CHAPTER 7

INTIGRATED MODEL AT DISTRIBUTAURY LEVEL, USING SOIL MOISTURE, RAINFALL RUNOFF, SYSTEM LOSS AND GROUND WATER MODULES ON GIS PLATEFORM

7.1. Introduction

A GIS based generic decision support system developed by M/S SMEC Pvt. limited; Australia for management of water resources in canal commands of Ghagra Gomti Basin in Uttar Pradesh, India for Irrigation department has been used (SMEC, 2010). The main developed canal command, ICROP model is calibrated from Visual MODFLOW by giving recharge from ICROP and tallying from observed ground water levels. Similarly for runoff component it has been calibrated from drainage model, integrated water quantity and quality simulation model (IQQM) through which generated runoff values are checked from observed runoff values.

7.2. ICROP Model

The iCROP model uses four levels of spatial units: Homogeneous Unit (HU), Sub-Irrigation Unit (SIU), Micro Sub-basin (MSB) and Sub-Basin (SB). The Sub-basin is the largest spatial unit within the iCROP model. This may be the gross command area of a Branch or a Main Canal. MSB is the gross command area of a canal, which may be either a Distributary or a Branch canal. A Sub-basin may consist of several MSBs. Micro Sub Basin (MSB) is the largest calculation unit for the model.

Sub-Irrigation Unit consists of one or more HUs. A HU in a SIU has the same potential to be waterlogged, soil characteristics, access to irrigation and depth to groundwater levels. They differ from each other in land use or crop grown. As the command area of a MSB is usually a large area having different water management practice at the canal head, middle and tail. Each MSB is further divided into different SIUs or Sub-Irrigation Units. SIUs can also be classified based on command and non-command area, distance from canals, susceptibility to be waterlogged, soil drainage and so on. A HU is the smallest calculation unit in the model. The classification is based mainly on land use.

Further each homogeneous unit is performed by a series of interlinked modules on daily basis:

(i) Soil moisture accounting and irrigation water requirement module

(ii) Rainfall-runoff module

(iii) System loss module

(iv) Groundwater system module.

7.2.1. Soil moisture accounting and irrigation water requirement module:

Irrigation demand module is similar to the procedure included in the IQQM software. The irrigation demands are computed differently for ponded crops (i.e. rice) and non-ponded crops (all other crops eg wheat, sugarcane etc). For all crops other than rice, crop water demand is computed using the potential evapotranspiration for a reference crop (ETo) and crop factors (FAO 56). Potential evapotranspiration for the reference crop is intended to be estimated using the Penman-Montieth procedure.

For rice crops, the irrigation requirement (Ireq) is computed as:

If Pdesirable ≤ Pactual ≤ Pmax then $I_{req} = 0$ (7.1)

If Pactual < Pdesirable then Ireq = (Pdesirable – Pactual)*Ahu*10 (7.2)

where

Ireq	= Crop irrigation water requirement (m3)
Pdesirable	= Desirable ponded depth (mm)
Pmax	= Max permissible ponding depth (mm)
Pactual	= Actual depth of ponding (mm)

For all other crops the irrigation requirement is computed as follows:

During the irrigation season, the estimate is based on the actual amount of soil water (SW) and the target level of soil water (TWL) for daily average irrigation requirement over all farms. Within a homogeneous unit the estimated requirement is:

If $SW \geq TWL$; then $I_{req} = 0$ (7.3)

If $SW < TWL$; then $I_{req} = (TWL - SW) * A_{hu} * 10$ (7.4)

The soil moisture on any given day is computed as:

For all crops (except rice during ponded days)

$$SW_t = SW_{t-1} + R_e + I_{sup} / (Ahu * 10) \quad (7.5)$$

$$SW_t = Max(WP, SW_t - \frac{K_C * ET_o}{K_e}) \quad (7.6)$$

$$SW_t = Max(FC, SW_t - S_L) \quad (7.7)$$

Where: SWt = Projected soil moisture at end of time step (mm)

SWt-1 = Actual soil moisture at beginning of time step (mm)

SWmax = Maximum available soil water (mm)

ETo = Reference crop potential evapotranspiration (mm)

Re = Effective rainfall less runoff

Kc = Crop factors

Ke = If method such as evaporation pans, Priestly-Taylor equation, Morton equation etc are used then this factor can be used to adjust this estimate to the Penman-Montieth ETo.

FC = Field capacity (mm) computed as

FC (in mm) = FC (%) * Root depth (mm) * Soil density/Water density

SL = Actual seepage from soil water store (mm)

$$SL = S_{L\max} * \frac{SW_{t-1}}{SW_{\max}} \quad (7.8)$$

For rice during ponded days

$$SW_t = SW_{\max}$$

$$SL = S_{L\max} \quad (7.9)$$

Where: SLmax = Maximum seepage from soil water store (mm)

The soil moisture is updated based on actual water supply through surface or groundwater sources, once irrigation requirements are computed. The calculations for soil moisture updating and irrigation requirements are carried out on a daily basis and results presented as a cumulative total for a week, season and simulation period as a whole.

7.2.2. Rainfall-runoff module:

Runoff from all land uses except ponded crops is estimated using the USDA SCS Curve Number method corrected for soil moisture (Sharpely and Williams, 1990). The approach adopted is similar to the one used in a number of widely used models such as SWAT, EPIC, PERFECT etc. The curve number varies non-linearly with the moisture content of the soil. The curve number decreases as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation. The SCS Curve Number approach has limitations but is one of the commonly used methods for the study areas with extremely limited or no data availability.

The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (7.10)$$

Where

Qsurf = Runoff (mm),

Rday I = Rainfall for the day (mm),

Ia = Initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm), and

S = Retention parameter (mm) that varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content.

The initial abstraction values for Indian conditions are taken from the recommended Handbook of Hydrology, 1972.

Runoff will only occur when Rday > Ia. The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. The Curve number for moisture condition II to the current soil moisture condition and slope of the catchment, are modified as that used in the SWAT model (Neitsch et al, 2002).

The recommended Curve Numbers have been grouped under four hydrologic soil groups based on infiltration characteristics of the soils under similar storm and cover conditions. The four soil groups are:

A: The soils have a high infiltration rate (i.e. low runoff potential) even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

B: The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D: (High runoff potential). The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have high swelling potential, soils that have a permanent water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

Runoff computed using the above steps is modified to take in to account the bunding around the farms built by farmers to capture runoff on the farm itself. The depth of bunding is an input parameter and runoff equal to bunding depth is retained on the farm to increase the infiltration and meet crop water requirements. However, if soil is saturated then this retention of some runoff on the farm is not done.

For ponded crops runoff is estimated as:

If Pactual(t) > Pmax then Qsurf = Pmax - Pactual(t) else Qsurf = 0. (5)

7.2.3. System Loss

The seepage losses from canal are calculated based on discharge Vs Wetted area relationships. The seepage from fields is calculated on daily basis. These values have been mostly taken from standard textbooks and FAO manuals.

7.2.4. Groundwater system module

This module simulates changes in groundwater storage due to recharge and usage. The groundwater store is treated as a two-dimensional process i.e. vertical and horizontal. The horizontal process drives the base flow component and vertical one for shallow aquifer. The variation in groundwater storage/levels in the current model set up is computed according to:

$$GWi - GWi\text{-}1 = MSBrecharge - GWuse - Baseflow \quad (7.11)$$

$$GLinc = (GWi - GWi\text{-}1)/(Ahu*10*Sy) \quad (7.12)$$

where:

GWi = Groundwater storage under each MSB for time step I (m3),

GLinc = Incremental change in groundwater level since previous time step (mm),

Sy = Specific yield of the aquifer (%) and

Baseflow = Baseflow to drainage system (m3)

7.2.5. Water Balance and Water Requirement Calculations

This is the main module of the model which manages calls to other modules and also aggregates water requirements of various MSBs, water required at the headworks, rostering decisions and supply of water among MSBs. The module operates in two modes i.e.:

Bottom up to cumulate orders of all MSBs including losses in the canal reaches linking MSBs subject to canal capacity constraints,

Top down starting from available water at headworks and then supplying water to various MSBs also taking into account losses in canal reaches linking MSBs.

7.2.6. Drinking Water and Industrial Water Requirement

Drinking water and industrial water requirement of each MSB are estimated outside this model and included as daily values. The model has an option to assign a priority to various demands to be applied during any period of shortage. For example, the model assigns the highest priority to drinking water, the next to industrial water and the third to irrigation use. The user can assign percentage water use from canal water as compared to ground water use.

7.2.7. Socio Economics

The effect of climatic parameters is incorporated using daily reference evapotranspiration. The effect on crop productivity of water availability and soil is simulated using water stress dependent production function and a multivariate regression analysis of actual productivity of crops and soil parameters such as calcareousness, sub-surface drainage, and soil slope, pH and texture.

An economic module using the crop production estimates from multiple regressions was developed as a post-processor to the water balance module. The module estimates gross margins for various crops, considering also cost of irrigation, groundwater or canal water. The effect of changing other inputs such as labour, agricultural equipment and fertilisers/pesticides is also modelled.

7.2.8. Model Inputs

The inputs to the model are:

7.2.8.1. Climatic

Daily rainfall,

Daily Pan Evaporation,

Reference Crop Evapotranspiration,

7.2.8.2. Flow data

Daily canal flow at headworks

Daily flows in drains

7.2.8.3. Infrastructure data

Canal capacities at various locations,

Cross-section information,

Lined versus unlined sections, and

Location and capacity of escape structures.

7.2.8.4. Cropping information

Crops planted and area under them during Kharif, Rabi and Jaayad,

Monthly crop factors for crops planted,

Irrigation efficiency including field channel losses,

Crop calendars showing planting and harvesting dates, and

Rice ponding requirements during its various stages of growth as desirable ponding depth and maximum permissible ponding depth, number of days before harvesting when irrigation is stopped.

7.2.8.5. Losses

Seepage losses from the canals built in different soil conditions under lined/unlined conditions,

Estimate of escape loss for typical field channels, and

Estimate of escape losses from Minors/Distributaries/Branch canal.

7.2.8.6. Water usage

Groundwater pumping capacity from aquifer, and

Drainage water use and locations.

7.2.8.7. Land use, soils and topography

Average slope in various homogeneous units of MSBs,

Land use in MSBs,

Soil types in MSBs,

Soil properties i.e. field capacity, wilting point, saturation moisture content, and

Specific yield of shallow and deep aquifers.

7.2.9. Model Interface

All the information related to Climate, Soil, Land use, Surface and Ground water infrastructure and water use details including crop information and Agro economic inputs with other modelling parameters required are to be filled in excel sheets at created MSB and polygon levels. The model interface has been shown in figure 7.1.

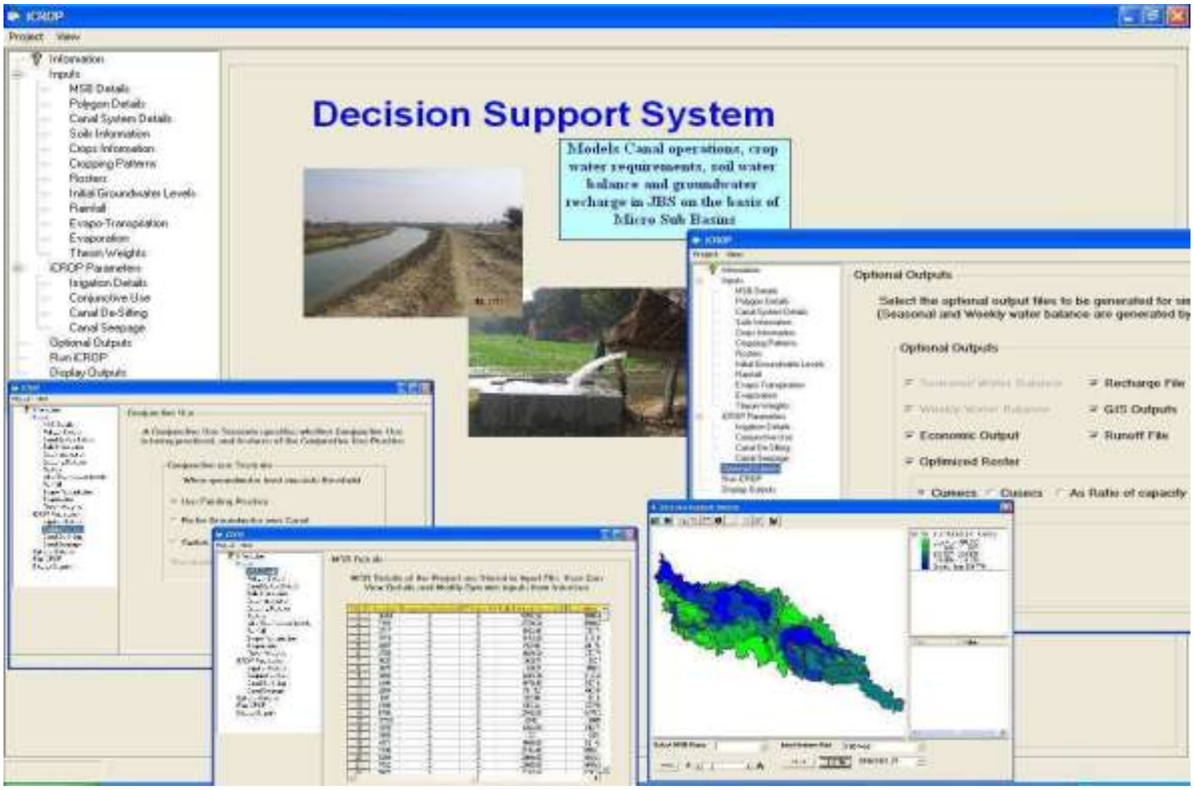

Figure 7.1-Interface of Decision support system, I CROP model

7.3. Model development for Ramganj distributaries command

Ramganj distributaury system having canal command area of 39861 ha provides canal supplies in the area through a canal network of 243 km through 35 number minors/distributaries for irrigating mainly rice and wheat cycle. The canal system lies between Gomti River and Balrampur drain doab having an area of 66939 ha, lying between 25^0 50′ 50″ to 26^0 13′ 35″ north latitude and 82^0 01′ 53″ to 82^0 25′ 43″ east longitude, in 9 blocks of Sutanpur, Pratapgarh and Jaunpur districts of Uttar Pradesh. The non canal command area lying between Gomti balrampur drain doab is irrigated by ground water irrigation.

Ramganj distributaury command is divided into 13 micro sub-basins (MSB) as shown in Figure 7.2. and further it has been divided in 34 Sub-Irrigation Units(SIU) as shown in Figure 7.3 on GIS platform depending upon the ground water levels below ground for modeling purposes. Each sub-Irrigation Unit consists of one or more homogenous unit (HU). A HU in a SIU has the same potential to be waterlogged, soil characteristics, access to irrigation and depth to groundwater levels. They differ from each other in land use or crop grown.

The area where ground water level lies between 0-3.0 m below has been marked as 1, the area where ground water level lies between 3.0-5.0 m below has been marked as 2, the area where ground water level lies between 5.0-8.0 m below has been marked as 3 and the area where ground water level is below 8 m has been marked as 4.

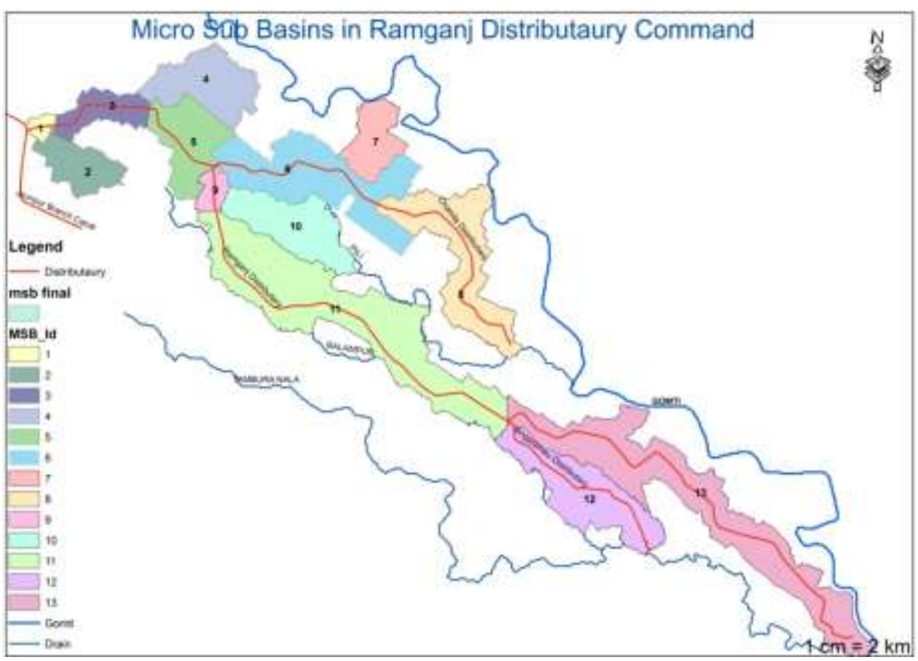

Figure 7.2. Micro sub-basins in Ramganj distributaury command

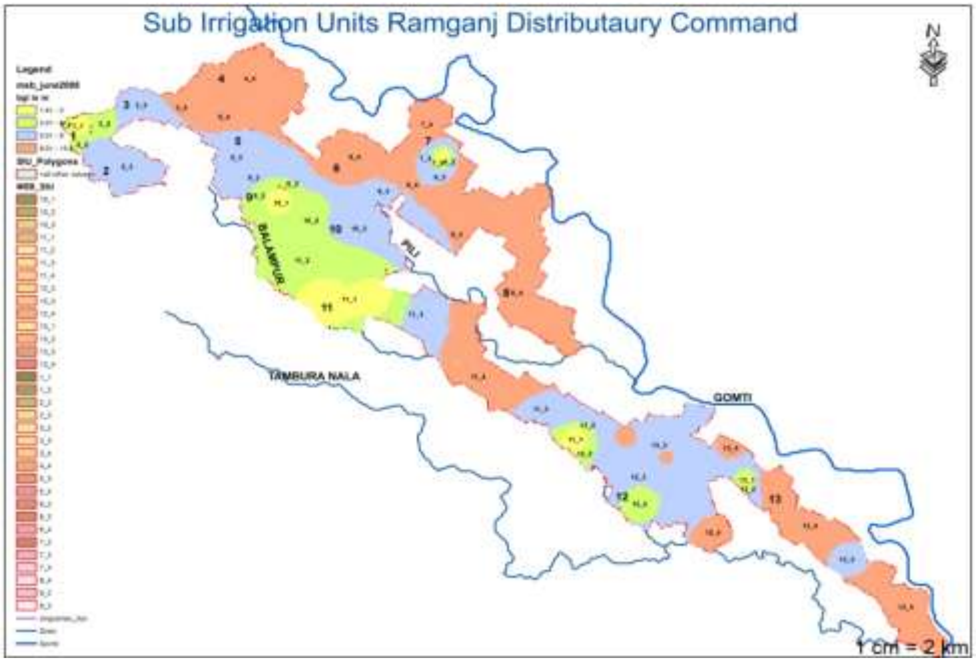

Figure 7.3. Sub Irrigation units in Ramganj distributaury command

The daily rainfall and evapotranspiration data collected has been used in the model run, through Thiesan weight percentage for the corresponding station, as shown in Table7.1.

Table 7.1.Thiesan weight percentage for the corresponding station

MSB ID	MSB Name	Station ID	Station Name	Percent Area
1	Ramganj Head - Beerpur	13	sultanpur	100
2	Beerpur Dy	13	sultanpur	100
3	Ramganj Beerpur - Ramganj Babhangawa	13	sultanpur	100
4	Babhangawa Dy	13	sultanpur	100
5	Ramganj Babhangawa- Chanda	13	sultanpur	100
6	Chanda Head - Karanpur	11	kadipur	78.38
6	Chanda Head - Karanpur	13	sultanpur	21.62
7	Karanpur Dy	11	kadipur	100
8	Chanda Dy	11	kadipur	100
9	Ramganj Chanda - Khandauli	13	sultanpur	100
10	Khandauli Dy	11	kadipur	82.13
10	Khandauli Dy	13	sultanpur	17.87
11	Ramganj Khandauli - Singramau	11	kadipur	33.52
11	Ramganj Khandauli - Singramau	5	patti	58.18
11	Ramganj Khandauli - Singramau	13	sultanpur	8.30
12	Singramau Dy	3	machlishahar	3.18
12	Singramau Dy	5	patti	96.82
13	Ramganj Singramau Tail	11	kadipur	35.37
13	Ramganj Singramau Tail	5	patti	11.98
13	Ramganj Singramau Tail	4	shahganj	36.22
13	Ramganj Singramau Tail	2	jaunpur	16.43

7.3.1 Model inputs

The data related to modeling inputs is placed as MSB details consisting of MSB ID, MSB name, Evaporation Station Number, Evapo-transpiration station number, daily domestic and industrial needs, as Polygon Details consisting of MSB ID, Index Class, Polygon area, maximum pumping rate, maximum pumping depth, specific yield and soil ID corresponding to each polygon.

The information related to Canal System Details consists of MSB ID, Reach ID, Name, Length of reaches, Actual and design capacity of canal system.

Soils Information sheet includes Soil ID, Soil name, Saturated hydraulic conductivity in mm/day, Field capacity in percentage, wilting point in percentage and Saturation moisture content in percentage while Crops Information sheet includes Crop Code, Crop name, Sowing date, crop period, season code and irrigation method corresponding to that crop.

For consideration of different land use options in the model, existing major eleven crops opted in the study area are considered. Normal yield values of different crops and the required inputs cost of materials and labour are taken for good irrigation practises. Selling price of produce is based on cost of crop fixed by the State Government for the year 2012-13.Crop yield reduction factors due to water logging, calcareousness, slope and soil texture are based on the analysis of crop cutting data of the corresponding area. Irrigation cost for ground water irrigation is based on current rates, while for surface water irrigation through canals; the seasonal rates for each crop fixed by the State Government are considered, as detailed in Table 7.2.

Table 7.2. Showing details of crop economics

Crop Code	Crop Name	Normal yield (Q/ha)	Waterlogged yield (Q/ha)	Yield Reduction Drainage	Yield Reduction Sub-Surf texture	Yield reduction Slope	Yield reduction Calcareous	Yield reduction factor (Water deficit)	Input Cost (Rs/ha)	Irrigation fee (canal) Rs/ha	Irrigation fee (Pumping) Rs/m3	Labour Input (Rs/ha)	Selling price (Rs/Q)	By Products selling price (Rs/ha)
1	Rice	50.00	45.02	-1.40	-10.49	-3.53	-2.96	1.2	23161	287	1	21200	1310	5000
2	Wheat	40.00	39.01	4.29	-2.46	-4.01	2.71	1	28400	287	1	17400	1400	18000
3	Sugarcane	580.00	565.63	0.00	0.00	0.00	0.00	1.2	40000	474	1	40000	280	0
4	Arhar	20.00	19.50	0.00	0.00	0.00	0.00	1.15	15800	212	1	15200	4300	1000
5	Maize	40.00	36.03	0.00	0.00	0.00	0.00	1.25	2500	173	1	10000	1310	3000
6	Pulses	15.00	14.64	0.00	0.00	0.00	0.00	1	6000	212	1	8000	4000	2500
7	Others_Rabi	20.00	19.50	0.00	0.00	0.00	0.00	0.7	14000	212	1	6000	3000	2000
8	Others_Jaayad	12.00	11.70	0.00	0.00	0.00	0.00	0.7	9000	212	1	6000	4000	1000
9	Others_Kharif	30.00	29.26	0.00	0.00	0.00	0.00	1.15	9000	173	1	9000	1500	4000
10	Mentha	1.50	1.46	0.00	0.00	0.00	0.00	1	25000	173	1	20000	100000	0
11	Barley	30.00	29.26	0.00	0.00	0.00	0.00	0.85	19500	287	1	14500	1100	8000

7.3.2-Model calibration: The developed canal command, ICROP model is calibrated from Visual MODFLOW by giving recharge from ICROP and tallying from observed ground water levels. Similarly for runoff component it has been calibrated from drainage model, integrated water quantity and quality simulation model (IQQM) through which generated runoff values are checked from observed runoff values.

7.3.3. Management Options: The different management scenario options are considered.

7.3.3.1. Rainfall-Daily- rainfall sequence of different dependability's has been considered. For modeling purposes rainfall sequence with 10% dependability is considered as dry rainfall sequence, rainfall sequence with 50% dependability is considered as normal rainfall sequence and the rainfall sequence with 90% dependability is considered as wet rainfall sequence,

7.3.3.2. Canal supply options-Canal supply options with design canal capacity, silted canal capacity, with changed rosters, along with head priority and tail priority has been considered. Options are tried both for lined and unlined sections of canals also.

7.3.3.3.Changed land use options-Existing land use options based on NIC statistics, based on remote sensing land use shape files along with field survey has been considered. For future scenarios different cropping patterns are considered as tabulated below in Table 7.3.

Table 7.3. Details of existing and proposed cropping patterns

Existing Cropping Pattern			Proposed Cropping pattern1		Proposed Cropping pattern2		Proposed Cropping pattern3	
Polygon Area	39860.91 ha							
	area in ha	% area	area in ha	% area	area in ha	% area	area in ha	% area
RICE_K	12585.2	31.57	19685.5	49.39	26785.8	67.2	12585.2	31.57
MAZE_K	3456.41	8.67	3456.41	8.67	3456.41	8.67	3456.41	8.67
Other_Kharif	2830.85	7.1	2830.85	7.1	2830.85	7.1	17031.4	42.73
Kharif_Fallow	14200.6	35.63	7100.28	17.81	0	0	0	0
Total Kharif	18872.5	47.35	25972.8	65.16	33073.1	82.97	33073.1	82.97
WHEAT	16953.7	42.53	21995.8	55.18	27037.9	67.83	16953.7	42.53
GRAM	2891.17	7.25	2891.17	7.25	2891.17	7.25	2891.17	7.25
Other_Rabi	3143.94	7.89	3143.94	7.89	3143.94	7.89	13228.2	33.19
Rabi_Fallow	10084.2	25.3	5042.12	12.65	0	0	0	0
Total Rabi	22988.8	57.67	28030.9	70.32	33073.1	82.97	33073.1	82.97
URD_J	11.85	0.03	11.85	0.03	11.85	0.03	11.85	0.03
Other_Jaayad	212.88	0.53	212.88	0.53	212.88	0.53	33061.2	82.94
Jaayad_Fallow	32848.3	82.41	32848.3	82.41	32848.3	82.41	0	0
Total Jayad	224.73	0.56	224.73	0.56	224.73	0.56	33073.1	82.97
SUGARCANE	91.45	0.23	91.45	0.23	91.45	0.23	91.45	0.23
Vegitation	1357.63	3.41	1357.63	3.41	1357.63	3.41	1357.63	3.41
Wasteland	5338.75	13.39	5338.75	13.39	5338.75	13.39	5338.75	13.39
Total cropping % of gross polygon area	42177.5	105.81	54319.9	136.27	66462.3	166.74	99310.6	249.14

7.3.3.4. Conjunctive use options: Canal water preference, ground water preference up to prescribed depth below ground levels and conjunctive use options are considered.

7.3.4. Model runs results: Different scenarios are tried.

7.3.4.1. Model run output for existing cropping Pattern of 105.81% of polygon area, 75% dependable rainfall, design canal flows, and conjunctive use are tabulated in Table 7.4.

Table 7.4. Model run out put showing details at existing cropping pattern of 105.81%, 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	20.1	44.8	68.9	1007.2	71.2
Canal supply	201.8	18.1	181.6	78.7	20.2	31.1	403.6	28.6
Drainage Reuse	0.0	0.0	2.8	1.2	0.0	0.0	2.8	0.2
Total	1118.0	100.0	230.8	100.0	64.9	100.0	1413.7	100.0
Outputs								
ET (Plants use)	337.3	34.1	264.1	65.8	79.3	67.9	680.6	45.1
Domestic & Industrial use	8.0	0.8	7.6	1.9	5.2	4.4	20.7	1.4
Canal net evaporation	0.7	0.1	0.4	0.1	0.1	0.1	1.2	0.1
Runoff	454.5	45.9	18.4	4.6	0.0	0.0	472.9	31.4
Escape flow (Net of reuse)	158.1	16.0	78.8	19.7	17.5	15.0	254.4	16.9
Base flow	31.5	3.2	31.7	7.9	14.7	12.6	77.9	5.2
Total	990.1	100.0	401.1	100.0	116.7	100.0	1507.8	100.0
Increase in subsurface storage	127.9		-170.3		-51.7		-94.1	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	201.8		181.6		20.2		403.6	
Outputs								
Evaporation losses	0.7	0.3	0.4	0.2	0.1	0.4	1.2	0.3
Seepage losses	16.0	7.9	22.0	12.1	2.4	12.1	40.4	10.0
Escape flow	158.1	78.4	76.0	41.8	17.5	86.5	251.6	62.3
Water supplied to farms	27.0	13.4	83.2	45.8	0.2	1.0	110.4	27.4
Total	201.8	100.0	181.6	100.0	20.2	100.0	403.6	100.0

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	7.3	22.0	37.5	2.4	97.8	40.4	14.5
Seepage from field	202.1	92.7	36.7	62.5	0.1	2.2	238.9	85.5
Total	218.1	100.0	58.7	100.0	2.5	100.0	279.3	100.0
Extractions								
For agriculture	0.0	0.0	144.7	78.6	0.0	0.0	144.7	59.5
For domestic and industrial use	8.0	20.2	7.6	4.1	5.2	26.1	20.7	8.5
Flow to drains/river	31.5	79.8	31.7	17.2	14.7	73.9	77.9	32.0
Total	39.5	100.0	184.0	100.0	19.9	100.0	243.4	100.0
Increase in subsurface storage	178.6		-125.3		-17.4		35.9	

With 75% dependable rainfall of 1007.2 mm, canal supply of 403, 6 mm at existing Cropping Pattern of 105.81%, ground water recharge in kharif period is 178.6 mm, while 125.3 mm is used in rabi period and 17.4 mm is used in jaayed period. If conjunctive use is applied an overall recharge of 35.9 mm is seen.

7.3.4.2. Model run output for proposed cropping Pattern of 136.27% of polygon area, 75% dependable rainfall, design canal flows and conjunctive use are tabulated in Table 7.5.

Table 7.5. Model run output at proposed cropping Pattern of 136.27%, 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	24.3	44.8	24.1	1007.2	67.4
Canal supply	201.8	18.1	141.3	74.1	141.3	75.9	484.4	32.4
Drainage Reuse	0.0	0.0	3.0	1.6	0.0	0.0	3.0	0.2
Total	**1118.0**	**100.0**	**190.5**	**100.0**	**186.0**	**100.0**	**1494.6**	**100.0**
Outputs								
ET (Plants use)	419.5	40.7	254.5	70.6	102.1	47.6	776.1	48.3
Domestic & Industrial use	8.0	0.8	7.6	2.1	5.2	2.4	20.7	1.3
Canal net evaporation	0.7	0.1	0.3	0.1	0.6	0.3	1.7	0.1
Runoff	415.7	40.3	17.9	4.9	5.1	2.4	438.7	27.3
Escape flow (Net of reuse)	158.1	15.3	54.7	15.2	89.4	41.6	302.2	18.8
Base flow	29.9	2.9	25.7	7.1	12.1	5.6	67.8	4.2
Total	**1031.9**	**100.0**	**360.7**	**100.0**	**214.6**	**100.0**	**1607.2**	**100.0**
Increase in subsurface storage	**86.1**		**-170.1**		**-28.5**		**-112.6**	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	**201.8**		**141.3**		**141.3**		**484.4**	
Outputs								
Evaporation losses	0.7	0.3	0.3	0.2	0.6	0.5	1.7	0.3
Seepage losses	16.0	7.9	17.1	12.1	14.7	10.4	47.8	9.9
Escape flow	158.1	78.4	51.7	36.6	89.4	63.3	299.2	61.8
Water supplied to farms	27.0	13.4	72.1	51.0	36.6	25.9	135.6	28.0
Total	**201.8**	**100.0**	**141.3**	**100.0**	**141.3**	**100.0**	**484.4**	**100.0**

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	8.3	17.1	31.3	14.7	68.3	47.8	17.7
Seepage from field	177.5	91.7	37.5	68.7	6.8	31.7	221.9	82.3
Total	**193.5**	**100.0**	**54.7**	**100.0**	**21.5**	**100.0**	**269.7**	**100.0**
Extractions								
For agriculture	0.0	0.0	166.1	83.3	0.0	0.0	166.1	65.3
For domestic and industrial use	8.0	21.0	7.6	3.8	5.2	30.0	20.7	8.1
Flow to drains/river	29.9	79.0	25.7	12.9	12.1	70.0	67.8	26.6
Total	**37.9**	**100.0**	**199.4**	**100.0**	**17.3**	**100.0**	**254.6**	**100.0**
Increase in subsurface storage	**155.6**		**-144.8**		**4.2**		**15.1**	

With 75% dependable rainfall of 1007.2 mm, canal supply of 484.4 mm at existing Cropping Pattern of 136.27%, ground water recharge in kharif period is 155.6 mm, while 144.8 mm is used in rabi period and 4.2 mm is used in jaayed period. If conjunctive use is applied an overall recharge of 15.1 mm is seen.

7.3.4.3. Model run output for proposed cropping pattern of 166.74% of polygon area , 75% dependable rainfall, design canal flows and conjunctive use are tabulated in Table 7.6.

Table 7.6. Model run output showing details at proposed cropping pattern of 166.74%, 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	20.0	44.8	68.9	1007.2	71.2
Canal supply	201.8	18.1	181.6	78.4	20.2	31.1	403.6	28.5
Drainage Reuse	0.0	0.0	3.7	1.6	0.0	0.0	3.7	0.3
Total	1118.0	100.0	231.6	100.0	64.9	100.0	1414.5	100.0
Outputs								
ET (Plants use)	396.2	40.2	292.5	68.6	87.5	71.4	776.1	50.6
Domestic & Industrial use	8.0	0.8	7.6	1.8	5.2	4.2	20.7	1.3
Canal net evaporation	0.7	0.1	0.4	0.1	0.1	0.1	1.2	0.1
Runoff	393.1	39.9	21.9	5.1	0.0	0.0	415.1	27.0
Escape flow (Net of reuse)	153.9	15.6	72.7	17.1	17.4	14.2	244.0	15.9
Base flow	33.7	3.4	31.3	7.3	12.4	10.1	77.4	5.0
Total	985.7	100.0	426.4	100.0	122.5	100.0	1534.6	100.0
Increase in subsurface storage	132.3		-194.8		-57.6		-120.1	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	201.8		181.6		20.2		403.6	
Outputs								
Evaporation losses	0.7	0.3	0.4	0.2	0.1	0.4	1.2	0.3
Seepage losses	16.0	7.9	22.0	12.1	2.4	12.1	40.4	10.0
Escape flow	153.9	76.3	69.1	38.0	17.4	86.2	240.4	59.6
Water supplied to farms	31.2	15.5	90.2	49.6	0.3	1.3	121.6	30.1
Total	201.8	100.0	181.6	100.0	20.2	100.0	403.6	100.0

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	6.7	22.0	32.4	2.4	97.3	40.4	13.1
Seepage from field	221.2	93.3	45.9	67.6	0.1	2.7	267.2	86.9
Total	237.2	100.0	67.9	100.0	2.5	100.0	307.6	100.0
Extractions								
For agriculture	0.0	0.0	199.6	83.7	0.0	0.0	199.6	67.0
For domestic and industrial use	8.0	19.1	7.6	3.2	5.2	29.5	20.7	7.0
Flow to drains/river	33.7	80.9	31.3	13.1	12.4	70.5	77.4	26.0
Total	41.7	100.0	238.5	100.0	17.5	100.0	297.7	100.0
Increase in subsurface storage	195.5		-170.6		-15.0		9.9	

With 75% dependable rainfall of 1007.2 mm, canal supply of 403.6 mm at existing Cropping Pattern of 166.74%, ground water recharge in kharif period is 195.5 mm, while 170.6 mm is used in rabi period and 15.0 mm is used in jaayed period. If conjunctive use is applied an overall recharge of 9.9 mm is seen.

7.3.4.4. Model run output at proposed cropping Pattern of 249.14% of polygon area, 75% dependable rainfall, design canal flows and conjunctive use are tabulated in Table 7.7.

Table 7.7. . Model run output showing at proposed cropping pattern of 249.14**,** 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	19.9	44.8	68.9	1007.2	71.2
Canal supply	201.8	18.1	181.6	78.2	20.2	31.1	403.6	28.5
Drainage Reuse	0.0	0.0	4.3	1.9	0.0	0.0	4.3	0.3
Total	**1118.0**	**100.0**	**232.2**	**100.0**	**64.9**	**100.0**	**1415.2**	**100.0**
Outputs								
ET (Plants use)	455.1	46.4	324.5	70.7	95.5	74.7	875.1	55.8
Domestic & Industrial use	8.0	0.8	7.6	1.6	5.2	4.1	20.7	1.3
Canal net evaporation	0.7	0.1	0.4	0.1	0.1	0.1	1.2	0.1
Runoff	331.1	33.7	25.3	5.5	0.1	0.0	356.4	22.7
Escape flow (Net of reuse)	150.8	15.4	70.9	15.4	17.3	13.5	239.0	15.2
Base flow	36.0	3.7	30.2	6.6	9.8	7.7	76.1	4.8
Total	**981.7**	**100.0**	**458.9**	**100.0**	**127.8**	**100.0**	**1568.4**	**100.0**
Increase in subsurface storage	**136.3**		**-226.7**		**-62.9**		**-153.2**	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	**201.8**		**181.6**		**20.2**		**403.6**	
Outputs								
Evaporation losses	0.7	0.3	0.4	0.2	0.1	0.4	1.2	0.3
Seepage losses	16.0	7.9	22.0	12.1	2.4	12.1	40.4	10.0
Escape flow	150.8	74.7	66.6	36.7	17.3	85.5	234.7	58.1
Water supplied to farms	34.3	17.0	92.6	51.0	0.4	2.0	127.3	31.5
Total	**201.8**	**100.0**	**181.6**	**100.0**	**20.2**	**100.0**	**403.6**	**100.0**

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	6.2	22.0	28.4	2.4	96.2	40.4	12.0
Seepage from field	239.9	93.8	55.5	71.6	0.1	3.8	295.5	88.0
Total	**255.9**	**100.0**	**77.5**	**100.0**	**2.5**	**100.0**	**336.0**	**100.0**
Extractions								
For agriculture	0.0	0.0	262.4	87.4	0.0	0.0	262.4	73.1
For domestic and industrial use	8.0	18.1	7.6	2.5	5.2	34.6	20.7	5.8
Flow to drains/river	36.0	81.9	30.2	10.1	9.8	65.4	76.1	21.2
Total	**44.0**	**100.0**	**300.2**	**100.0**	**15.0**	**100.0**	**359.2**	**100.0**
Increase in subsurface storage	**211.9**		**-222.7**		**-12.4**		**-23.2**	

With 75% dependable rainfall of 1007.2 mm, canal supply of 403.6 mm at existing Cropping Pattern of 249.14%, ground water recharge in kharif period is 211.9 mm, while 222.7 mm is used in rabi period and 12.4mm is used in jaayed period. If conjunctive use is applied an overall depletion of 23.2 mm is seen.

7.3.4.5. Area of cultivation and gross margin to farmers

With the implementation of conjunctive use at 75% dependable rainfall and designed canal flows, the area of cultivation and gross margin to farmers can be increased even to double, as tabulated below in Table 7.8,as a result of model runs in different scenarios.

Tale 7.8, showing results of gross margin in different model run scenarios

S.N	Cropped area (% of polygon area of 39860.9 ha)				Cropping Intensity in %	Area under cultivation in Ha	Gross Profit in crore	Ground water depletion in mm
	Karif	Rabi	Jaid	Total				
1	2	3	4	5	6	7	8	9
1	47.3	57.7	0.6	105.8	162.77	42177.5	16.67	35.9
2	65.2	70.3	0.6	136.3	209.69	54319.9	20.86	15.1
3	83	83	0.6	166.7	256.46	66462.3	24.93	9.9
4	83	83	83	249.1	383.23	99310.6	34.6	-23.24

7.4. Summary and Conclusions

In Ramganj distributaury command at 75% dependable rainfall , if canal supplies are made at design discharge and conjunctive use is opted, an area of 166.74%(82.97% kharif,82.97 % rabi,0.56% jaayed and 0.23 % sugarcane) of polygon area or 256.52%

cropping intensity can be irrigated and ground water can be kept sustainable with an overall net recharge of 9.9mm per year. The gross margin to farmers and area of cultivation can even be doubled by bringing additional area under cultivation.