total annual yield desired to be released in the failure years from reservoir.

6.7 APPLICATION OF YIELD MODEL TO HARBHANGI IRRIGATION PROJECT

6.7.1 Computation of β_t of the Project

From the annual flow-duration curve obtained from the 42 years flows, the β_t values for the 75% water year dependability (a normal year), 90% water year dependability (a low flow water year) and 100% water year dependability are estimated and for these flows and for the average flow year for the within-year inflow distribution coefficients β_t for 12 within-year periods of the reservoir are calculated and furnished in Table-2.2. Also the variation is plotted in Fig.-6.3.

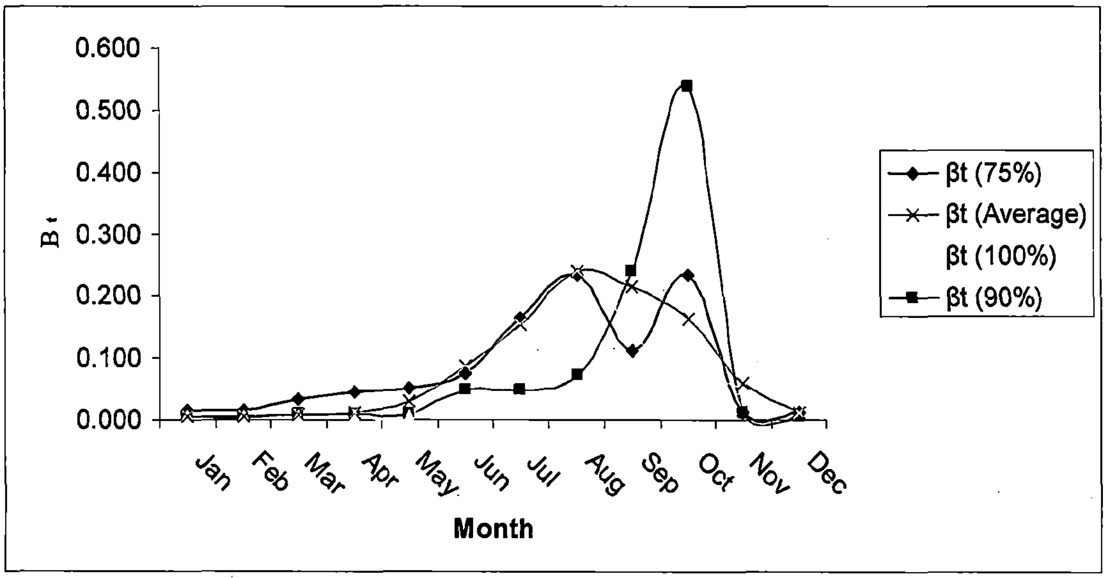


Fig.-6.3 Monthly Variation of β_t

The β_t values are computed for the 75% and 90% water year dependabilities for two within-year periods for the monsoon and non-monsoon are 0.8189 and 0.1811 and 0.9486 and 0.0514, respectively.

6.7.2 Evaporation Parameters of the Harbhangi Reservoir

With the available elevation-area-capacity data, above said curve of the reservoir is drawn and evaporation parameters are determined and given bellow.

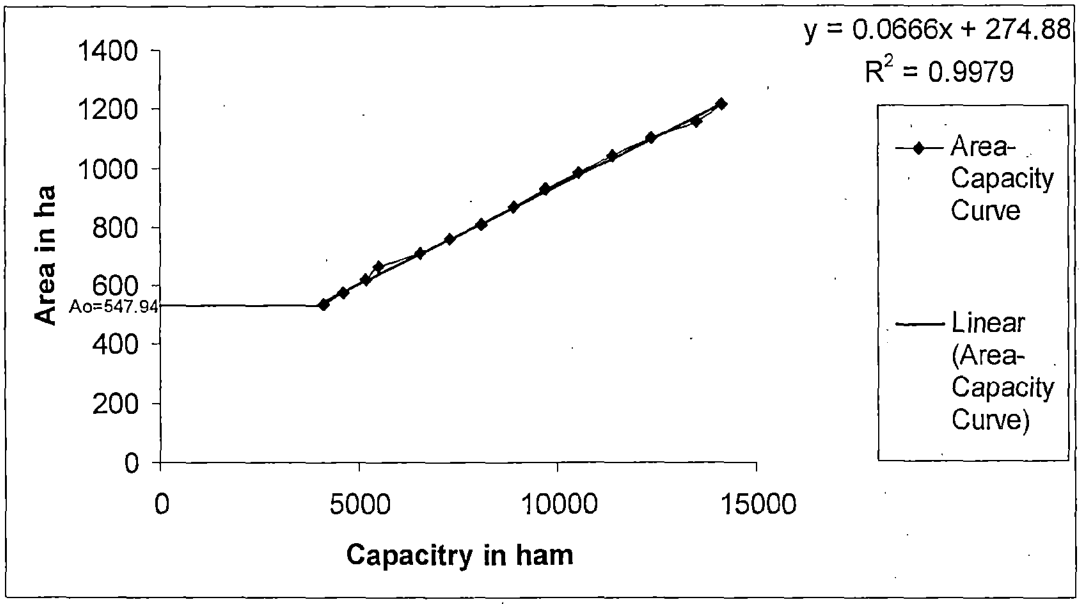


Fig.-6.4 Evaporation Parameter Computation

Hence the evaporation parameters are

A_0 =Area at dead storage level as per linear assumption = 547.94 ha

A_a =Area per unit active storage volume = 0.0666 ha/ham

D= Depth of average annual evaporation =1.347m

El_r=Evaporation for unit active storage (A_aXD) = 0.0897 ham

6.7.3 Computation of γ_t

Average annual and monthly evaporation coefficients (γ_t) are calculated from the daily pan evaporation data available for the period 2001-2003 in Dhaugaon hydrometeorological station. Pan coefficient for the reservoir is taken 0.9 for arid region.

Lake Evaporation=P_c*Pan Evaporation where P_c=pan coefficient

Table-6.1 Average monthly pan evaporation data of Dhaugaon station

Month	Monthly Pan Evaporation in mm	Monthly Lake Evaporation in mm	Monthly Evaporation Coefficient (γ_t)
January	93.9	84.51	0.0627
February	123.6	111.24	0.0826
March	155.3	139.77	0.1038
April	188.9	170.01	0.1262
May	227.8	205.02	0.1522
June	141.4	127.26	0.0945
July	118.3	106.47	0.0791
August	98	88.2	0.0655
September	96.2	86.58	0.0643
October	91.8	82.62	0.0613
November	81.5	73.35	0.0545
December	79.8	71.82	0.0533
Annual	1496.5	1346.85	

For within year constraints, Case-I with two within-year periods and Case-II with twelve within-year periods are considered. Within-year inflows to the reservoir are taken as per the β_t values. The Case-IA and Case-IB for the normal and low flow water years, respectively, and Case-IIA and Case-IIB for the normal and low flow water years, respectively are considered. The K_t values for both the cases for scheduled irrigation target and minimum irrigation target are same as the crop area required for the minimum food requirement are taken in proportion to the scheduled cropping pattern. For the various values of ø, i.e., failure fraction annual firm, secondary and total yields were calculated for the existing live storage capacity of reservoir of 10.025Tham for 75% water year dependability. Single yield model is run for minimum nutritional target and studied for the maximum reliability which can be achieved for normal flow year and low flow year. Multi yield model is run for the scheduled irrigation target. Models are run using the LINDO package for LP model solutions. Main aim of the yield model is to increase the irrigation intensity and likely switch over to the better cash crops like sugarcane.

6.8 RESULTS AND ANALYSIS

6.8.1 Single Yield Model

About 80% of the annual irrigation target, i.e., 13.22Tham can be achieved as single yield for the scheduled irrigation intensity with twelve within-year period analysis. Thus, single yield can be achieved for irrigation target for the minimum food production requirement i.e. 12.00Tham. This analysis is done for the normal flow year. Total annual irrigation target i.e. 16.37Tham can be achieved at 95% dependable flow. Similarly, for critical flow condition, about 70% of the annual irrigation target i.e.10.5Tham can be achieved as single yield for the same within-year period and total target cam be achieved with 75% dependable flow.

6.8.2 Multi Yield Model

For the various values of ø, annual firm, secondary and total yields are calculated for 75% water year dependability and are plotted with their corresponding ø values for the cases I(A) and II(A) in Figures-4.3 and 4.4,Table-4.7 and 4.8 respectively. The total annual yield for cases I(B) and II(B) is also plotted in these figures. It is observed that the total optimal yield increases nonlinearly with the decrease of annual firm yield or ø and becomes constant at the maximum value, i.e., maximum probable reservoir yield for ø equal to 0.44 and 0.36 for normal and low flow year, respectively for cases-I(A) and I(B). Similarly ø equal to 0.44 and 0.48 for normal and low flow years, respectively for cases-II(A) and II(B). Total annual yield for normal and low flow condition for cases-I(A) and I(B) is 21.93Tham and 20.84Tham, respectively, where as for cases-II(A) and II(B) it is 21.93Tham and 15.24Tham, respectively. So, it is found that due to 12 monthly within-year periods, the annual yield variation is very high as compared with two within-year time periods, which is obvious. Firm yield and total yield decrease with the decrease of value of β_t for the non-monsoon season, i.e., non uniform inflow pattern.

To satisfy the annual irrigation target of 16.63Tham for scheduled irrigation intensity of the project the multi yield model results show that for both the cases-I(A) and II(A) the annual release reliability of firm yield can be achieved at 95% dependability for the given irrigation target as total yield.

Table-6.2 Yield chart for two time within-year period

Two Period Yield Scenario (Normal flow condition)					Two Period Yield Scenario (Critical flow condition)				
Sl.No.	Failure Fraction	Firm Yield in Tham	Secondary Yield in Tham	Total Yield in Tham	Sl.No.	Failure Fraction	Firm Yield in Tham	Secondary Yield in Tham	Total Yield in Tham
1	upto	10.46	11.8	22.26	1	upto	8.07	13.16	21.23
2	0.47	10.46	11.8	22.26	2	0.38	8.07	13.16	21.23
3	0.48	10.66	11.55	22.21	3	0.39	8.18	12.8	20.98
4	0.50	10.81	10.81	21.62	4	0.40	8.29	12.43	20.72
5	0.60	11.47	7.65	19.12	5	0.50	9.20	9.2	18.40
6	0.70	11.99	5.14	17.13	6	0.60	9.92	6.62	16.54
7	0.80	12.42	3.1	15.52	7	0.70	10.52	4.51	15.03
8	0.90	12.77	1.42	14.19	8	0.80	11.01	2.75	13.76
9	0.99	13.04	0.13	13.17	9	0.90	11.43	1.27	12.70
					10	0.99	11.75	0.12	11.87

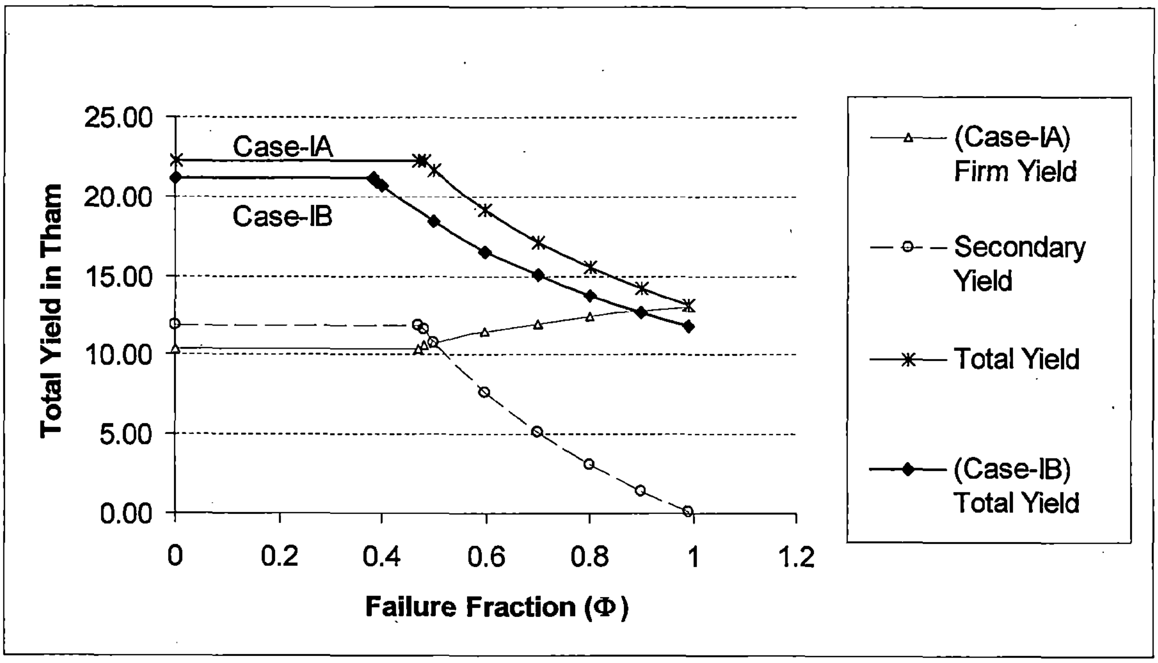


Fig.-6.5 Variation of Yields with Failure Fraction (two period)

Table-6.3 Yield chart for twelve within-year time period

Twelve Period Yield Scenario (Normal flow condition)					Twelve Period Yield Scenario (Critical flow condition				
Sl.No.	Failure Fraction	Firm Yield in Tham	Secondary Yield in Tham	Total Yield in Tham	Sl.No.	Failure Fraction	Firm Yield in Tham	Secondary Yield in Tham	Total Yield in Tham
1	upto	10.00	12.22	22.22	1	upto	7.17	8.42	15.59
2	0.45	10.00	12.22	22.22	2	0.46	7.17	8.42	15.59
3	0.46	10.15	11.92	22.07	3	0.51	7.32	7.13	14.45
4	0.50	10.48	10.48	20.96	4	0.54	7.57	6.33	13.9
5	0.60	11.16	7.44	18.6	5	0.60	8.31	5.54	13.85
6	0.70	11.71	5.02	16.73	6	0.65	8.94	4.75	13.69
7	0.80	12.15	3.04	15.19	7	0.72	9.48	3.69	13.17
8	0.90	12.52	1.39	13.91	8	0.77	9.94	2.9	12.84
9	0.99	12.80	0.11	12.91	9	0.99	10.80	0.11	10.91

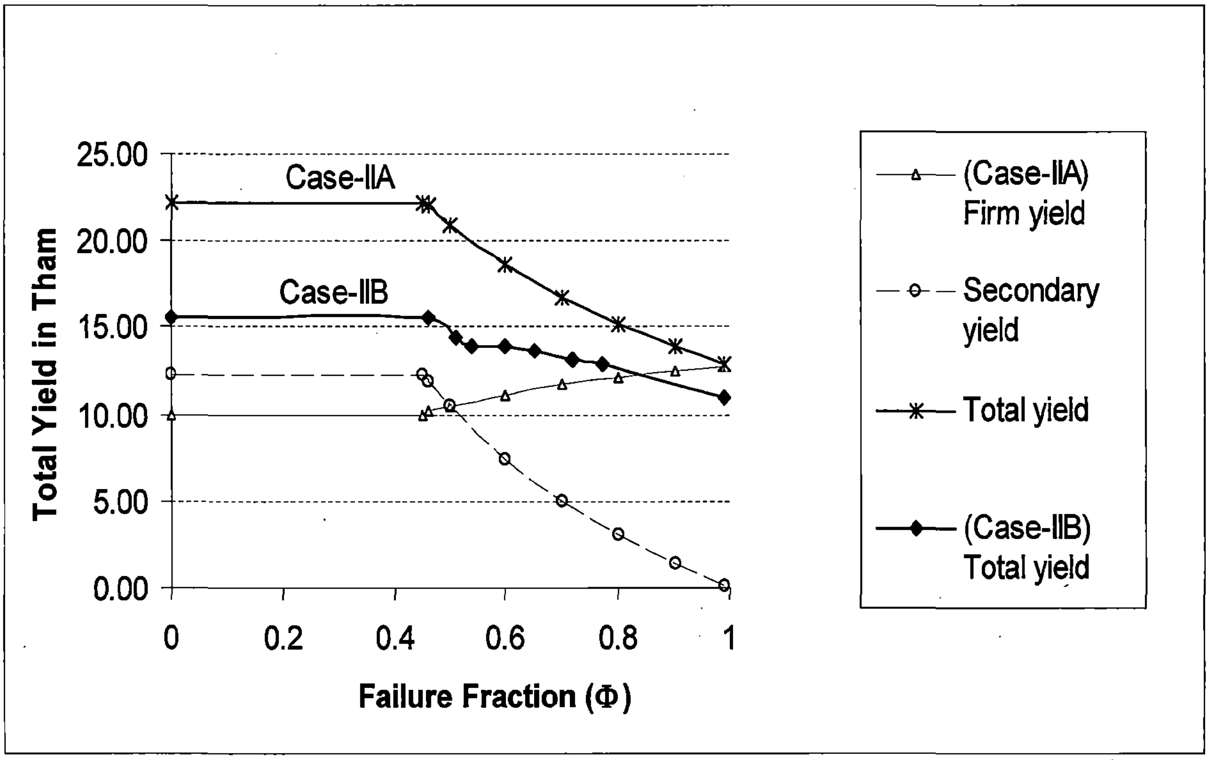


Fig.- 6.6 Variation of Yields with Failure Fraction (twelve period)

6.9 CONCLUSION

a) Total annual irrigation water requirement of the project comes out to be 16.37Tham instead of 18.67Tham (Dept. project report).

b) Value of annual irrigation water requirement for the minimum crop produce required of the project command area for the stabilized population, (i.e., no growth stage by 2041 A.D.) is estimated to be 12.00 Tham.

c) It is observed that on increase of annual firm yield, the corresponding secondary annual yield decreases at a higher rate in comparison to the increase in firm yield, resulting decrease in total annual yield.

d) For achieving a firm annual irrigation target of 12.00 Tham for the minimum crop produce at 100% annual release reliability, can be achieved with the existing capacity of 10.025Tham.

6.10 FORMULATION OF YIELD MODEL FOR DSS

The yield model developed is to be solving using linear programming (LP) technique. A computer program for solving linear programming was developed using FORTRAN language.

The most important and tedious job is to prepare input data matrix for a LP problem. The input data can be easily prepared by manually if the LP problem is small one. With some difficulty, it can be prepared for medium size LP problem. But for the large size problems, it is almost difficult tax to prepare an input data matrix without committing error. Hence it was necessary to device an algorithm and code it in the form of a computer program for generating the coefficient matrices necessary for the yield model formulation as per the data input requirement for the LP solution program. Here, the input data for the previously available FORTRAN program to prepare the yield model input matrix are almost all parameters of the yield model.

6.10.1 The Coefficient Matrix Generation Algorithm

If the coefficients of the over year storage continuity equation containing the subscript j for the year are appearing by shifting diagonally in every subsequent year. Similar trend is observed in the other equations also. Other information required for generation of non-zero coefficients in this equation is in-built in the equation itself. The complete input data requirement for generation of non-zero coefficients in this model is separated out, the required input data shall be as follows:

Number of years of flow record (MMOC), Annual flow values, Values of θp,j, or the allowable deficit, Number of within year periods (MMWC), Bt values for within-year periods, Kt values for within-year periods and failure fraction.

Note that the over-year and within year variables are separated out and arranged in a specific chronological order; e.g. the over-year storage variables, the annual excess release variables i.e. over year spill, the annual firm yield, annual secondary yields, the active storage, the within-year storage variables, the within year firm and within year secondary yield. It should now be easy to note down the column index number (CIN) for start of the different variables. Now, the program is modified to take the column index number according to input value of MMOC and MMWC by keeping the sequence of the variables fixed as mentioned above.

6.10.2 The Basic Algorithm

a. Set the time index/indices (annual and/or within-year) to 1

b. CINs' of all the variables to their initial values are established as per the data set.

c. Set the CIN of the first variable appearing in the equation (time-dependant or otherwise)

d. Record the numerical coefficient of this variable (either in-built in the equation mainly in the form of ± 1 or to be extracted from the data set).

e. If the next variable is also time dependent, increment the CIN (for the year or within-year period), and record its numerical coefficient as in step 4. Alternatively, if the next variable is time-dependent, note its CIN, and record its numerical coefficient.

f. If the list of all variables is exhausted go to step (g), otherwise go to step (e).

g. Increment the time index by one, and increment the CIN of each time-dependent variable if required in accordance with the form of the equation. If all the time periods (annual or within-year) are not over then go to step ©, otherwise terminate.

The steps (a) to (g) constitute the basic algorithm for generating the non-zero coefficients for a given equation. The columns that do not contain the non-zero coefficients were required to be set equal to zero, and which automatically remain zero in this process as an array of a given dimension declared by a computer program is initialized to zero.

6.10.3 Final Reservoir Yield Solution Program

LP solution FORTRAN program coupled with the matrix generation program to make it easier for getting the LP solution in one step. This improved FORTRAN program is has the following advantage and suitability over the previous program.

1. Column Index Number (CIN) is automatically calculated and fixed as per MMOC and MMWC.
2. It is used to get annual total yield, firm yield and secondary yield.
3. It can be run in Visual Basic (VB) environment to achieve the objectives with two options i.e. a. maximize the yield and b. minimize the spill.

4. One failure fraction parameter is introduced to study the behavior of the secondary yield and total yield with increase in firm yield. Alternatively, this can be utilized for the study of release reliability of the reservoir towards the mandatory demand of the command area.
5. This program can be used for the number of reservoirs but for the VB it is designed for single reservoir.
6. Error introduced in handling the huge input matrix is completely avoided.
7. One target flow value introduced which will assign θj value for the secondary yield after comparing annual flow value in each step.

This program is run for this reservoir yield study and results are compared with the LINDO solution. Results are perfectly matching. Hence, for the multi reservoir system or for the single reservoir it is better to use this program to get the solution immediately. Also, the data input procedure is very simple. Hence, error in preparing number of equations for small reservoir the yield model solution in LINDO can be avoided. Flow chart for the generation of the coefficient matrix is given in fig.-6.7

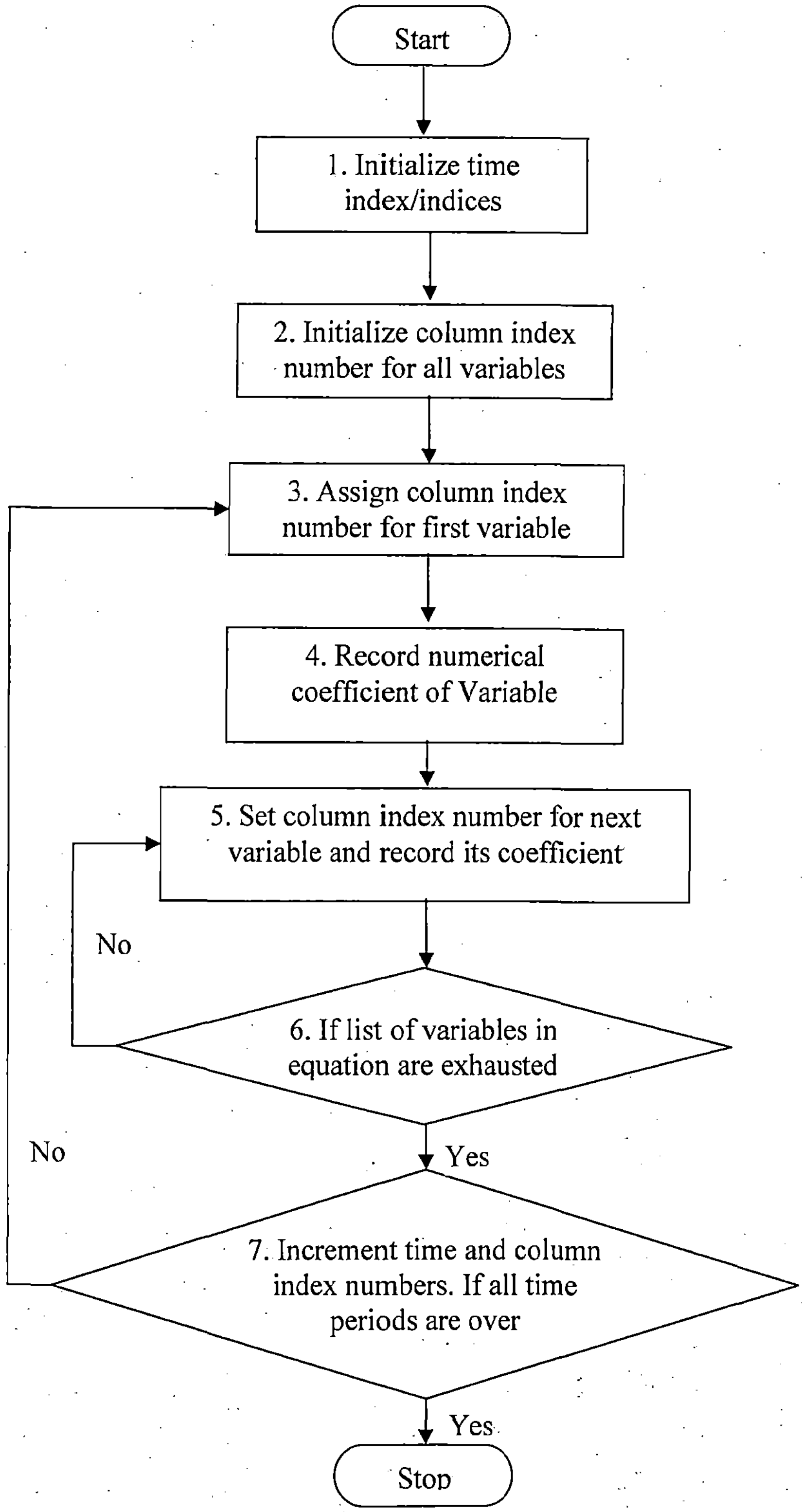


Fig-6.7 Flow Chart for Coefficient Matrix Generation

CHAPTER-7

IRRIGATION SCHEDULING

7.1 GENERAL

Irrigation is essential for optimal agricultural production in arid and semi-arid regions where rainfall is inadequate and highly non-uniform temporal distribution to sustain ideal crop. Indeed, in more humid areas irrigation has now become the primary tool to increase and stabilize agricultural production in view of uncertainties of rainfall and frequent droughts, and to feed an ever increasing world population. Also, the excessive use of water has led to a range of environmental problems such as water logging, leaching of agro-chemicals leading to salinization and consequent groundwater pollution. Thus, inappropriate water use is a new threat to large areas of productive irrigated land. Irrigation scheduling is the technique to apply the water to the crop timely and accurately considering current spatial and temporal distribution of cropping pattern and soil moisture condition. Hence, it is the primary tool to improve water use efficiency and raise yields, and in turn will lead to higher incomes and higher dependable water availability from limited resources, and provoke a positive effect on the quality of soils and groundwater.

Total crop water use of all the crops of any basin is the summation of root water uptake, soil evaporation, interception and the spatial as well temporal pattern of soil water use.

Though a large number of irrigation scheduling methods are available but most common methods are being used as follows:-

a. Feel the soil in hand and study the appearance of soil to provide the irrigation, is a very crude method and an expert knowledge required over the valuation of soil moisture at that time, to take the decision.

b. Gravimetric soil moisture sample, tensiometers and electrical resistance blocks involve labour intensive field works in sampling and measuring the moisture content of the soil. Also the standard sampling may not be well representative of the total area.

c. Water budget or water balance approach requires some climatic parameters like temperature, radiation, wind speed, humidity and expected rainfall depending on the models used and does not require any field work.

Water balance approach is much flexible and user friendly with provision to modify each input variable as per actual site and management requirements using MS Excel spread sheet.

7.2 WATER BALANCE APPROACH

The water balance method of irrigation scheduling is simply same as reservoir storage simulation. Daily outflow, evaporation and other losses are subtracted from reservoir storage and inflow to the reservoir is added such that knowing of initial storage of reservoir on the beginning of a given day and the sum of flows on that day, the final storage of the reservoir can be calculated at the end of that day.

In field, for irrigation scheduling, soil mass is taken as a reservoir and its water content is treated as reservoir storage which is balanced. The amount of water that is lost as ET_c is analogous to withdrawals. The water that enters the soil reservoir (as rain or irrigation) is analogous to inflow into the reservoir. It is possible to know how much water is left in the soil reservoir at anytime, thus indicating whether the irrigation is needed or not.

The initial balance can be determined by direct observation or assessed after a thorough wetting of the soil by irrigation or rains. Daily quantities of ET_c are depleted until the soil water has been reduced to the desired level. At that point irrigation should be applied with net amount equivalent to the accumulated ET_c losses since the last irrigation. The soil profile is thus recharged to full capacity, and the cycle repeats. If full recharge is not desired or not possible, the new balance can be determined from the net irrigation amount or by field observations. This method, however, may not work well at locations where contributions to ET_c from a water table, or other source, cannot be quantified. However here the water balancing is taken up on ten daily basis.

The equation for first day of any period (t) is calculated from the soil water on the previous period (t –1), plus the rain and irrigation and minus ET_c, drainage and runoff that occurred since the previous day as:

$$S_t = S_{(t-1)} + R_t + I_t - ET_t^c - (D_t + R_t^o) \quad (7.1)$$

where S_t= Soil water content at the end of t[th] period day (mm); $S_{(t-1)}$ = Soil water content at the beginning of t[th] period (mm); R_t = rain during t[th] period (mm); I_t = irrigation depth during t[th] period(mm); ET_t^c = actual crop-evapotranspiration during t[th] period (mm); $D_t + R_t^o$ = drainage and runoff that occurred t[th] period [redacted] (mm). To carry out water balance, the soil water content is determined using gravimetric soil moisture sample, irrigation and rainfall depth is measured or calculated. If rain exceeds the depth of water depleted from field capacity, the difference is considered as deep percolation and/or surface runoff and is not available for plants. The actual ET_t^c, which is the actual daily withdrawal in the water balance equation (Eq.4.1), is not measured easily and is estimated from weather and crop type data.

7.2.1 Definitions

The frequently used terms for the crop scheduling by water balance method is briefly explained bellow:

(a) Available soil moisture

It is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point, referred to as the available water storage capacity.

(b) Saturation

Saturation occurs when all the voids in the soil are completely filled with water. Although there is plenty of water available to the crop at saturation, water uptake is seriously curtailed by the lack of oxygen in the soil at soil water contents greater than field capacity.

(c) Field capacity

Field capacity is the water content of the soil where all free water has been drained form the soil through gravity. Sandy soils may drain within a few hours but fine textured soils such as clay may take a few days to drain. Proper irrigation brings soil moisture up to filed capacity.

(d) Management allowable depletion (MAD)

The MAD is the percent of field capacity or in depth of available soil moisture upto which it is allowed to be depleted before irrigation is applied. Irrigation is promptly applied when the allowable amount of water is depleted from the root zone. Depletion beyond the allowable amount stresses plants and reduces crop yield. For setting allowable depletion limits it is important to note that a dry soil layer below the soil will restrict root development and result in a shallow rooting depth. June and July months generally produce more rainfall than evaporation for most crops. During the period, if irrigation is needed then a lighter than normal application of water to partially refill the soil water deficit is recommended which maximizes the use of rainfall while minimizing the leaching potential of agrichemicals within the soil profile. As crop nears mid-season stage, typical period for most crops' critical growth stage and the peak crop water use, the allowable soil moisture depletion limit is reduced to minimize the risk of plant moisture stress and subsequent economic yield losses. AS crops near maturity, the soil water depletion may be increased to greater limits without causing stress. This factor varies but is usually around 50% and also be termed as maximum soil water deficit (MSWD).

7.3 CROP SCHEDULING

7.3.1 Soil Parameter Estimation

a. Different crop are grown in different soils, primarily according to their water requirement but sometimes farmers have changed the soil criteria as per irrigation practice and availability of cultivable land with the ayacut area. The water holding capacity (C) (Source: - http://www.ext.colostate.edu/pubs/crops) for the each crop is taken with respect to type of soil and normally expressed as mm/m depth.

b. Root depths (d) of the different stages for all the crops are taken tentatively. Root depth for the early stage and development stage is taken around 300mm and for the mid stage & late stage, different values are taken for the different crops (Source:- Irrigation water management, FAO, http://www.fao.org/docrep-26/6/2008).

c. Maximum available soil moistures (D_m) for the crop in different stages are depending upon the root depth of the crop for respective stages and calculated as follows:-

$$D_m = C * d \quad (7.2)$$

d. Management Allowable Depletion (MAD) for all the crops are different during different stages with respect to the sensitivitiness of the crops in respective stages. 50% depletion is allowed in early stage and development stage. Then in mid stage it is kept constant and subsequently increased to the 70% in late stage. (Source http://www.cdfa.ca.gov)

Depletion depth (DL)=MAD*D_m (7.3)

For each type crop a standard soil type, root depth and MAD for the different stages of that crop is taken on basis of the practice of the project, also studying different papers on this aspect. The details are furnished in the Table-7.1.An average root depth value for the initial stage and developing stage, also a single root depth for mid stage and late stage is considered for each crop type. Similarly the MAD for the each crop type is taken 50% for all stages except late stage, when MAD is taken 70% (source:Parhi, P ,WRIS-2007). With the above soil parameters, the field capacity of the early stage and mid stage calculated and field capacity for the different periods of the developing stage is interpolated. The field capacity calculated for the late stage is assumed to be achieved at the end period of the late stage. So, the field capacity of the other periods of the late period will be interpolated with similar manner.

Table-7.1 Soil parameters of all the crops

Crop type	Soil Type	Water Holding Capacity in mm/m	Root Depth in mm			
			Initial Stage	Developing Stage	Mid Stage	Late Stage
Paddy-K	Silty Clay	140	300	300	500	500
Paddy-R	Silty clay	120	300	300	500	500
Raggi	Clayey Silty	130	300	300	800	800
Maize	Silty Clay loam	150	300	300	900	900
Groundnut	Sandy Clay	120	300	300	700	700
Sugarcane	Silty Clay	120	300	300	1200	1200
Pulses	Clayey loam	120	300	300	900	900
Vegetable	Sandy clay	120	300	300	700	700
Potato	Clayey sand	120	300	300	700	700
Mustard	Silty Clay	120	300	300	700	700

e. It is observed that the evapotranspiration of the crop will go on decreasing with depletion in soil moisture beyond the field capacity. Hence soil coefficient (K_s) is introduced along with crop coefficient and calculated as per the Table-7.2 (Source: http://www.ext.colostate.edu/pubs/crops/04707.html).These values are generalize with a linear correlation equation given in Fig. - 1.Derived equation:

$$K_s=-.0035*(\text{Depletion in }\%)+1.013 \text{ (Limited to 1)} \qquad (7.4)$$

where K_s = soil coefficient

Table-7.2 Soil coefficient

Depletion %	0	5	10	15	20	25	30
KS	1	0.98	0.97	0.96	0.95	0.94	0.92
Depletion %	35	40	45	50	60	70	
KS	0.9	0.89	0.87	0.85	0.8	0.74	

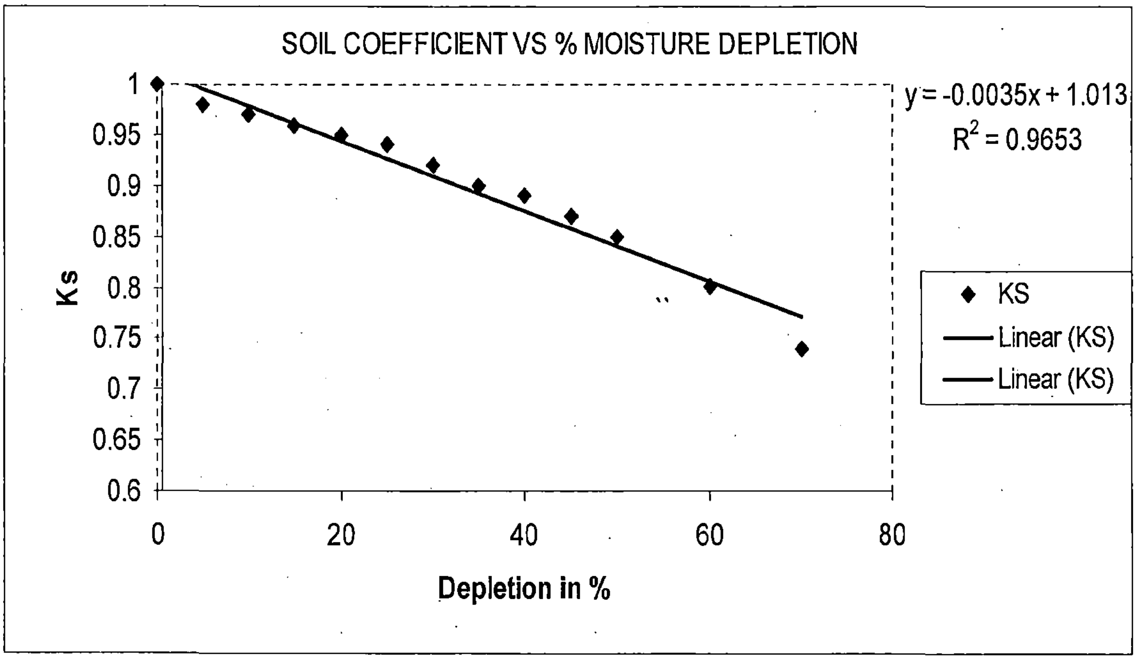


Fig.-7.1 Soil Coefficient Variation Curve

7.3.2 Calculation of CWR of the crops (Ten daily).

Crop water requirement of each crop is previously calculated with single crop coefficient method. Considering the initial and final soil moisture condition of each time period, the K_s (soil coefficient) is estimated and average soil moisture depletion for each time period is calculated. Then Ks is incorporated for estimating crop water requirement.

Detail steps are as follows:-

a. Calculation of ET_t^o for required period from the available hydro- meteorological data. The detail procedure for calculation is discussed in previous chapter.

b. K_c values, corrected K_c values and crop water requirement for all the crops of the project for different time period are calculated previously for study of the yield model of the reservoir is taken same for the scheduling calculation.

c. Actual field crop evapotranspiration (ET_t^c) required at field considering soil coefficient and crop coefficient is

$$ET_t^c = K_s * K_c * ET_0 \quad (7.5)$$

7.3.3 Irrigation scheduling (for each crop)

The irrigation scheduling is prepared for the individual crop for one hectare basing on the following principles.

a. For each crops the initial soil moisture of the field will be assumed according to the standard available moisture during month of plantation and initial irrigation will be applied to the field to bring the soil moisture to field capacity.

b. Next irrigation will be provided when the final soil moisture of field will exceed the management allowable depletion (MAD) and irrigation will be applied to bring the soil moisture back to the field capacity.

c. Effective rainfall for the ten daily is taken one third of the previously calculated monthly effective rainfall. Also effective rainfall and field ET_c are considered simultaneously because the scheduling is prepared for ten daily.

d. The field capacity of the soil is taken maximum available soil moisture and MAD is taken 0 during the land preparation period for the paddy crops.

Considering the above criterion the scheduling is prepared for all the crops in excel sheet for ten daily with water balance method utilizing equation-7.1-7.5 and one sample calculation for late paddy crop of khariff period is attached (Table-7.3)

7.3.4 Determination of Crop Area (for each zone)

Canal network system having total ayacut area of 9650 Ha is divided into five zones according to the ayacut area covered under the major distributaries, availability of control system (Head regulator or cross regulator) and its location with respect to the starting point of the irrigation diversion. Number of canals, total ayacut area and design discharge of each zone is furnished in Table no.7.4A. All the head regulator details are furnished in Table-7.4A and 7.4B. It is assumed that the cropping pattern and irrigation intensity of the each zone will be same that of whole command area and cropping areas for different crops of each zone are calculated and furnished in Table-7.5. Major canals included in different zone, their self ayacut and total ayacut are previously furnished in the Table-2.3.

IRRIGATION SCHEDULING OF THE EARLY PADDY ON TEN DAILY BASIS

Application efficiency =	0.7 (γa)
Root depth of Rice =	300 mm(Initial and growing stage)
	500 mm(mid and late stage)
Water retention in silty clay =	140 mm/m
Maximum allowable deficit=	50 %(Initial and growing stage)
	70 %(late stage)

Maximum available soil moisture= (Field Capacity=fc)	42 mm(Initial and growing stage)
	70 mm(mid and late stage)
Managment allowable depletion=	21 mm(Initial stage)
	35 mm(mid stage)
	49 mm(late stage)

Table-7.3 Irrigation scheduling of late paddy (sample crop)

Month	Crop Period	Initial Soil Moisture in mm	Rainfall of the Period in mm	Total Soil Moisture During Period in mm	Average Depletion of the Period	Soil Coefficient for Max Depletion (Ks)	Soil Coefficient (Ks) for Min Depletion	Crop Water Requiremen t at field in mm (as per Kc)	Crop Water Requirement at field in mm(with Ks)	Final Soil Moisture in mm	Depletion in mm	MAD in mm	Irrigation Required to Reach Field Capacity in mm	Actual Irrigation Releas in mm	Irrigation Released to Field in mm
(a)	(b)	(c)=(i)+(o)	(d)	(e)= ©+(d)	(h)=0.5*((f)+(g))	(i)=1.013-.0035*(g)	(j)=1.013-.0035*(f)	(k)	(l)=(k)*((i)+(j))*.5	(m)=(e)-(l)	(n)=(fc)-(m)	(o)	(p)=fc-(m)	q=Round (p)	(r)=(n)/γa
May			26.4												
			26.4			1.00				0.0			70.0	70.0	100.00
	LP	70.0	26.4	96.4	0.0	1.00	1.00	70.00	70.00	26.4	0.0	0.0	43.6	40.0	57.14
Jun	LP	66.4	42.6	109.0	33.7	1.00	1.00	70.0	69.83	39.2	0.0	0.0	30.8	30.0	42.86
	LP	69.2	42.6	111.8	22.6	1.00	1.00	70.0	70.00	41.8	0.0	0.0	28.2	30.0	42.86
	ES	70.0	42.6	112.6	20.1	1.00	1.00	142.7	142.70	-30.1	100.1	21.0	100.1	100.0	142.86
Jul	ES	69.9	49.3	119.2	85.8	0.42	1.00	148.50	148.50	-29.3	99.3	24.5	99.3	100.0	142.86
	DVS	42.0	49.3	91.3	84.9	0.88	1.00	92.60	65.68	25.6	30.4	28.0	16.4	20.0	28.57
	DVS	42.0	49.3	91.3	19.5	0.70	1.00	92.20	86.49	4.8	58.2	31.5	37.2	40.0	57.14
Aug	MS	44.8	49.7	94.5	62.3	0.78	0.89	89.40	71.06	23.4	46.6	35.0	46.6	50.0	71.43
	MS	70.0	49.7	119.7	33.3	0.86	1.00	91.00	80.99	38.7	31.3	35.0	0.0	0.0	0.00
	MS	38.7	49.7	88.4	44.7	0.71	0.86	92.20	78.97	9.4	60.6	35.0	60.6	60.0	85.71
Sep	MS	69.4	46.0	115.5	43.7	0.86	1.00	88.10	75.33	40.1	29.9	35.0	0.0	0.0	0.00
	MS	40.1	46.0	86.1	42.7	0.69	0.86	93.40	80.66	5.5	64.5	35.0	64.5	60.0	85.71
	LS	65.5	46.0	111.5	49.3	0.85	0.99	87.8	73.79	37.7	32.3	49.0	0.0	0.0	0.00
Oct			34.8												
														600.0	857.1

Note:-When the final moisture of ten day block period will be negative then the irrigation will be provided to the field in five day interval to bring the soil moisture to field capacity.

Table-7.4A Details of Each Irrigation Zone (based on distributary)

Sl.No.	Name of the Canal	Name of the Parent Canal	Ayacut Area in ha	Self Ayacut area in ha	Zone No	FSD in m	Group Ayacut Area in ha	Design Discharge in m3/s	Zone Design Discharge in m3/s
1	Left Distributary	Main Canal	2300	618.58	A	1.05	2300	3.05	3.0500
2	Right Distributary	RD 0.0Km-5.4Km		220.2	B	1.64	1720	10.193	2.51
3	Right Distributary	RD 5.4Km-11.4Km		172.43	C		1990		2.76
4	Khariaguda Disrtibutary	Right Distributary	1718.53	356.05	C	1.00		2.3866	
5	Kadaguda Disrtibutary	Right Distributary	2580	359.87	D	1.1	2580	3.8066	4.23
6	Karadakana Distributary	Kadaguda Disrtibutary	924.9	302.97	D	0.75		1.2576	
7	Right Distributary	RD11.58Km-21.47Km(Tail)	785	275	E	0.8	1060	1.5887	1.59

Table-7.4B Head regulator gates of Harbhangi irrigation project

Sl. No.	Name of Canal	Design discharge in cumec	Bed width in m	Full Supply Depth in m	No of Shutters	Shutter Size in m	Shutter Opening Height in m	Irrigation Zone
1	Scouring Sluice of Barrage				6	1.85X3.3	NA	NA
2	Head Regulator (Main Canal)	13.34	10.25	1.850	5	1.80X2.35	1.850	NA
3	HR of Left Distributary	3.049	4.9	1.050	2	1.50X1.8	1.050	A
4	HR of Right Distributary	10.192	8	1.640	6	1.60X1.8	1.640	NA
5	Takarda Distributary	1.0984	3	0.700	2	2.20X2.0	0.700	B
6	Raibondha Minor	0.734	2.8	0.700	2	1.00X1.25	0.700	B
7	Khariaguda Distributary	2.3866	4	1.000	2	2.1X1.2	1.000	C
8	Kadaguda Distributary	4.2301	5.6	1.100	3	1.5X1.25	1.100	C
9	Karadakana Distributary	1.26	3.25	0.750	2	1.00X1.25	0.750	D
10	Baharapur Distributary	1.5	3.25	0.800	2	1.45X1.15	0.800	D
11	Right Distributary (at RD11.5Km)	1.59	3.6	0.800	2	1.45X1.15	0.800	E

Table 7.5 Cropping area distribution for all crops in each zone

Name of Crop	Total Croping Area	Total area of each zone	Zone wise crop area distribution				
			A	B	C	D	E
		% of Basin CCA	2300	1720	1985	2580	1065
		Conveyance Losses	0.90	0.85	0.80	0.75	0.70
Early Paddy	2500	0.26	596	446	514	668	276
Mid Paddy	3100	0.32	739	553	638	829	342
Late Paddy	1850	0.19	441	330	381	495	204
Raggi	440	0.05	105	78	91	118	49
Groundnut	750	0.08	179	134	154	201	83
Maize	150	0.02	36	27	31	40	17
Sugarcane	360	0.04	86	64	74	96	40
Dalua Paddy	1500	0.16	358	267	309	401	166
Pulses	1050	0.11	250	187	216	281	116
Groundnut (Rabi)	2050	0.21	489	365	422	548	226
Vegetable up	1400	0.15	334	250	288	374	155
Vegetable low	1400	0.15	334	250	288	374	155
Patato	400	0.04	95	71	82	107	44
Mustard	700	0.07	167	125	144	187	77
Total	17650	1.83	4209	3147	3632	4719	1950

7.3.5 Irrigation Water Requirement (Each zone)

a. Conveyance losses of the different zones are taken separately so that average conveyance losses will be 0.8(used previously for the project CWR).Abstract of the periodical (ten daily) irrigation water requirement of all the crops is furnished in Table-7.6

b. Water requirement in each zone at field for irrigating all the crops are calculated for each ten daily period and total year and water requirement at the diversion point is calculated for all the zones separately after incorporating the respective zone's conveyance

Table7.6 Periodical irrigatio water requirement for all crops at field (mm per ha)

SL. NO.	CROP NAME		Early Paddy	Mid Paddy	Late Paddy	Raggi	Groundnut	Maize	Sugarcane	Dalua Paddy	Pulses	Groundnut (Rabi)	Vegetable (up)	Vegetable (low)	Patato	Mustard
	Month	TIME PERIOD														
1	Jan	1-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	185.71	171.43	0.00	0.00	0.00	152.38	142.86
2		11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	128.57	0.00	0.00	0.00	57.14	0.00	0.00
3		21-31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	128.57	0.00	0.00	114.29	38.10	0.00	119.05
4	Feb	1-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	85.71	0.00	0.00	0.00	38.10	0.00	0.00
5		11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	114.29	0.00	57.14	0.00	152.38	0.00	0.00
6		21-28	0.00	0.00	0.00	0.00	0.00	0.00	47.62	157.14	0.00	19.05	0.00	0.00	0.00	0.00
7	Mar	1-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.10	0.00	0.00	0.00	0.00
8		11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	228.57	0.00	114.29	0.00	114.29	0.00	0.00
9		21-31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Apr	1-10	0.00	0.00	0.00	0.00	0.00	0.00	38.10	214.29	0.00	114.29	0.00	0.00	0.00	0.00
11		11-20	0.00	0.00	0.00	0.00	0.00	0.00	19.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12		21-30	0.00	0.00	0.00	0.00	0.00	0.00	38.10	128.57	0.00	0.00	0.00	0.00	0.00	0.00
13	May	1-10	0.00	0.00	0.00	0.00	0.00	0.00	19.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14		11-20	100.00	0.00	0.00	0.00	0.00	0.00	228.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15		21-31	57.14	71.43	71.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Jun	1-10	42.86	42.86	42.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17		11-20	42.86	42.86	42.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18		21-30	142.86	42.86	42.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Jul	1-10	142.86	142.86	114.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20		11-20	28.57	128.57	114.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21		21-31	57.14	0.00	114.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	Aug	1-10	71.43	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23		11-20	0.00	0.00	71.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24		21-31	85.71	85.71	28.57	0.00	47.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table7.6 Periodical irrigatio water requirement for all crops at field (mm per ha)

SL. NO.	CROP NAME		Early Paddy	Mid Paddy	Late Paddy	Raggi	Groundnut	Maize	Sugarcane	Dalua Paddy	Pulses	Groundnut (Rabi)	Vegetable (up)	Vegetable (low)	Patato	Mustard
	Month	TIME PERIOD														
25	Sep	1-10	0.00	0.00	85.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26		11-20	85.71	85.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27		21-30	0.00	85.71	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Oct	1-10	0.00	71.43	71.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29		11-20	0.00	0.00	71.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30		21-31	0.00	0.00	71.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	Nov.	1-10	0.00	0.00	85.71	0.00	76.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.38	0.00
32		11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.19
33		21-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71.43	0.00	0.00	0.00	0.00	0.00	0.00
34	Dec	1-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	19.05	0.00	38.10	32.38	38.10	0.00
35		11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	38.10	0.00	19.05	0.00	19.05	47.62
36		21-31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	185.71	19.05	0.00	133.33	38.10	38.10	47.62
	Total in mm		857.14	900.00	1128.57	0.00	123.81	0.00	390.48	1828.6	247.62	342.86	304.76	470.48	280.00	383.33

loss for tan daily basis. Irrigation water requirement for each zone during each period considering all crops is calculated.

$$Q_{t,z} = \sum_{\forall crops}(IWR_{t,c} X A_{c,z} X 0.001) \qquad (7.6)$$

where $Q_{t,z}$: water requirement of any time period of a zone in ham,

$A_{c,z}$: area of a crop in a zone in ha,

$IWR_{t,c}$: irrigation water requirement of any crop for a time period t in mm.

Water requirement of each zone is furnished in **Table-7.7(a) to 7.7(e)**

7.3.6 Gate Opening (Disributaries)

Canal discharge required for running the canal continuously for five days to meet the irrigation requirement of the ten days for each zone which is estimated previously is calculated for each ten day (period of consideration) as follows:-

$$q_{t,z} = (Q_{t,z} * 10^4) / (24*5*3600) \ m^3/s \qquad (7.7)$$

where $q_{t,z}$:canal discharge within any time period 't' for a zone 'z'

If required discharge is more than the design discharge then canal will be supplied with design discharge and time of irrigation will be increased to fulfill ten daily crop water requirements at field.

$$IT_{t,z} = (q_{t,z}/(Q_D * 3600)) \qquad (7.8)$$

where $IT_{t,z}$: canal running time in hours

Then gate will be opened for each discharge for each time period in proportionate to the maximum height of opening assuming the design discharge can be released to the canal with opening the gate to the full height. Incase, total ayacut area of a zone is not covered

Table-7.7a Periodical crop water requirement in zone-A

Sl. No.	Crop Name		Early Paddy	Mid Paddy	Late Paddy	Raggi	Groundnut	Maize	Sugarcane	Dalua Paddy	Pulses	Groundnut (Rabi)	Vegetable (up)	Vegetable (low)	Patato	Mustard	Total Water in Ham	Opening Hours (Canal Runs Full)
	Period																	
1	Jan	1-10	0	0	0	0	0	0	0	73873	47619	0	0	0	16085	26508	164.08	149.0
2		11-20	0	0	0	0	0	0	0	51143	0	0	0	21206	0	0	72.35	66.0
3		21-31	0	0	0	0	0	0	0	51143	0	0	42413	14138	0	22090	129.78	118.0
4	Feb	1-10	0	0	0	0	0	0	0	34095	0	0	0	14138	0	0	48.23	44.0
5		11-20	0	0	0	0	0	0	0	45460	0	31048	0	56550	0	0	133.06	121.0
6		21-28	0	0	0	0	0	0	4550	62508	0	10349	0	0	0	0	77.41	70.0
7	Mar	1-10	0	0	0	0	0	0	0	0	0	20698	0	0	0	0	20.70	19.0
8		11-20	0	0	0	0	0	0	0	90921	0	62095	0	42413	0	0	195.43	178.0
9		21-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
10	Apr	1-10	0	0	0	0	0	0	3640	85238	0	62095	0	0	0	0	150.97	137.0
11		11-20	0	0	0	0	0	0	1820	0	0	0	0	0	0	0	1.82	2.0
12		21-30	0	0	0	0	0	0	3640	51143	0	0	0	0	0	0	54.78	50.0
13	May	1-10	0	0	0	0	0	0	1820	0	0	0	0	0	0	0	1.82	2.0
14		11-20	66222	0	0	0	0	0	21841	0	0	0	0	0	0	0	88.06	80.0
15		21-31	37841	58651	35000	0	0	0	0	0	0	0	0	0	0	0	131.49	120.0
16	Jun	1-10	28381	35190	21000	0	0	0	0	0	0	0	0	0	0	0	84.57	77.0
17		11-20	28381	35190	21000	0	0	0	0	0	0	0	0	0	0	0	84.57	77.0
18		21-30	94603	35190	21000	0	0	0	0	0	0	0	0	0	0	0	150.79	137.0
19	Jul	1-10	94603	117302	56000	0	0	0	0	0	0	0	0	0	0	0	267.90	244.0
20		11-20	18921	105571	56000	0	0	0	0	0	0	0	0	0	0	0	180.49	164.0
21		21-31	37841	0	56000	0	0	0	0	0	0	0	0	0	0	0	93.84	85.0
22	Aug	1-10	47302	82111	0	0	0	0	0	0	0	0	0	0	0	0	129.41	118.0
23		11-20	0	0	35000	0	0	0	0	0	0	0	0	0	0	0	35.00	32.0
24		21-31	56762	70381	14000	0	9471	0	0	0	0	0	0	0	0	0	150.61	137.0
25	Sep	1-10	0	0	42000	0	0	0	0	0	0	0	0	0	0	0	42.00	38.0
26		11-20	56762	70381	0	0	0	0	0	0	0	0	0	0	0	0	127.14	116.0
27		21-30	0	70381	49000	0	0	0	0	0	0	0	0	0	0	0	119.38	109.0
28	Oct	1-10	0	58651	35000	0	0	0	0	0	0	0	0	0	0	0	93.65	85.0
29		11-20	0	0	35000	0	0	0	0	0	0	0	0	0	0	0	35.00	32.0
30		21-31	0	0	35000	0	0	0	0	0	0	0	0	0	0	0	35.00	32.0
31	Nov	1-10	0	0	42000	0	15153	0	0	0	0	0	0	0	3418	0	60.57	55.0
32		11-20	0	0	0	0	0	0	0	0	0	0	0	0	0	4860	4.86	4.0
33		21-30	0	0	0	0	0	0	0	28413	0	0	0	0	0	0	28.41	26.0
34	Dec	1-10	0	0	0	0	0	0	0	39778	5291	0	14138	12017	4021	0	75.24	69.0
35		11-20	0	0	0	0	0	0	0	39778	10582	0	7069	0	2011	8836	68.28	62.0
36		21-31	0	0	0	0	0	0	0	73873	5291	0	49481	14138	4021	8836	155.64	142.0

Table-7.7b Periodical crop water requirement in zone-B

Sl. No.	Crop Name / Period		Early Paddy	Mid Paddy	Late Paddy	Raggi	Groundnut	Maize	Sugarcane	Dalua Paddy	Pulses	Groundnut (Rabi)	Vegetable (up)	Vegetable (low)	Patató	Mustard	Total Water in Ham	Opening Hours (Canal Runs Full)
1	Jan	1-10	0	0	0	0	0	0	0	58336	37714	0	0	0	12728	21008	129.79	144.0
2		11-20	0	0	0	0	0	0	0	40387	0	0	0	16807	0	0	57.19	63.0
3		21-31	0	0	0	0	0	0	0	40387	0	0	33613	11204	0	17507	102.71	114.0
4	Feb	1-10	0	0	0	0	0	0	0	26924	0	0	0	11204	0	0	38.13	42.0
5		11-20	0	0	0	0	0	0	0	35899	0	24538	0	44818	0	0	105.25	117.0
6		21-28	0	0	0	0	0	0	3585	49361	0	8179	0	0	0	0	61.13	68.0
7	Mar	1-10	0	0	0	0	0	0	0	0	0	16359	0	0	0	0	16.36	18.0
8		11-20	0	0	0	0	0	0	0	71798	0	49076	0	33613	0	0	154.49	171.0
9		21-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
10	Apr	1-10	0	0	0	0	0	0	2868	67311	0	49076	0	0	0	0	119.25	132.0
11		11-20	0	0	0	0	0	0	1434	0	0	0	0	0	0	0	1.43	2.0
12		21-30	0	0	0	0	0	0	2868	40387	0	0	0	0	0	0	43.25	48.0
13	May	1-10	0	0	0	0	0	0	1434	0	0	0	0	0	0	0	1.43	2.0
14		11-20	52471	0	0	0	0	0	17210	0	0	0	0	0	0	0	69.68	77.0
15		21-31	29983	46471	27731	0	0	0	0	0	0	0	0	0	0	0	104.18	116.0
16	Jun	1-10	22487	27882	16639	0	0	0	0	0	0	0	0	0	0	0	67.01	74.0
17		11-20	22487	27882	16639	0	0	0	0	0	0	0	0	0	0	0	67.01	74.0
18		21-30	74958	27882	16639	0	0	0	0	0	0	0	0	0	0	0	119.48	132.0
19	Jul	1-10	74958	92941	44370	0	0	0	0	0	0	0	0	0	0	0	212.27	235.0
20		11-20	14992	83647	44370	0	0	0	0	0	0	0	0	0	0	0	143.01	159.0
21		21-31	29983	0	44370	0	0	0	0	0	0	0	0	0	0	0	74.35	82.0
22	Aug	1-10	37479	65059	0	0	0	0	0	0	0	0	0	0	0	0	102.54	114.0
23		11-20	0	0	27731	0	0	0	0	0	0	0	0	0	0	0	27.73	31.0
24		21-31	44975	55765	11092	0	7507	0	0	0	0	0	0	0	0	0	119.34	132.0
25	Sep	1-10	0	0	33277	0	0	0	0	0	0	0	0	0	0	0	33.28	37.0
26		11-20	44975	55765	0	0	0	0	0	0	0	0	0	0	0	0	100.74	112.0
27		21-30	0	55765	38824	0	0	0	0	0	0	0	0	0	0	0	94.59	105.0
28	Oct	1-10	0	46471	27731	0	0	0	0	0	0	0	0	0	0	0	74.20	82.0
29		11-20	0	0	27731	0	0	0	0	0	0	0	0	0	0	0	27.73	31.0
30		21-31	0	0	27731	0	0	0	0	0	0	0	0	0	0	0	27.73	31.0
31	Nov	1-10	0	0	33277	0	12011	0	0	0	0	0	0	0	2705	0	47.99	53.0
32		11-20	0	0	0	0	0	0	0	0	0	0	0	0	0	3852	3.85	4.0
33		21-30	0	0	0	0	0	0	0	22437	0	0	0	0	0	0	22.44	25.0
34	Dec	1-10	0	0	0	0	0	0	0	31412	4190	0	11204	9524	3182	0	59.51	66.0
35		11-20	0	0	0	0	0	0	0	31412	8381	0	5602	0	1591	7003	53.99	60.0
36		21-31	0	0	0	0	0	0	0	58336	4190	0	39216	11204	3182	7003	123.13	137.0

Table-7.7c Periodical crop water requirement in zone-C

Sl. No.	Crop Name / Period		Early Paddy	Mid Paddy	Late Paddy	Raggi	Groundnut	Maize	Sugarcane	Dalua Paddy	Pulses	Groundnut (Rabi)	Vegetable (up)	Vegetable (low)	Patato	Mustard	Total Water in Ham	Opening Hours (Canal Runs Full)
1	Jan	1-10	0	0	0	0	0	0	0	71732	46500	0	0	0	15619	25714	159.57	161.0
2		11-20	0	0	0	0	0	0	0	49661	0	0	0	20643	0	0	70.30	71.0
3		21-31	0	0	0	0	0	0	0	49661	0	0	41286	13762	0	21429	126.14	127.0
4	Feb	1-10	0	0	0	0	0	0	0	33107	0	0	0	13762	0	0	46.87	47.0
5		11-20	0	0	0	0	0	0	0	44143	0	30214	0	55048	0	0	129.40	130.0
6		21-28	0	0	0	0	0	0	4405	60696	0	10071	0	0	0	0	75.17	76.0
7	Mar	1-10	0	0	0	0	0	0	0	0	0	20143	0	0	0	0	20.14	20.0
8		11-20	0	0	0	0	0	0	0	88286	0	60429	0	41286	0	0	190.00	191.0
9		21-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
10	Apr	1-10	0	0	0	0	0	0	3524	82768	0	60429	0	0	0	0	146.72	148.0
11		11-20	0	0	0	0	0	0	1762	0	0	0	0	0	0	0	1.76	2.0
12		21-30	0	0	0	0	0	0	3524	49661	0	0	0	0	0	0	53.18	54.0
13	May	1-10	0	0	0	0	0	0	1762	0	0	0	0	0	0	0	1.76	2.0
14		11-20	64500	0	0	0	0	0	21143	0	0	0	0	0	0	0	85.64	86.0
15		21-31	36857	57054	34107	0	0	0	0	0	0	0	0	0	0	0	128.02	129.0
16	Jun	1-10	27643	34232	20464	0	0	0	0	0	0	0	0	0	0	0	82.34	83.0
17		11-20	27643	34232	20464	0	0	0	0	0	0	0	0	0	0	0	82.34	83.0
18		21-30	92143	34232	20464	0	0	0	0	0	0	0	0	0	0	0	146.84	148.0
19	Jul	1-10	92143	114107	54571	0	0	0	0	0	0	0	0	0	0	0	260.82	263.0
20		11-20	18429	102696	54571	0	0	0	0	0	0	0	0	0	0	0	175.70	177.0
21		21-31	36857	0	54571	0	0	0	0	0	0	0	0	0	0	0	91.43	92.0
22	Aug	1-10	46071	79875	0	0	0	0	0	0	0	0	0	0	0	0	125.95	127.0
23		11-20	0	0	34107	0	0	0	0	0	0	0	0	0	0	0	34.11	34.0
24		21-31	55286	68464	13643	0	9226	0	0	0	0	0	0	0	0	0	146.62	148.0
25	Sep	1-10	0	0	40929	0	0	0	0	0	0	0	0	0	0	0	40.93	41.0
26		11-20	55286	68464	0	0	0	0	0	0	0	0	0	0	0	0	123.75	125.0
27		21-30	0	68464	47750	0	0	0	0	0	0	0	0	0	0	0	116.21	117.0
28	Oct	1-10	0	57054	34107	0	0	0	0	0	0	0	0	0	0	0	91.16	92.0
29		11-20	0	0	34107	0	0	0	0	0	0	0	0	0	0	0	34.11	34.0
30		21-31	0	0	34107	0	0	0	0	0	0	0	0	0	0	0	34.11	34.0
31	Nov	1-10	0	0	40929	0	14762	0	0	0	0	0	0	0	3319	0	59.01	59.0
32		11-20	0	0	0	0	0	0	0	0	0	0	0	0	0	4714	4.71	5.0
33		21-30	0	0	0	0	0	0	0	27589	0	0	0	0	0	0	27.59	28.0
34	Dec	1-10	0	0	0	0	0	0	0	38625	5167	0	13762	11698	3905	0	73.16	74.0
35		11-20	0	0	0	0	0	0	0	38625	10333	0	6881	0	1952	8571	66.36	67.0
36		21-31	0	0	0	0	0	0	0	71732	5167	0	48167	13762	3905	8571	151.30	152.0

Table-7.7d Periodical crop water requirement in zone-D

Sl. No.	Crop Name Period		Early Paddy	Mid Paddy	Late Paddy	Raggi	Ground nut	Maize	Sugarcane	Dalua Paddy	Pulses	Groundnut (Rabi)	Vegetable (up)	Vegetable (low)	Patato	Mustard	Total Water in Ham	Opening Hours (Canal Runs Full)
1	Jan	1-10	0	0	0	0	0	0	0	106388	68816	0	0	0	23293	38163	236.66	155.0
2		11-20	0	0	0	0	0	0	0	73653	0	0	0	30531	0	0	104.18	68.0
3		21-31	0	0	0	0	0	0	0	73653	0	0	61061	20354	0	31803	186.87	123.0
4	Feb	1-10	0	0	0	0	0	0	0	49102	0	0	0	20354	0	0	69.46	46.0
5		11-20	0	0	0	0	0	0	0	65469	0	44735	0	81415	0	0	191.62	126.0
6		21-28	0	0	0	0	0	0	6531	90020	0	14912	0	0	0	0	111.46	73.0
7	Mar	1-10	0	0	0	0	0	0	0	0	0	29823	0	0	0	0	29.82	20.0
8		11-20	0	0	0	0	0	0	0	130939	0	89469	0	61061	0	0	281.47	185.0
9		21-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
10	Apr	1-10	0	0	0	0	0	0	5224	122755	0	89469	0	0	0	0	217.45	143.0
11		11-20	0	0	0	0	0	0	2612	0	0	0	0	0	0	0	2.61	2.0
12		21-30	0	0	0	0	0	0	5224	73653	0	0	0	0	0	0	78.88	52.0
13	May	1-10	0	0	0	0	0	0	2612	0	0	0	0	0	0	0	2.61	2.0
14		11-20	95429	0	0	0	0	0	31347	0	0	0	0	0	0	0	126.78	83.0
15		21-31	54531	84592	50510	0	0	0	0	0	0	0	0	0	0	0	189.63	125.0
16	Jun	1-10	40898	50755	30306	0	0	0	0	0	0	0	0	0	0	0	121.96	80.0
17		11-20	40898	50755	30306	0	0	0	0	0	0	0	0	0	0	0	121.96	80.0
18		21-30	136327	50755	30306	0	0	0	0	0	0	0	0	0	0	0	217.39	143.0
19	Jul	1-10	136327	169184	80816	0	0	0	0	0	0	0	0	0	0	0	386.33	254.0
20		11-20	27265	152265	80816	0	0	0	0	0	0	0	0	0	0	0	260.35	171.0
21		21-31	54531	0	80816	0	0	0	0	0	0	0	0	0	0	0	135.35	89.0
22	Aug	1-10	68163	118429	0	0	0	0	0	0	0	0	0	0	0	0	186.59	123.0
23		11-20	0	0	50510	0	0	0	0	0	0	0	0	0	0	0	50.51	33.0
24		21-31	81796	101510	20204	0	13673	0	0	0	0	0	0	0	0	0	217.18	143.0
25	Sep	1-10	0	0	60612	0	0	0	0	0	0	0	0	0	0	0	60.61	40.0
26		11-20	81796	101510	0	0	0	0	0	0	0	0	0	0	0	0	183.31	120.0
27		21-30	0	101510	70714	0	0	0	0	0	0	0	0	0	0	0	172.22	113.0
28	Oct	1-10	0	84592	50510	0	0	0	0	0	0	0	0	0	0	0	135.10	89.0
29		11-20	0	0	50510	0	0	0	0	0	0	0	0	0	0	0	50.51	33.0
30		21-31	0	0	50510	0	0	0	0	0	0	0	0	0	0	0	50.51	33.0
31	Nov	1-10	0	0	60612	0	21878	0	0	0	0	0	0	0	4950	0	87.44	57.0
32		11-20	0	0	0	0	0	0	0	0	0	0	0	0	0	6997	7.00	5.0
33		21-30	0	0	0	0	0	0	0	40918	0	0	0	0	0	0	40.92	27.0
34	Dec	1-10	0	0	0	0	0	0	0	57286	7646	0	20354	17301	5823	0	108.41	71.0
35		11-20	0	0	0	0	0	0	0	57286	15293	0	10177	0	2912	12721	98.39	65.0
36		21-31	0	0	0	0	0	0	0	106388	7646	0	71238	20354	5823	12721	224.17	147.0

Table-7.7e Periodical crop water requirement in zone-E

Sl. No.	Crop Name / Period		Early Paddy	Mid Paddy	Late Paddy	Raggi	Groundnut	Maize	Sugarcane	Dalua Paddy	Pulses	Groundnut (Rabi)	Vegetable (up)	Vegetable (low)	Patato	Mustard	Total Water in Ham	Opening Hours (Canal Runs Full)
1	Jan	1-10	0	0	0	0	0	0	0	40857	26286	0	0	0	8940	14667	90.75	159.0
2		11-20	0	0	0	0	0	0	0	28286	0	0	0	11733	0	0	40.02	70.0
3		21-31	0	0	0	0	0	0	0	28286	0	0	23467	7822	0	12222	71.80	125.0
4	Feb	1-10	0	0	0	0	0	0	0	18857	0	0	0	7822	0	0	26.68	47.0
5		11-20	0	0	0	0	0	0	0	25143	0	17143	0	31289	0	0	73.57	129.0
6		21-28	0	0	0	0	0	0	2540	34571	0	5714	0	0	0	0	42.83	75.0
7	Mar	1-10	0	0	0	0	0	0	0	0	0	11429	0	0	0	0	11.43	20.0
8		11-20	0	0	0	0	0	0	0	50286	0	34286	0	23467	0	0	108.04	189.0
9		21-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
10	Apr	1-10	0	0	0	0	0	0	2032	47143	0	34286	0	0	0	0	83.46	146.0
11		11-20	0	0	0	0	0	0	1016	0	0	0	0	0	0	0	1.02	2.0
12		21-30	0	0	0	0	0	0	2032	28286	0	0	0	0	0	0	30.32	53.0
13	May	1-10	0	0	0	0	0	0	1016	0	0	0	0	0	0	0	1.02	2.0
14		11-20	36667	0	0	0	0	0	12190	0	0	0	0	0	0	0	48.86	85.0
15		21-31	20952	32476	19333	0	0	0	0	0	0	0	0	0	0	0	72.76	127.0
16	Jun	1-10	15714	19486	11600	0	0	0	0	0	0	0	0	0	0	0	46.80	82.0
17		11-20	15714	19486	11600	0	0	0	0	0	0	0	0	0	0	0	46.80	82.0
18		21-30	52381	19486	11600	0	0	0	0	0	0	0	0	0	0	0	83.47	146.0
19	Jul	1-10	52381	64952	30933	0	0	0	0	0	0	0	0	0	0	0	148.27	259.0
20		11-20	10476	58457	30933	0	0	0	0	0	0	0	0	0	0	0	99.87	174.0
21		21-31	20952	0	30933	0	0	0	0	0	0	0	0	0	0	0	51.89	91.0
22	Aug	1-10	26190	45467	0	0	0	0	0	0	0	0	0	0	0	0	71.66	125.0
23		11-20	0	0	19333	0	0	0	0	0	0	0	0	0	0	0	19.33	34.0
24		21-31	31429	38971	7733	0	5206	0	0	0	0	0	0	0	0	0	83.34	146.0
25	Sep	1-10	0	0	23200	0	0	0	0	0	0	0	0	0	0	0	23.20	41.0
26		11-20	31429	38971	0	0	0	0	0	0	0	0	0	0	0	0	70.40	123.0
27		21-30	0	38971	27067	0	0	0	0	0	0	0	0	0	0	0	66.04	115.0
28	Oct	1-10	0	32476	19333	0	0	0	0	0	0	0	0	0	0	0	51.81	91.0
29		11-20	0	0	19333	0	0	0	0	0	0	0	0	0	0	0	19.33	34.0
30		21-31	0	0	19333	0	0	0	0	0	0	0	0	0	0	0	19.33	34.0
31	Nov	1-10	0	0	23200	0	8330	0	0	0	0	0	0	0	1900	0	33.43	58.0
32		11-20	0	0	0	0	0	0	0	0	0	0	0	0	0	2689	2.69	5.0
33		21-30	0	0	0	0	0	0	0	15714	0	0	0	0	0	0	15.71	27.0
34	Dec	1-10	0	0	0	0	0	0	0	22000	2921	0	7822	6649	2235	0	41.63	73.0
35		11-20	0	0	0	0	0	0	0	22000	5841	0	3911	0	1117	4889	37.76	66.0
36		21-31	0	0	0	0	0	0	0	40857	2921	0	27378	7822	2235	4889	86.10	150.0

under a distributary but a major part of the ayacut area is its command area then required discharge for that canal will be determined on proportionate to the ayacut area of that zone. However the running period of the canal will be same as that zone.

$$h_{t,z} = H_{\max} * \left(\frac{q_{t,z}}{Q_D} \right)^{\frac{2}{3}} \tag{7.9}$$

where Q_D: Design discharge of the concern canal

$h_{t,z}$: Height of opening of HR gate at any time t

H_{max} : Maximum height of opening of HR gate of that canal.

The details of time of opening, height of opening and discharge in the canal are furnished in Table-7.8

7.4 RESULTS AND DISCUSSION

a. Canal releases required for running the canal for minimum five days considering 50% time period (i.e. OFF/ON process) to meet the water requirement of ten daily periods is being satisfied during the major periods in all the distributaries.

b. It is observed that during month October, November and March, the required water release is very less for some time periods. Hence, the canals may be closed during these periods for the maintenance purpose.

c. During period July 1-10, the water requirement is very high, thus the running period is more than 240 hours which is impossible, so crop (paddy crop) plantation date has to be staggered so as to accommodate the required release within the canal design discharge.

However, canal release quantity, duration and sequence can be optimized to reduce the running period of the main canal and major distributaries by considering the periodical water requirement of the minor canals.

Table-7.8 Gate opening of major canals for all Irrigation Zones (ten daily)

Sl. No	Name of Canal		Left Distributary			Takarda Distributary		
	Gate Size (No of Gates) →		1.50X1.8			2.20X2.0		
			2			2		
	Governing Irrigation Zone		A			B		
	Month	Period	Discharge in cumec	No of hours in ten days	Height of opening in m	Discharge in cumec	No of hours in ten days	Height of opening in m
1	Jan	1-10	3.05	149	1.05	1.10	144	0.70
2		11-20	1.67	66	0.70	0.58	63	0.46
3		21-31	3.00	118	1.04	1.04	114	0.68
4	Feb	1-10	1.12	44	0.54	0.39	42	0.35
5		11-20	3.05	121	1.05	1.07	117	0.69
6		21-28	1.79	70	0.74	0.62	68	0.48
7	Mar	1-10	0.48	19	0.31	0.17	18	0.20
8		11-20	3.05	178	1.05	1.10	171	0.70
9		21-31	0.00	0	0.00	0.00	0	0.00
10	Apr	1-10	3.05	137	1.05	1.10	132	0.70
11		11-20	0.04	2	0.06	0.01	2	0.03
12		21-30	1.27	50	0.59	0.44	48	0.38
13	May	1-10	0.04	2	0.06	0.01	2	0.03
14		11-20	2.04	80	0.80	0.71	77	0.52
15		21-31	3.04	120	1.05	1.06	116	0.68
16	Jun	1-10	1.96	77	0.78	0.68	74	0.51
17		11-20	1.96	77	0.78	0.68	74	0.51
18		21-30	3.05	137	1.05	1.10	132	0.70
19	Jul	1-10	3.05	244	1.05	1.10	235	0.70
20		11-20	3.05	164	1.05	1.10	159	0.70
21		21-31	2.17	85	0.84	0.75	82	0.54
22	Aug	1-10	3.00	118	1.04	1.04	114	0.68
23		11-20	0.81	32	0.43	0.28	31	0.28
24		21-31	3.05	137	1.05	1.10	132	0.70
25	Sep	1-10	0.97	38	0.49	0.34	37	0.32
26		11-20	2.94	116	1.02	1.02	112	0.67
27		21-30	2.76	109	0.98	0.96	105	0.64
28	Oct	1-10	2.17	85	0.84	0.75	82	0.54
29		11-20	0.81	32	0.43	0.28	31	0.28
30		21-31	0.81	32	0.43	0.28	31	0.28
31	Nov	1-10	1.40	55	0.62	0.49	53	0.41
32		11-20	0.11	4	0.11	0.04	4	0.08
33		21-30	0.66	26	0.38	0.23	25	0.25
34	Dec	1-10	1.74	69	0.72	0.60	66	0.47
35		11-20	1.58	62	0.68	0.55	60	0.44
36		21-31	3.05	142	1.05	1.10	137	0.70

N.B. :- All gates of a canal will be opened upto same height for each time period

Table-7.8 contd.

Sl. No.	Name of Canal		Raibondha Minor			Khariaguda Distributary		
	Gate Size (No of Gates) →		1.00X1.25			2.1X1.2		
			2			2		
	Governing Irrigation Zone		B			C		
	Month	Period ↓	Discharge in cumec	No of hours in ten days	Height of opening in m	Discharge in cumec	No of hours in ten days	Height of opening in m
1	Jan	1-10	0.74	144	0.70	2.39	161	1.00
2		11-20	0.39	63	0.46	1.41	71	0.70
3		21-31	0.70	114	0.68	2.39	127	1.00
4	Feb	1-10	0.26	42	0.35	0.93	47	0.53
5		11-20	0.71	117	0.68	2.39	130	1.00
6		21-28	0.41	68	0.47	1.50	76	0.74
7	Mar	1-10	0.11	18	0.20	0.41	20	0.31
8		11-20	0.74	171	0.70	2.39	191	1.00
9		21-31	0.00	0	0.00	0.00	0	0.00
10	Apr	1-10	0.74	132	0.70	2.39	148	1.00
11		11-20	0.01	2	0.04	0.03	2	0.06
12		21-30	0.29	48	0.38	1.06	54	0.58
13	May	1-10	0.01	2	0.04	0.03	2	0.06
14		11-20	0.47	77	0.52	1.71	86	0.80
15		21-31	0.71	116	0.68	2.39	129	1.00
16	Jun	1-10	0.45	74	0.51	1.65	83	0.78
17		11-20	0.45	74	0.51	1.65	83	0.78
18		21-30	0.74	132	0.70	2.39	148	1.00
19	Jul	1-10	0.74	235	0.70	2.39	263	1.00
20		11-20	0.74	159	0.70	2.39	177	1.00
21		21-31	0.50	82	0.54	1.83	92	0.84
22	Aug	1-10	0.69	114	0.67	2.39	127	1.00
23		11-20	0.19	31	0.28	0.68	34	0.43
24		21-31	0.74	132	0.70	2.39	148	1.00
25	Sep	1-10	0.23	37	0.32	0.82	41	0.49
26		11-20	0.68	112	0.67	2.39	125	1.00
27		21-30	0.64	105	0.64	2.33	117	0.98
28	Oct	1-10	0.50	82	0.54	1.82	92	0.84
29		11-20	0.19	31	0.28	0.68	34	0.43
30		21-31	0.19	31	0.28	0.68	34	0.43
31	Nov	1-10	0.33	53	0.41	1.18	59	0.63
32		11-20	0.03	4	0.08	0.10	5	0.12
33		21-30	0.15	25	0.24	0.55	28	0.38
34	Dec	1-10	0.40	66	0.47	1.46	74	0.72
35		11-20	0.37	60	0.44	1.33	67	0.68
36		21-31	0.74	137	0.70	2.39	152	1.00

Table-7.8 contd.

Sl. No	Name of Canal		Kadaguda Distributary			Karadakana Distributary		
	Gate Size (No of Gates)		1.5X1.25			1.00X1.25		
			3			2		
	Governing Irrigation Zone		D			D		
	Month	Period	Discharge in cumec	No of hours in ten days	Height of opening in m	Discharge in cumec	No of hours in ten days	Height of opening in m
1	Jan	1-10	4.23	155	1.10	1.26	155	0.75
2		11-20	2.41	68	0.76	0.72	68	0.52
3		21-31	4.23	123	1.10	1.26	123	0.75
4	Feb	1-10	1.61	46	0.58	0.48	46	0.39
5		11-20	4.23	126	1.10	1.26	126	0.75
6		21-28	2.58	73	0.79	0.77	73	0.54
7	Mar	1-10	0.69	20	0.33	0.21	20	0.22
8		11-20	4.23	185	1.10	1.26	185	0.75
9		21-31	0.00	0	0.00	0.00	0	0.00
10	Apr	1-10	4.23	143	1.10	1.26	143	0.75
11		11-20	0.06	2	0.06	0.02	2	0.04
12		21-30	1.83	52	0.63	0.54	52	0.43
13	May	1-10	0.06	2	0.06	0.02	2	0.04
14		11-20	2.93	83	0.86	0.87	83	0.59
15		21-31	4.23	125	1.10	1.26	125	0.75
16	Jun	1-10	2.82	80	0.84	0.84	80	0.57
17		11-20	2.82	80	0.84	0.84	80	0.57
18		21-30	4.23	143	1.10	1.26	143	0.75
19	Jul	1-10	4.23	254	1.10	1.26	254	0.75
20		11-20	4.23	171	1.10	1.26	171	0.75
21		21-31	3.13	89	0.90	0.93	89	0.61
22	Aug	1-10	4.23	123	1.10	1.26	123	0.75
23		11-20	1.17	33	0.47	0.35	33	0.32
24		21-31	4.23	143	1.10	1.26	143	0.75
25	Sep	1-10	1.40	40	0.53	0.42	40	0.36
26		11-20	4.24	120	1.10	1.26	120	0.75
27		21-30	3.99	113	1.06	1.19	113	0.72
28	Oct	1-10	3.13	89	0.90	0.93	89	0.61
29		11-20	1.17	33	0.47	0.35	33	0.32
30		21-31	1.17	33	0.47	0.35	33	0.32
31	Nov	1-10	2.02	57	0.67	0.60	57	0.46
32		11-20	0.16	5	0.12	0.05	5	0.08
33		21-30	0.95	27	0.41	0.28	27	0.28
34	Dec	1-10	2.51	71	0.78	0.75	71	0.53
35		11-20	2.28	65	0.73	0.68	65	0.50
36		21-31	4.23	147	1.10	1.26	147	0.75

Table-7.8 contd.

Sl. No	Name of Canal		Bharapur Distributary			Right Distributary(11.5Km to Tail)		
	Gate Size (No of Gates) →		1.45X1.15			1.45X1.15		
			2			2		
	Governing Irrigation Zone		D			E		
	Month	Period ↓	Discharge in cumec	No of hours in ten days	Height of opening in m	Discharge in cumec	No of hours in ten days	Height of opening in m
1	Jan	1-10	1.50	159	0.80	1.59	159	0.80
2		11-20	0.85	70	0.55	0.93	70	0.56
3		21-31	1.50	125	0.80	1.59	125	0.80
4	Feb	1-10	0.57	47	0.42	0.62	47	0.43
5		11-20	1.50	129	0.80	1.59	129	0.80
6		21-28	0.91	75	0.58	0.99	75	0.58
7	Mar	1-10	0.24	20	0.24	0.26	20	0.24
8		11-20	1.50	189	0.80	1.59	189	0.80
9		21-31	0.00	0	0.00	0.00	0	0.00
10	Apr	1-10	1.50	146	0.80	1.59	146	0.80
11		11-20	0.02	2	0.05	0.02	2	0.04
12		21-30	0.65	53	0.46	0.70	53	0.46
13	May	1-10	0.02	2	0.05	0.02	2	0.04
14		11-20	1.04	85	0.63	1.13	85	0.64
15		21-31	1.50	127	0.80	1.59	127	0.80
16	Jun	1-10	1.00	82	0.61	1.08	82	0.62
17		11-20	1.00	82	0.61	1.08	82	0.62
18		21-30	1.50	146	0.80	1.59	146	0.80
19	Jul	1-10	1.50	259	0.80	1.59	259	0.80
20		11-20	1.50	174	0.80	1.59	174	0.80
21		21-31	1.11	91	0.65	1.20	91	0.66
22	Aug	1-10	1.50	125	0.80	1.59	125	0.80
23		11-20	0.41	34	0.34	0.45	34	0.34
24		21-31	1.50	146	0.80	1.59	146	0.80
25	Sep	1-10	0.50	41	0.38	0.54	41	0.39
26		11-20	1.50	123	0.80	1.59	123	0.80
27		21-30	1.41	115	0.77	1.53	115	0.78
28	Oct	1-10	1.11	91	0.65	1.20	91	0.66
29		11-20	0.41	34	0.34	0.45	34	0.34
30		21-31	0.41	34	0.34	0.45	34	0.34
31	Nov	1-10	0.72	58	0.49	0.77	58	0.49
32		11-20	0.06	5	0.09	0.06	5	0.09
33		21-30	0.34	27	0.30	0.36	27	0.30
34	Dec	1-10	0.89	73	0.56	0.96	73	0.57
35		11-20	0.81	66	0.53	0.87	66	0.54
36		21-31	1.50	150	0.80	1.59	150	0.80

CHAPTER-8

DEVELOPMENT OF DSS FOR WATER RESOURCES MANAGEMENT

8.1 GENERAL

Water resources management using decision support system is one of the emerging approaches for the optimal use of the canal network system of an irrigation project to maximize the crop produce. Maintaining the least possible gap between the demand and the supply is a real challenge for irrigation managers because there is a need to assess the quantum of water available and demand at micro level in real-time. The distributaries of any canal network are usually the last point of controlling irrigation release of the project because after that point, the irrigation is either field-to-field or under the direct control of the farmers.

The distributary-level water demands are aggregated to assess irrigation supply requirements at higher levels (branch canals and main canals) of the irrigation system after accounting for transmission losses. The operational efficiencies depend on the extent to which the irrigation supplies match the demands at each hierarchical level of the network. Thus, estimation of water demand of individual distributary of the canal network is critical for improving the overall operational efficiencies of large irrigation systems.

The domain of decision problems regarding water resources such as water use allocation etc. is complex and difficult. This is due to the number of stakeholders pursuing multiple and conflicting objectives, the influence of the spatial distribution of land uses, socio-economic activities and the constraints regarding environmental quality. Decision Support System (DSS), a computer based tool which provides modeling and simulation facilities, may help in generating what-if scenarios to aid irrigation officers in implementing the water management policies efficiently and to deal with the problem.

facilities, may help in generating what-if scenarios to aid irrigation officers in implementing the water management policies efficiently and to deal with the problem.

8.2 HISTORICAL BACKGROUND OF DSS

The DSSs, introduced in 70s, have also changed their concept and advanced with the advancement in computer and information technology. Further, the introduction of Graphical User Interface (GUI) and expert system, have added much more in the popularity of modern days advanced DSS. Therefore, the progress made in area of DSS is described as "not a single, clean innovation that occurred overnight, but more like a tide moving in many currents and eddies over a period of time" (Keen and Wanger, 1979).

8.2.1 Definition

The DSS is defined as: *"Computer based information system that are designed with the expressed purpose of improving the processes and outcome of human decision making"* (Osmoud et al., 1997). Sparge and Carlson described a DSS as *"Interactive computer based system to help decision makes to use data and models to solve a problem."* (1982)

8.2.2 Characteristics of DSS

A DSS is a set of tools that helps in decision-making such as data, models, software interface, and the user into an effective decision making system. Parker and Al Utabi (Mizanur, 2002, dissertation) reviewed 350 research papers and articles related to DSS in 1986 and listed following characteristics of a typical DSS. A DSS,

- assist managers in their decision making process;
- support and enhance managerial judgment;
- improve the effectiveness of decision making rather than the efficiency;
- combine the use of models or analytical technique with data access functions;

focus on features, which make them easy to be used interactively by inexperienced users.

8.2.3 Components of DSS

A decision Support system may be studied in four major modules. The relationships among these components are shown in Figure 8.1. The components arc:

i) User: User interacts with the system through a computer directly or indirectly wherever it is located.

ii) Database: In a DSS, data is the most important part. The data, attribute as well as geographical, is stored in a well organize manner. These days, either type of data is managed using relational database management system (RDBMS) and file system objects (FSO)

iii) Models base: It is a set of system analysis tools. These tools operate on a particular set of data under the supervision of user and generate decisions.

iv) User interface: In present day DSSs, the user interacts with data and models through graphics rather than text based instruction. Hence, it is known as Graphical User Interlace. This interface links the user, the data and the models together.

8.3 STRATEGIES TO DEVELOP A DSS

8.3.1 Approaches

There are two basic approaches in developing a DSS: model centric approach and data centric approach. In a model centric approach a DSS is build around a model or a set of models. In such system the model is first selected and then other components are designed with model requirement. Data centric DSS are those which basically stores all type of with model requirement. Data centric DSS are those which basically stores all type of available data related to a particular problem. Other components are designed for a general use. At a later stage the models are selected which may use the entire data or a part of it.

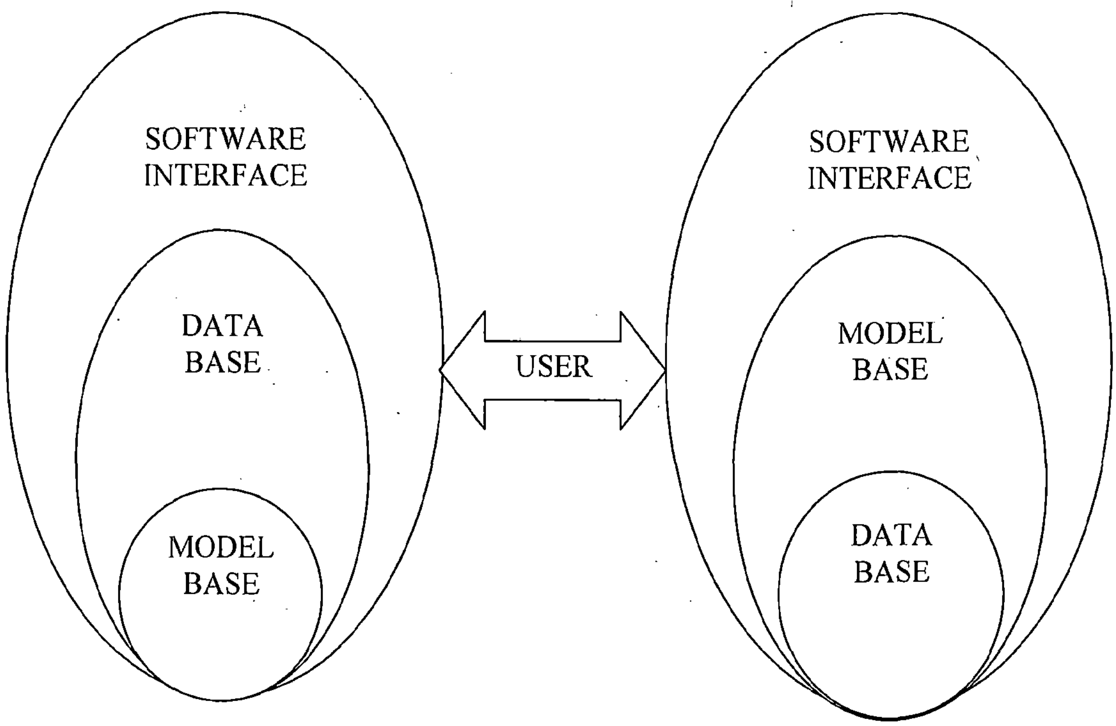


Fig.-8.1 Relationship among the DSS

8.3.2 DSS Tools

DSS tools can be thought of DSS building blocks. These are used to create a Specific DSS, or are incorporated into DSS generators. These are programming languages, statistical analysis packages, optimization packages, data base management systems, and Graphical user interface packages.

i) ***Programming languages:*** A variety of programming languages have been used in creating DSS modules. One class of languages is procedure-oriented languages, such as BASIC, FORTRAN, PASCAL, widely accepted and available on most computer creation and then later use of the modular DSS. There are always new languages being developed like C++, Java, *C#* etc. These languages may still require programmers to describe a procedure for the computer to follow, but features have been included in the languages that make them especially attractive in dealing with real life problems. Problem-oriented languages can also be used with a DSS. A problem-oriented language allows the programmer to describe the characteristics of a problem to be solved rather than a procedure to be followed.

ii) ***Statistical Analysis Packages:*** A DSS frequently requires statistical analysis capabilities. For example, regression analysis may be needed to determine the relationship between a dependent and an independent variable. A number of statistical analysis packages have been developed and are available on many computer systems.

iii) ***Optimization Packages:*** A function of a DSS may be to suggest the best solutions to certain problems, and this procedure may require support from optimization package. This particular problem can often be analyzed through linear programming. The analyst develops an objective function and constraint equations, the mathematical formulation of the problem is then entered into an optimization package. The package performs the laborious calculations required to analyze the problem and generates the optional output.

iv) ***Data Base Management System:*** A DSS requires efficient data handling capabilities. The user must be able to enter new data, update existing data, extract data, analysis data, display data, and present data in reports. If used RDBMS, above user-friendly queries are above supported.

data, display data, and present data in reports. If used RDBMS, above user-friendly queries are above supported.

v) ***The Software Interface:*** The user interacts with the DSS through the software interface, which provides communication among various DSS tools. A DSS can be directed in several different ways. One approach is to have a *menu-driven system.* The user simply selects the desired options from a series of menus. This approach is very effective with novice users who need considerable guidance. Another approach is to have *a macro command language* through which the user directs the system. Microsoft Visual Basic software is simple and conventional one for using as Graphical User Interface (GUI).

8.3.3 Microsoft Visual Basic

Visual Basic (VB) is an object oriented programming development system for creating applications that run under any of Microsoft windows environment. It makes developing and debugging objects relatively easy. As such, the user has very close focus to step through the lines of code as the application runs and to see where errors occur. Windows works in an event driven environment, meaning user in control, and programs need to respond to events (such as mouse-click, keyboard entry etc) It uses an integrated development environment (IDE) and the major components:

a. An extensive collection of prewritten tools, called controls. These controls are accessible as icons within a graphical programming environment for creating customized windows components (e.g., menus, dialog boxes, text boxes, flexible grids, etc.)

Creation of a user interface and adding basic instructions to carry out the actions associated with each of the control are two basic steps in VB programming. The basic object related concepts used in VB are discussed below:

Forms

In VB, a window is called a form. Each form includes a title bar at the top. It may include a menu bar. All controls can be dragged and dropped in the form.

Controls

The icons with which the user interacts are called controls. Commonly used controls are command buttons, check boxes, list boxes and menus.

Objects

The forms and controls are collectively referred as objects. Most of the objects are associated with the events. They are also associated with their own properties and methods.

8.4 DEVELOPMENT OF HARABHANGI PROJECT DSS (HCSDSS)

HCSDSS is Microsoft Window based DSS system for irrigation management and canal scheduling. HCDSS is developed to manage the irrigation water available within the project area. It will help the DM to take decision regarding duration of opening and height of the opening for each distributary for a fixed duration (ten daily) crop water requirement. The conceptual diagram of the DSS is given in Fig.-8.2. The front end functionality (like graphical user interface) is developed in Visual Basic 6 and backend programs (i.e. models) are written in FORTRAN and integrated as dynamic link libraries in visual basic. The software has four basic modules viz: (i) ET_O calculation, (ii) Crop water requirement (iii) Canal scheduling, and (iv) Reservoir yield estimation.

software has four basic modules viz: (i) ET_O calculation, (ii) Crop water requirement (iii) Canal scheduling, and (iv) Reservoir yield estimation.

8.4.1 Software Development Using VB-6

At the startup, a Visual Basic project template of type 'standard EXE' is chosen. References allow selecting another application's object library. A reference has a file with an .olb extension that provides documentation information about available objects to do Automation controllers. One can retrieve description about how to call methods, arguments, set properties and so on. But only required references are to be selected since it adds overhead to the application. Following is a list of the references added to the project:

i. Visual Basic for application
ii. Visual Basic Runtime objects and procedures
iii. Visual Basic objects and procedures
iv. Microsoft Runtime Scripting

Here, first three references are necessary for any VB standard application to use basic functionality. Microsoft Runtime Scripting is required to use New File System Object (FSO) for creating, copying, moving and deleting the files. In order to make the user interface interactive, following components (i.e. additional control libraries) are also added in the project:

i. Microsoft Common Dialog Control 6.0
ii. Microsoft FlexiGrid Control 6.0
iii. Microsoft Rich Textbox Control

Organizing the Application:

In order to make the application work in different machines fixed path failed. Therefore relative path for all the files referred in the code set were written. Two folders are created which holds the necessary files created for the application during the run time. List of the main folder are given bellow in Fig.-8.3

8.4.2 Application Layout

Forms:

There are nineteen standard Form in all modules with one splash form. The view of the Project explorer is shown below (Fig.-8.4). Form module (.frm) contains procedures to handle events, general procedure, and form level declaration of variables, constants, types and external procedures. Different controls are pasted on the body of the form. Each of the control is associated with a list of events and properties which are set at design time and run time.

The components and controls are placed over the form and the properties of all items including the form are set. Then the form is saved in the requisite folder. The position of each component is controlled at runtime to adjust with the monitor size of a computer. Similarly, the position of the different controls is also fixed with code control during run time. The visibility and enable/disable of the different controls are set on different events with code module.

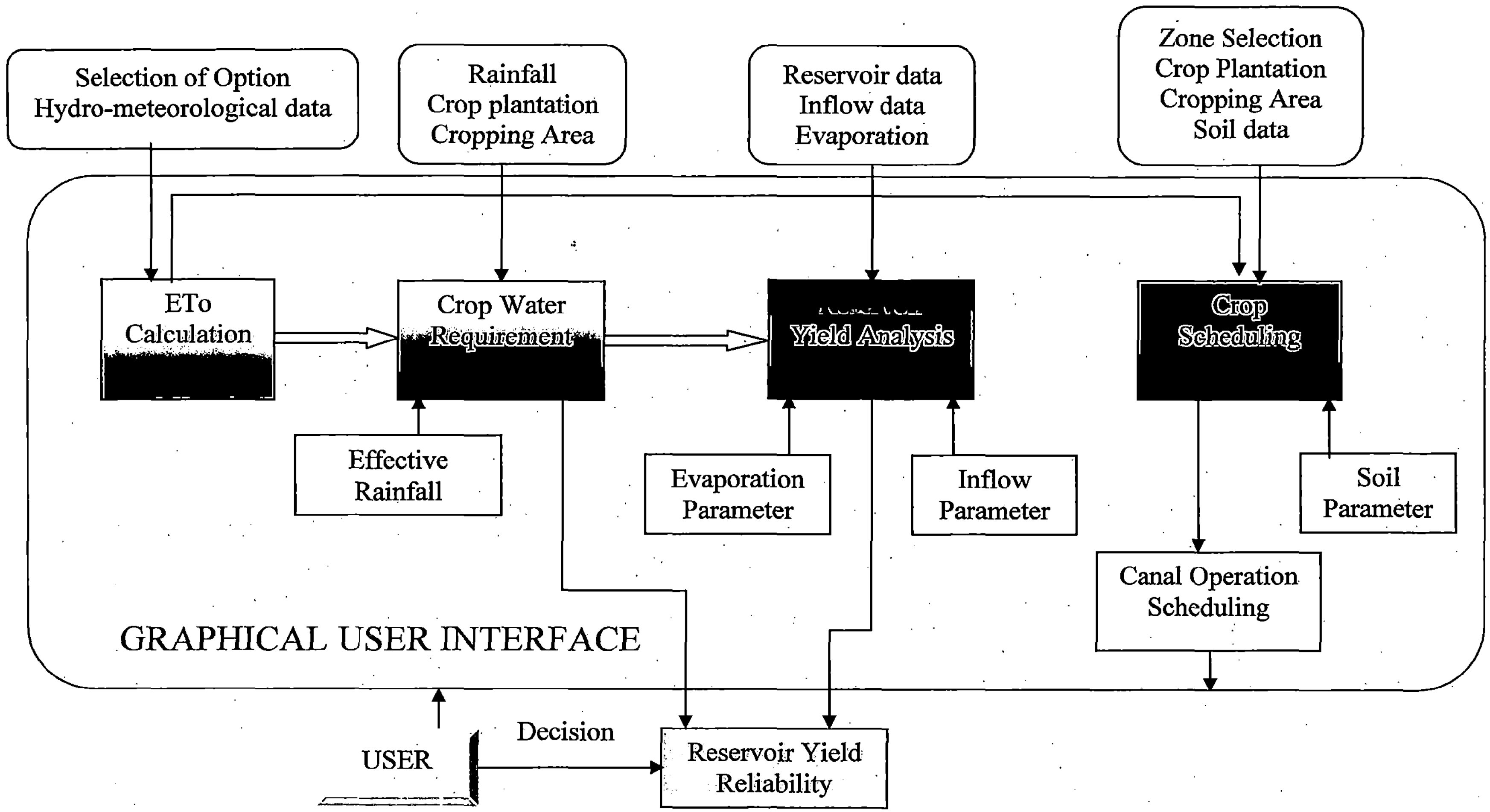


Fig.-8.2 Conceptual Diagram of HCSDSS

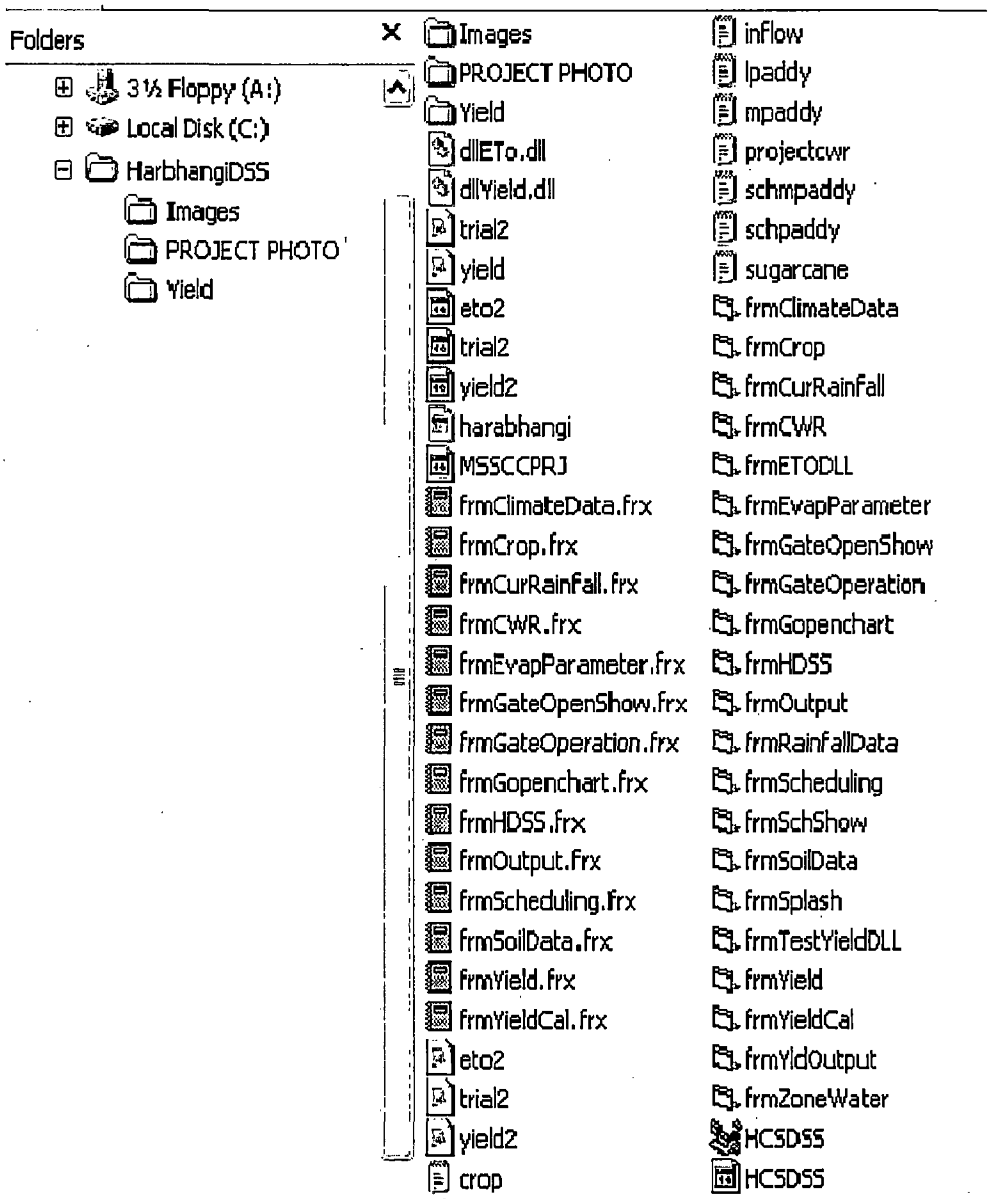


Fig.-8.3 Folder and File details of HCSDSS

Integration of DLLs

FORTRAN programs are developed for estimation ETo and study the within year reservoir yield for which the DLLs are prepared and integrated the respective form for running the program at the back end.

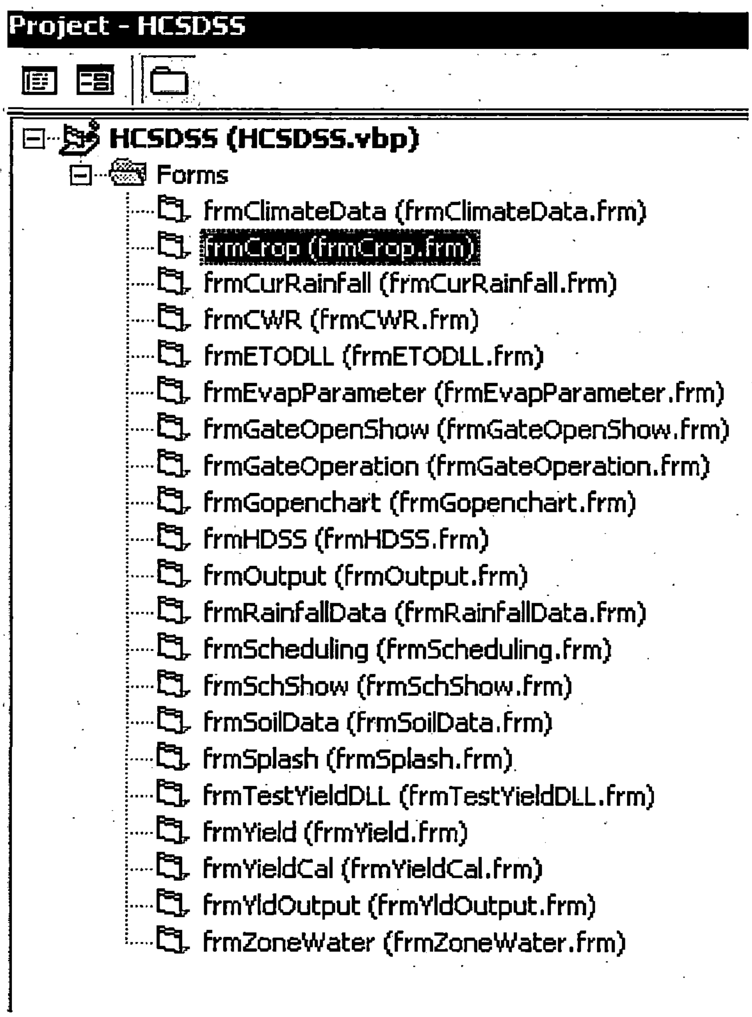


Fig.-8.4 Total Form Modules of HCSDSS

8.5 APPLICATION OF HCSDSS

The splash form (Fig-8.5) appears on screen till the project is loaded for execution. Splash form contains general information like project name, working platform and copyright information etc.

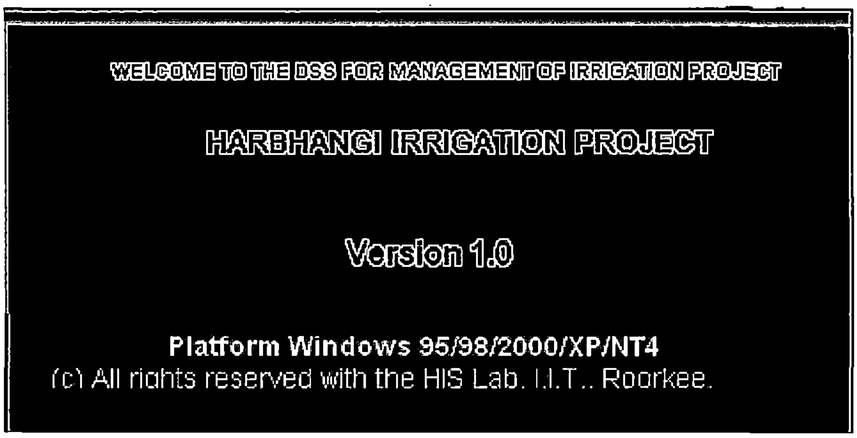


Fig.-8.5 Splash Form Layout of HCSDSS

Then the main window of HCSDSS appears as seen in Fig-8.7. The main toolbar has five icons for main functionality. The same may also be accessed using the menu bar that has some additional features as well. The schematic of the menu structure is shown in figure-8.6.

MENU STRUCTURE

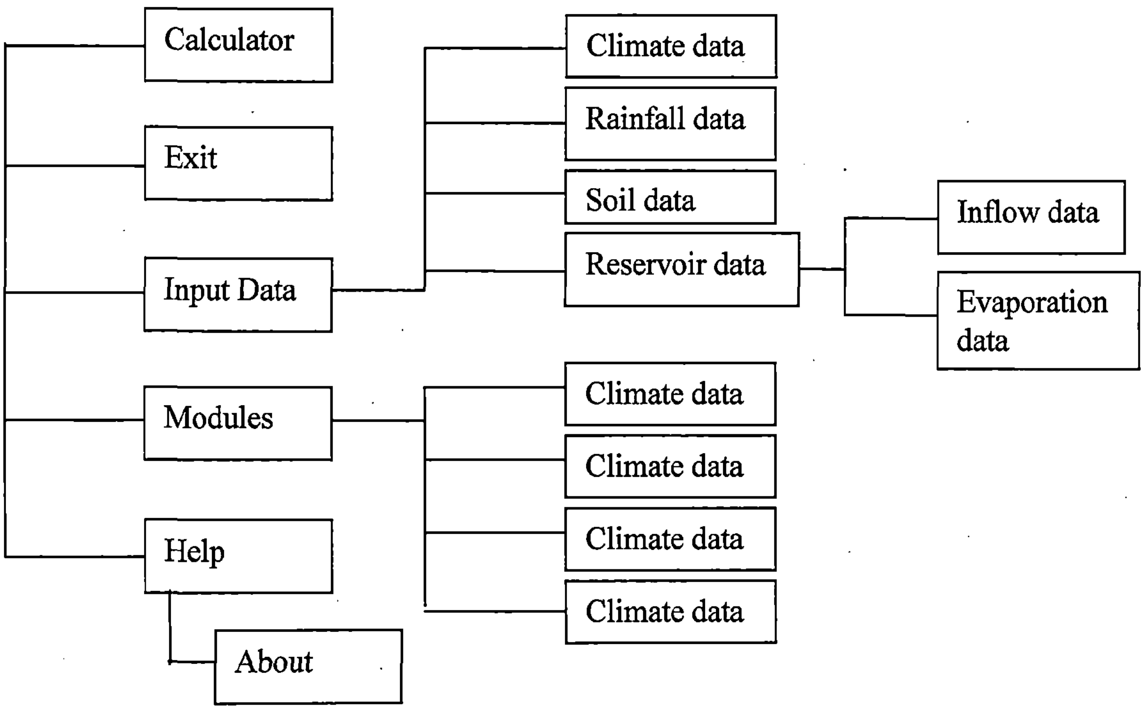


Fig.-8.6 Schematic Diagram of Menu Structure

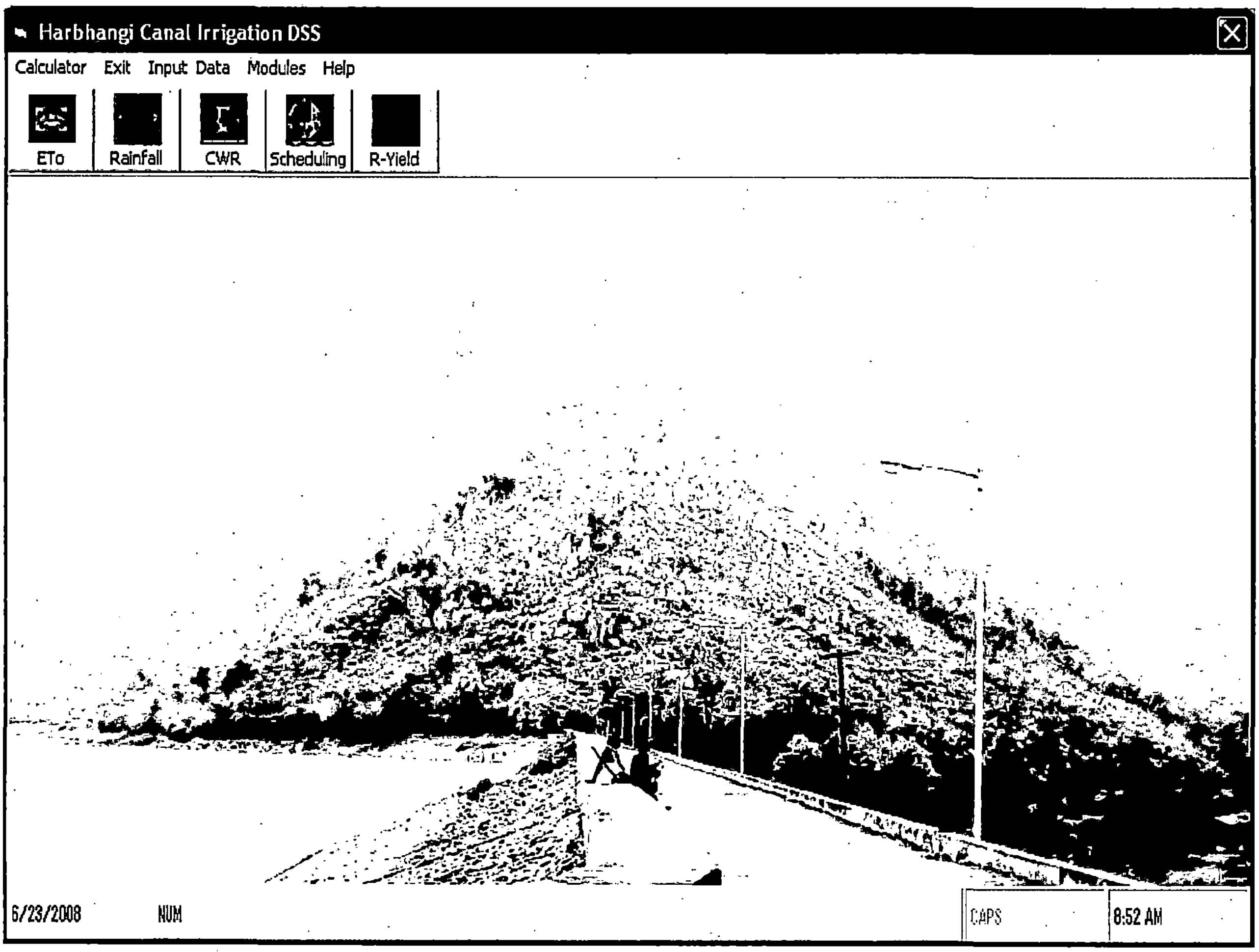


Fig.-8.7 Application of the Main Tool Bar

8.5.1 Calculation of ET_0 by Penmann-Monteith using ETo module

The user can estimate reference evapotranspiration for any time period for the project area by selecting the time period option and entering required hydrometeorological data (i.e. maximum temperature, minimum temperature, relative humidity, sunshine hour and wind velocity) for that time period as per standard format (Fig.-8.8).If the user will select the annual option, he has to enter the 365 days daily hydrometeorological data otherwise program will not calculate the ET_0. However, for the other periods the second option will be selected. ET_0 will be calculated by Penman-Monteith method as discussed briefly in chapter-

5. However, daily ET_0 has to be calculated selecting **ten daily option** for the whole year for further analysis i.e. estimation of CWR of the project and crop scheduling.

The calculation is completed with running the FORTRAN DLL in the background and result will be displayed in a text box as shown in Fig-8.9. A printout of the output data for the project based on average daily data is given in appendix – E.

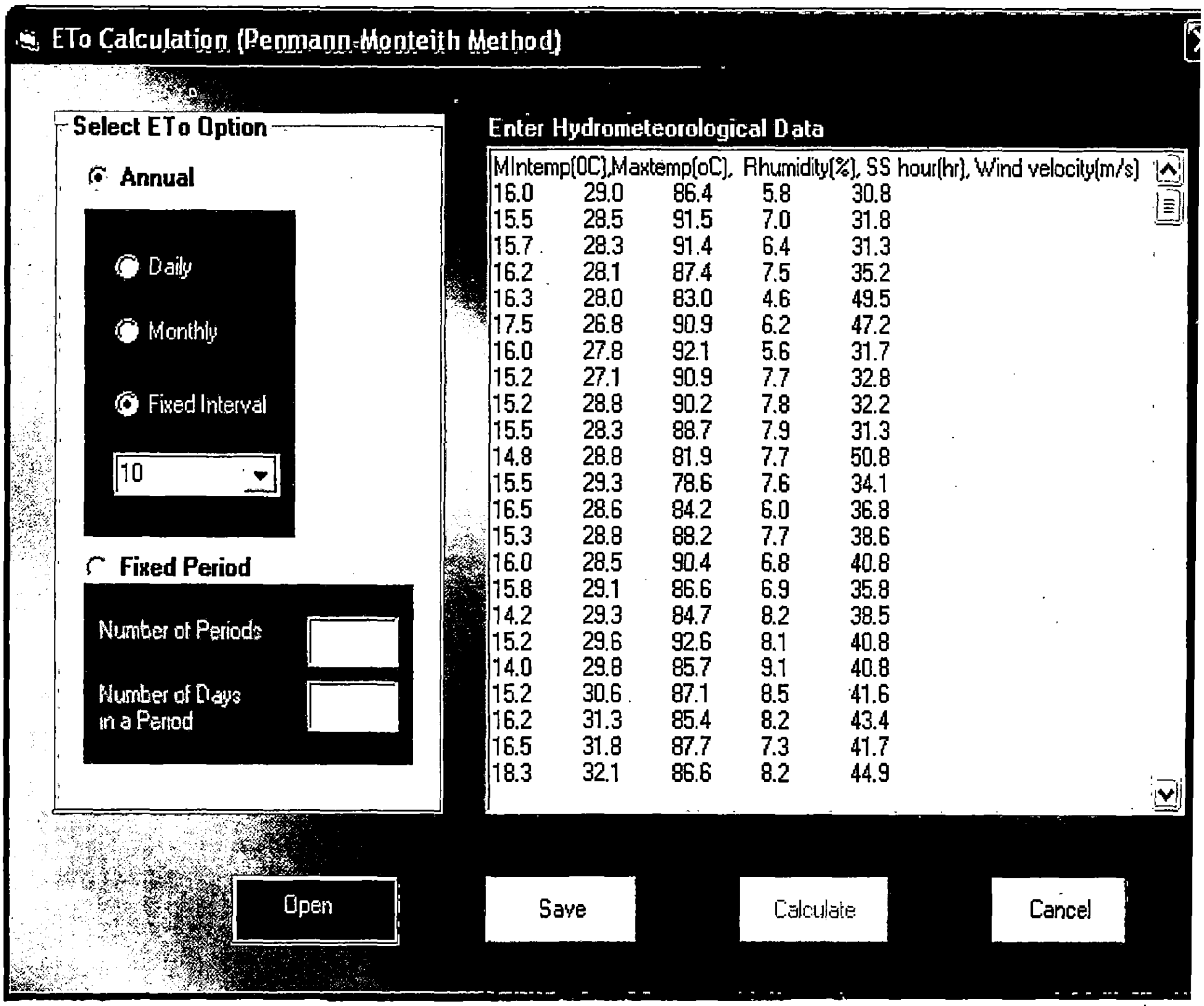


Fig.-8.8 Data File Creation for Running the Et_0 Calculation

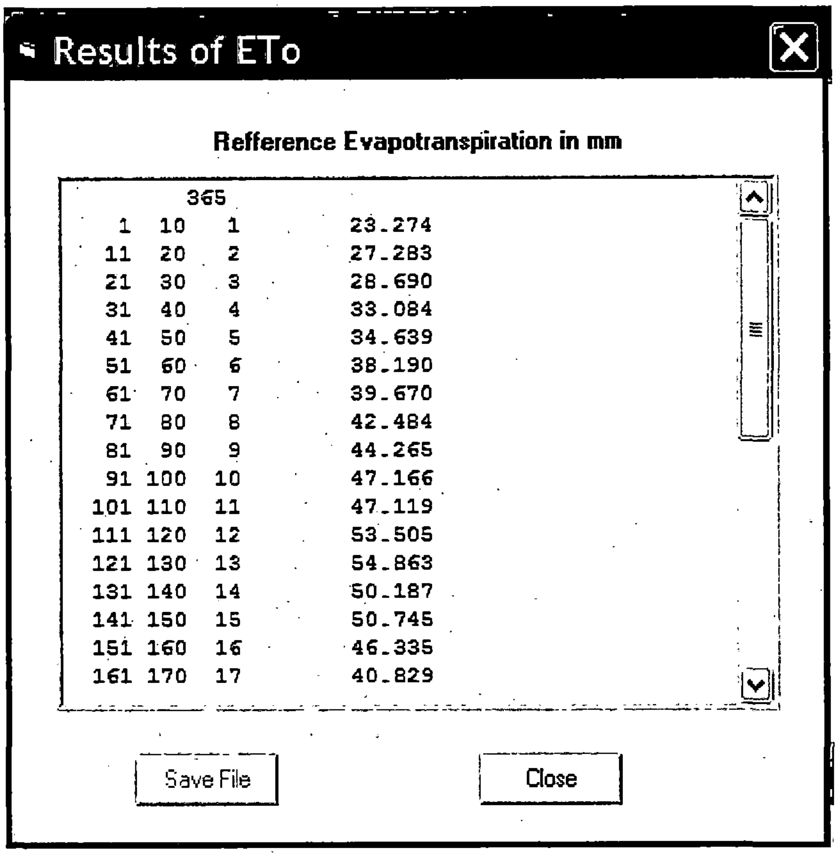


Fig.-8.9 Results of ET_0 Calculation

8.5.2 Estimation of Crop Water Requirement (CWR) using CWR Module

Effective rainfall of the command area can be calculated using any of the three options (fixed percentage, FAO or USDA method), selected by the user.User has to enter the monthly rainfall or weighted rainfall of the catchment and results are saved to a file as per user option and also displayed on the screen as shown in Fig.-8.10. The results are further used to calculate CWR and irrigation scheduling for further use in subsequent analysis. The output file of the effective rainfall is attached in appendix-E.

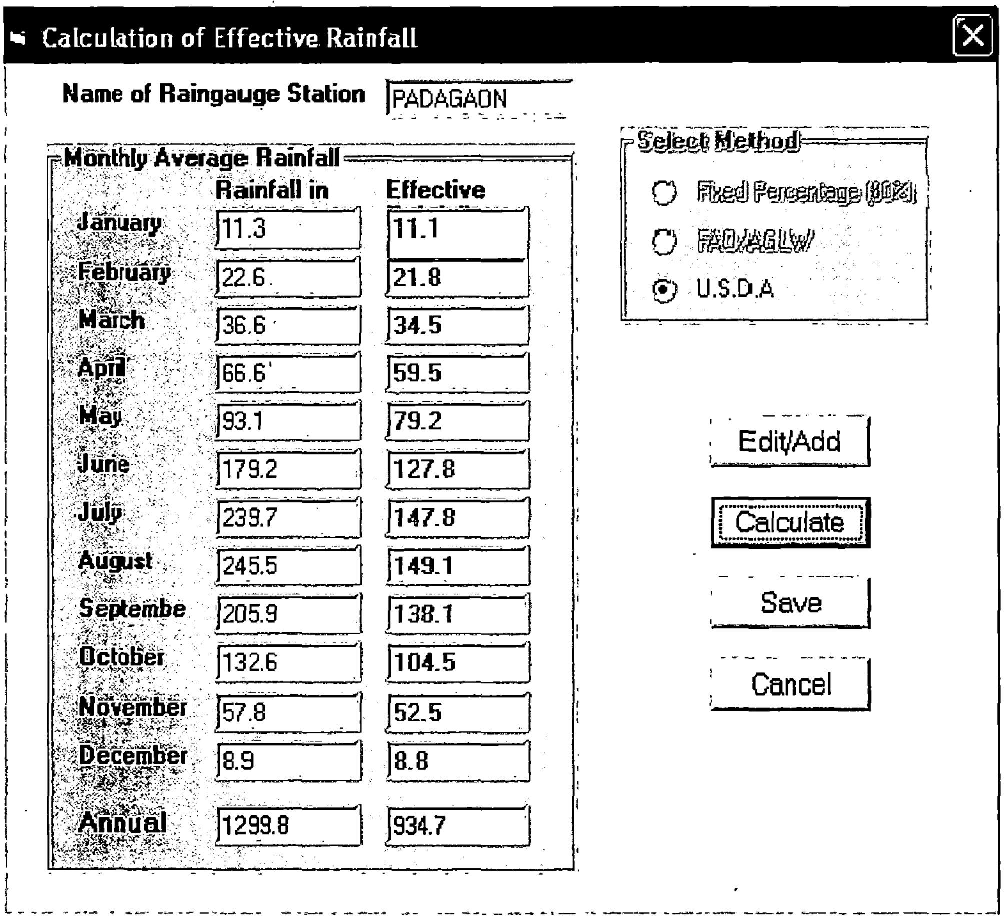


Fig.-8.10 Effective Rainfall Calculation

The details of Crop period and crop coefficient for the different crops (as proposed in project report) are taken as static data for calculating CWR of the individual crop and for the whole project on ten daily basis. However, the crop area and date of plantation of the each crop is to be entered for the analysis season. The methodology is based on the details presented in chapter-5. The crop water requirement of the crop, its result and project crop water requirement is shown in Fig-8.11 to Fig-8.13.The output file for the crop water requirement of early paddy (as a sample crop) and output file for CWR of project for all the crops are attached in appendix-F.

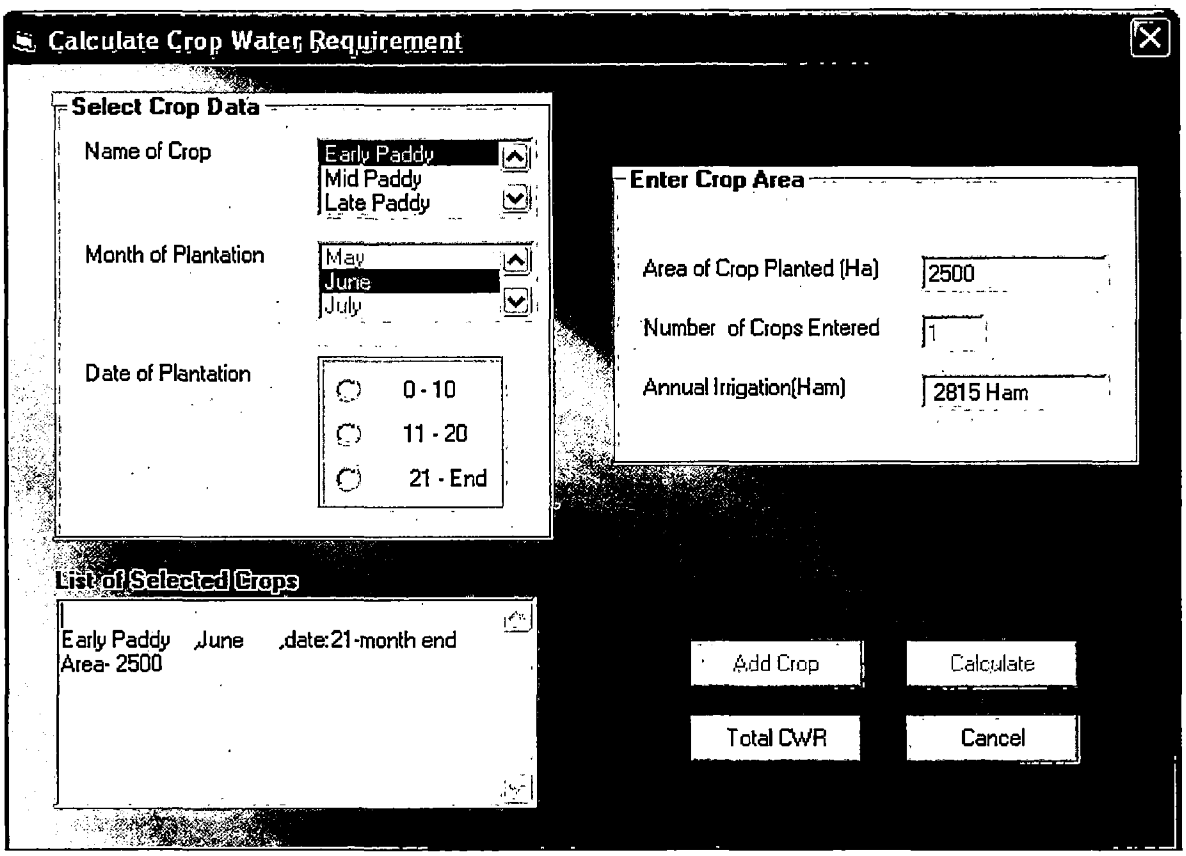


Fig.-8.11 Crop Data Selection

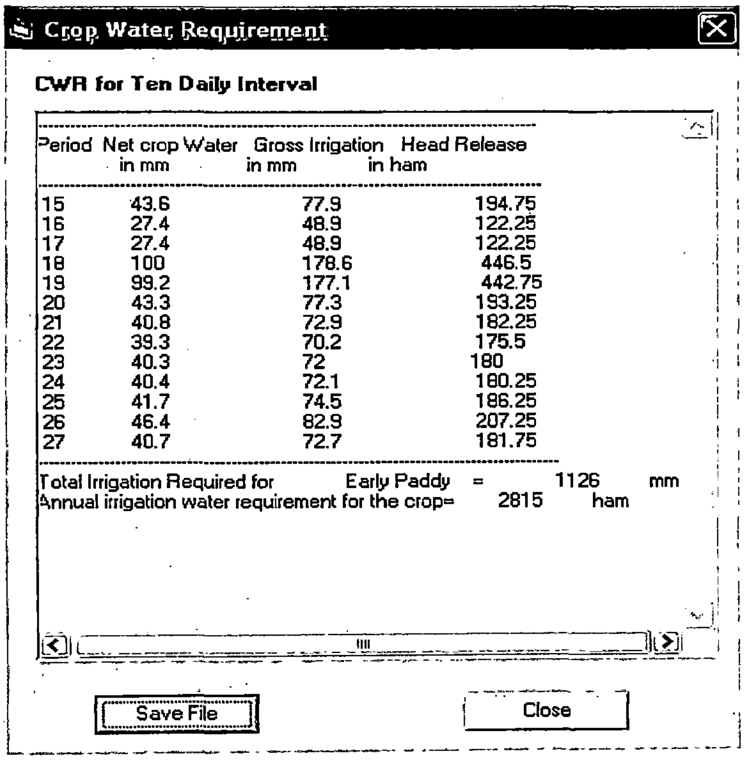
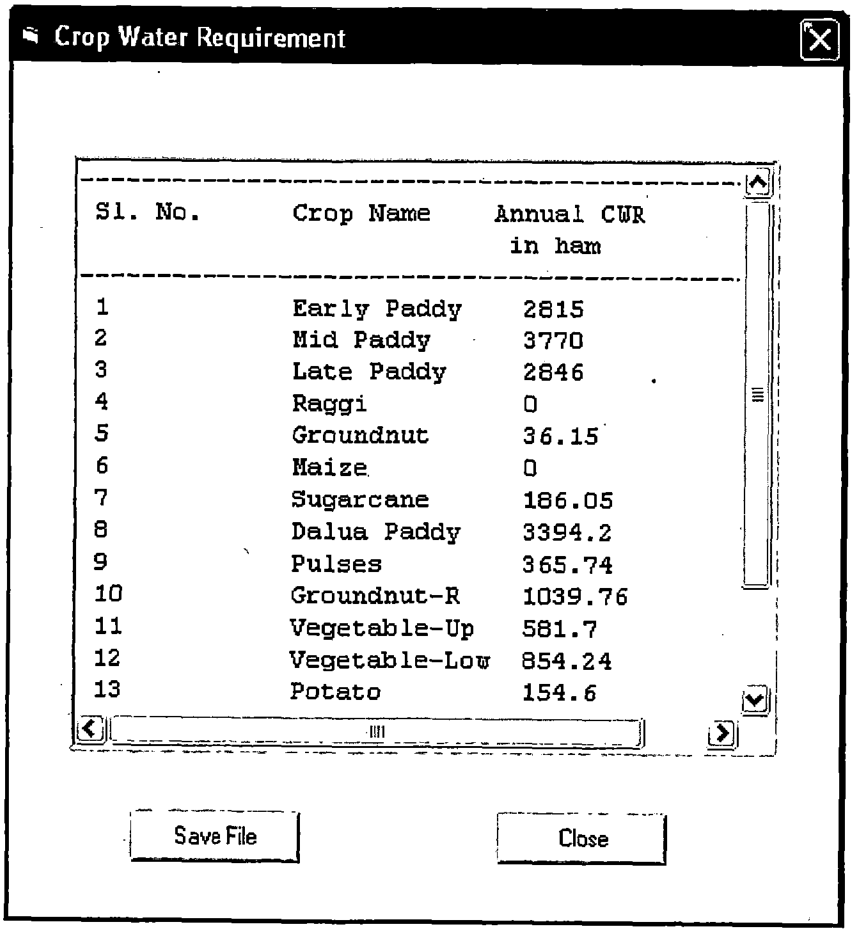


Fig.-8.12 CWR of Individual Crop



Sl. No.	Crop Name	Annual CWR in ham
1	Early Paddy	2815
2	Mid Paddy	3770
3	Late Paddy	2846
4	Raggi	0
5	Groundnut	36.15
6	Maize	0
7	Sugarcane	186.05
8	Dalua Paddy	3394.2
9	Pulses	365.74
10	Groundnut-R	1039.76
11	Vegetable-Up	581.7
12	Vegetable-Low	854.24
13	Potato	154.6

Fig.-8.13 Annual CWR for the Total Project

8.5.3 Preparation of crop scheduling

Scheduling is calculated for the standard cropping pattern of the project or current scheduling of any individual crop.

8.5.3.1 Standard Scheduling

Total scheduling procedure with calculation details in excel sheet is discussed in chapter-7. The effective rainfall calculated previously will be taken same for the scheduling purpose. Other time period option to be selected, crop area and soil data for individual crop of the each zone has to be entered by the user to calculate total irrigation required on ten daily bases for the respective crop and zone. Standard format for the selection of the crop is furnished in Fig.-8.14. Then total crop water requirement of the each zone is calculated accordingly and this will enable irrigation managers to decide on the 'water indents' for each distributary, by estimating in advance the irrigation releases required at the head of the distributary for ten daily cycle of its operation. The sample calculation for a crop of a zone is given in fig-8.15 and zone water requirement of one zone is furnished in Fig-8.16. The results are also saved in an output file as given in appendix –G for a sample crop of zone-A.

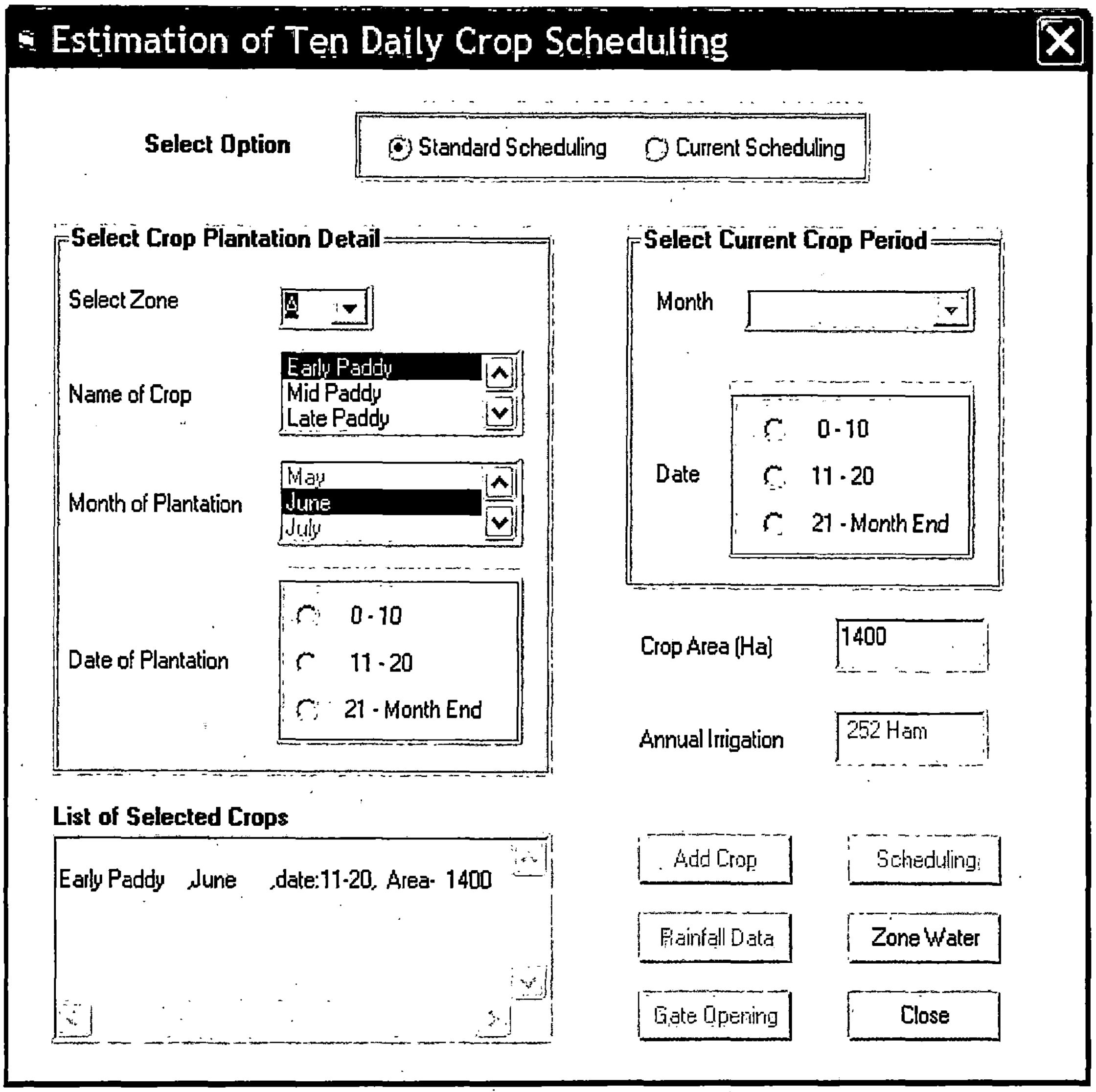
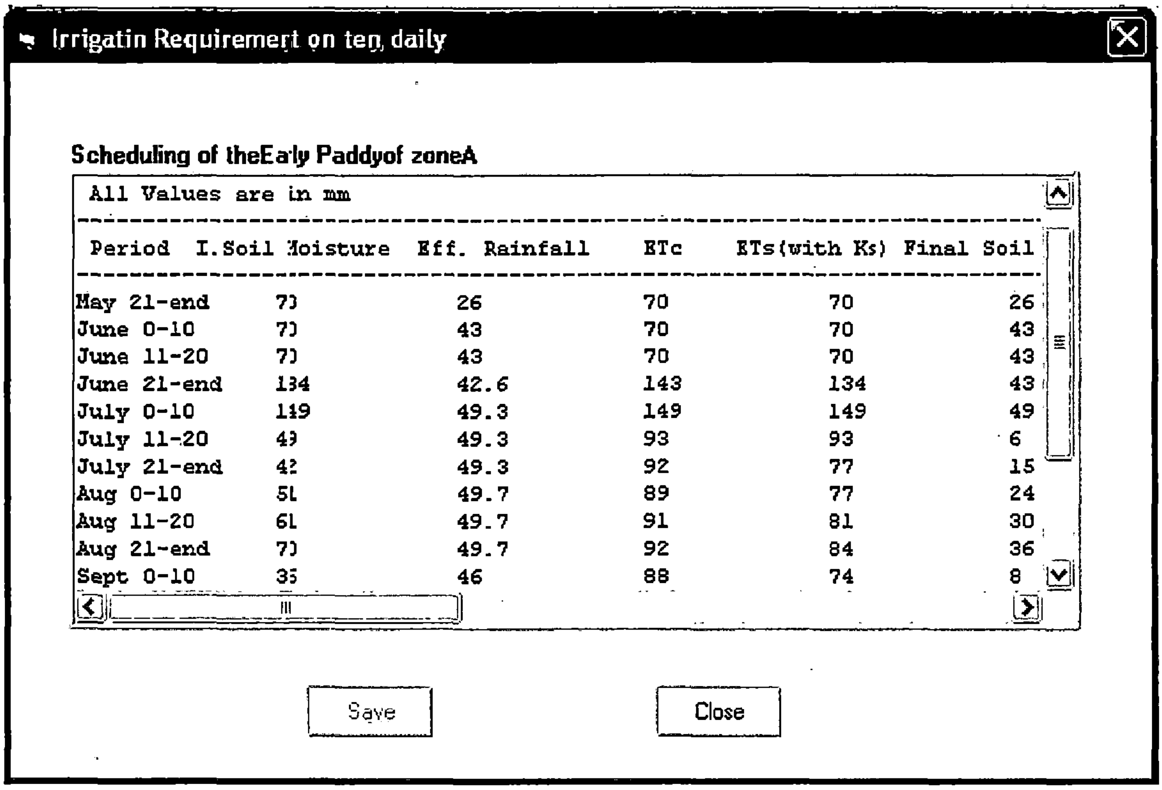


Fig-8.14 Crop Option Selection for Scheduling



Irrigatin Requirement on ten daily

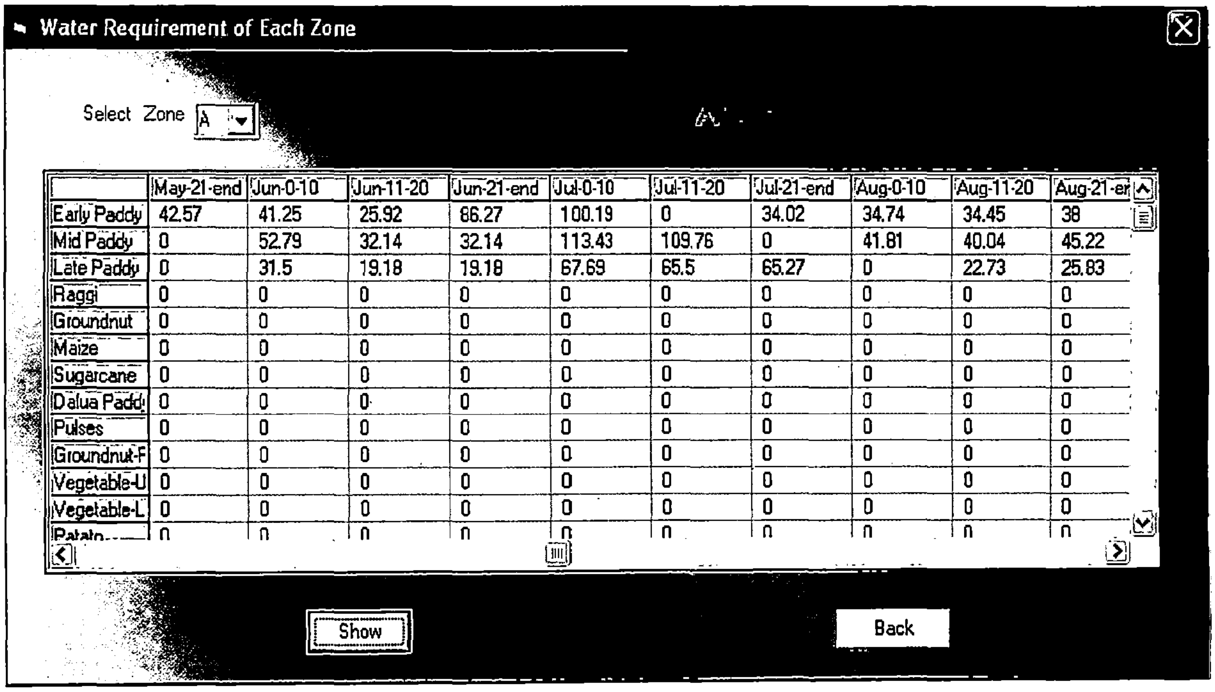
Scheduling of theEarly Paddyof zoneA

All Values are in mm

Period	I.Soil Moisture	Eff. Rainfall	ETc	ETs(with Ks)	Final Soil
May 21-end	70	26	70	70	26
June 0-10	70	43	70	70	43
June 11-20	70	43	70	70	43
June 21-end	134	42.6	143	134	43
July 0-10	149	49.3	149	149	49
July 11-20	49	49.3	93	93	6
July 21-end	42	49.3	92	77	15
Aug 0-10	51	49.7	89	77	24
Aug 11-20	61	49.7	91	81	30
Aug 21-end	70	49.7	92	84	36
Sept 0-10	35	46	88	74	8

Save Close

Fig.-8.15 Periodical Irrigation Scheduling for a Sample Crop



Water Requirement of Each Zone

Select Zone A

	May-21-end	Jun-0-10	Jun-11-20	Jun-21-end	Jul-0-10	Jul-11-20	Jul-21-end	Aug-0-10	Aug-11-20	Aug-21-en
Early Paddy	42.57	41.25	25.92	86.27	100.19	0	34.02	34.74	34.45	38
Mid Paddy	0	52.79	32.14	32.14	113.43	109.76	0	41.81	40.04	45.22
Late Paddy	0	31.5	19.18	19.18	67.69	65.5	65.27	0	22.73	25.83
Raggi	0	0	0	0	0	0	0	0	0	0
Groundnut	0	0	0	0	0	0	0	0	0	0
Maize	0	0	0	0	0	0	0	0	0	0
Sugarcane	0	0	0	0	0	0	0	0	0	0
Dalua Padd	0	0	0	0	0	0	0	0	0	0
Pulses	0	0	0	0	0	0	0	0	0	0
Groundnut-F	0	0	0	0	0	0	0	0	0	0
Vegetable-U	0	0	0	0	0	0	0	0	0	0
Vegetable-L	0	0	0	0	0	0	0	0	0	0
Potato	0	0	0	0	0	0	0	0	0	0

Show Back

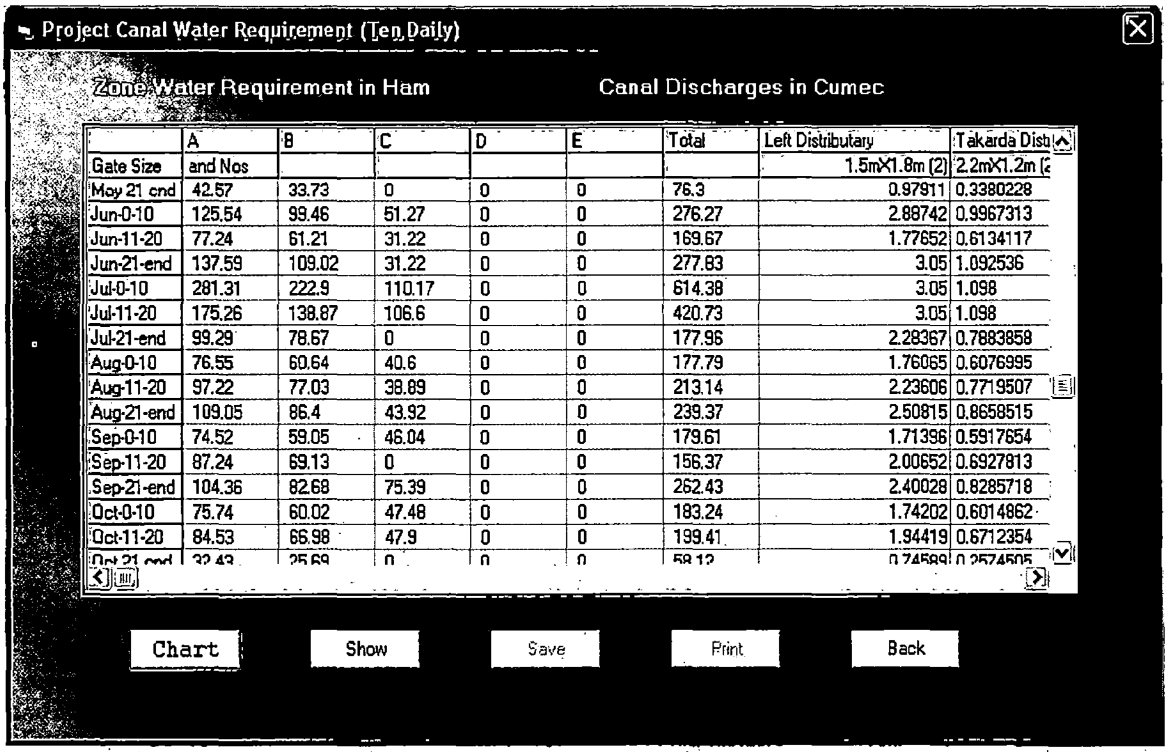
Fig.-8.16 Periodical Irrigation Water Requirement of a Zone

Taking OFF-ON, the standard irrigation operation practices of the project, the following guidelines are fixed for operating distributaries of the canal network:

a. The canals will run at least for 50% time period of the total cropping period.

b. If canal running time with the full discharge capacity is more than 50% time period then the canal will run up to required running time period with full carrying capacity.

On these principles, discharge in distributaries are finalized and are furnished in Fig.-8.17

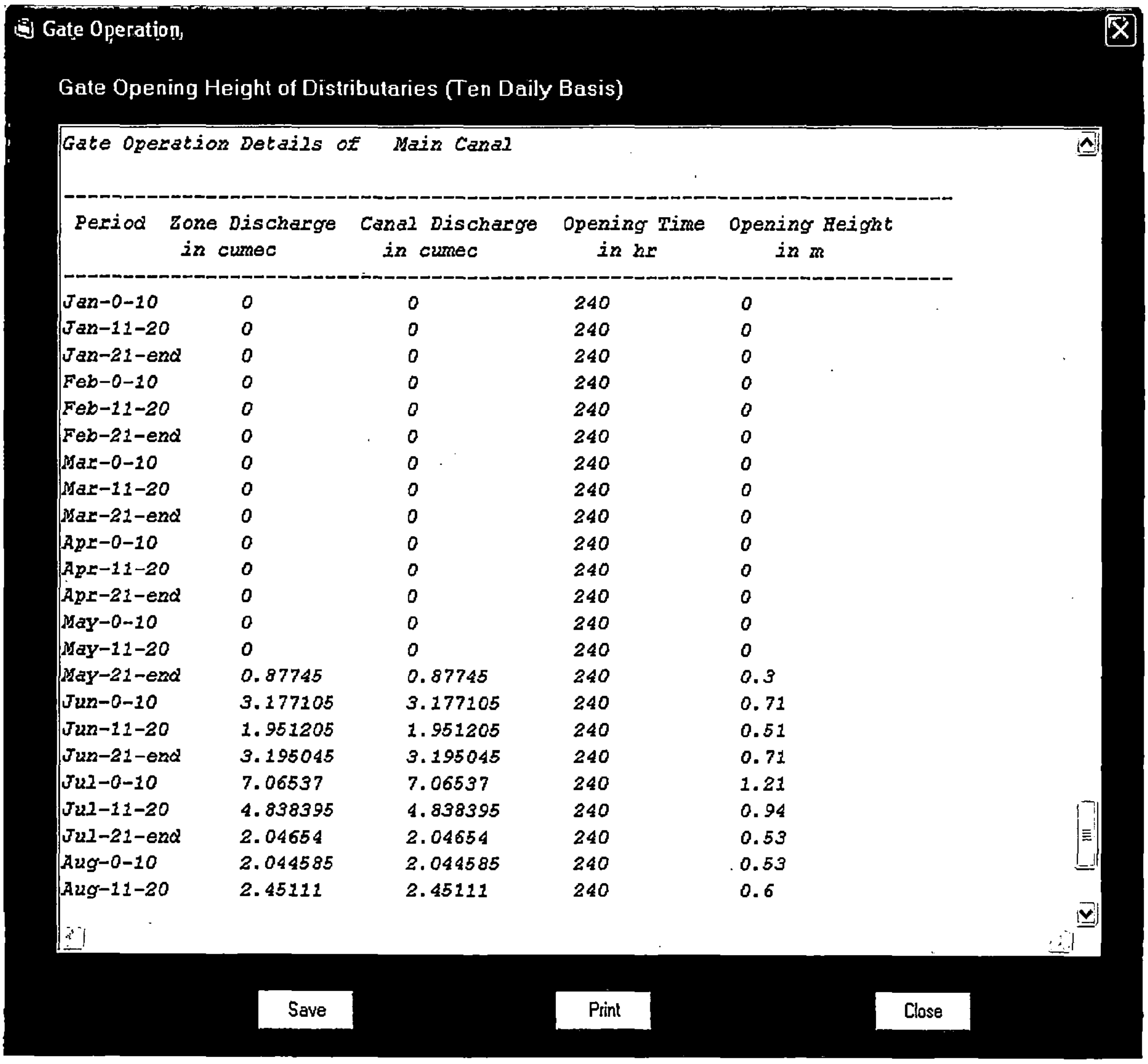


	A	B	C	D	E	Total	Left Distributary	Takarda Dist
Gate Size	and Nos						1.5mX1.8m (2)	2.2mX1.2m (
May 21 end	42.57	33.73	0	0	0	76.3	0.97911	0.3380228
Jun-0-10	125.54	99.46	51.27	0	0	276.27	2.88742	0.9967313
Jun-11-20	77.24	61.21	31.22	0	0	169.67	1.77652	0.6134117
Jun-21-end	137.59	109.02	31.22	0	0	277.83	3.05	1.092536
Jul-0-10	281.31	222.9	110.17	0	0	614.38	3.05	1.098
Jul-11-20	175.26	138.87	106.6	0	0	420.73	3.05	1.098
Jul-21-end	99.29	78.67	0	0	0	177.96	2.28367	0.7883858
Aug-0-10	76.55	60.64	40.6	0	0	177.79	1.76065	0.6076995
Aug-11-20	97.22	77.03	38.89	0	0	213.14	2.23606	0.7719507
Aug-21-end	109.05	86.4	43.92	0	0	239.37	2.50815	0.8658515
Sep-0-10	74.52	59.05	46.04	0	0	179.61	1.71396	0.5917654
Sep-11-20	87.24	69.13	0	0	0	156.37	2.00652	0.6927813
Sep-21-end	104.36	82.68	75.39	0	0	262.43	2.40028	0.8285718
Oct-0-10	75.74	60.02	47.48	0	0	183.24	1.74202	0.6014862
Oct-11-20	84.53	66.98	47.9	0	0	199.41	1.94419	0.6712354
Oct-21-end	32.43	25.69	0	0	0	58.12	0.74589	0.2574505

Fig.-8.17 Periodical Irrigation Water Requirement of all Zone and Distributaries

Gate Opening

The height of the gate opening of the distributary is fixed with proportion to the total gate opening height in accordance to the required discharge from time to time. However, discharge in main canal is not checked because the design discharge of the main canal is almost equal to the discharges of all the distributaries. The results are furnished in a text box as shown in Fig.8.18 and the output file is given in appendix-H



Period	Zone Discharge in cumec	Canal Discharge in cumec	Opening Time in hr	Opening Height in m
Jan-0-10	0	0	240	0
Jan-11-20	0	0	240	0
Jan-21-end	0	0	240	0
Feb-0-10	0	0	240	0
Feb-11-20	0	0	240	0
Feb-21-end	0	0	240	0
Mar-0-10	0	0	240	0
Mar-11-20	0	0	240	0
Mar-21-end	0	0	240	0
Apr-0-10	0	0	240	0
Apr-11-20	0	0	240	0
Apr-21-end	0	0	240	0
May-0-10	0	0	240	0
May-11-20	0	0	240	0
May-21-end	0.87745	0.87745	240	0.3
Jun-0-10	3.177105	3.177105	240	0.71
Jun-11-20	1.951205	1.951205	240	0.51
Jun-21-end	3.195045	3.195045	240	0.71
Jul-0-10	7.06537	7.06537	240	1.21
Jul-11-20	4.838395	4.838395	240	0.94
Jul-21-end	2.04654	2.04654	240	0.53
Aug-0-10	2.044585	2.044585	240	0.53
Aug-11-20	2.45111	2.45111	240	0.6

Fig.-8.18 Periodical Discharge and Opening of Gate Height for all Distributaries

8.5.3.2 Current Scheduling

Scheduling of any crop for the running period can be prepared with the selection of the date of plantation and present date. During this period the rainfall of the command area is to be entered along with soil parameters to get the present soil moisture position and irrigation requirement of that crop up to end of that crop period is calculated periodically.

8.5.4 Determination of Assured Yield of the Reservoir

The data file will generated by selecting the options and entering the other data such as monthly evaporation, monthly inflow to reservoir and reservoir parameter as per the specified format given in Fig.-8.19 in HCDSS to formulate the yield model as single reservoir multi yield model for the Harbhangi irrigation project to get the firm yield and secondary yield for normal flow condition.

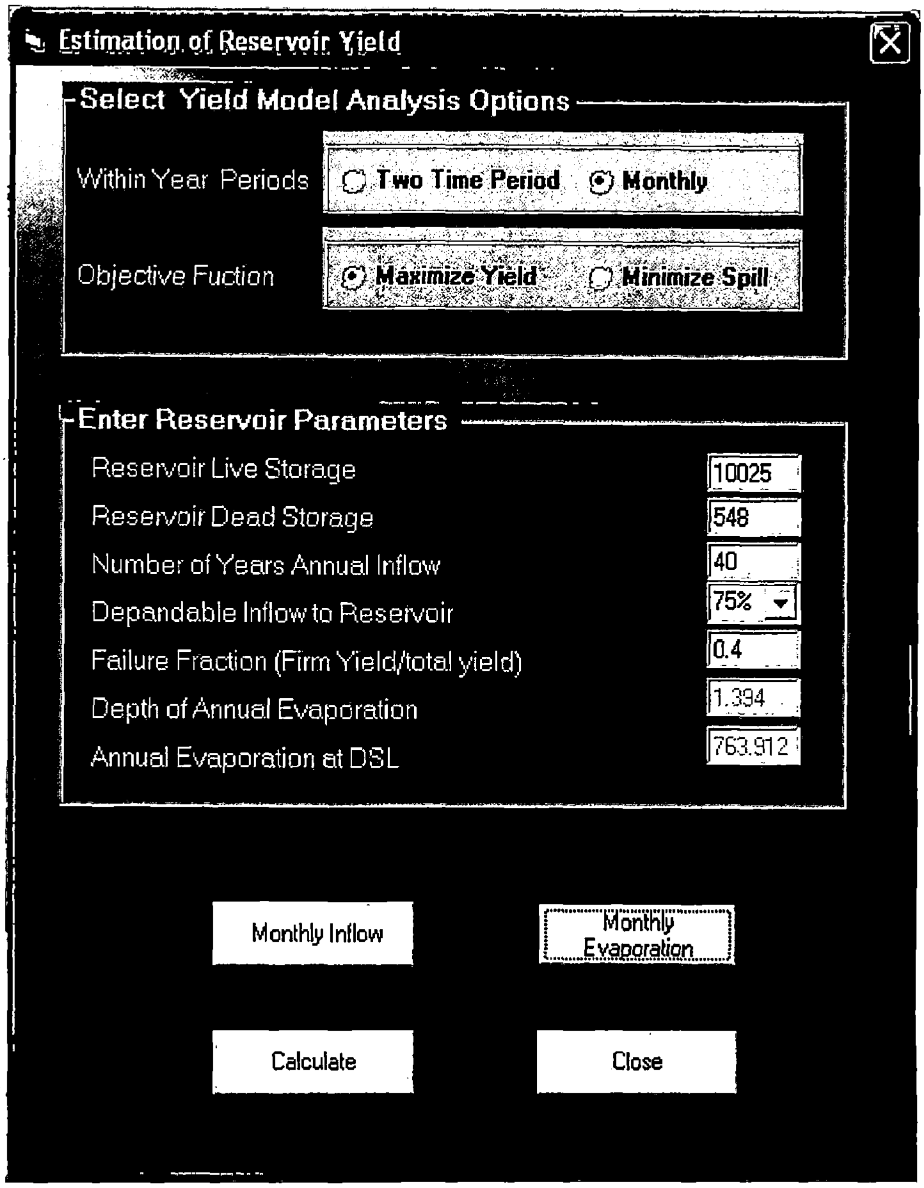


Fig.-8.19 Creation of Data File to Run Yield Model

The following steps are followed to formulate yield model data file:

1. Objective function is to be selected out of maximize yield or minimize spill.
2. Within year period option i.e. two time period or twelve time period to be selected.
3. Number of year's inflow data to be used for analysis i.e. maximum over year constrainted (MMOC).
4. β_t values for the critical flow year are calculated basing on the selection of option of dependability and monthly inflow value.
5. Evaporation parameters i.e. monthly reservoir evaporation, average reservoir slope are entered for calculating periodical evaporation ratio (γ_t).
6. Live storage capacity, dead storage capacity and failure fraction (ratio between firm yield and total yield) are also entered.

A FORTRAN program was developed to create LP matrix incorporating these parameters and solve the matrix to give Periodical total yield, annual firm yield and annual secondary yield. It was integrated in the DSS as a DLL. Result for a sample calculation of twelve time period (within year) and maximize yield is shown in Fig.-8.20. The input data file and output file, created with the DSS is attached in Appendix-I

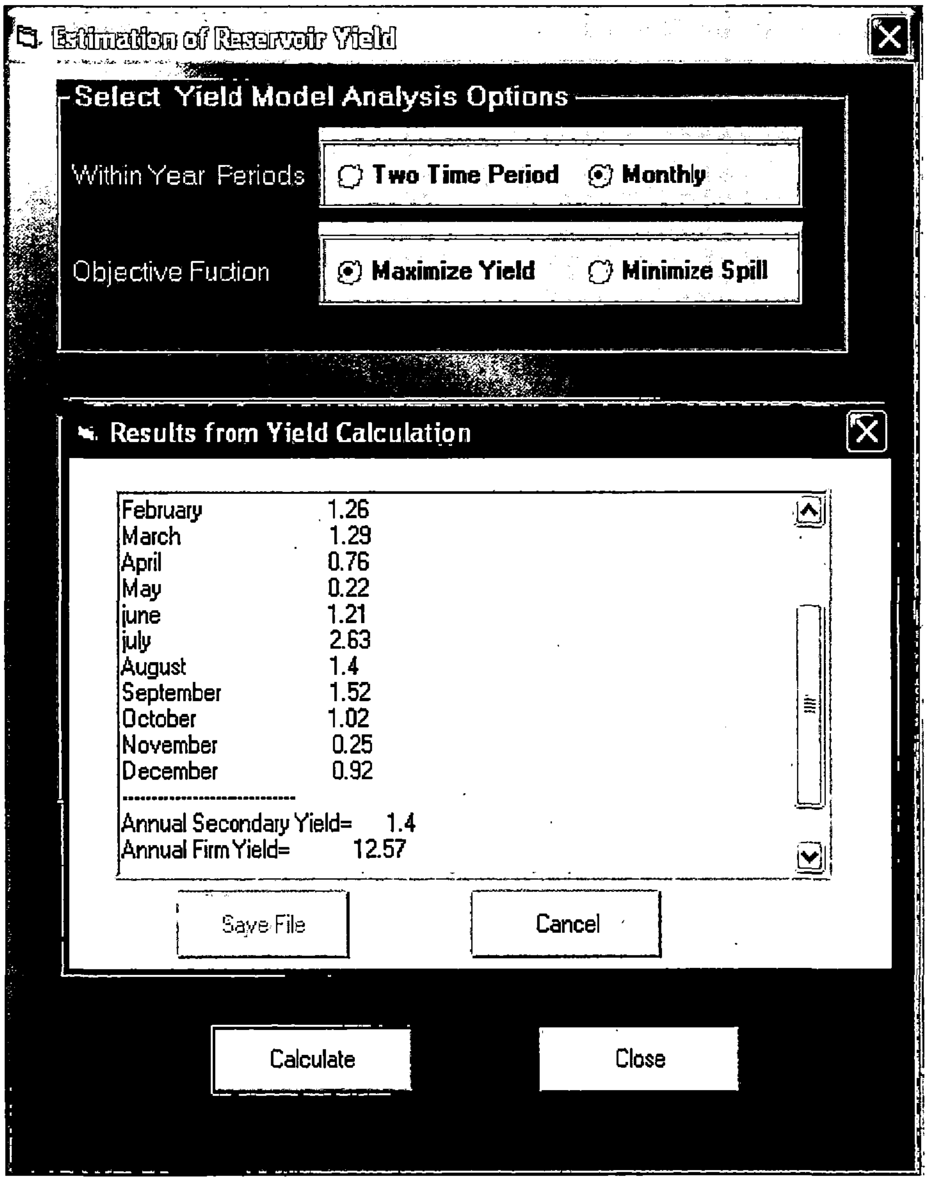


Fig.-8.20 Calculation of Periodical Yields with Yield Model

8.6 RESULTS AND DISCUSSION

With the application of DSS in Harbhangi Irrigation project, it is found that project yield with normal flow distribution, is satisfying the minimum water requirement and 80% of the CWR for scheduled cropping pattern as firm yield for the total period. Following are the additional advantages that can be achieved using the DSS approach of irrigation management:

i. Daily ET_0 of the project can be revised for each year with present updated hydrometeorological data.

ii. Crop water requirement (CWR) of the project can be modified for each year according to the annual cropping plan of the project. Also, the proposed cropping plan can be refined with the availability of the water in the reservoir after the monsoon period.

iii. From the present cropping plan, periodical water release in different distributaries can be ascertained and it can be compared with design discharge, i.e., carrying capacity of the canal before finalization of the crop plan.

iv. Canal operation schedule, i.e., periodical gate opening can be tentatively fixed for each distributary based on present cropping pattern.

v. Annual firm yield, secondary yield and total yield of the reservoir can be calculated with different dependable inflows.

vi. These yields can be compared with CWR of the project for scheduled cropping pattern and for the cropping pattern fulfilling minimum requirements of the projected basin population to ascertain the viability of the project.

vii. The DSS is very user friendly for irrigation management purposes.

CHAPTER-9

CONCLUSION

This study was undertaken for the Harbhangi irrigation project in which the major water requirement of the project is to meet irrigation demand of the project command area and to divert the surplus water to Rushikulya river basin which is experiencing frequent draught condition and water scarcity. The objective of implementing a tailor-made decision support system integrating methodologies is for estimation of inflow into the reservoir, calculation of ET_c from ET_o using Penman-Monteith Method, to find the reservoir yield to do irrigation scheduling including gate operations.

HCDSS, the developed DSS for Harbhangi canal system is a step forward towards intelligent irrigation planning and systematic operation of the canal system over the traditional irrigation management. From the practical experience of the project authority and release record of the project, this reservoir is surplus in water.

Following are the results of the study carried out for the project:

a. Daily ET_o was calculated with the program developed in FORTRAN using Penmann-Monteith method. It has been observed that the results are around 5% less over the monthly ETo calculated by CROPWAT for the available present data.

b. The estimated crop water requirement of the project is 16.35 Tham for the scheduled cropping pattern as compared to the project value of 18.67 Tham.

c. Crop scheduling model is developed for the project with soil moisture balancing method incorporating soil coefficient (Ks) which results less irrigation water requirement over the CWR with prevailing cropping pattern.

d. Running the yield module of the reservoir with 40 years inflow data, the maximum annual firm yield which can be achieved for the normal flow condition at 100% project dependability is 12.8 Tham. A maximum total annual yield of the reservoir is 22.23 Tham on an annual project dependability of 75% with a annual firm yield of 10.0 Tham.

e. Irrigation scheduling of the crop results around 5.2% less water requirement over the water requirement of 16.37 Tham, calculated previously. Also, periodical gate operation for the whole year for each distributary is tentatively proposed.

f. Less water requirement periods, i.e., during month of October, November and March can be avoided for irrigation to facilitate the canal maintenance.

g. An overall result shows the successful application of the DSS will have the following advantages such as:

    i. It has more user friendly visual interface to handle the different modules.

    ii. It is more flexible as the user will enter or select the almost all information as per the present condition.

    iii. Reservoir study can be updated using the current data.

9.1 FUTURE SCOPE OF WORK

a. There is a strong need to use a relational database management system like MS Access for better management, retrieval and updating of the data.

b. Reservoir status and the irrigation release requirement relationship are not established.

c. The periodical canal discharge and canal opening height are calculated as per the standard project practice with some modified principles but the optimization model can be used for minimizing the main canal and distributaries running time.

d. Detail calculation of water requirement at the minor canal level to optimize the gate operation of the distributaries. Reservoir operation with inflow to the reservoir and outflow for the irrigation demand of the project command area can be simulated on real time basis.

e. GIS application to the DSS can improve the real time study of the total cropping area, types of crop and moisture condition of the soil, which can be utilized for irrigation management.

REFERENCES

Akhand, N.A., Larson, D.L., and Slack, D.C. (1995). "Canal irrigation allocation planning model." *Transactions ofASAE.* 38(2), 545-550.

Arumugam, N., and Mohan, S. (1997). "Integrated decision support system for tank irrigation system operation." *J. Water Resources Planning and Management,* ASCE, 123(5), 40-49.

Awchi T.A.1. (2005). Optimal planning and operation of a reservoir. PhD Thesis, Deptt. of Hydrology, Indian Institute of Technology, Roorkee.

Bomman, B.J., and Hill, R.W. (1989). "LP operation model for on-demand canal systems." J. Irrigation and Drainage Engineering, ASCE, 115(4), 687-700.

Brouwer, C., Prins, K. (1989). "Irrigation water management: Irrigation scheduling", FAO-1989

Central Water Commission, Government of India. (1998). "Water related statistics." R.K.Puram, New Delhi, p314.

Chang, Y., Hubrechts, L., and Feyen, J. (1993). "Evaluation of DMIS: A decision support system for the management of the field irrigation schedule of medium to large scale irrigation schemes."*Bull. Rech. Agron. Gembloux,* 28(2-3), 329-340.

Dahe, P.D., and Srivastava, O.K. (2000). "Assessment of reliable reservoir yield for an irrigation project." Proceedings of the National Seminar on Irrigation Strategies - Present and Future, Irrigation Management and Training Institute Thuvakudy, Tiruchirappali, Tamil Nadu, India, volume section on Theme II, 5-15

Dahe, P.D. (2000). Planning for optimal development of a river basin. Ph.D. Thesis, Deptt. of Hydrology, University of Roorkee, Roorkee.

Dandy, G.C., Connarty, M.C., and Loucks, D.P. (1997). "Comparison of yield assessment of multiple reservoir systems." *J. Water Resources Planning and Management,* ASCE, 123(6), 350-358.

Das, B. (1993). An integrated optimization simulation approach for optimal operation of a large irrigation canal system. Ph.D. thesis, School of Civil Engineering, Asian Institute of Technology, Bankok, Thailand.

Deepti Rani (2005). Multilevel optimization of a water resources system. PhD Thesis, Deptt. of Hydrology, Indian Institute of Technology, Roorkee.

Draper, A.J., and Lund, J.R. (2004). "Optimal hedging and carryover storage value."J. *Water Resources Planning and Management, ASCE,* 130(1), 83-87.

Evans, Robert, Cassel, D.K., Sneed, R.F. (1996). "Soil, water, and crop characteristics important to irrigation scheduling" North Carolina Co-operative Society, AG 452-1, June, 1996

FAO. (1991). Improved Irrigation System Performance for Sustainable Agriculture, Proceedings of the Regional Workshop on Improved Irrigation System Performance for Sustainable Agriculture, Bankok, Food and Agriculture Organization, Rome.

Flynn, L.E., and Marino, M.A. (1987). "Optimal aqueduct capacity and distribution policy: continuous approach." *J. Water Resources Planning and Management,* ASCE, 113(4), 533-549.

Ghahraman, B., and Sepaskhah, A.R. (2002). "Optimal allocation of water from a single purpose reservoir to an irrigation project with pre-determined multiple cropping patterns. "*J. of Irrigation Science,* 21, 127-137.

Hasan, M., Hussein, I., and Wahshah, S. (2000). "Applying a decision support system to optimize water movements: The King Abdallah canal at the Jordan Valley."/. *Environmental Hydrology,* 8, 8-17.

Hashimoto, T., Stedinger, J.R., and Loucks, D.P. (1982). "Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation." *Water Resources Research,* 18(1), 14-20.

Hershaeur, J., Karim, A., Owens, H., and Philipakis, A. (1989). "A field observation study of an expert system prototype development." Information and Management, 17, 107-116.

Jacucci, G., Kabat, P., Pereira, L.S., Verrier, P., Steduto, P., Uhrik,C. Betanzon, G., Huygen, J., Broek, B., and Teixeira, J.L. (1994). "The HYDRA project : a decision support for irrigation water management." International Conference on Land and Water Resources Management in the Mediterranean Region, Valenzano, Bari, Italy, 4-8 September, 1994, 6, 1-19.

Jena J. (2005). System analysis of an irrigation and cascade hydropowcr scheme. PhD Thesis, Deptt. of Hydrology, Indian Institute of Technology, Roorkee.

\ **Jena J. and Srivastava D.K.** (2005). "Optimal allocation of irrigation water through canal network with minimum seepage and evaporation criteria." Proceedings of the International Conference on Hydrological Perspectives for Sustainable Development, Vol-II, 23-25 February 2005, Deptt. of Hydrology, Indian Institute of Technology. Roorkee. p728-738.

K. Geetha & S. K. Mishra & T. I. Eldho & A. K. Rastogi & R. P. Pandey. (2007) "SCS-CN-based Continuous Simulation Model for Hydrologic Forecasting", Water resources manage, Springer,

Kaca, E., Labedzki, L., Lukaszewicz, H., Lojek, W., and Ragab, R. (1996). "IRRDIS: a model for irrigation control and water distribution." In: El Quosy DE.D., Van, D.B.B. and Pereira, L.S. (eds). Sustainability of irrigated agriculture: crop-water-environment models. *Proceedings of Workshop at the 16" 1CID Congress,* Cairo, Egypt,September 1996,187-198

Lohani, V.K., and Fontane, D.G. (1988). "Water distribution system design - A dynamic programming approach." *Irrigation and Power,* October, 69-79

Loucks, D.P., Stedinger, J.R., and Haith, D.A. (1981). *Water Resources Systems Planning and Analysis.* Prentice-Hall, Inc., Englewood Cliffs, N.J.

Marino, MA., and Flynn, L.E. (1987). "Optimal aqueduct capacity and distribution policy : discrete approach." *J. Water Resources Planning and Management,* ASCE, 113(4), 551-561.

Minstry of Food, Agriculture and Fisheries (2002). "Water conservation fact sheet"

Mass, A., Hufschmidt, M.M., Dorfman, R., Thomas, Jr., H.A., Marglin, S.A., and Fair, G.M. (1962). *Design of water resources systems.* Harward University Press, Cambridge, Mass.

Mujumdar, P.P., and Teegavarapu, R. (1998). "Short-term reservoir operation model for multicrop irrigation." *Hydrological Sciences J.,* 43(3), 479-494.

Muspratt, M.A. (1971). "Optimal distribution of water to irrigation canals." *Journal of Hydrology*, (14), 19-28.

Nino Ohle (1998). "Optimization of water-use efficiency of canal networks in Chile with one dimensional computer model." *Thesis Abstract, submitted to Faculty of Civil Engineering, University of Hanover.* May 1998.

Panigrahi R.K., and Srivastava, O.K. (2005). "Assessment of optimal yield in a system of reservoirs." Proceedings of the International Conference on Hydrological Perspectives for Sustainable Development, Vol-II, 23-25 February 2005, Deptt. of Hydrology, Indian Institute of Technology, Roorkee. p587-598.

Parhi P.K., Mishra S.K. and Singh Ranveer (2008). "Scheduling of irrigation for wheat in a semi-humid tropical canal using water balance approach" J. IWRS, 28(1), p1-10.

Rajput, T.B.S., and Michael, A.M. (1990). "Scheduling canal delivery on the basis of soil moisture balance." J. IWRS, 10(2), 33-43.

Rajput, T.B.S. (1992). "Optional operation policies of a canal system under different levels of rotation." J. IWRS, 12(30), 252-259.

Rao, K.V. (1995). "Integrated decision support system for conjunctive use in irrigation projects. Ph.D. Thesis, IARI, New Delhi"

S. K. Mishra & R. P. Pandey & M. K. Jain & Vijay P. Singh. (2007) "A Rain Duration and Modified AMC-dependent SCS-CN Procedure for Long Duration Rainfall-runoff Events"

S. K. MISHRA1*, VIJAY P. SINGH2, J. J. SANSALONE2 and V. ARAVAMUTHAN2 (2003) "A Modified SCS-CN Method: Characterization and Testing", Water Resources Management, 17, 37-68.

Shin, J., and Re Velle, C. (1994). "Water supply operations during drought: continuous hedging rule." *J. Water Resources Planning and Management,* ASCE, 120(5), 613-629.

Shih, J., and Re Velle, C. (1995). "Water supply operations during drought : A discrete hedging rule." *European Journal of Operational Research^* 82, 163--175.

Sinha, A.K., Rao, B.V., and Lall, U. (1999b). "Yield model for screening multipurpose reservoir systems." */. Water Resources Planning and Management,* ASCE, 125(6), 325-332.

Stedinger, J.R. (1984). "The performance of LDR models in preliminary design and reservoir operation." *Water Resources Research,* 20(2), 215-224.

Surendra Kumar Mishra* and Vijay P. Singh. (2004) "Validity and extension of the SCS-CN method for computing infiltration and rainfall-excess rates", Hydrological Process,Willey Interscience, 18,3323-3345 (2004).

Terjung,W. H., J. T., H-Y. Ji I , P. A. O'Rourke 2 and P. E. Todhunter

Vedula, S., and Mujumdar, P.P. (1992). "Optimal reservoir operation for irrigation of multiple crops." Water Resources Research, 28(1), 1-9."

Water Science and Technology Board (1986). "Drought management and its impact on public water systems." *Colloquium Report, National Research Council,* National Academy Press, Washington, D.C."

APPENDIX-A

```
SUMQ=       1223.72  SUMRF=      3402.31

1           BSOLVE REGRESSION ALGORITHM

  ICON =   4    PH =   .31402330E+04    ITERATION           NO. =  1

  ICON =   4    PH =   .19589560E+04    ITERATION           NO. =  2

  ICON =   4    PH =   .93333220E+03    ITERATION           NO. =  3

  ICON =   4    PH =   .72514990E+03    ITERATION           NO. =  4

  ICON =   4    PH =   .71757270E+03    ITERATION           NO. =  5

  ICON =   4    PH =   .71728230E+03    ITERATION           NO. =  6

  ICON =   4    PH =   .71727830E+03    ITERATION           NO. =  7

  SOLUTION OF THE EQUATION

  B( 1)= ,    .12485520E+02

  B( 2)= ,    .24381480E+02

  B( 3)= ,    .28759330E+01

  B( 4)= ,    .26574030E+02

   EFFICIENCY=      78.595
```

DAY	RAINFALL	S	RF-EXCESS	INFILT	BASEFLOW	RUNOFF(C)	RUNOFF(O)	EVAPTRA	AMOIST	PANC
1	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
2	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
3	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
4	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00

DAY	RAINFALL	S	RF-EXCESS	INFILT	BASEFLOW	RUNOFF(C)	RUNOFF(O)	EVAPTRA	AMOIST	PANC
5	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
6	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
7	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
8	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
9	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
10	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
11	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
12	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
13	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
14	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
15	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
16	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
17	.00	12.49	.00	.00	.00	.00	.05	.00	.00	1.00
18	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
19	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
20	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
21	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
22	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
23	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
24	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
25	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
26	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
27	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
28	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
29	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
30	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
31	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
32	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
33	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
34	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
35	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
36	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
37	.00	12.49	.00	.00	.00	.00	.03	.00	.00	1.00
38	.88	12.49	.00	.00	.00	.00	.12	.00	.00	1.00
39	.00	12.49	.00	.00	.00	.00	.08	.00	.00	1.00

APPENDIX-B

SUMQ= 1502.79 SUMRF= 3580.82

1 BSOLVE REGRESSION ALGORITHM

ICON	=	4	PH	=	5.36E+03	ITERATION NO.	=	1
ICON	=	4	PH	=	3.25E+03	ITERATION NO.	=	2
ICON	=	4	PH	=	1.70E+03	ITERATION NO.	=	3
ICON	=	4	PH	=	1.49E+03	ITERATION NO.	=	4
ICON	=	4	PH	=	1.49E+03	ITERATION NO.	=	5
ICON	=	4	PH	=	1.49E+03	ITERATION NO.	=	6
ICON	=	4	PH	=	1.49E+03	ITERATION NO.	=	7

SOLUTION OF THE EQUATION

B(1)=	","	1.172E+01	11.72
B(2)=	","	1.922E+01	19.22
B(3)=	","	2.96E+00	2.96
B(4)=	","	1.541E+01	15.41

EFFICIENCY= 75.556
RMSE= 1.166807963
Relative Error= -1.910512059

DAY	RAINFALL	S	RF-EXCESS	INFILT	BASEFLOW	RUNOFF(C)	RUNOFF(O)	EVAPTRA	AMOIST	PANC	Error Sq.	Erroe	Abs Error
1	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
2	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
3	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
4	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
5	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
6	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
7	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
8	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02
9	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004	0.02

10	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
11	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
12	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
13	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
14	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
15	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
16	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
17	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
18	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
19	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
20	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
21	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
22	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
23	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
24	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
25	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
26	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
27	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
28	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
29	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
30	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
31	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
32	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
33	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
34	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
35	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
36	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
37	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
38	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
39	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
40	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
41	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
42	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
43	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
44	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
45	0	11.72	0	0	0	0	0.02	0	0	1	0.02	0.0004		0.02
46	8.3	11.72	0	0	0	0	0.72	0	0	1	0.72	0.5184		0.72
47	17.3	11.72	0	5.58	0	0	2.56	0	0	1	2.56	6.5536		2.56
48	0	11.72	0	0	0.35	0.35	0.95	0	0	1	0.6	0.36	0.6	
49	0	11.72	0	0	0.33	0.33	0.42	0	0	1	0.09	0.0081		0.09
50	0	11.72	0	0	0.31	0.31	0.11	0	0	1	-0.2	0.04	0.2	
51	0	11.72	0	0	0.29	0.29	0.05	0	0	1	-0.24	0.0576		0.24
52	19.8	11.72	0	8.08	0.27	0.27	2.64	0	0	1	2.37	5.6169		2.37
53	0	11.72	0	0	0.76	0.76	1.23	0	0	1	0.47	0.2209		0.47
54	0	11.72	0	0	0.71	0.71	0.52	0	0	1	-0.19	0.0361		0.19
55	0	11.72	0	0	0.67	0.67	0.15	0	0	1	-0.52	0.2704		0.52
56	0	11.72	0	0	0.63	0.63	0.08	0	0	1	-0.55	0.3025		0.55

APPENDIX-C

SCS-CN-based continuous Simulation Model for Hydrologic forecasting (calibration)

CN_0= Initial curve number =	62
λ=Coefficient of initial abstraction =	0.07
α=Exponent of initial abstraction =	0.8
β=Coefficient of antecedent moisture =	7.5
K=Storage Coefficient =	4.5
S_{abs}=Maximum possible water retention in mm =	243
θ_w=Wilting point of the soil =	145
θ_f=Field Capacity of soil =	160
C_1=Coefficient of transpiration =	0.2
C_2=Coefficient of sub-soil drainage =	0.6
C_3=Unsaturated soil zone runoff Coefficient =	0.12
PANC = Pan coefficient =	0.6
E= Exponent of ground water zone =	0.1
BCOEF= Ground water zone runoff coeffcient =	0.1

C0= 0.1 C1= 0.1 C2= 0.8

P=Total Rainfallin mm
I_a=Initial abstraction in mm
S=Potential max. retention in mm
SRO=Surface runoff
P_e=Total Effective Rainfallin mm
F_t=Infiltration in mm
Ev_t=Evaporation at time t in mm
TR_t=Transpiration in time t in mm
ET_t=Total evapotranspiration in mm
DR_t=Sub soil drainage in mm
THR_t=Through flow in mm
TRO_t=Total runoff in mm

S_0= $(25400/CN_0)-254$ 155.68

SL. NO.	(P)	EV_t	(I_a)	$(P_{e(t)})$	$ANTRF_t$	Am_t	$S_{t(m)}$	CN_t	RO_t	SRO_t	F_t	Ev_t	TR_t	ET_t	DR_t	THR_t	PR_t	DSP_t	BF_t	TRO_t	S_{t+1}	obvs
1	0	3.1	0.00	0.00	0.0	0.00	155.7	62.0	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	157.5	0.05
2	0	2.9	0.00	0.00	0.0	0.00	157.5	61.7	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	159.3	0.05
3	0	2.95	0.00	0.00	0.0	0.00	159.3	61.5	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	161.0	0.05
4	0	3.2	0.00	0.00	0.0	0.00	161.0	61.2	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	163.0	0.05
5	0	2.2	0.00	0.00	0.0	0.00	163.0	60.9	0.0	0.0	0.0	1.3	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	164.3	0.05
6	0	2.75	0.00	0.00	0.0	0.00	164.3	60.7	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	165.9	0.05
7	0	1.205	0.00	0.00	0.0	0.00	165.9	60.5	0.0	0.0	0.0	0.7	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	166.7	0.05
8	0	3.05	0.00	0.00	0.0	0.00	166.7	60.4	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	168.5	0.05
9	0	2.25	0.00	0.00	0.0	0.00	168.5	60.1	0.0	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	169.8	0.05
10	0	2.6	0.00	0.00	0.0	0.00	169.8	59.9	0.0	0.0	0.0	1.6	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	171.4	0.05
11	0	2.8	0.00	0.00	0.0	0.00	171.4	59.7	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	173.1	0.05
12	0	3.45	0.00	0.00	0.0	0.00	173.1	59.5	0.0	0.0	0.0	2.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	175.2	0.05
13	0	3	0.00	0.00	0.0	0.00	175.2	59.2	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	177.0	0.05
14	0	2.9	0.00	0.00	0.0	0.00	177.0	58.9	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	178.7	0.05
15	0	3.6	0.00	0.00	0.0	0.00	178.7	58.7	0.0	0.0	0.0	2.2	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	180.9	0.05
16	0	2.05	0.00	0.00	0.0	0.00	180.9	58.4	0.0	0.0	0.0	1.2	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	182.1	0.05
17	0	2.95	0.00	0.00	0.0	0.00	182.1	58.2	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	183.9	0.05

18	0	2.95	0.00	0.00	0.0	0.00	183.9	58.0	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	185.6	0.03
19	0	3	0.00	0.00	0.0	0.00	185.6	57.8	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	187.4	0.03
20	0	3.3	0.00	0.00	0.0	0.00	187.4	57.5	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	189.4	0.03
21	0	3.7	0.00	0.00	0.0	0.00	189.4	57.3	0.0	0.0	0.0	2.2	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	191.6	0.03
22	0	2.8	0.00	0.00	0.0	0.00	191.6	57.0	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	193.3	0.03
23	0	3.35	0.00	0.00	0.0	0.00	193.3	56.8	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	195.3	0.03
24	0	2.6	0.00	0.00	0.0	0.00	195.3	56.5	0.0	0.0	0.0	1.6	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	196.9	0.03
25	0	3.3	0.00	0.00	0.0	0.00	196.9	56.3	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	198.9	0.03
26	0	3.55	0.00	0.00	0.0	0.00	198.9	56.1	0.0	0.0	0.0	2.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	201.0	0.03
27	0	3	0.00	0.00	0.0	0.00	201.0	55.8	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	202.8	0.03
28	0	3.65	0.00	0.00	0.0	0.00	202.8	55.6	0.0	0.0	0.0	2.2	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	205.0	0.03
29	0	6.15	0.00	0.00	0.0	0.00	205.0	55.3	0.0	0.0	0.0	3.7	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	208.7	0.03
30	0	3.15	0.00	0.00	0.0	0.00	208.7	54.9	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	210.6	0.03
31	0	2.4	0.00	0.00	0.0	0.00	210.6	54.7	0.0	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	212.0	0.03
32	0	3.0303	0.00	0.00	0.0	0.00	212.0	54.5	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	213.8	0.03
33	0	4.0293	0.00	0.00	0.0	0.00	213.8	54.3	0.0	0.0	0.0	2.4	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	216.2	0.03
34	0	3.4965	0.00	0.00	0.0	0.00	216.2	54.0	0.0	0.0	0.0	2.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	218.3	0.03
35	0	8.5581	0.00	0.00	0.0	0.00	218.3	53.8	0.0	0.0	0.0	5.1	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	223.5	0.03
36	0	4.1625	0.00	0.00	0.0	0.00	223.5	53.2	0.0	0.0	0.0	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	226.0	0.03
37	0	3.8628	0.00	0.00	0.0	0.00	226.0	52.9	0.0	0.0	0.0	2.3	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	228.3	0.03
38	0.88	4.5621	0.88	0.00	0.0	0.00	228.3	52.7	0.0	0.0	0.0	2.7	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	231.0	0.12
39	0	4.1292	0.00	0.00	0.0	0.00	231.0	52.4	0.0	0.0	0.0	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	233.5	0.08
40	2.75	4.2957	2.75	0.00	0.0	0.00	233.5	52.1	0.0	0.0	0.0	2.6	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	236.1	0.11
41	0.13	4.3623	0.13	0.00	0.0	0.00	236.1	51.8	0.0	0.0	0.0	2.6	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	238.7	0.07
42	0	4.0959	0.00	0.00	0.0	0.00	238.7	51.6	0.0	0.0	0.0	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	241.1	0.05
43	0	3.9627	0.00	0.00	0.0	0.00	241.1	51.3	0.0	0.0	0.0	2.4	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	55.8	0.05
44	3.5	3.8295	3.50	0.00	0.0	0.00	55.8	82.0	0.0	0.0	0.0	2.3	8.4	10.7	16.3	2.0	14.3	1.3	0.1	2.1	82.9	0.05
45	124.1	3.9294	5.80	118.30	0.0	0.00	82.9	75.4	69.6	7.0	48.7	2.4	3.0	5.4	0.1	0.0	0.1	0.8	0.1	7.0	39.6	0.05
46	0.13	4.0959	0.13	0.00	118.3	81.57	12.9	95.2	0.0	6.3	0.0	2.5	17.0	19.5	42.0	5.0	37.0	1.4	0.1	11.4	74.4	21.6
47	0	4.329	0.00	0.00	118.3	81.57	35.5	87.7	0.0	5.6	0.0	2.6	12.5	15.1	28.5	3.4	25.1	1.4	0.1	9.2	79.1	15.2
48	0	4.5621	0.00	0.00	118.3	81.57	38.9	86.7	0.0	5.1	0.0	2.7	11.8	14.5	26.4	3.2	23.3	1.4	0.1	8.4	79.9	8.59
49	41.5	4.6287	5.59	35.91	118.3	81.57	39.6	86.5	17.1	6.3	18.8	2.8	11.7	14.5	26.1	3.1	22.9	1.4	0.1	9.5	61.3	5.11
50	19.3	4.5288	4.29	15.01	154.2	93.13	24.3	91.3	5.7	6.2	9.3	2.7	14.7	17.5	35.2	4.2	31.0	1.4	0.1	10.6	67.7	8.35
51	0.63	4.0626	0.63	0.00	50.9	53.52	37.8	87.0	0.0	5.6	0.0	2.4	12.0	14.5	27.1	3.3	23.9	1.4	0.1	9.0	79.4	9.58
52	0	4.329	0.00	0.00	50.9	53.52	47.4	84.3	0.0	5.0	0.0	2.6	10.1	12.7	21.3	2.6	18.8	1.3	0.1	7.7	81.5	5.26
53	3.15	4.5954	3.15	0.00	50.9	53.52	49.2	83.8	0.0	4.5	0.0	2.8	9.8	12.5	20.3	2.4	17.9	1.3	0.1	7.1	82.0	3.12
54	0.13	5.3946	0.13	0.00	50.9	53.52	49.6	83.7	0.0	4.1	0.0	3.2	9.7	12.9	20.0	2.4	17.6	1.3	0.1	6.6	82.6	2.78
55	2.78	4.9617	2.78	0.00	15.0	29.06	61.1	80.6	0.0	3.7	0.0	3.0	7.4	10.4	13.2	1.6	11.6	1.3	0.1	5.4	84.6	2.34
56	28.83	4.6287	5.92	22.91	0.0	0.00	84.6	75.0	4.9	3.8	18.0	2.8	2.7	5.5	0.0	0.0	0.0	0.0	0.0	3.8	72.0	1.85

APPENDIX-D

SCS-CN-based continuous Simulation Model for Hydrologic forecasting (validation)

CNo= Initial curve number =	62		
λ=Coefficient of initial abstraction =	0.07		P=Total Rainfallin mm
α=Exponent of initial abstraction =	0.8		I_a=Initial abstraction in mm
β=Coefficient of antecedent moisture =	7.5		S=Potential max. retention in mm
K=Storage Coefficient =	4.5		SRO=Surface runoff
S_{abs}=Maximum possible water retention in mm =	243		P_e=Total Effective Rainfallin mm
θ_w=Wilting point of the soil =	145		F_t=Infiltration in mm
θ_f=Field Capacity of soil =	160		Ev_t=Evaporation at time t in mm
C_1=Coefficient of transpiration =	0.2		TR_t=Transpiration in time t in mm
C_2=Coefficient of sub-soil drainage =	0.6		ET_t=Total evapotranspiration in mm
C_3=Unsaturated soil zone runoff Coefficient =	0.12		DR_t=Sub soil drainage in mm
PANC = Pan coefficient =	0.6		THR_t=Through flow in mm
E= Exponent of ground water zone =	0.1		TRO_t=Total runoff in mm
BCOEF=Ground water zone runoff coeffcient	0.1		

C0= 0.1 C1= 0.1 C2= 0.8

$S_{0=}$ $(25400/CN_0)$-254 155.7

SL. NO.	(P)	EV_i	(I_a)	$(P_{e(t)})$	(ANTR F_t)	Am_t	$S_{t(m)}$	CN_t	RO_t	SRO_t	F_t	Ev_t	TR_t	ET_t	DR_t	THR_t	PR_t	DSP_t	BF_t	TRO_t	S_{t+1}	obvs
1	0	3.1	0.00	0.00	0.0	0.00	155.7	62.0	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	157.5	0.05
2	0	2.9	0.00	0.00	0.0	0.00	157.5	61.7	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	159.3	0.05
3	0	3.1	0.00	0.00	0.0	0.00	159.3	61.5	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	161.1	0.03
4	0	2.9	0.00	0.00	0.0	0.00	161.1	61.2	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	162.9	0.03
5	0	2.95	0.00	0.00	0.0	0.00	162.9	60.9	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	164.6	0.03
6	0	3.2	0.00	0.00	0.0	0.00	164.6	60.7	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	166.6	0.03
7	0	2.2	0.00	0.00	0.0	0.00	166.6	60.4	0.0	0.0	0.0	1.3	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	167.9	0.03
8	0	2.75	0.00	0.00	0.0	0.00	167.9	60.2	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	169.5	0.03
9	0	1.205	0.00	0.00	0.0	0.00	169.5	60.0	0.0	0.0	0.0	0.7	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	170.3	0.03
10	0	3.05	0.00	0.00	0.0	0.00	170.3	59.9	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	172.1	0.03
11	0	2.25	0.00	0.00	0.0	0.00	172.1	59.6	0.0	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	173.4	0.03
12	0	2.6	0.00	0.00	0.0	0.00	173.4	59.4	0.0	0.0	0.0	1.6	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	175.0	0.03
13	0	2.8	0.00	0.00	0.0	0.00	175.0	59.2	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	176.7	0.03
14	0	3.45	0.00	0.00	0.0	0.00	176.7	59.0	0.0	0.0	0.0	2.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	178.8	0.03
15	0	3	0.00	0.00	0.0	0.00	178.8	58.7	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	180.6	0.03

SL. NO.	(P)	EV_t	(I_a)	$(P_{e(t)})$	(ANTR F_t)	Am_t	$S_{t(m)}$	CN_t	RO_t	SRO_t	F_t	Ev_t	TR_t	ET_t	DR_t	THR_t	PR_t	DSP_t	BF_t	TRO_t	S_{t+1}	obvs
16	0	2.9	0.00	0.00	0.0	0.00	180.6	58.5	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	182.3	0.03
17	0	3.6	0.00	0.00	0.0	0.00	182.3	58.2	0.0	0.0	0.0	2.2	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	184.5	0.03
18	0	2.05	0.00	0.00	0.0	0.00	184.5	57.9	0.0	0.0	0.0	1.2	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	185.7	0.02
19	0	2.95	0.00	0.00	0.0	0.00	185.7	57.8	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	187.5	0.02
20	0	2.95	0.00	0.00	0.0	0.00	187.5	57.5	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	189.2	0.02
21	0	3	0.00	0.00	0.0	0.00	189.2	57.3	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	191.0	0.02
22	0	3.3	0.00	0.00	0.0	0.00	191.0	57.1	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	193.0	0.02
23	0	3.7	0.00	0.00	0.0	0.00	193.0	56.8	0.0	0.0	0.0	2.2	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	195.2	0.02
24	0	2.8	0.00	0.00	0.0	0.00	195.2	56.5	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	196.9	0.02
25	0	3.35	0.00	0.00	0.0	0.00	196.9	56.3	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	198.9	0.02
26	0	2.6	0.00	0.00	0.0	0.00	198.9	56.1	0.0	0.0	0.0	1.6	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	200.5	0.02
27	0	3.3	0.00	0.00	0.0	0.00	200.5	55.9	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	202.5	0.02
28	0	3.55	0.00	0.00	0.0	0.00	202.5	55.6	0.0	0.0	0.0	2.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	204.6	0.02
29	0	3	0.00	0.00	0.0	0.00	204.6	55.4	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	206.4	0.02
30	0	3.65	0.00	0.00	0.0	0.00	206.4	55.2	0.0	0.0	0.0	2.2	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	208.6	0.02
31	0	6.15	0.00	0.00	0.0	0.00	208.6	54.9	0.0	0.0	0.0	3.7	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	212.3	0.02
32	0	3.15	0.00	0.00	0.0	0.00	212.3	54.5	0.0	0.0	0.0	1.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	214.2	0.02
33	0	2.4	0.00	0.00	0.0	0.00	214.2	54.3	0.0	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	215.6	0.02
34	0	3.0303	0.00	0.00	0.0	0.00	215.6	54.1	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	217.4	0.02
35	0	4.0293	0.00	0.00	0.0	0.00	217.4	53.9	0.0	0.0	0.0	2.4	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	219.8	0.02
36	0	3.4965	0.00	0.00	0.0	0.00	219.8	53.6	0.0	0.0	0.0	2.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	221.9	0.02
37	0	8.5581	0.00	0.00	0.0	0.00	221.9	53.4	0.0	0.0	0.0	5.1	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	227.1	0.02
38	0	4.1625	0.00	0.00	0.0	0.00	227.1	52.8	0.0	0.0	0.0	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	229.6	0.02
39	0	3.8628	0.00	0.00	0.0	0.00	229.6	52.5	0.0	0.0	0.0	2.3	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	231.9	0.02
40	0	4.5621	0.00	0.00	0.0	0.00	231.9	52.3	0.0	0.0	0.0	2.7	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	234.6	0.02
41	0	4.1292	0.00	0.00	0.0	0.00	234.6	52.0	0.0	0.0	0.0	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	237.1	0.02
42	0	4.2957	0.00	0.00	0.0	0.00	237.1	51.7	0.0	0.0	0.0	2.6	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	239.7	0.02
43	0	4.3623	0.00	0.00	0.0	0.00	239.7	51.5	0.0	0.0	0.0	2.6	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	242.3	0.02
44	0	4.0959	0.00	0.00	0.0	0.00	242.3	51.2	0.0	0.0	0.0	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	55.6	0.02
45	0	3.9627	0.00	0.00	0.0	0.00	55.6	82.0	0.0	0.0	0.0	2.4	8.5	10.8	16.4	2.0	14.4	1.3	0.1	2.1	82.9	0.02
46	0	3.8295	0.00	0.00	0.0	0.00	82.9	75.4	0.0	0.0	0.0	2.3	3.0	5.3	0.1	0.0	0.0	0.7	0.1	0.1	88.3	0.02
47	0	3.9294	0.00	0.00	0.0	0.00	88.3	74.2	0.0	0.0	0.0	2.4	1.9	4.3	0.0	0.0	0.0	0.0	0.0	0.0	92.6	0.02
48	0	4.0959	0.00	0.00	0.0	0.00	92.6	73.3	0.0	0.0	0.0	2.5	1.1	3.5	0.0	0.0	0.0	0.0	0.0	0.0	96.1	0.01
49	0	4.329	0.00	0.00	0.0	0.00	96.1	72.5	0.0	0.0	0.0	2.6	0.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	99.1	0.01
50	0	4.5621	0.00	0.00	0.0	0.00	99.1	71.9	0.0	0.0	0.0	2.7	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	101.8	0.01
51	0	4.6287	0.00	0.00	0.0	0.00	101.8	71.4	0.0	0.0	0.0	2.8	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	104.6	0.01

APPENDIX-E

Ten Daily ETo for the total year (from Jan-0 to 10) in mm

1	10	1	23.176
11	20	2	27.071
21	31	3	31.742
32	41	4	33.217
42	51	5	34.776
52	59	6	31.154
60	69	7	38.671
70	79	8	41.561
80	90	9	48.733
91	100	10	47.419
101	110	11	47.338
111	120	12	52.645
121	130	13	55.179
131	140	14	49.919
141	151	15	56.198
152	161	16	46.328
162	171	17	40.824
172	181	18	31.077
182	191	19	36.675
192	201	20	31.306
202	212	21	30.999
213	222	22	28.337
223	232	23	30.137
233	243	24	31.327
244	253	25	27.337
254	263	26	32.355
264	273	27	31.980
274	283	28	32.810
284	293	29	31.481
294	304	30	36.434
305	314	31	29.229
315	324	32	27.096
325	334	33	23.762
335	344	34	24.031
345	354	35	22.972
355	365	36	24.723

Effective Rainfall Of the PADAGAON Raingauge Station

3.7	3.7	3.7
7.3	7.3	7.3
11.5	11.5	11.5
19.8	19.8	19.8
26.4	26.4	26.4
42.6	42.6	42.6
49.3	49.3	49.3
49.7	49.7	49.7
46	46	46
34.8	34.8	34.8
17.5	17.5	17.5
2.9	2.9	2.9

APPENDIX-F

Period	Net crop Water in mm	Gross Irrigation in mm	Head Release in ham
15	43.6	77.9	194.75
16	27.4	48.9	122.25
17	27.4	48.9	122.25
18	100	178.6	446.5
19	99.2	177.1	442.75
20	43.3	77.3	193.25
21	42.9	76.6	191.5
22	39.5	70.5	176.25
23	41.3	73.8	184.5
24	42.6	76.1	190.25
25	42.2	75.4	188.5
26	47.3	84.5	211.25
27	41.8	74.6	186.5

Total Irrigation Required for Early Paddy = 1140.2 mm
Annual irrigation water requirement for the crop= 2850.5 ham

Sl. No.	Crop Name	Annual CWR in ham
1	Early Paddy	2850.5
2	Mid Paddy	3806.49
3	Late Paddy	2869.905
4	Raggi	0
5	Groundnut	31.8
6	Maize	0
7	Sugarcane	186.516
8	Dalua Paddy	3390.75
9	Pulses	364.77
10	Groundnut-R	1032.175
11	Vegetable-Up	567.7
12	Vegetable-Low	841.12
13	Potato	154.36
14	Mustard	272.51

Annual CWR of the project = 16368.6 Ham

APPENDIX-G

Irrigation Scheduling of Sugarcane Crop All Values are in mm

Period	I.Soil Moisture	Eff. Rainfall	ETc	ETs(with Ks)	Final Soil Moisture		Irr. Req.(field)	Irr Applied
March 0-10	13	11.5	15	14	11	31	24	27
March 11-20	42	11.5	17	15	39	0	60	66
March 21-end	39	11.5	19	19	31	0	0	0
April 0-10	31	19.8	34	31	20	22	0	0
April 11-20	42	19.8	34	29	33	34	42	47
April 21-end	67	19.8	37	33	54	0	65	72
May 0-10	54	26.4	39	33	47	70	0	0
May 11-20	118	26.4	50	44	100	0	134	148
May 21-end	100	26.4	57	50	76	92	0	0
June 0-10	168	42.6	47	43	168	0	176	195
June 11-20	168	42.6	41	41	169	0	0	0
June 21-end	169	42.6	31	31	181	0	0	0
July 0-10	181	49.3	37	37	193	0	0	0
July 11-20	193	49.3	32	32	211	0	0	0
July 21-end	211	49.3	31	31	229	0	0	0
Aug 0-10	229	49.7	29	29	250	0	0	0
Aug 11-20	250	49.7	30	30	269	0	0	0
Aug 21-end	269	49.7	32	32	287	0	0	0
Sept 0-10	287	46	28	28	305	0	0	0
Sept 11-20	305	46	33	33	319	0	0	0
Sept 21-end	319	46	32	32	332	0	0	0
October 0-10	332	34.8	33	33	334	0	0	0
October 11-20	334	34.8	32	32	337	0	0	0
October 21-end		337	34.8	37	37	335	0	0
November 0-10	335	17.5	30	30	323	0	0	0
November 11-20		323	17.5	27	27	313	0	0
November 21-end		313	17.5	18	18	312	0	0
December 0-10	312	2.9	19	19	297	0	0	0
December 11-20		297	2.9	17	17	282	0	0
December 21-end		282	2.9	19	19	266	0	0
January 0-10	42	3.7	18	16	30	138	13	15

total Irrigation Required at field for Sugarcane = 514.0263 mm
Annual irrigation water requirement for the crop= 44.21 Ham

APPENDIX-H

Gate Operation Details of Left Distributary Zone- A

Period	Zone Discharge in cumec	Canal Discharge in cumec	Opening Time in hr	Opening Height in m
Jan-0-10	0	0	0	0
Jan-11-20	0	0	0	0
Jan-21-end	0	0	0	0
Feb-0-10	0	0	0	0
Feb-11-20	0	0	0	0
Feb-21-end	0	0	0	0
Mar-0-10	0	0	0	0
Mar-11-20	0	0	0	0
Mar-21-end	0	0	0	0
Apr-0-10	0	0	0	0
Apr-11-20	0	0	0	0
Apr-21-end	0	0	0	0
May-0-10	0	0	0	0
May-11-20	0	0	0	0
May-21-end	0.97911	0.97911	120.78	0.49
Jun-0-10	2.88742	2.88742	120.78	1.01
Jun-11-20	1.77652	1.77652	120.78	0.73
Jun-21-end	3.05	3.05	125.32	1.05
Jul-0-10	3.05	3.05	256.22	1.05
Jul-11-20	3.05	3.05	159.63	1.05
Jul-21-end	2.28367	2.28367	120.78	0.87
Aug-0-10	1.76065	1.76065	120.78	0.73
Aug-11-20	2.23606	2.23606	120.78	0.85
Aug-21-end	2.50815	2.50815	120.78	0.92
Sep-0-10	1.71396	1.71396	120.78	0.71
Sep-11-20	2.00652	2.00652	120.78	0.79
Sep-21-end	2.40028	2.40028	120.78	0.89
Oct-0-10	1.74202	1.74202	120.78	0.72
Oct-11-20	1.94419	1.94419	120.78	0.78
Oct-21-end	0.74589	0.74589	120.78	0.41
Nov-0-10	0.70518	0.70518	120.78	0.4
Nov-11-20	0	0	0	0
Nov-21-end	0	0	0	0
Dec-0-10	0	0	0	0
Dec-11-20	0	0	0	0
Dec-21-end	0	0	0	0

Gate Operation Details of Takarda Distributary Zone- B

Period	Zone Discharge in cumec	Canal Discharge in cumec	Opening Time in hr	Opening Height in m
Jan-0-10	0	0	0	0
Jan-11-20	0	0	0	0
Jan-21-end	0	0	0	0
Feb-0-10	0	0	0	0
Feb-11-20	0	0	0	0
Feb-21-end	0	0	0	0
Mar-0-10	0	0	0	0
Mar-11-20	0	0	0	0
Mar-21-end	0	0	0	0
Apr-0-10	0	0	0	0
Apr-11-20	0	0	0	0
Apr-21-end	0	0	0	0
May-0-10	0	0	0	0
May-11-20	0	0	0	0
May-21-end	0.77579	0.3380228	120.78	0.32
Jun-0-10	2.28758	0.9967313	120.78	0.66
Jun-11-20	1.40783	0.6134117	120.78	0.47
Jun-21-end	2.50746	1.092536	120.78	0.7
Jul-0-10	2.52	1.098	245.72	0.7
Jul-11-20	2.52	1.098	153.09	0.7
Jul-21-end	1.80941	0.7883858	120.78	0.56
Aug-0-10	1.39472	0.6076995	120.78	0.47
Aug-11-20	1.77169	0.7719507	120.78	0.55
Aug-21-end	1.9872	0.8658515	120.78	0.6
Sep-0-10	1.35815	0.5917654	120.78	0.46
Sep-11-20	1.58999	0.6927813	120.78	0.51
Sep-21-end	1.90164	0.8285718	120.78	0.58
Oct-0-10	1.38046	0.6014862	120.78	0.47
Oct-11-20	1.54054	0.6712354	120.78	0.5
Oct-21-end	0.59087	0.2574505	120.78	0.27
Nov-0-10	0.5589	0.2435207	120.78	0.26
Nov-11-20	0	0	0	0
Nov-21-end	0	0	0	0
Dec-0-10	0	0	0	0
Dec-11-20	0	0	0	0
Dec-21-end	0	0	0	0

APPENDIX-I

```
CREATED INPUT FILE
40      -MMOC(OVER YEAR CONSTRAINT)
12      -MMWC(WITHIN YEAR CONSTRAINT)
.76446,10.025 (EVo, LIVE STORAGE)
27.37         -INFLOWS
35.227
44.108
32.869
36.954
27.26
29.578
17.126
30.762
32.474
31.031
33.172
29.442
29.789
31.501
22.42
20.555
18.589
8.432
29.291
18.956
26.197
22.48
17.093
16.091
27.179
23.761
14.164
25.146
26.224
35.55
24.45
12.659
22.731
16.51
21.576
23.299
23.072
22.351
24.827
21.576,.9     -TARGET FLOW (DEPENDABILITY
.0149         -BETA (FLOW RATIO)
.0144
.0332
.0446
.0512
.0754
.1642
.2335
.1124
.2333
.0116
11
```

.0609 -GAMMA (EVAPORATION COEFFICIENT)
.0796
.1004
.1219
.1792
.0932
.076
.0631
.0624
.0595
.0523
.0516
1.395
10.72 -AKT(IRRIGATION TARGET RATIO)
9.01
9.25
5.44
1.54
8.68
18.8
10.03
10.9
7.3
1.8
6.55 1

OUTPUT FILE

Reservoi Yield of Project

Period	Total Reservoir yield
january	1.5
February	1.26
March	1.29
April	0.76
May	0.22
june	1.21
july	2.62
August	1.4
September	1.52
October	1.02
November	0.25
December	0.92

Annual Sondary Yield= 1.4 Tham
Annual Firm Yield= 12.58 Tham
Annual Total Yield= 13.97 Tham