Conjunctive Use Modeling of Surface water and Groundwater

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Annual Water Availability in India

Total precipitation	**4000 BCM**
Annual water availability (after accounting for losses in the form evaporation etc.)	**1869 BCM**
Utilizable water (the available water cannot be fully utilized due to topographical and hydrological constraints and the need for allowing certain amount of water to flow in the river for maintaining the river regime.)	**1123 BCM**
- **Surface water** - **Ground water**	**690 BCM** **433 BCM**

Per Capita Water Availability with Time

Year	Population (in millions)	Per Capita water availability (in cubic meter)
1951	361	5177
2001	1027	1820
2025 (projected)	1394	1341
2050 (projected)	1640	1140

India's Water Demands for Various Uses

Use	Year 2010		Year 2025		Year 2050	
	Water Demand (BCM)	% of total demand	Projected Demand (BCM)	% of total demand	Projected Demand (BCM)	% of total demand
Irrigation	557	78%	611	72%	807	69%
Domestic	43	6%	62	7%	111	9%
Industries	37	5%	67	8%	81	7%
Environment	5	1%	10	1%	20	2%
Others	68	10%	93	12%	161	13%
Total	710	100%	843	100%	1180	100%

Background

- Importance of Agriculture in India
  - Livelihood of more than 65% people
- Importance of Irrigation
  - Survival of Agriculture
  - Practised on ~17% of arable land of world
  - Produces 1/3 of total food production
- Importance of Irrigation Management
  - Consumes of more than 70% of fresh water
  - Even 2% increase in operational efficiency
  - Can create additional potential of 5 lakh ha

Background

- With launching of 5-year plans in 1950-51, the objective was to achieve increased irrigation and irrigation potential increased from 22.5 Mha in 1951 to 107 Mha presently.
- However, by the 4th 5-year plan, twin problem of waterlogging & salinity started invading the irrigation commands.
- Within 10 years of commissioning of Bhakhra, Chambal, Gandak, and Sarda-Sahayak projects, large parts of command areas got waterlogged.

Background

- Some other major projects with waterlogging conditions:
  - Tungabhadra command
  - Mahi-Kadana command
  - Parts of Haryana, Punjab, UP, Bihar etc.
- 18% of 25 major command areas in 13 states of India had gone waterlogged by the year 2000.

Background

- Other water-related problems of irrigation systems:
  - Poor utilisation of created potential
  - Inefficient distribution of irrigation water
  - Excess water at head
  - Tail end is deprived of even basic
- Present systems
  - Water distribution plan is fixed before the crop season – Supply-based systems
  - Spatial variation in terms of crops, soil, rainfall, groundwater conditions etc. is not considered resulting in sub-optimal use

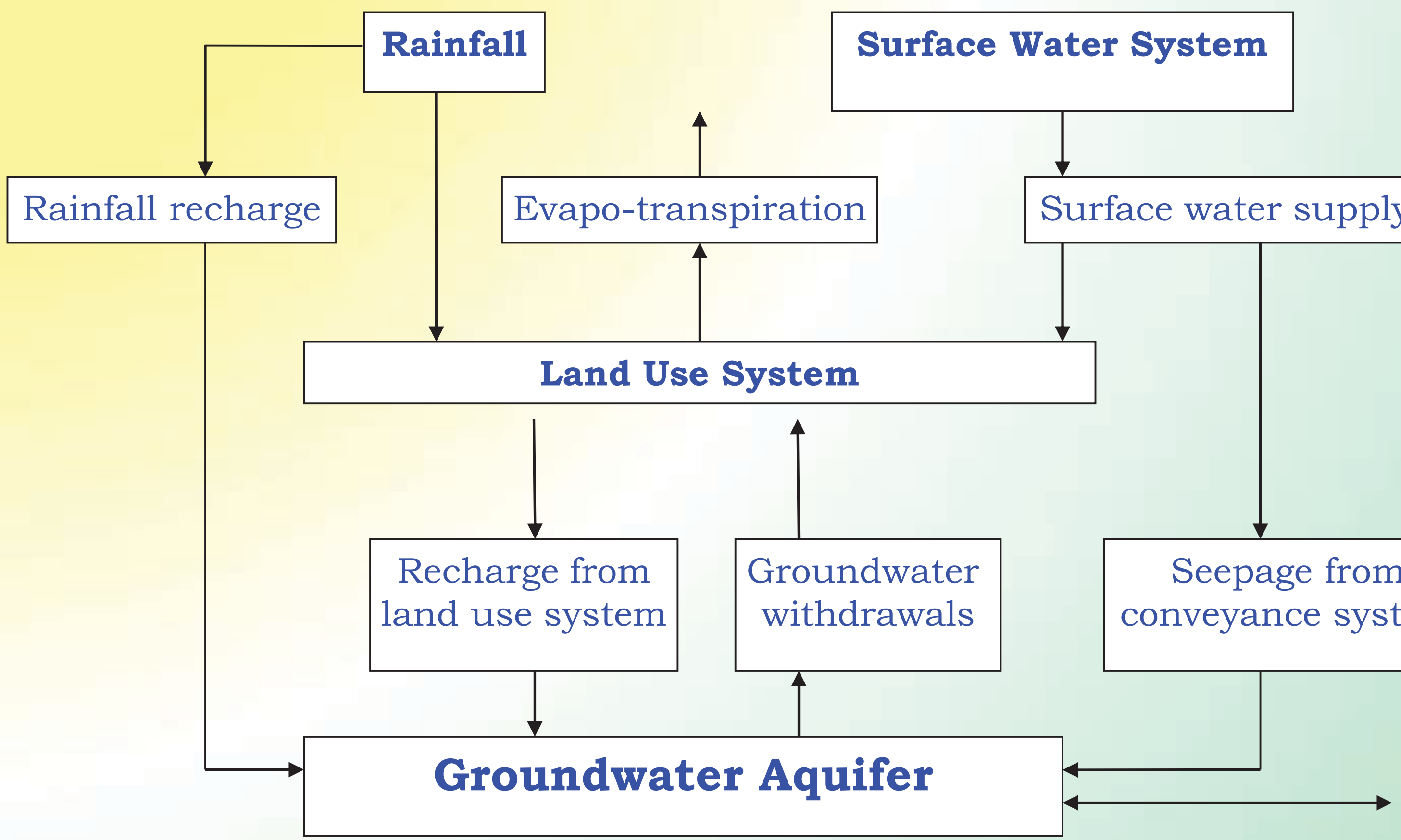
Background

- Possible improvements:
  - Determination of real-time demands based on existing cropping pattern, rainfall, and climate
  - Rational operation of canal system according to demand & supply
  - Conjunctive use of surface & groundwater to optimize an environmentally sound operation

Concept of Conjunctive Use

- Recognizes unified nature of surface and groundwater resources as a single resource
- Process takes advantage of the interaction between surface and groundwater resources
- NWP – 1987, 2002, and 2013 recommend for the adoption of conjunctive use right from project planning stage

Concept of Conjunctive Use



Concept of Conjunctive Use

- Objectives of conjunctive use:
  - A higher total amount of supply.
  - Better regulation of the combined system, using the storage volume of the aquifer.
  - Savings in evaporation losses from surface
  - Higher flexibility in supply according to the demand curve
  - Mixing of different quality water to reduce salinity

Concept of Conjunctive Use

- Reduction of capital and operational expenditures by shortening route for surface water.
- Arresting depletion of groundwater table in areas where no surface irrigation exists and excessive groundwater extraction is done, by introducing surface irrigation from small rivers which will also help the groundwater regime through recharge.

Concept of Conjunctive Use

- Three strategies:
  - Allocating parcels of land permanently to a particular use
  - Allocating surface and groundwater in time
  - Space and time integration

Conjunctive Use Models

- Conjunctive Use Models:
  - For optimum development of dam & GW, optimization of cropping pattern, evaluation of plans for surface and GW use etc.
  - Optimization & simulation
  - Spatial variability is considered in only a few models

Conjunctive Use Models

- General form of Conjunctive Use Equation:

$$\text{Max. } Z = (BI + BR) - (CSW + OCS + CGW + OCG)$$

where,

$BI = f_1 \{A_i, a_{ij}, q_{bj}, b_j, P_j, s, Y_j, P_j, C_j, \text{land capability}\}$

$BR = f_2 \{A_i, a_{ij}, P_t, C_j, \text{land capability}\}$

$CSW = f_3 \{\text{life of system, discount rate, development cost of } SWC_i\}$

$OCS = f_4 (\text{operation year, component life, discount rate, } SW_{it}\}$

$CGW = f_5 \{\text{life of system, discount rate, development cost of } GWC_i\}$

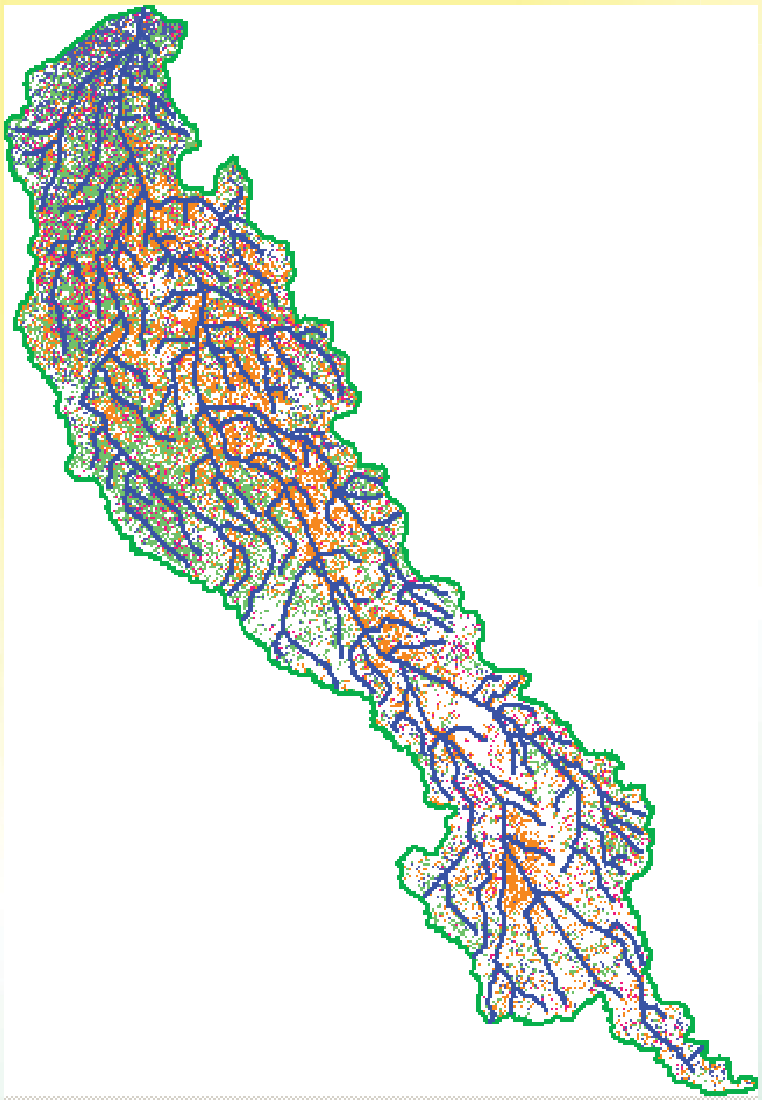
$OCG = f_6 \{GW_{it}, H_i (GW_{it}, \beta_{ip}), CP_i (H_i)\}$

Conjunctive Use Models

- Various Constraints:
  - Crop water balance constraint
  - Recharge balance constraint
  - Drawdown constraint
  - Capacity constraints
  - Land constraint
  - Miscellaneous other constraints
  - Cropping Pattern restrictions
  - Limits on groundwater pumping
  - Limits on surface water supply

Simulation of Conjunctive Operation of an Irrigation System in GIS Environment

Conceptualize



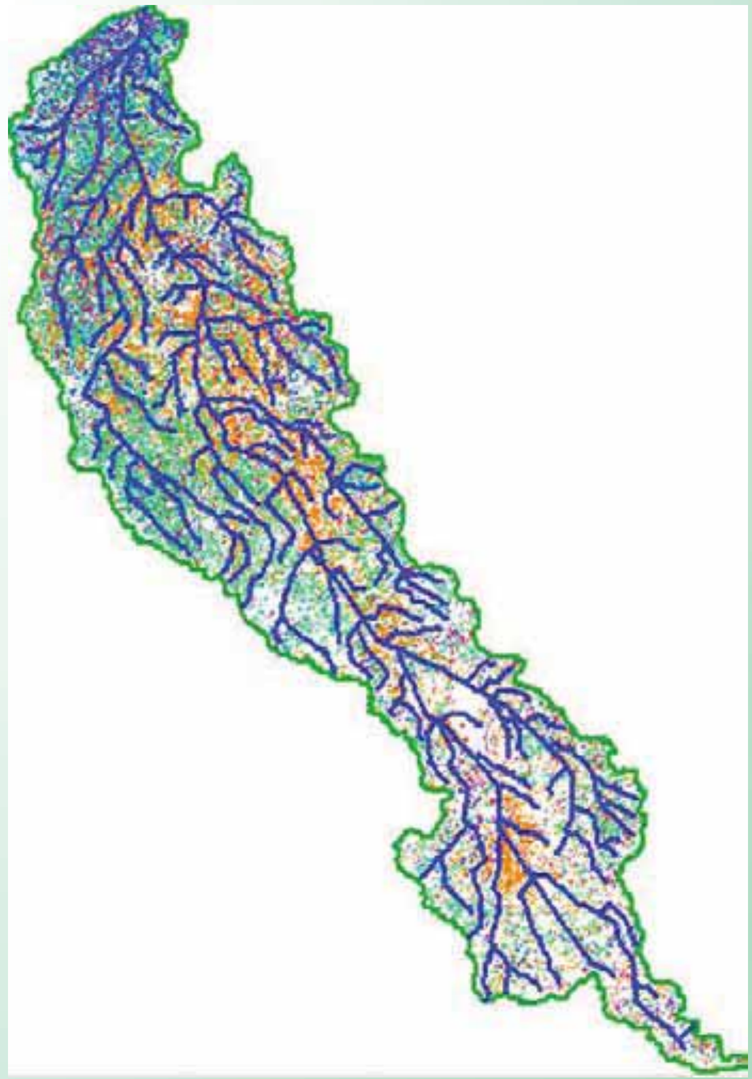
- Let us visualize an irrigation command
  - An irrigation manager is responsible for operation of a large canal network
  - There are a variety of crops that vary in characteristics and from field to field
  - Soil types vary
  - Rainfall conditions vary
  - Groundwater conditions vary
  - Canal system characteristics vary

Need of Management Tool

Clearly, it can be realized that an Irrigation Manager needs a tool which can integrate all the relevant information and the processes to formulate a water distribution plan for the operation of canal network

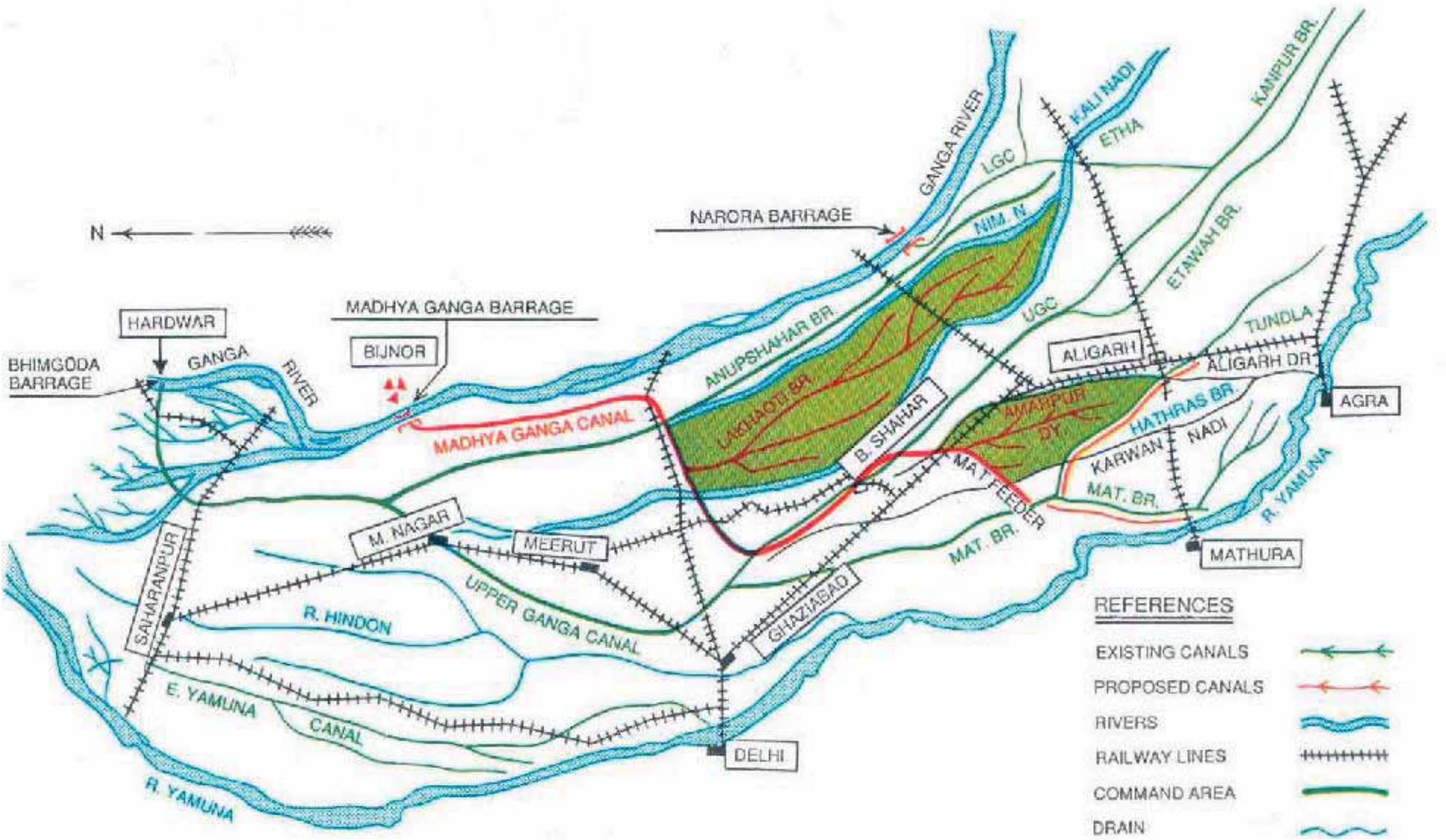
Problem Definition

- Allocation of canal water and groundwater in an irrigation command in real-time considering water demand, supply, and groundwater conditions:
  - Where
  - When
  - Why
  - How much

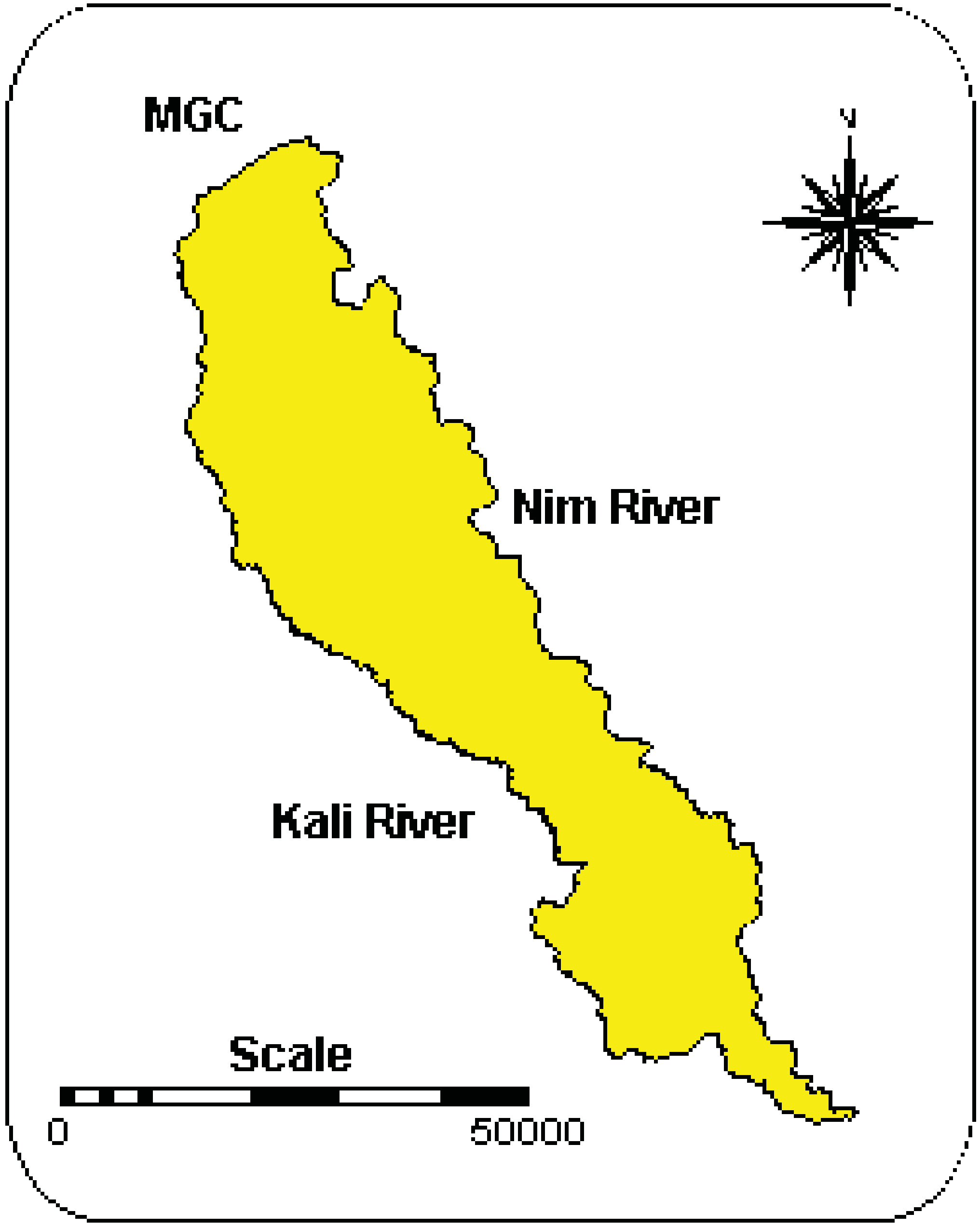


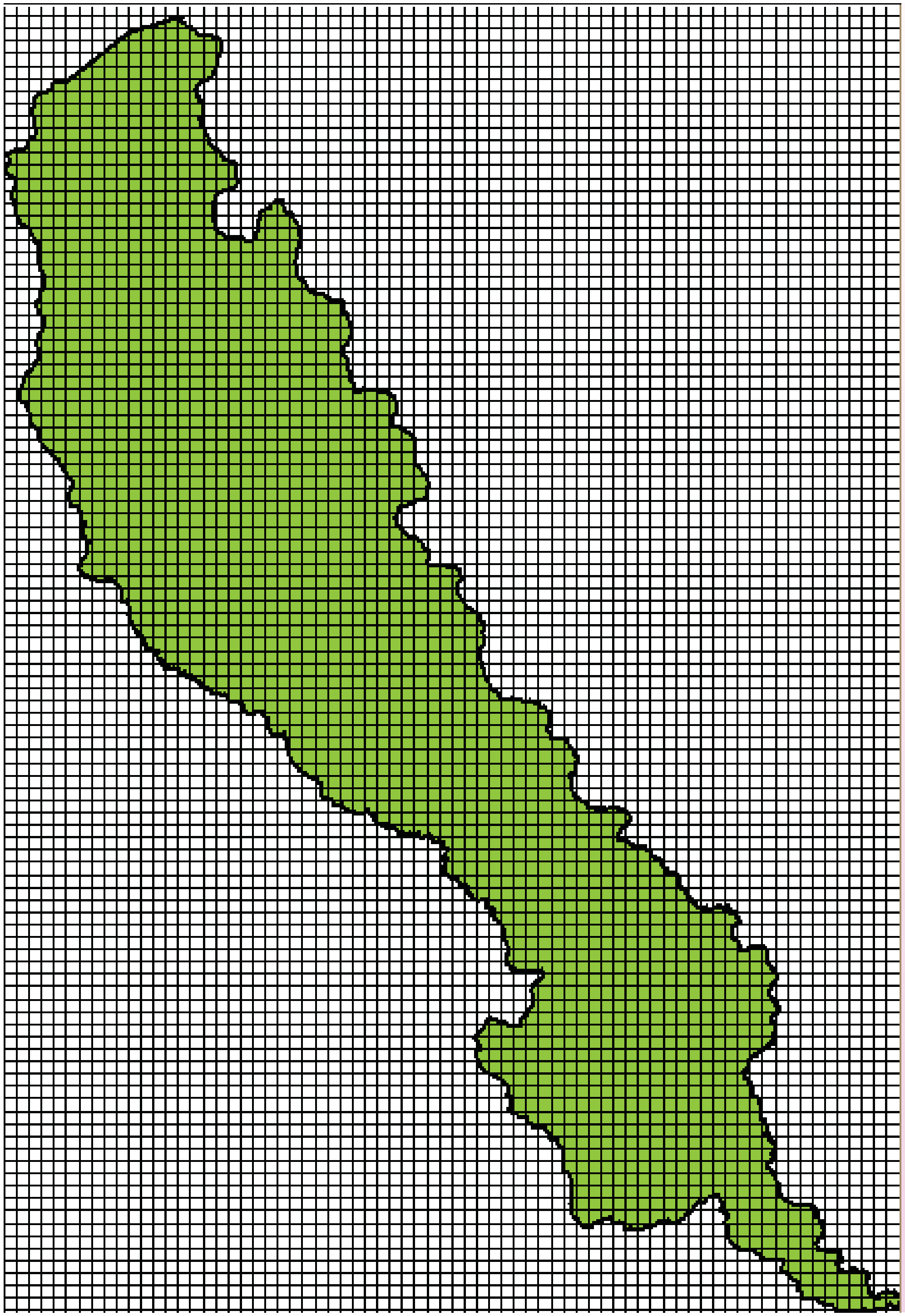
Database Development for Lakhaoti Command Area

Schematic Map of Study Area

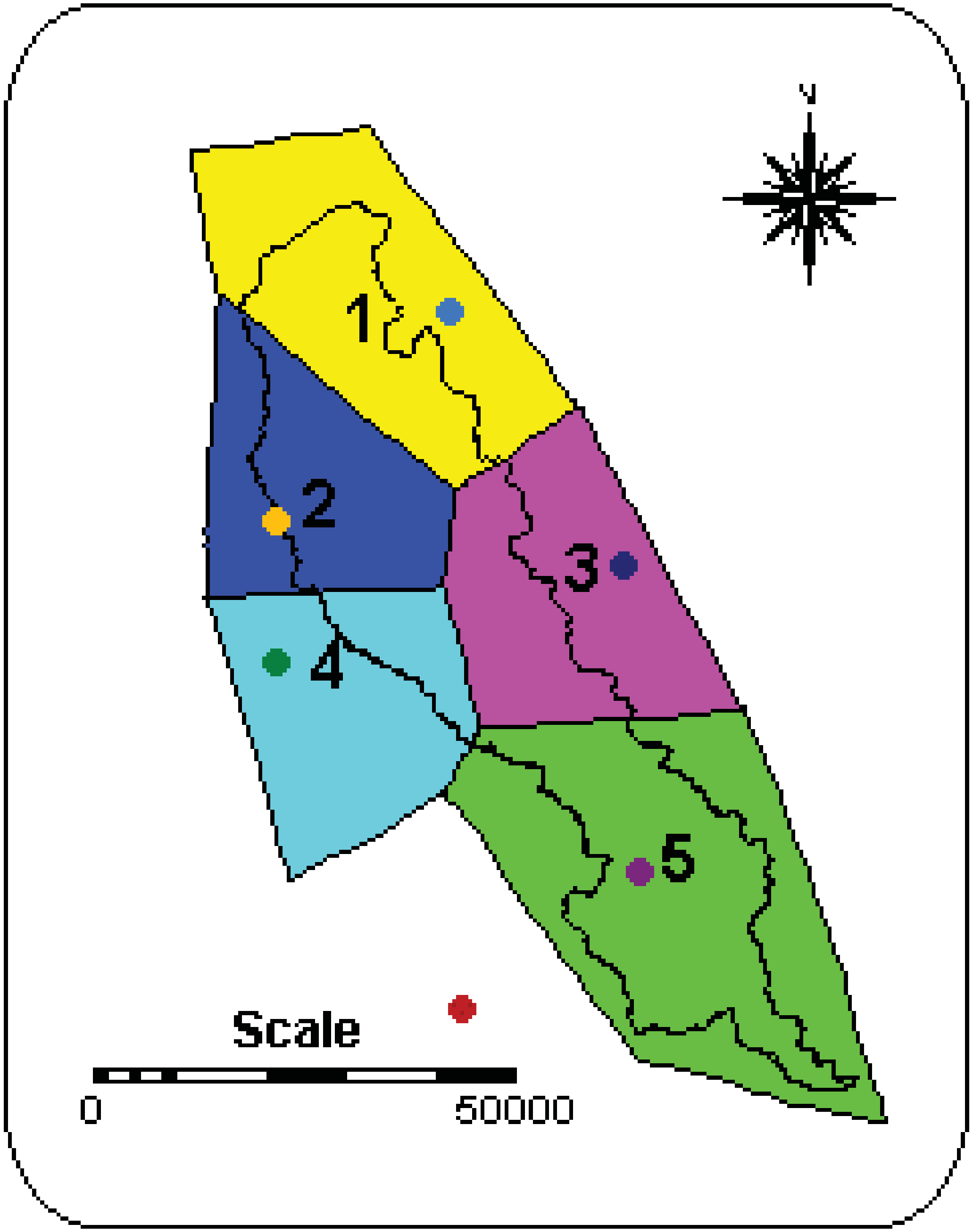


Lakhaoti Command Boundary as Digitized from Toposheets



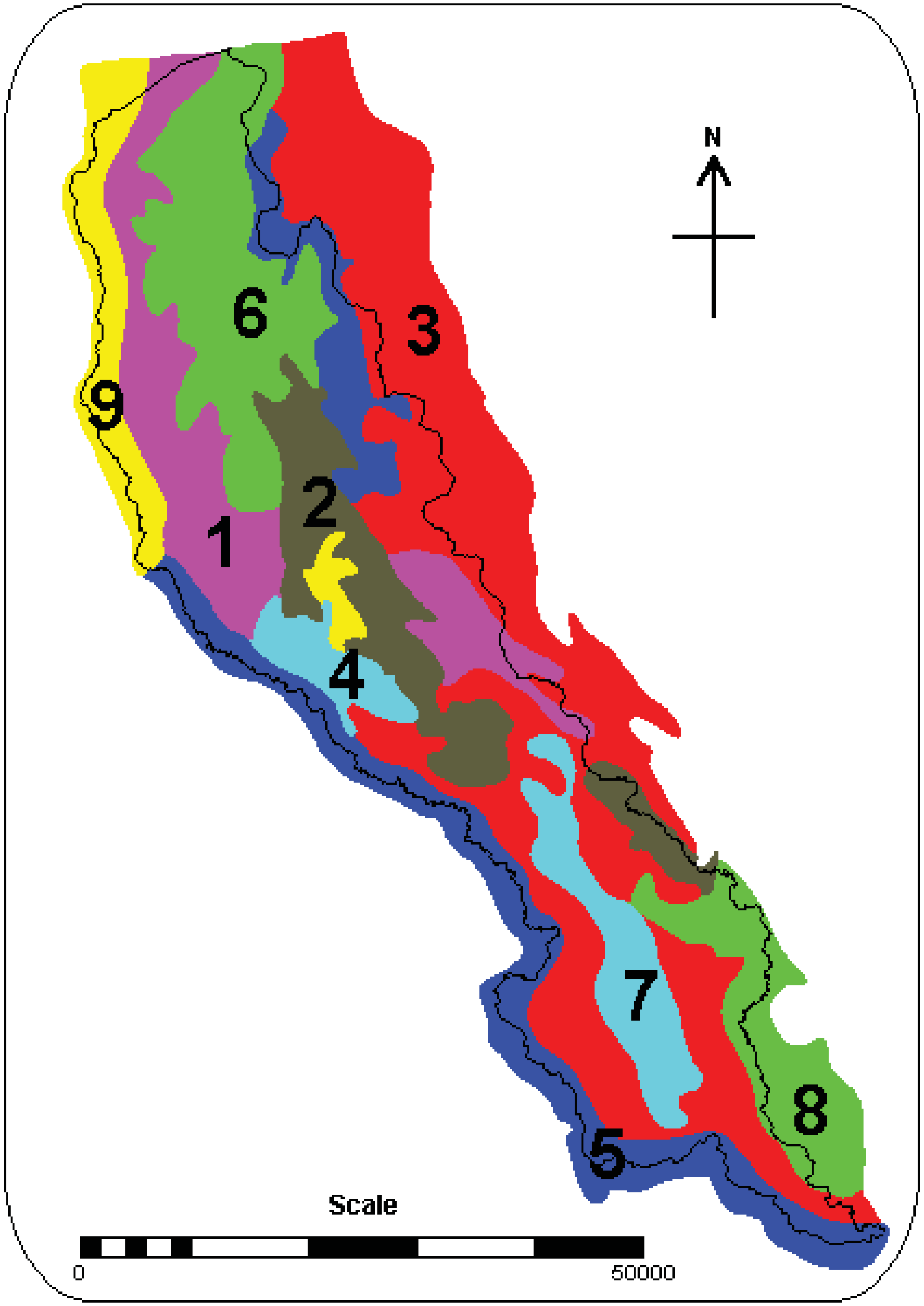


Area representation in grid form

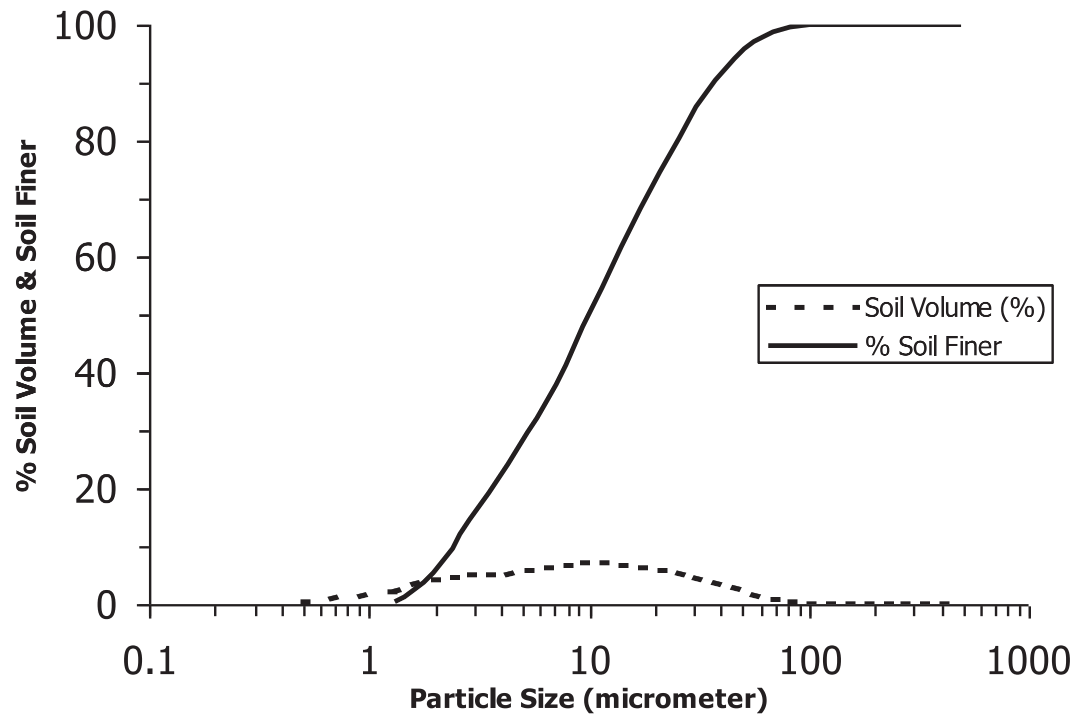


Thiessen Polygons of Rainfall Stations

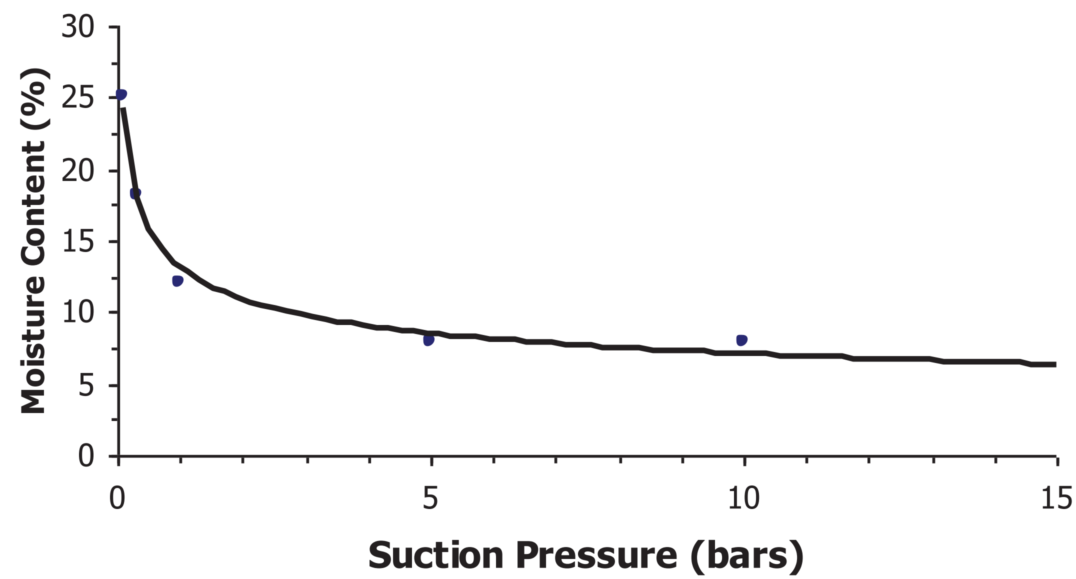
Soil Types in Lakhaoti Command



Particle size distribution for Soil-6



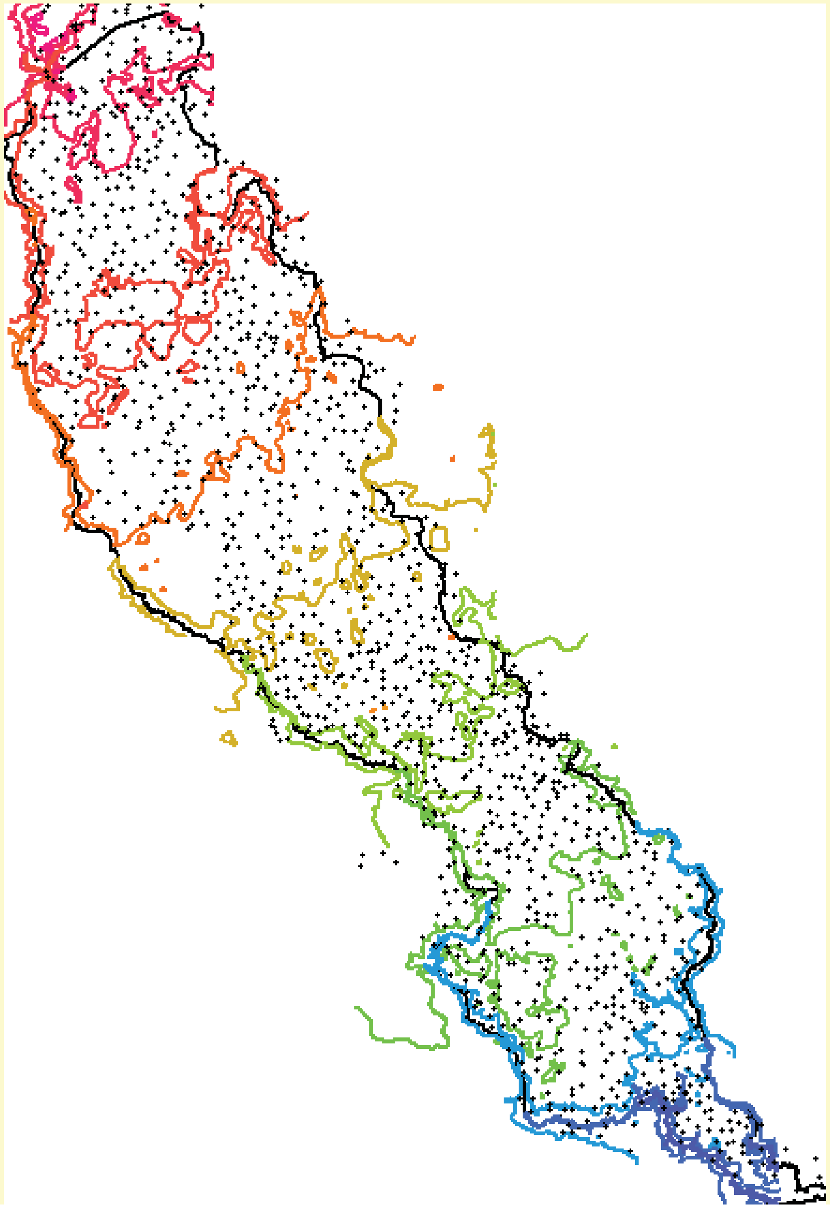
Moisture characteristic curve for Soil-6



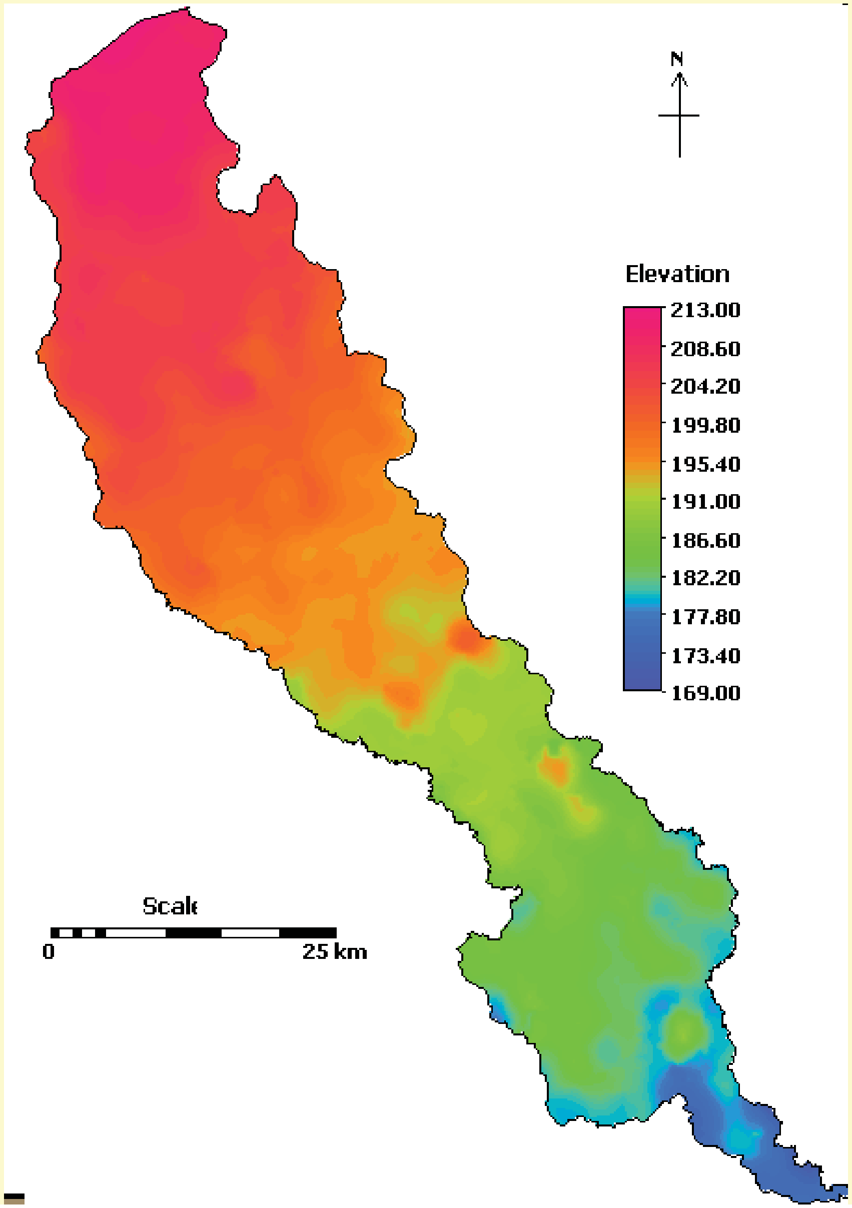
Characteristics of Various Soil Types

Soil Type	Identifier	Field Capacity	Permanent Wilting Point	Specific Gravity
Soil 088	1	18.92	10.45	2.70
Soil 099	2	20.38	07.92	2.58
Soil 086	3	22.87	14.45	2.57
Soil 134	4	14.08	04.16	2.60
Soil 197	5	08.84	03.12	2.65
Soil 112	6	17.56	07.50	2.67
Soil 102	7	24.68	14.33	2.63
Soil 159	8	18.18	10.12	2.62
Soil 203	9	19.22	05.50	2.67

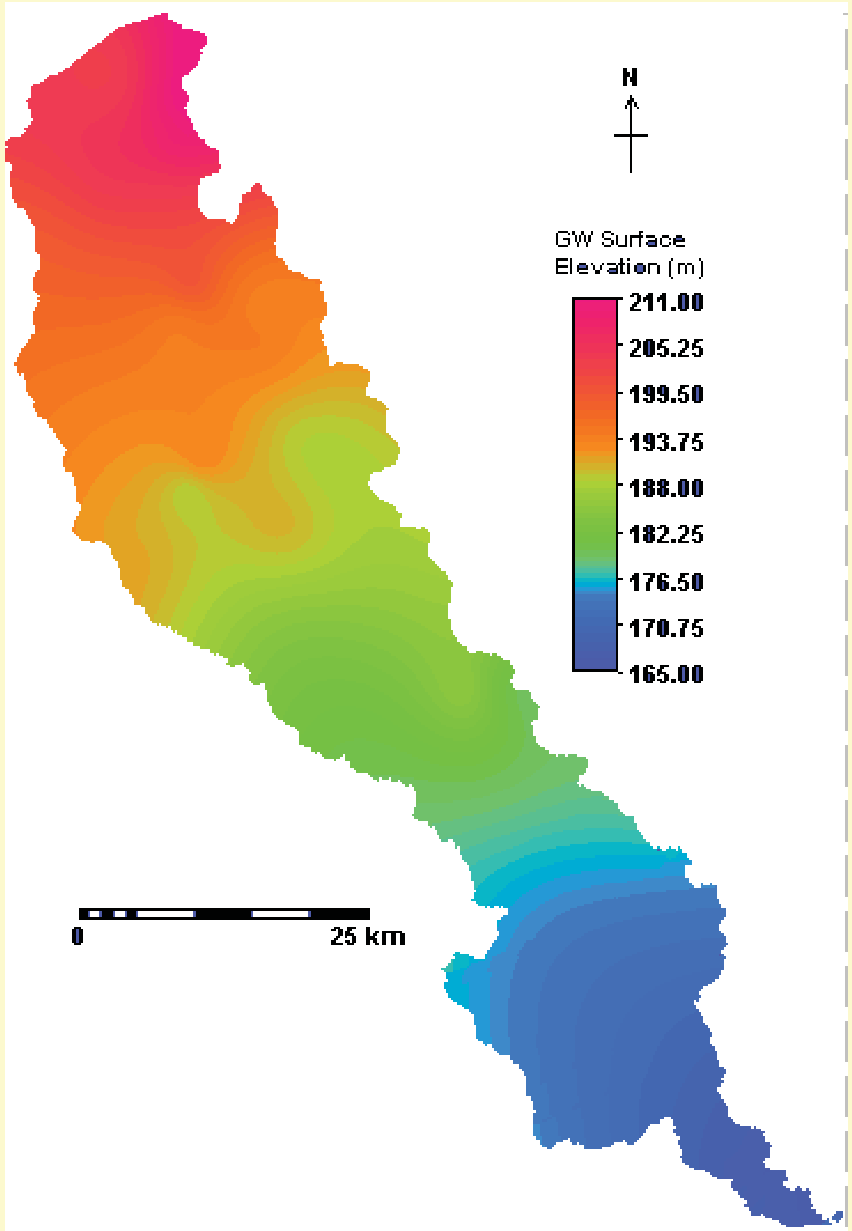
Contours & Spot Levels



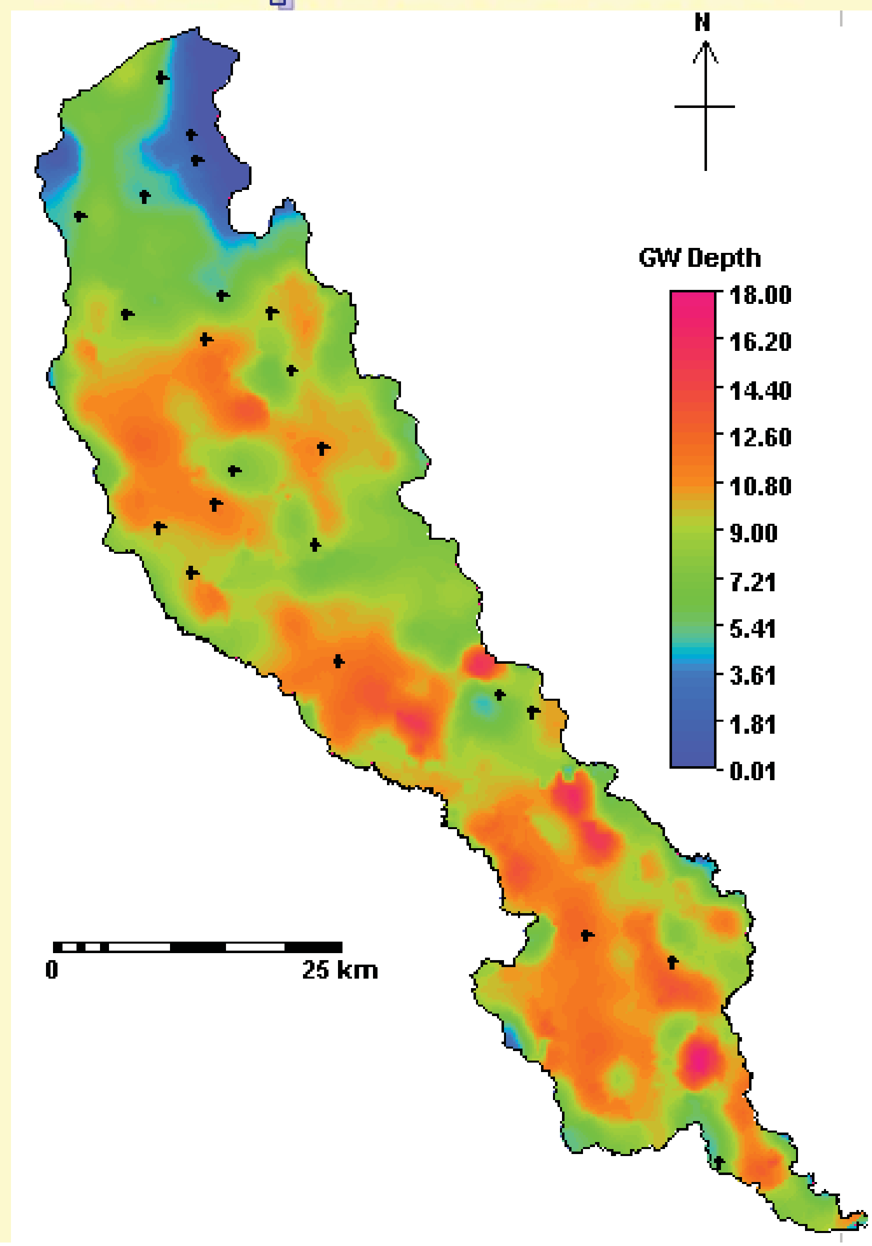
Digital Elevation Map



GW Surface in October



GW Depth in October



REMOTE SENSING ANALYSIS

Remote sensing data used for

- Getting actual cropping pattern
- Layout of canal network

Data & software used

- IRS-1C/1D Satellite, LISS-III Sensor (24 m)
  PAN Sensor (6 m)
- Path – 97, Row – 51, SAT – 40%
- Dates - June 3, 1998; July 23, 1998;
  October 9, 1998; October 31, 1998;
  November 26, 1998; March 2, 1999
- Image Processing System – ERDAS IMAGINE

CROP CALENDAR OF MAJOR CROPS

Crop	Months											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Sugarcane	←	—	—	—	—	—	—	—	—	—	—	→
Moong (Pulse)	—	→									←	—
Urad (Pulse)	←	—	→									
Rice				←	—	—	→					
Maize			←	—	—	→						
Arhar (Pulse)			←	—	—	—	—	→				
Guar (Fodder)				←	—	—	→					
Gram							←	—	—	—	→	
Mustard							←	—	—	—	→	
Potato								←	—	—	→	
Wheat								←	—	—	—	→

STEPS OF ANALYSIS

Crops in command on different dates

- Jun 3 - Sugarcane, Pulses
- Jul 23 – Sugarcane + all Kharif crops (Rice fields with water signature)
- Oct 9 - Sugarcane, Rice, Arhar, Guar
- Oct 31 - Sugarcane, Rice, Arhar
- Nov 26 – Sugarcane + all Rabi crops except wheat
- Mar 02 - Wheat + Gram + Mustard

Procedure of crop discrimination

- Multi-temporal attribute
- Unsupervised classification

Image on July 23

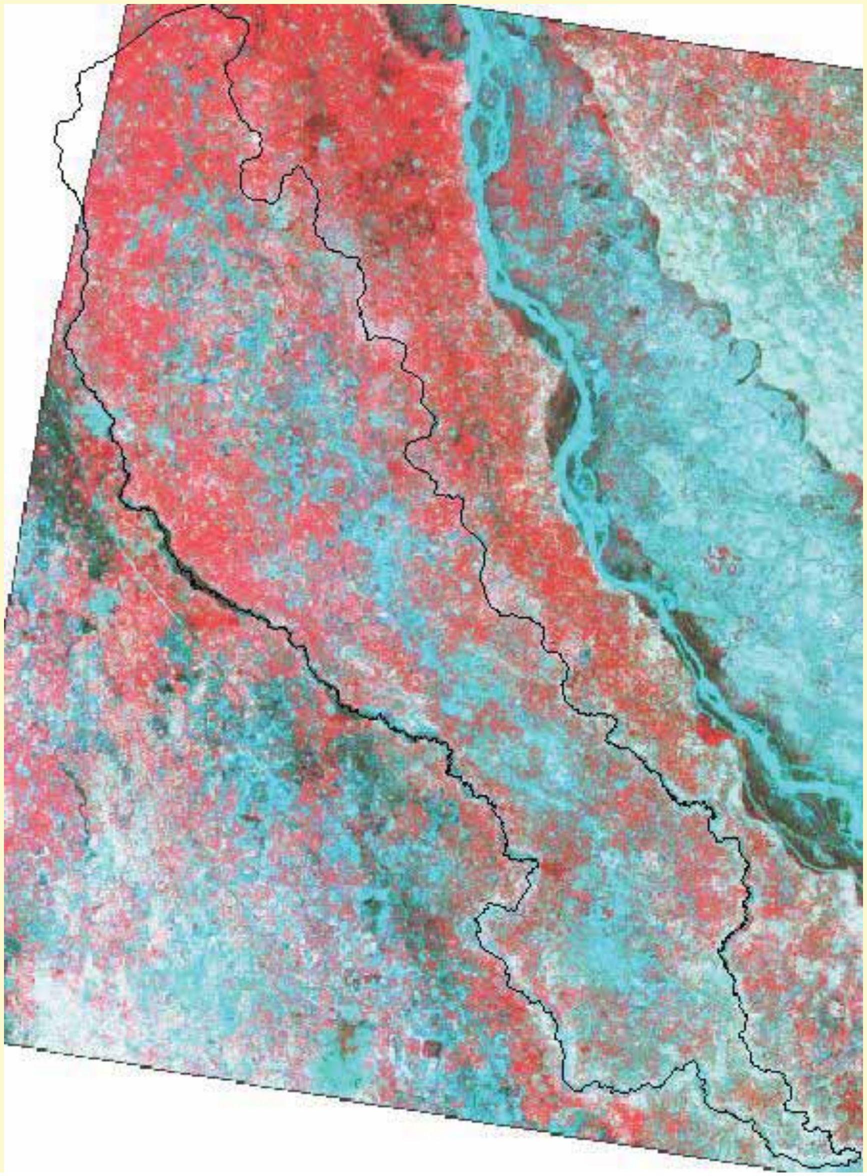
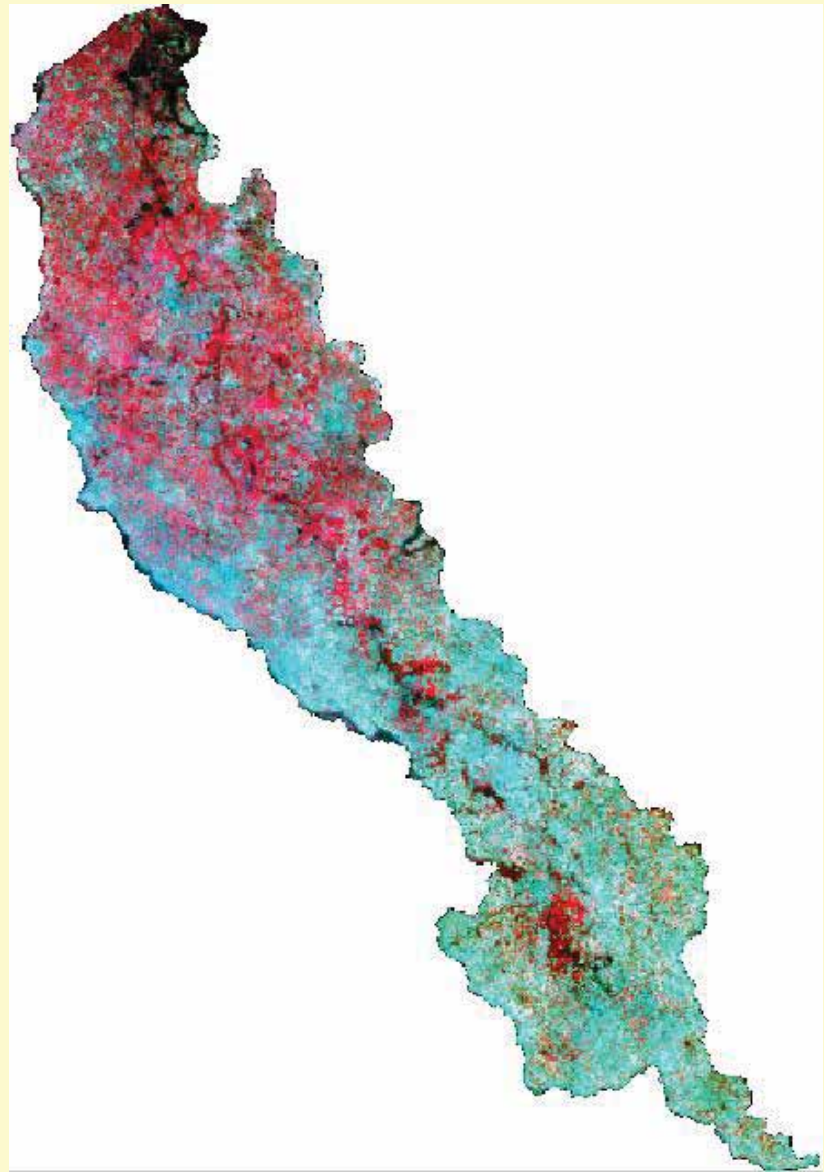


Image on Oct. 09

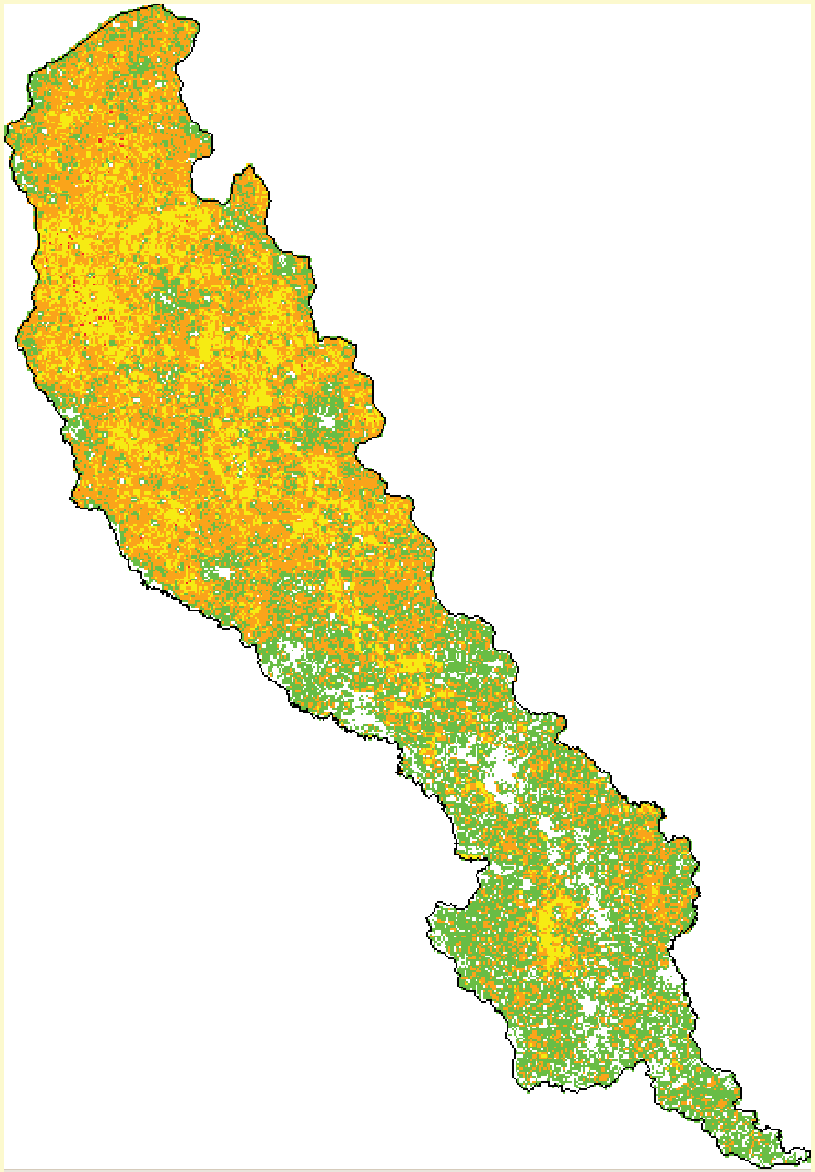


RESULTS OF REMOTE SENSING ANALYSIS

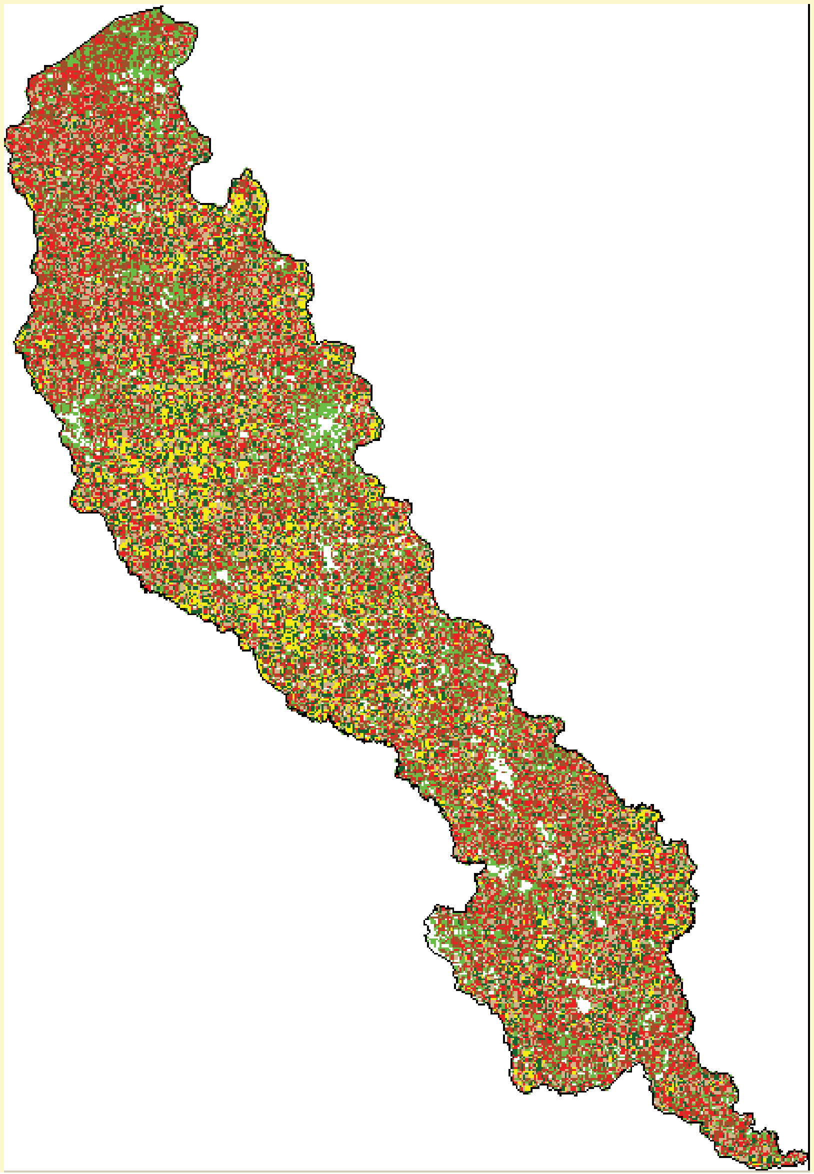
Name of Crop	Estimated Crop Area (ha)	Planned Crop Area (ha)
Sugarcane	17878	21426
Rice	43887	48254
Maize	38330	37551
Arhar (pulse)	9148	10950
Guar (fodder)	2360	9694
Gram	2360	1191
Mustard	7176	6436
Potato	4156	2615
Wheat	90829	98063

RESULTS OF REMOTE SENSING ANALYSIS

Kharif crops map

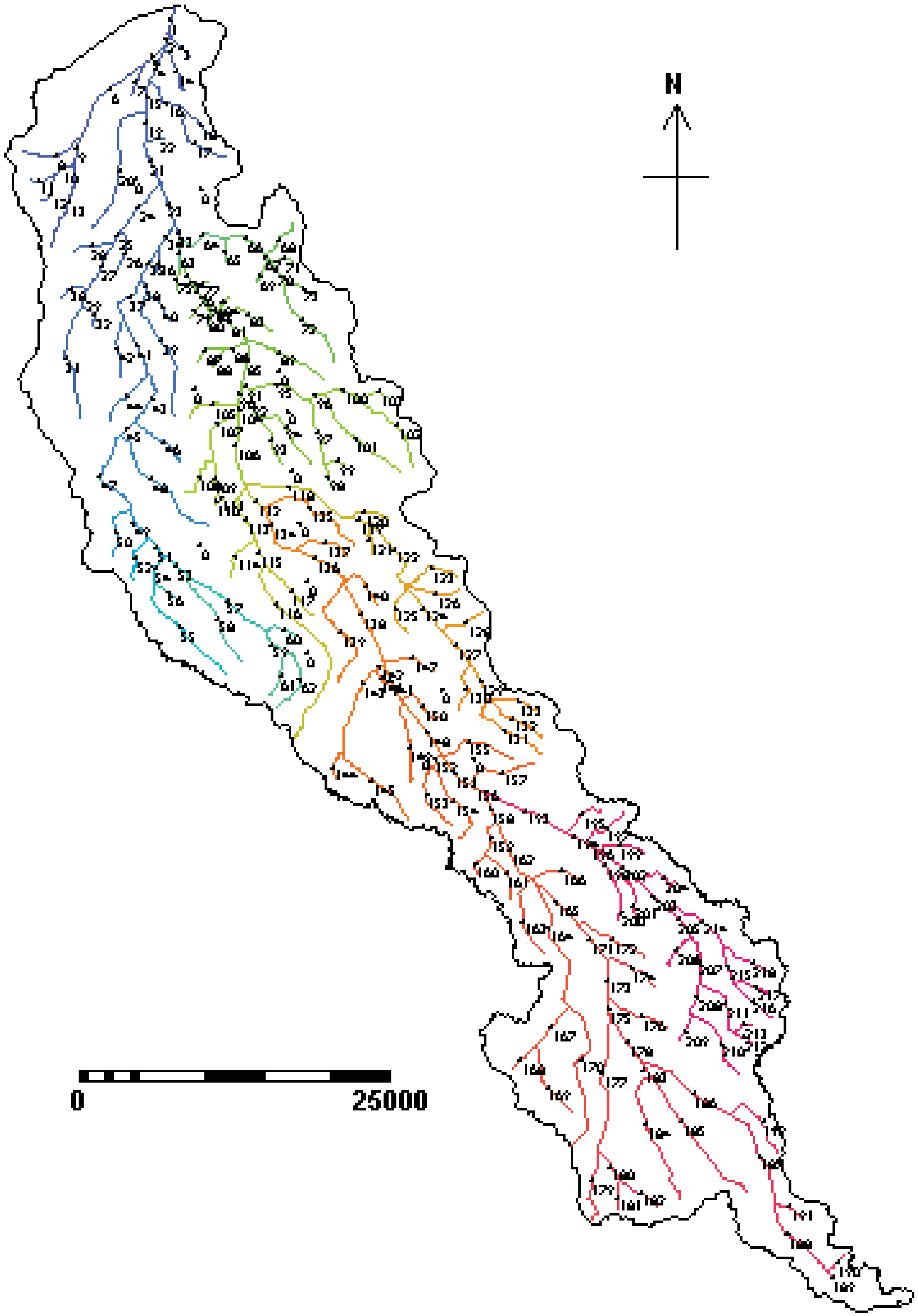


Rabi crops map

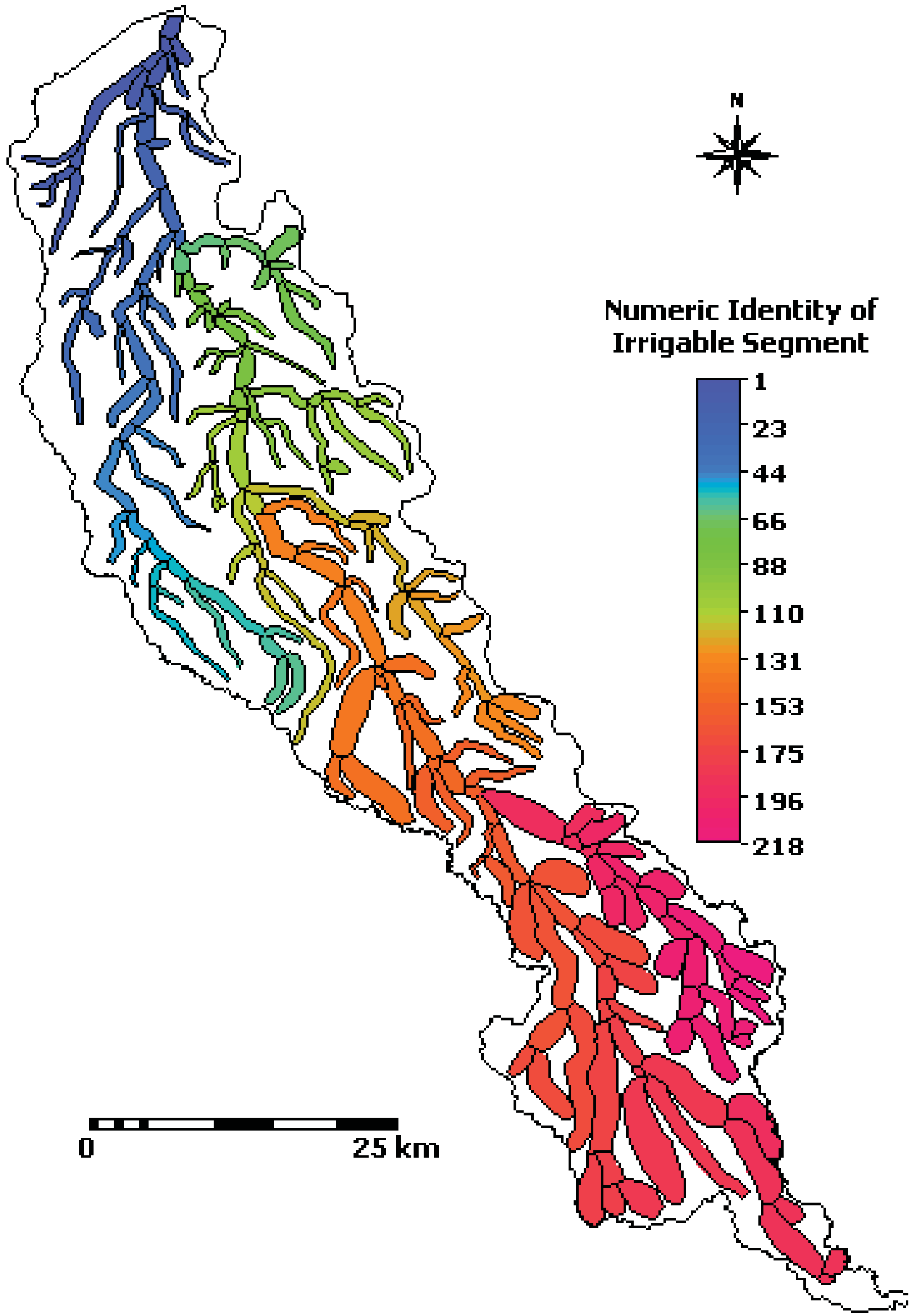


CROP CHARACTERISTICS

Crop Characteristic	Sugarcane	Maize	Rice	Arhar	Guar	Gram	Mustard	Potato	Wheat
Fraction of available soil water	0.65	0.60	1.00	0.50	0.50	0.50	0.50	0.25	0.50
Max. root depth (mm)	1000	900	500	900	1000	1000	1000	500	1000
Time to max. root depth (weeks)	15	9	9	9	6	9	9	9	9
Starting week (calendar week)	14	25	27	25	27	42	42	44	47
Period of crop (week)	51	15	17	20	13	20	18	17	18
Standing water depth required (mm)	0	0	100	0	0	0	0	0	0
Time of standing water depth (week)	0	0	15	0	0	0	0	0	0
Water depth req. for land preparation (mm)	50	50	150	50	50	50	50	50	50
Time of initial land preparation (week)	1	1	1	1	1	1	1	1	1



Canal Network Layout



Irrigable commands of different canal segments

CHARACTERIZATION OF CANAL SYSTEM

Segment Name	Numeric Identity	Discharge (Cumec)	Length (m)	Bed Width (m)	Water Depth (m)	Design PPA (ha)	Calculated PPA (ha) at Head of Dist./Minor	Conveyance Efficiency
B_Lakhaoti1	1	63.71	2344	35.00	2.25	5416	5447	0.9951
B_Lakhaoti2	2	63.13	1167	34.84	2.24	-	-	0.9951
M_Bahapur	3	0.18	2663	1.20	0.50	169	170	-
B_Lakhaoti3	4	60.54	2963	33.70	2.22	-	-	0.9920
D_Partapur1	5	2.17	2222	7.00	0.80	1208	1202	-
D_Partapur2	6	1.72	8072	5.92	0.75	-	-	-
M_Bhimyari	7	0.30	2831	1.50	0.55	236	229	-
M_Pali	8	0.25	5305	1.25	0.55	200	199	-
D_Partapur3	9	0.92	2068	4.39	0.54	-	-	-
M_Tajpur1	10	0.28	1988	1.50	0.55	166	168	-
M_Tajpur2	11	0.10	2063	0.67	0.43	-	-	-
M_Sherpur	12	0.09	2804	1.00	0.35	75	78	-

DATABASE FOR GROUNDWATER SIMULATION

Purpose of groundwater simulation

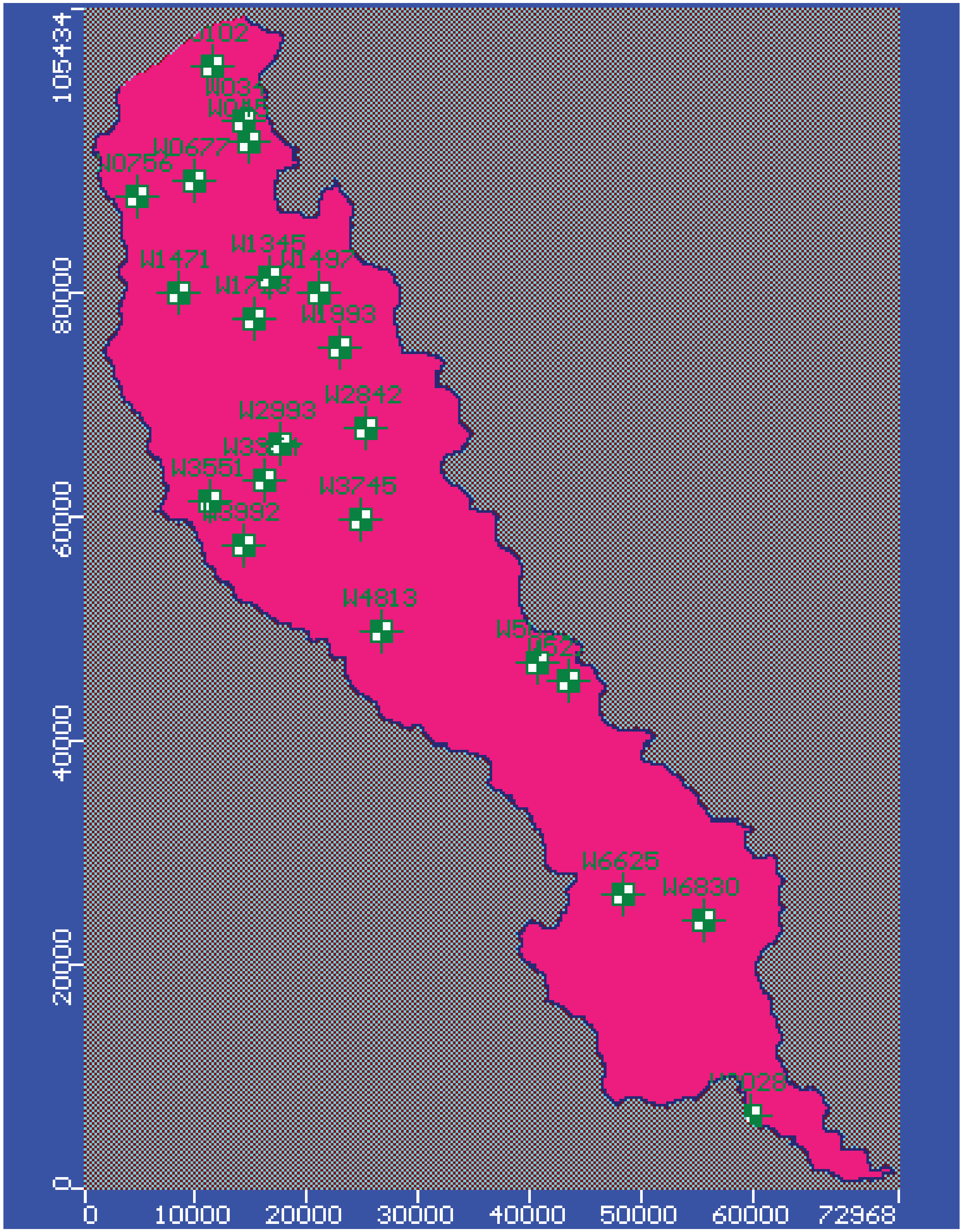
To find the periodic groundwater surface

Software used

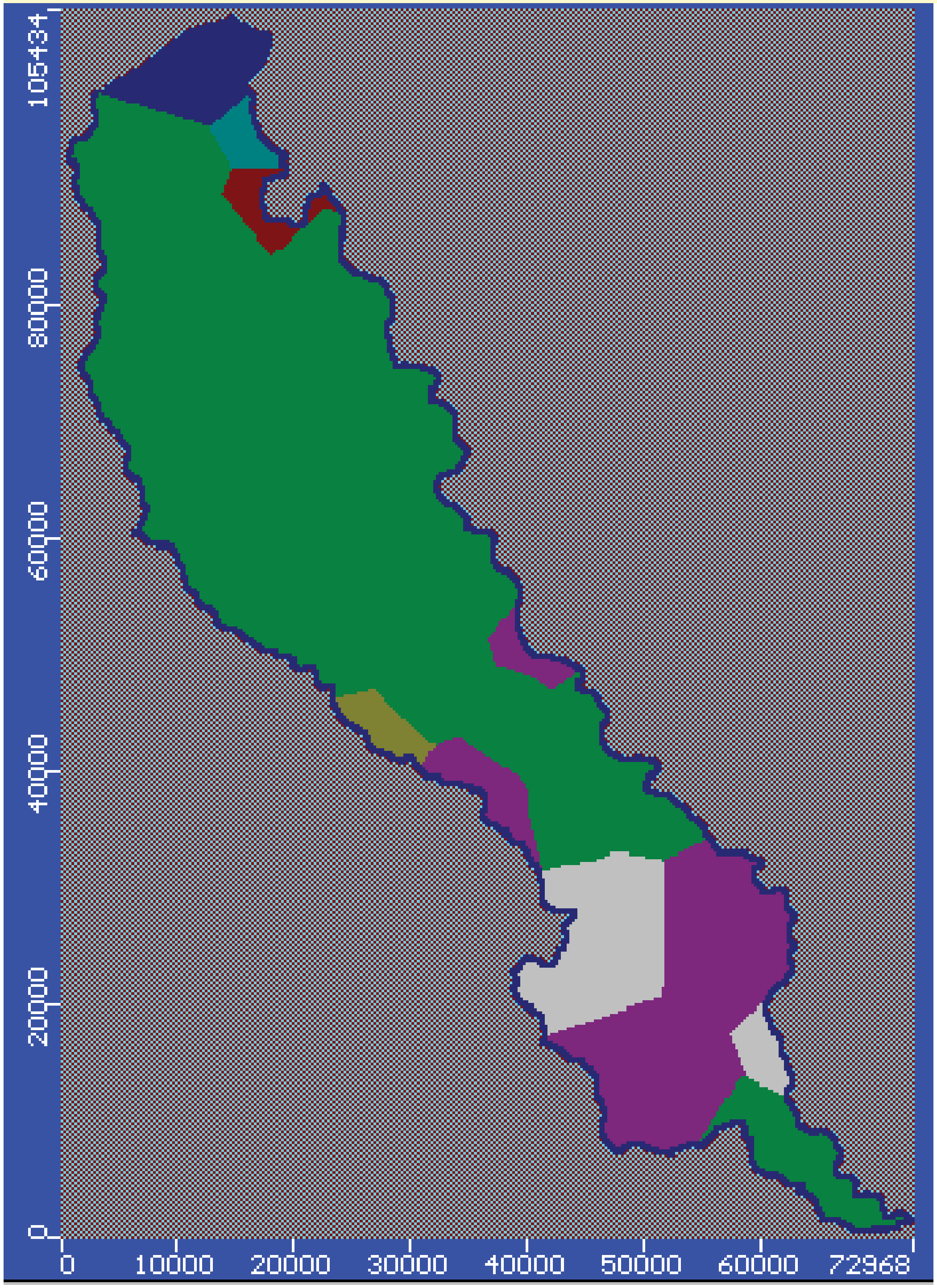
Visual MODFLOW 3.0.0

Database development

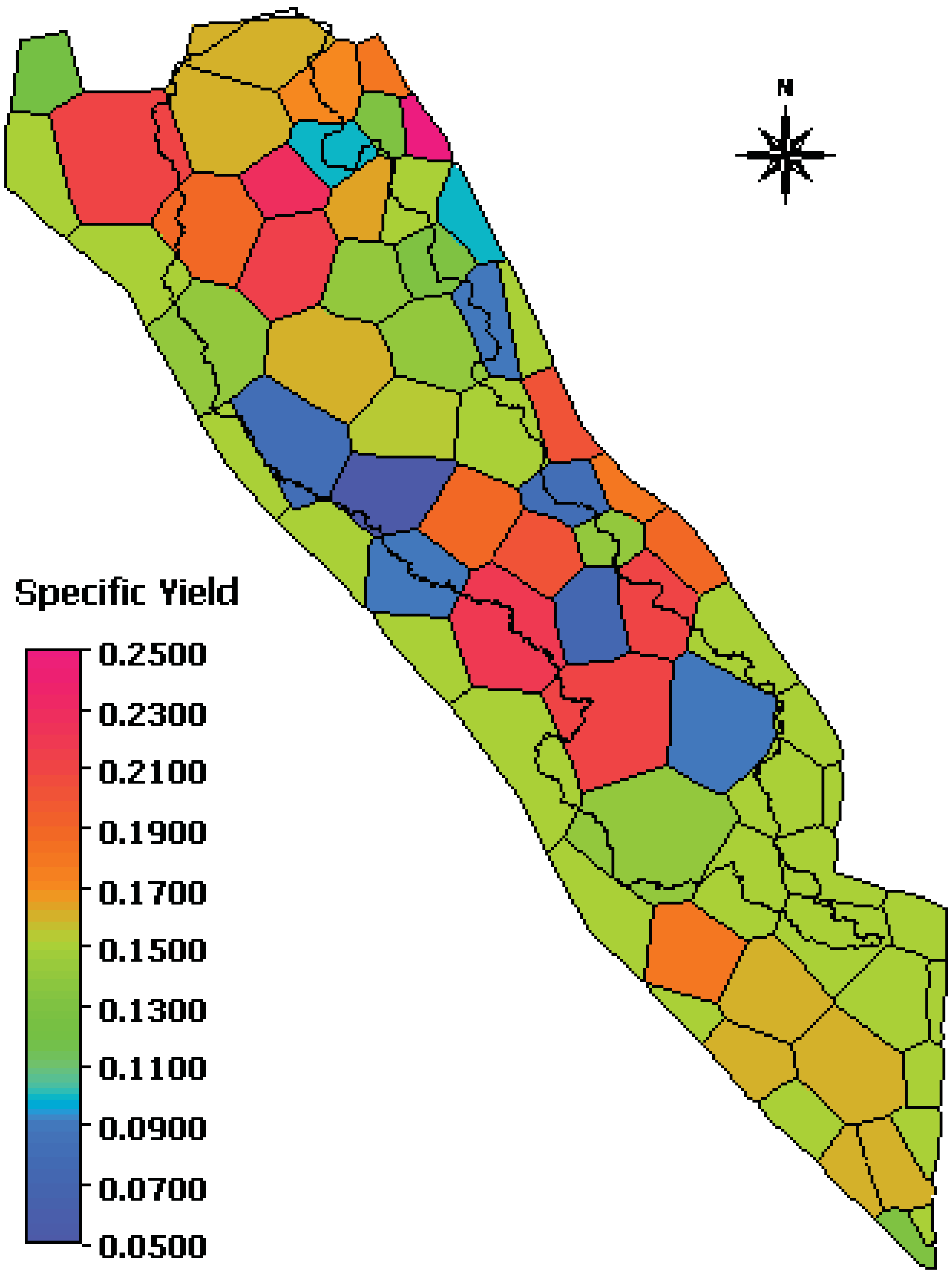
- Base Map of command – Imported from GIS
- Surface elevation map – Imported from GIS
- Initial GW surface – Imported from GIS
- Aquifer characteristics – Taken from study
- Distributed pumping/recharge - Calculated
- Boundary conditions (Rivers & Recharge)
  - Recharge calculated for MGC
  - River levels obtained from field



Base map in VMOD & Location of obs. wells



Initial conductivity map of command



Initial storage characteristic map of command

REFERENCE CROP EVAPO-TRANSPIRATION

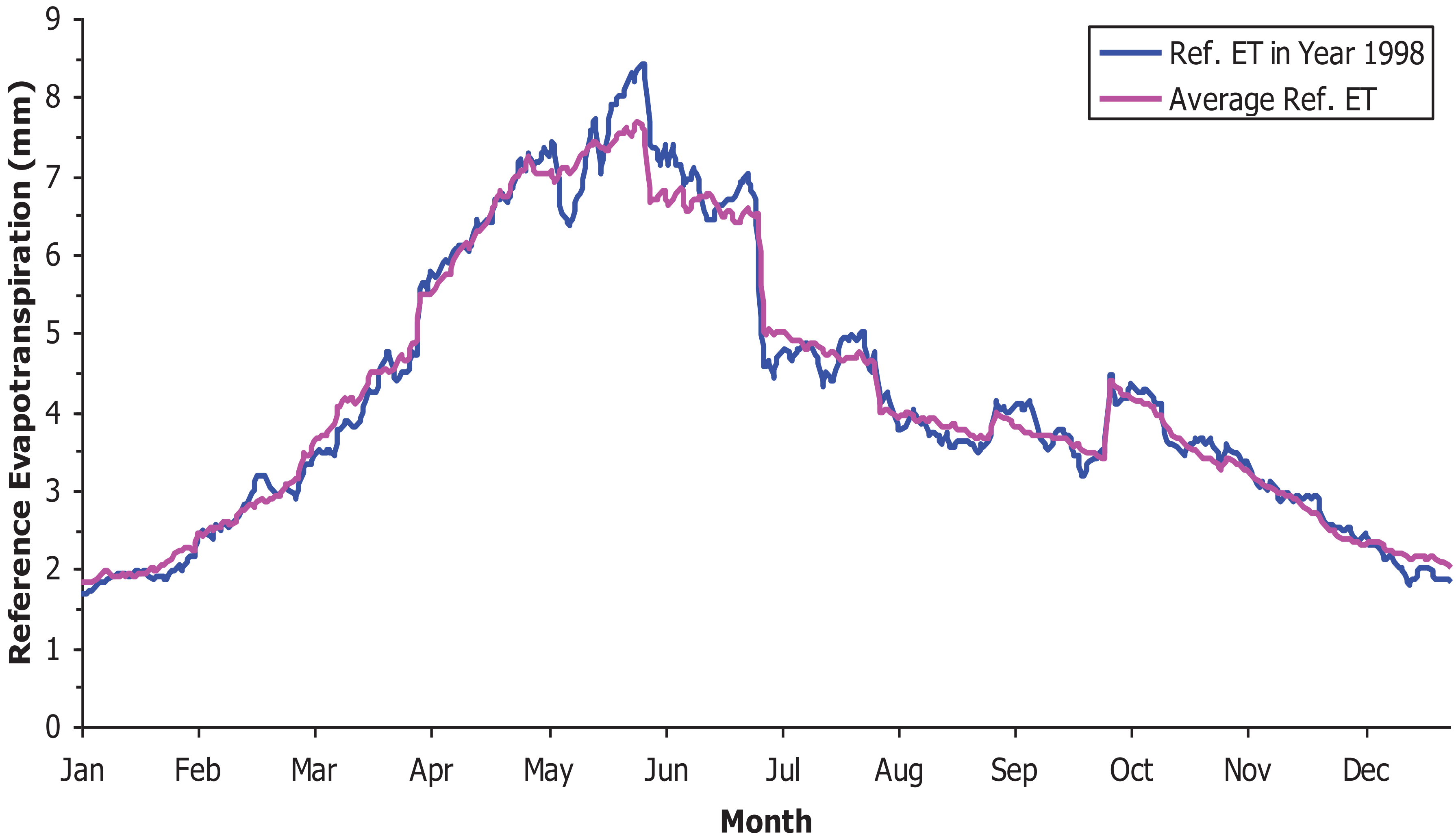
Purpose

To find actual crop ET & irrigation demand

Data & method used

- Daily Max. - Min. temperature data of Bulandshahr
- Daily Max. - Min. relative humidity data of Bulandshahr
- Monthly wind velocity data of command
- Used FAO recommended Penman-Monteith Method

REFERENCE CROP EVAPO-TRANSPIRATION



DATABASE CONTENTS

Finally, the database contains:

Spatial Data:

- Crop map
- Soil map
- Rainfall map
- Digital elevation map
- Groundwater depth map
- Canal network & canal-irrigable areas
- Aquifer characteristics

Attribute Data:

- Actual rainfall
- Reference crop evapo-transpiration
- Crop, soil, and canal system characteristics

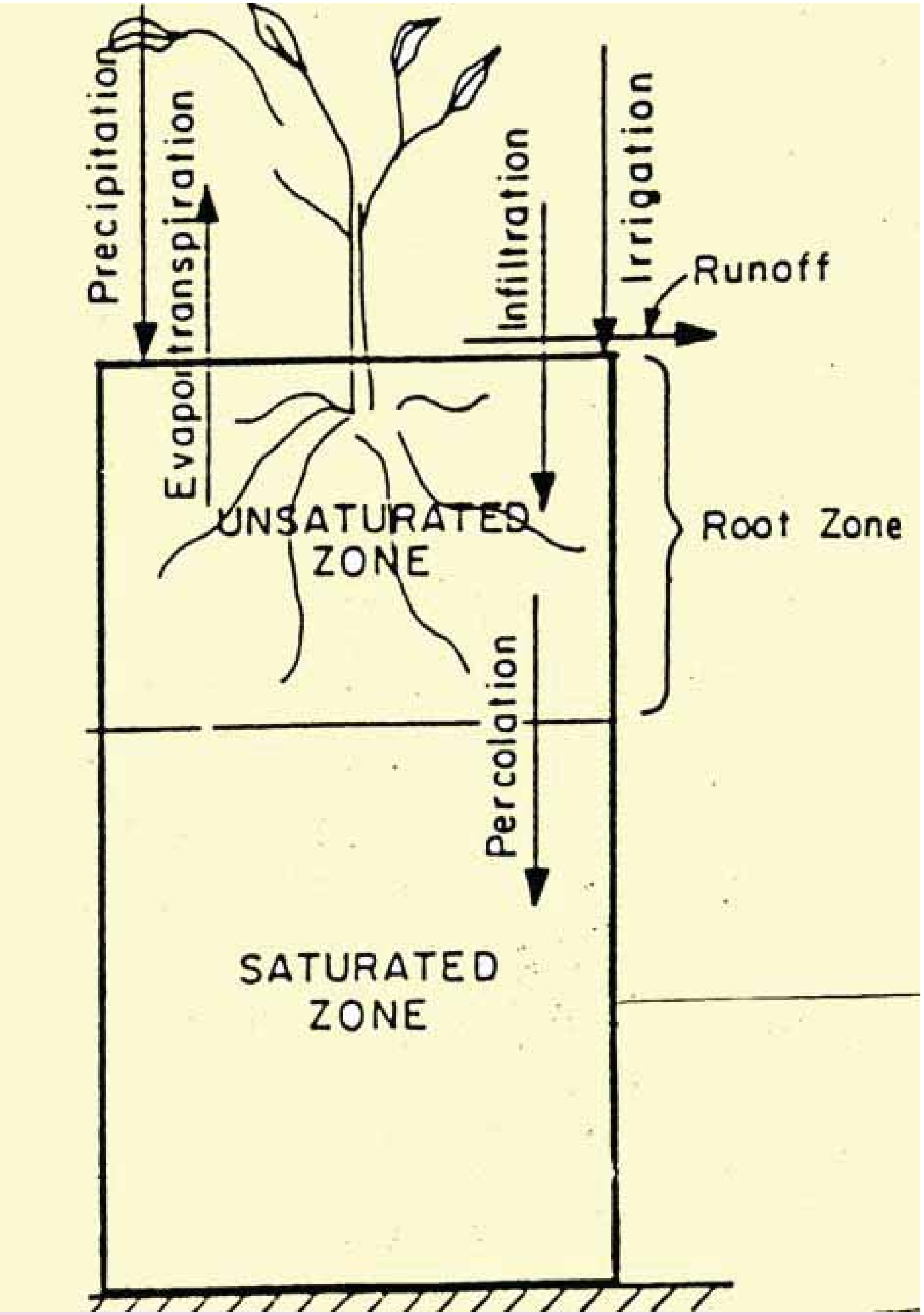
Soil Water Balance Model (SWBM)

OBJECTIVE

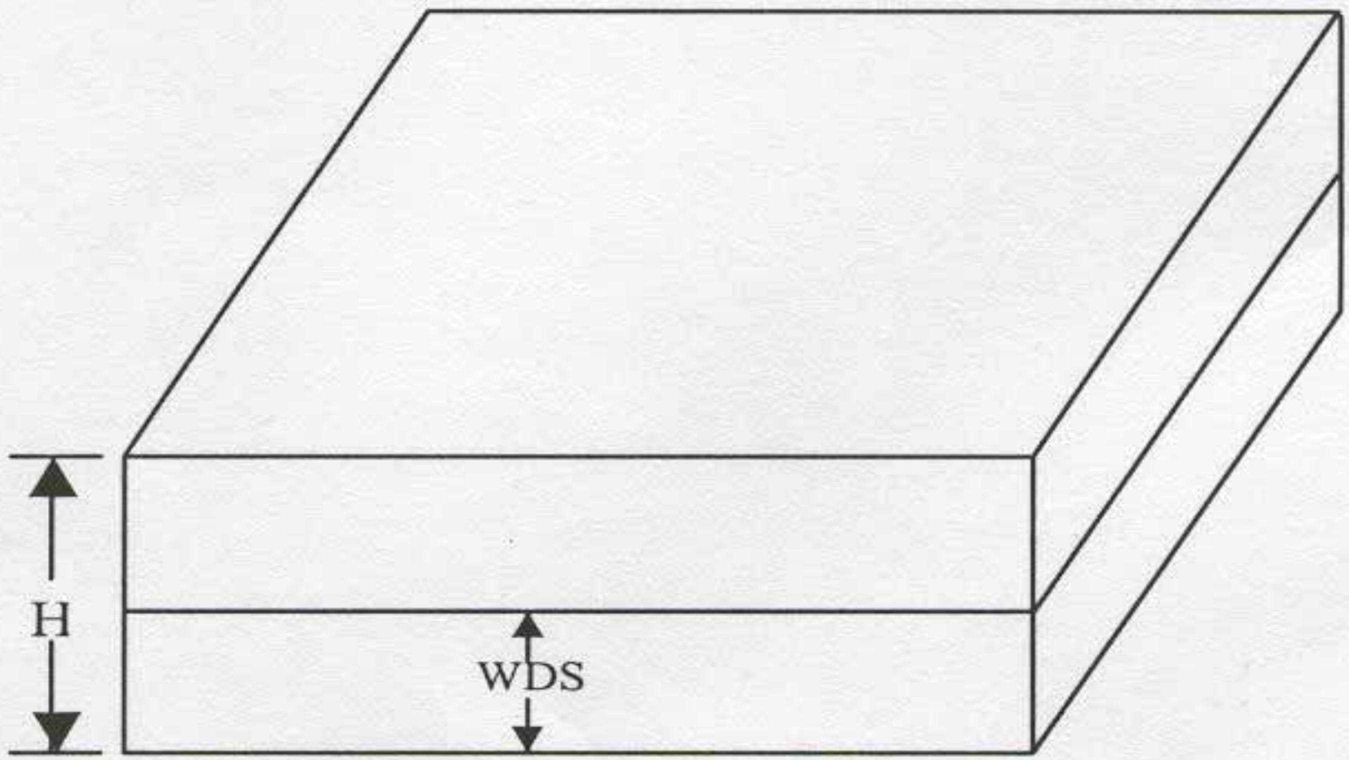
To simulate moisture variation in root zone for:

- Finding irrigation demands in a week
- Finding final water content at the end of week
- Finding stress conditions in the command
- Finding spatial GW recharge in the command

Components of Water Balance in the Root Zone

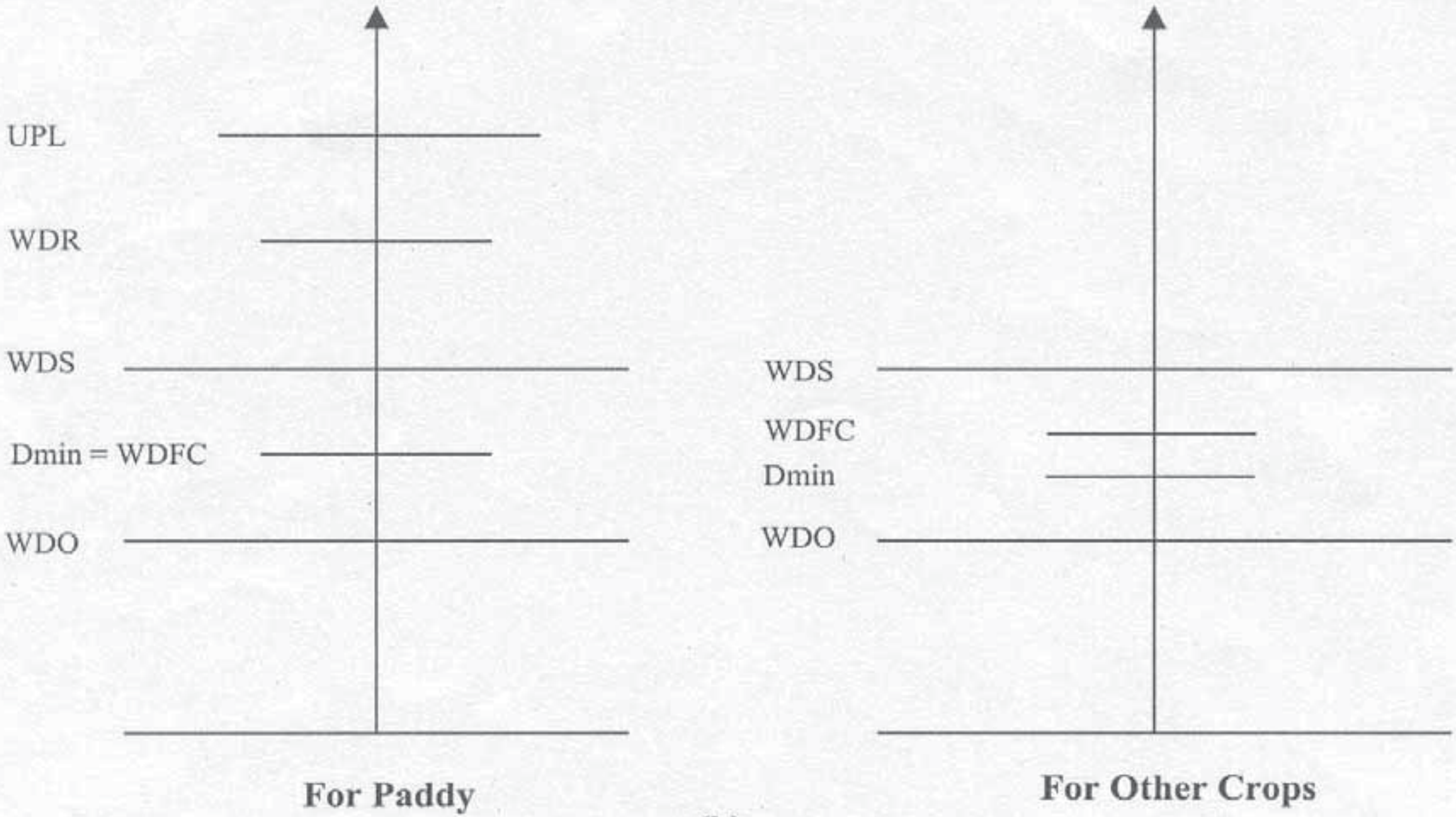


SOIL RESERVOIR



(a)

DEFINITION SKETCH FOR DIFFERENT WATER DEPTHS



(b)

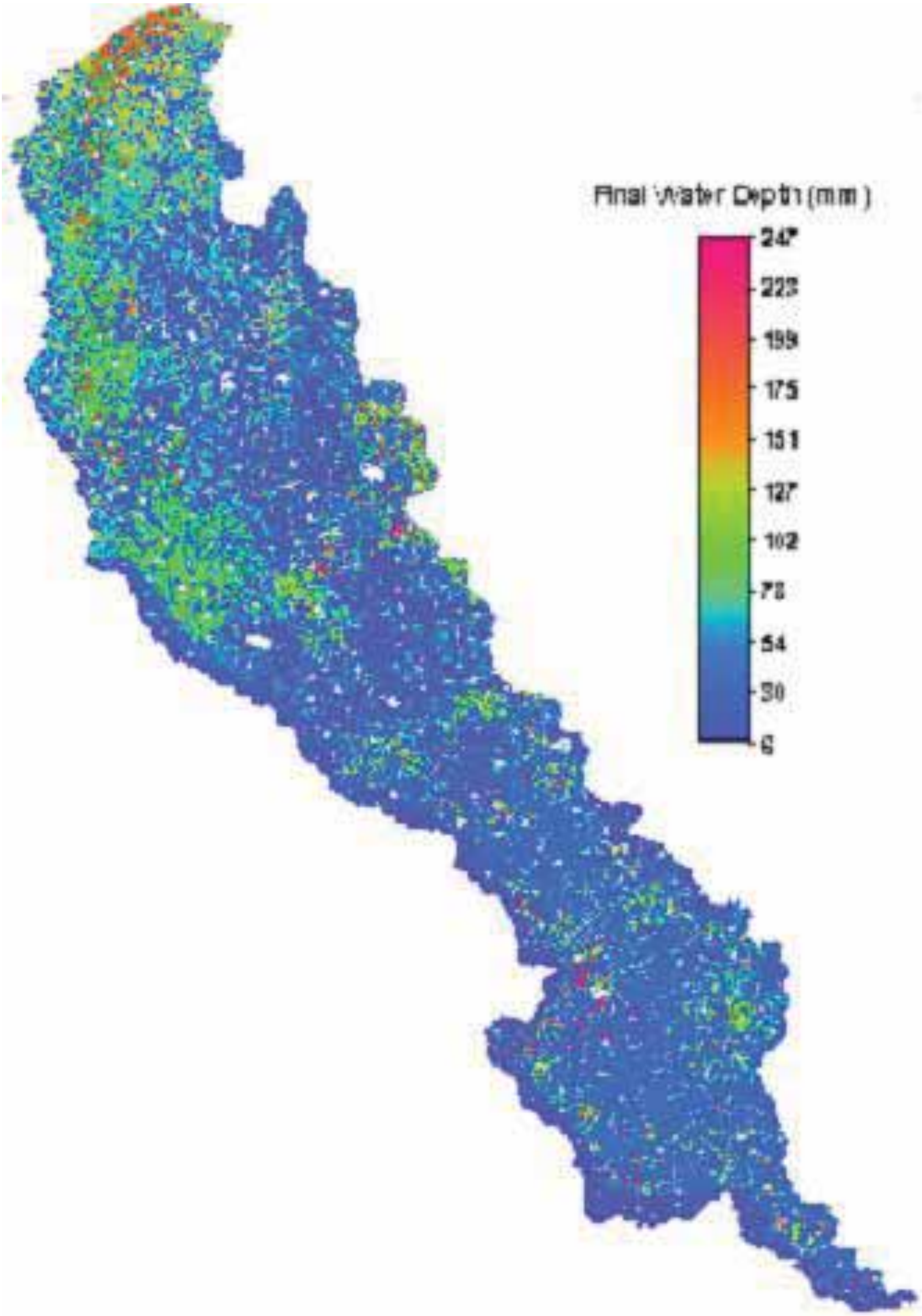
Input Data

- **Spatial Data** - crop, soil, Thiessen polygon, DEM, flow direction, GW depth, initial soil moisture, irrigation application
- **Attribute Data**
  - **Crop** - max. root depth, time of max. root, fraction of available water without stress, water for land preparation, time of land preparation, starting week and total weeks of crop, standing water depth, bund height, weekly crop coefficients
  - **Soil** - specific gravity, porosity, field capacity, permanent wilting point, capillary height, and hydraulic conductivity
- **Temporal Data** – rainfall, reference evapo-transpiration, initial moisture content, irrigation supply

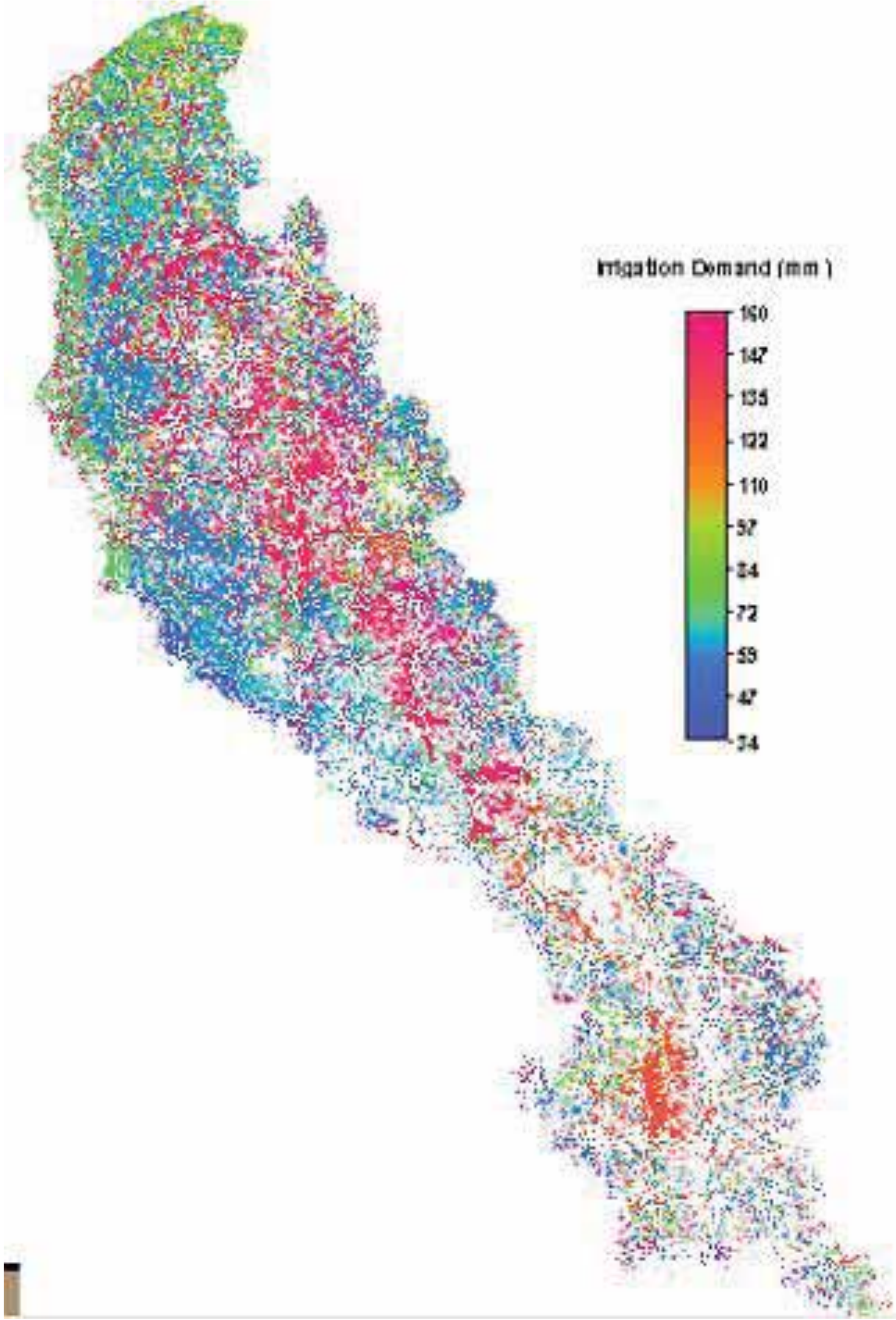
Model Output

Grid-wise information on:

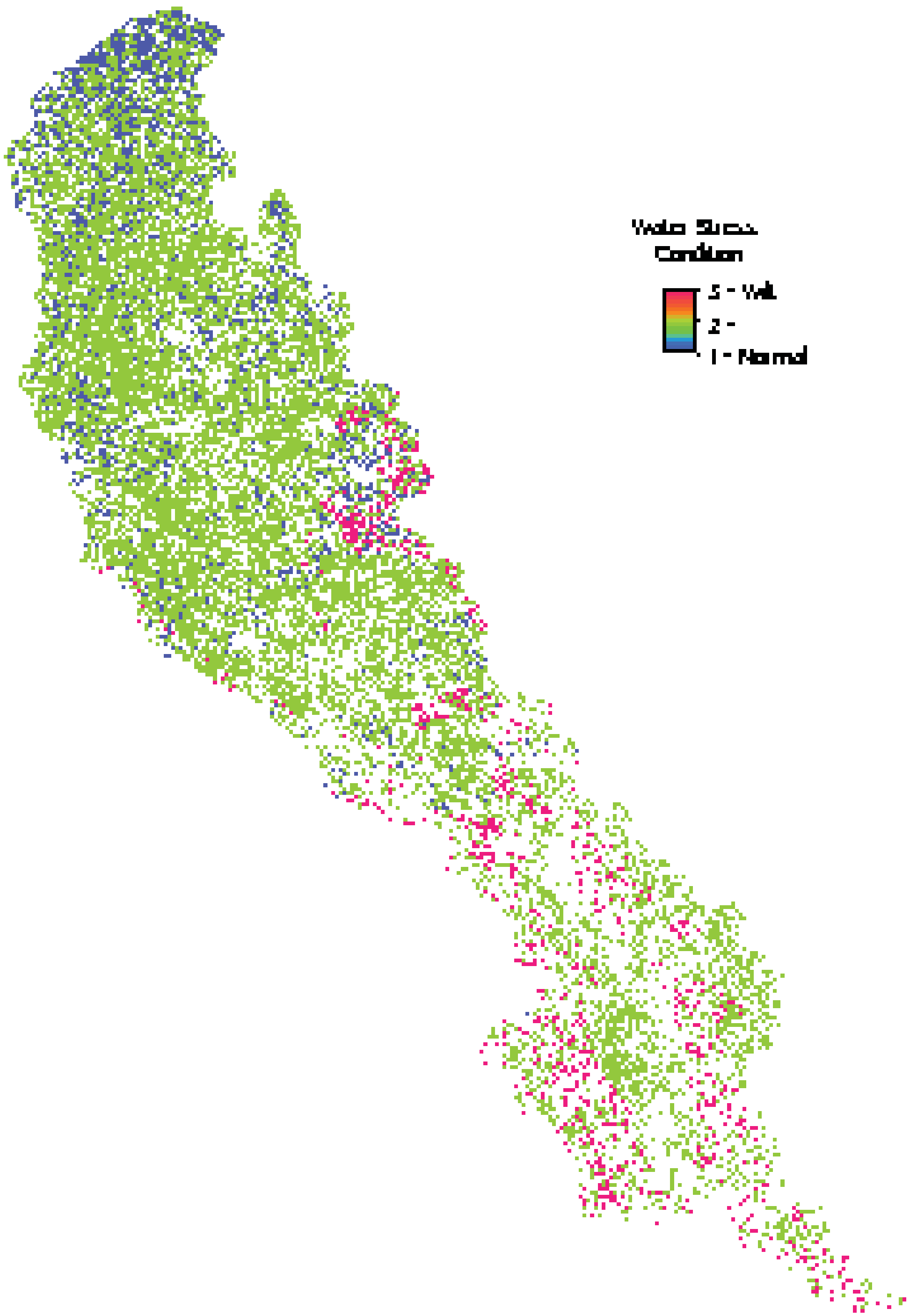
- Final water depth at the end of week
- Supplementary irrigation demand
- Stress condition
- Deep percolation



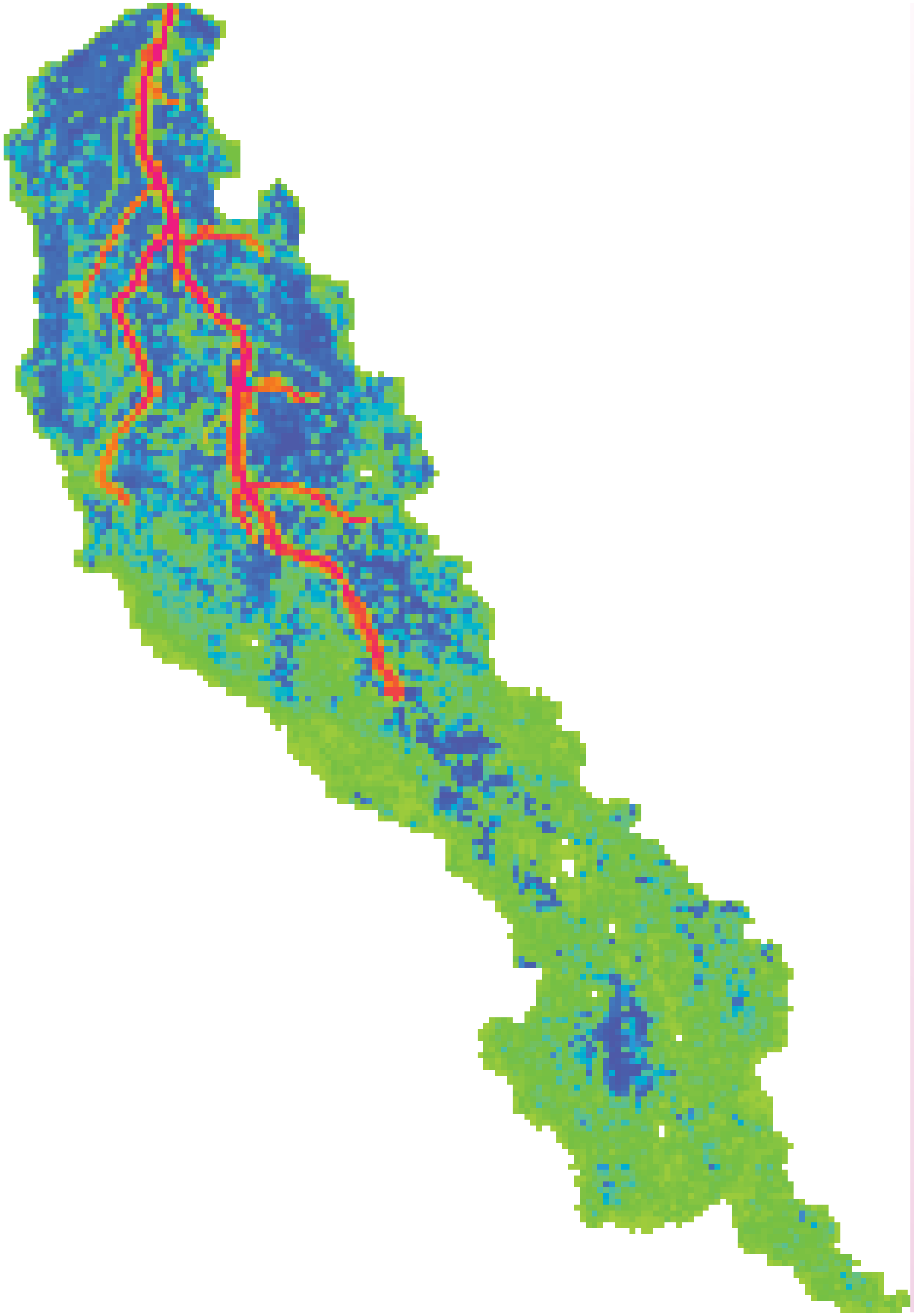
Final Water Depth in Command at End of Week 30



Irrigation Demands in Command



Stress Conditions in the Command



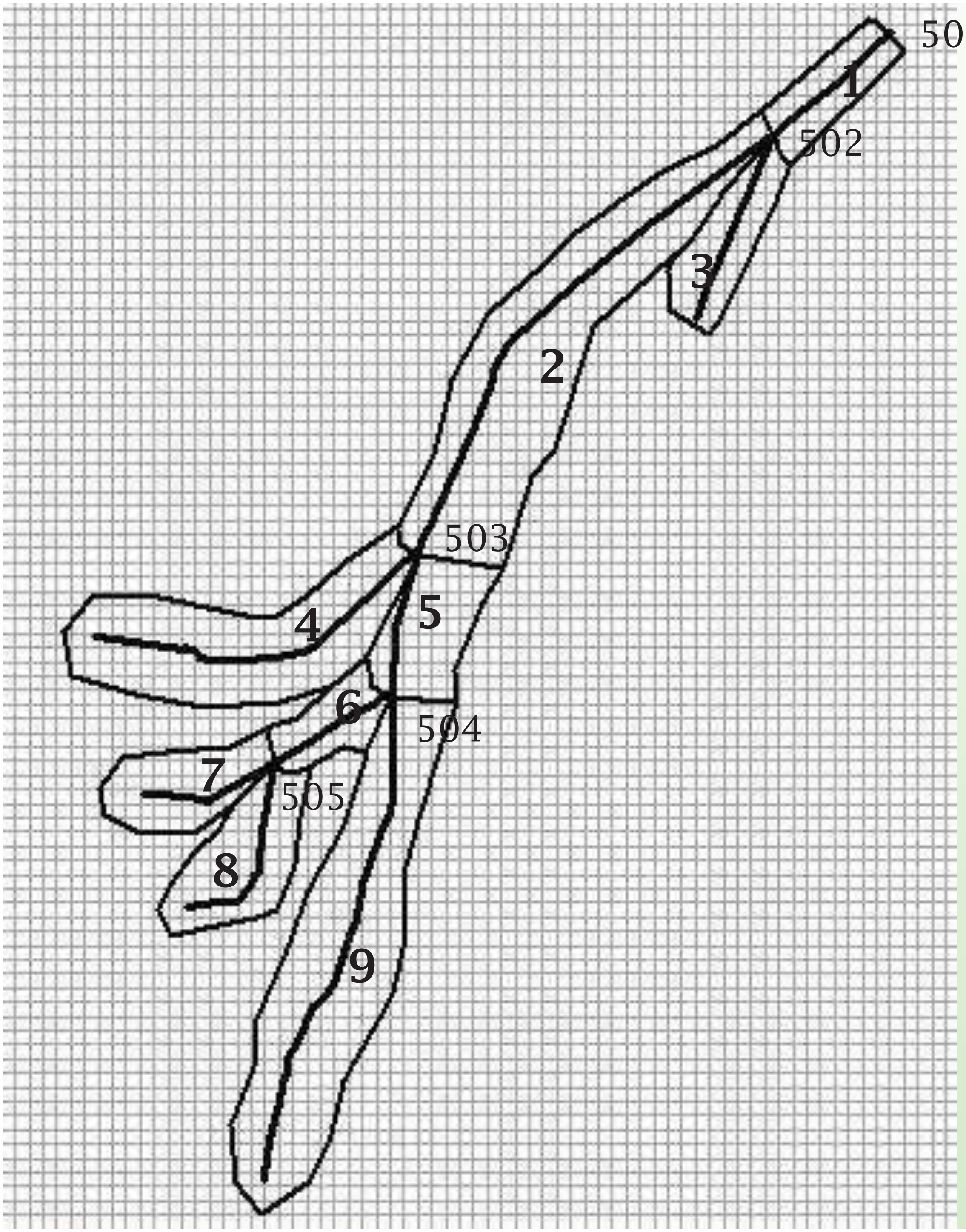
Deep Percolation in the Command

CANAL NETWORK SIMULATION MODEL (CNSM)

OBJECTIVE

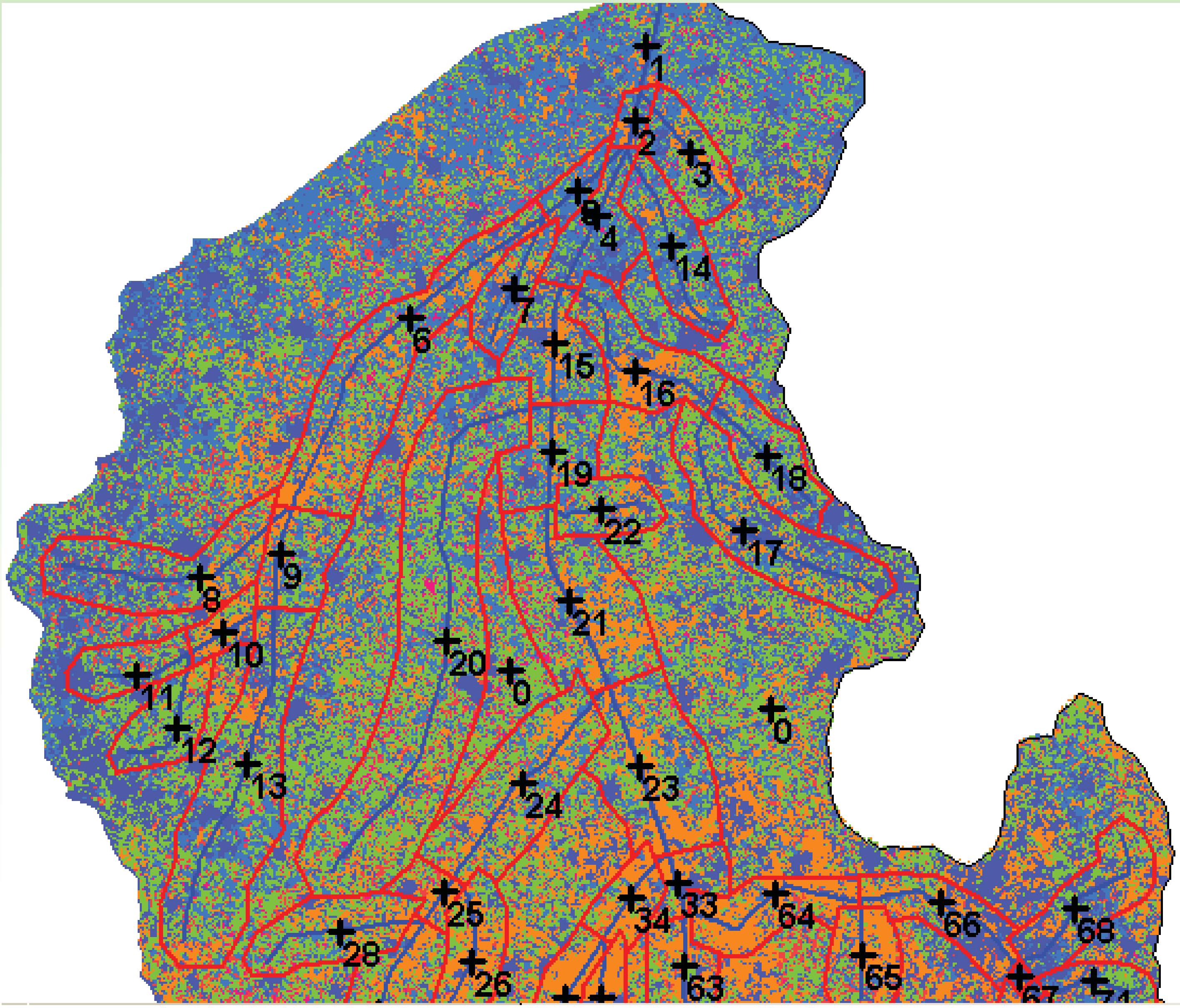
To simulate weekly operation of a canal network governed by:

- Distributed irrigation demands
- Availability of canal water at head
- Prevailing groundwater conditions



Identification of Different Nodes & Segments in a Canal Network

REPRESENTATION OF CANAL NETWORK



Input Data

- **Spatial Data** - crop, irrigation demands, irrigable command areas, and GW depth
- **Attribute Data of Canal System**

  For each segment:

  name and identification number, discharge capacity, length, bed width, water depth, side slope, irrigable area, conveyance η, application η, field channel η, seepage rate, seepage calculation procedure (1–conveyance η , 2–specified formula, 3–seepage rate), priority of segment, number of tube wells operating in irrigable command, average power of pumping sets, number of hours of power supply

Different Policies of Canal Operation

If demand > supply, there is need to operate the system with some specified operation policy.

Five policies specified in model are:

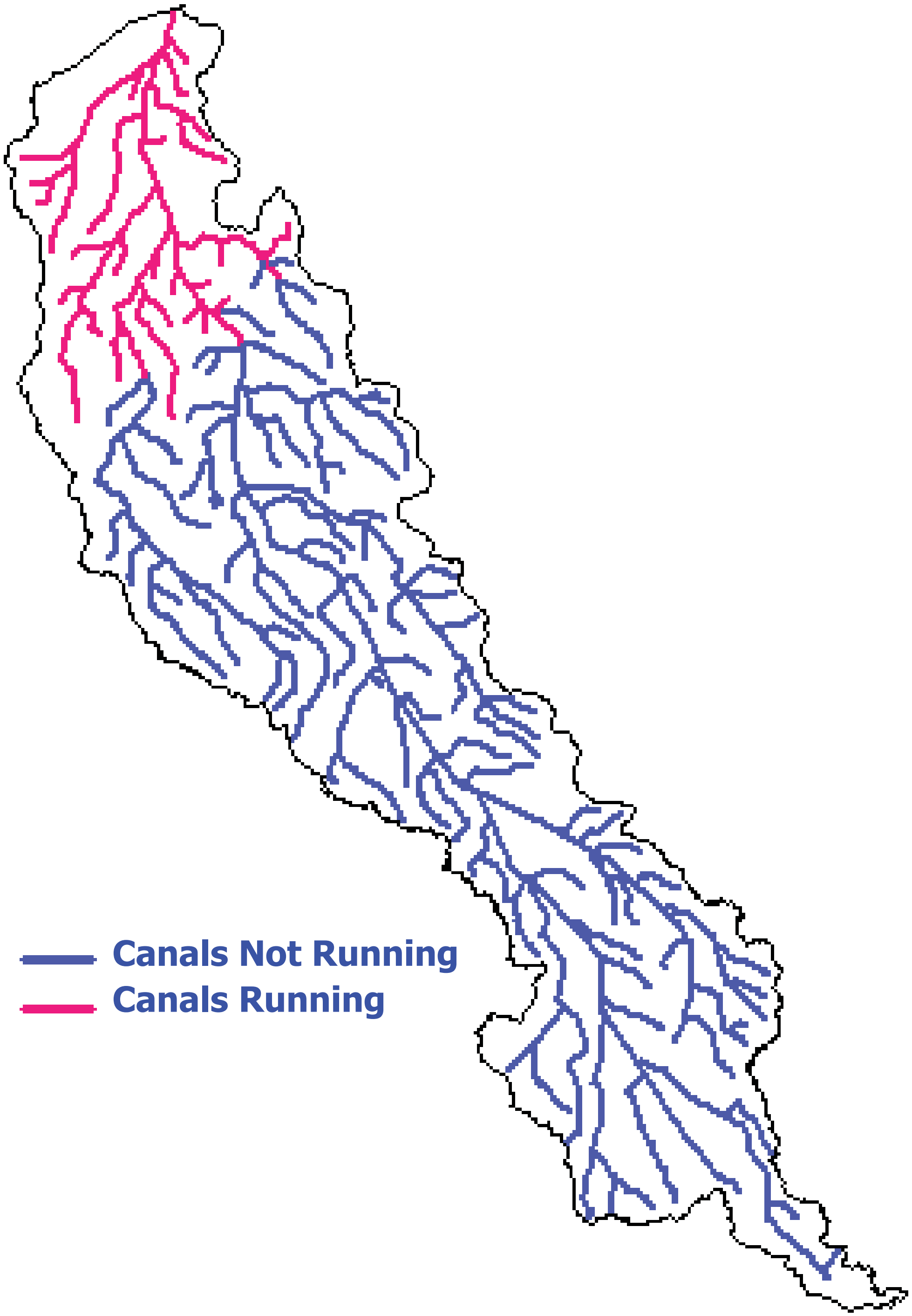
a) Policy – 1: Head-reach priority

b) Policy – 2: Conjunctive use

c) Policy – 3: Proportionate supply

d) Policy – 4: Tail-reach priority

e) Policy – 5: Conjunctive use with minimum energy demand for pumping GW

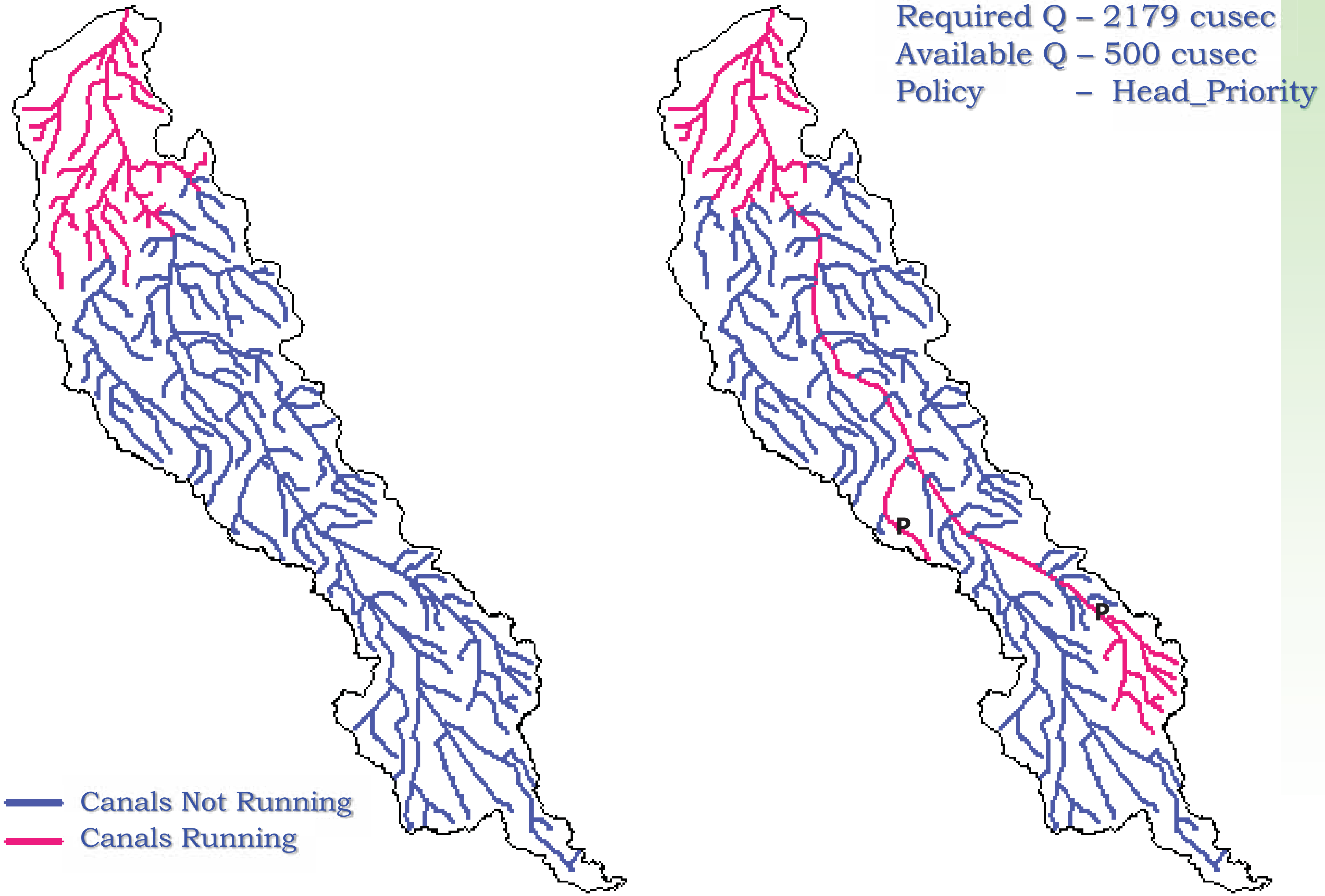


Results of Canal Operation with Policy of Head_Priority

Required Q – 2179 cusec
Available Q – 500 cusec

Effect of Prioritization

Required Q – 2179 cusec
Available Q – 500 cusec
Policy – Head_Priority

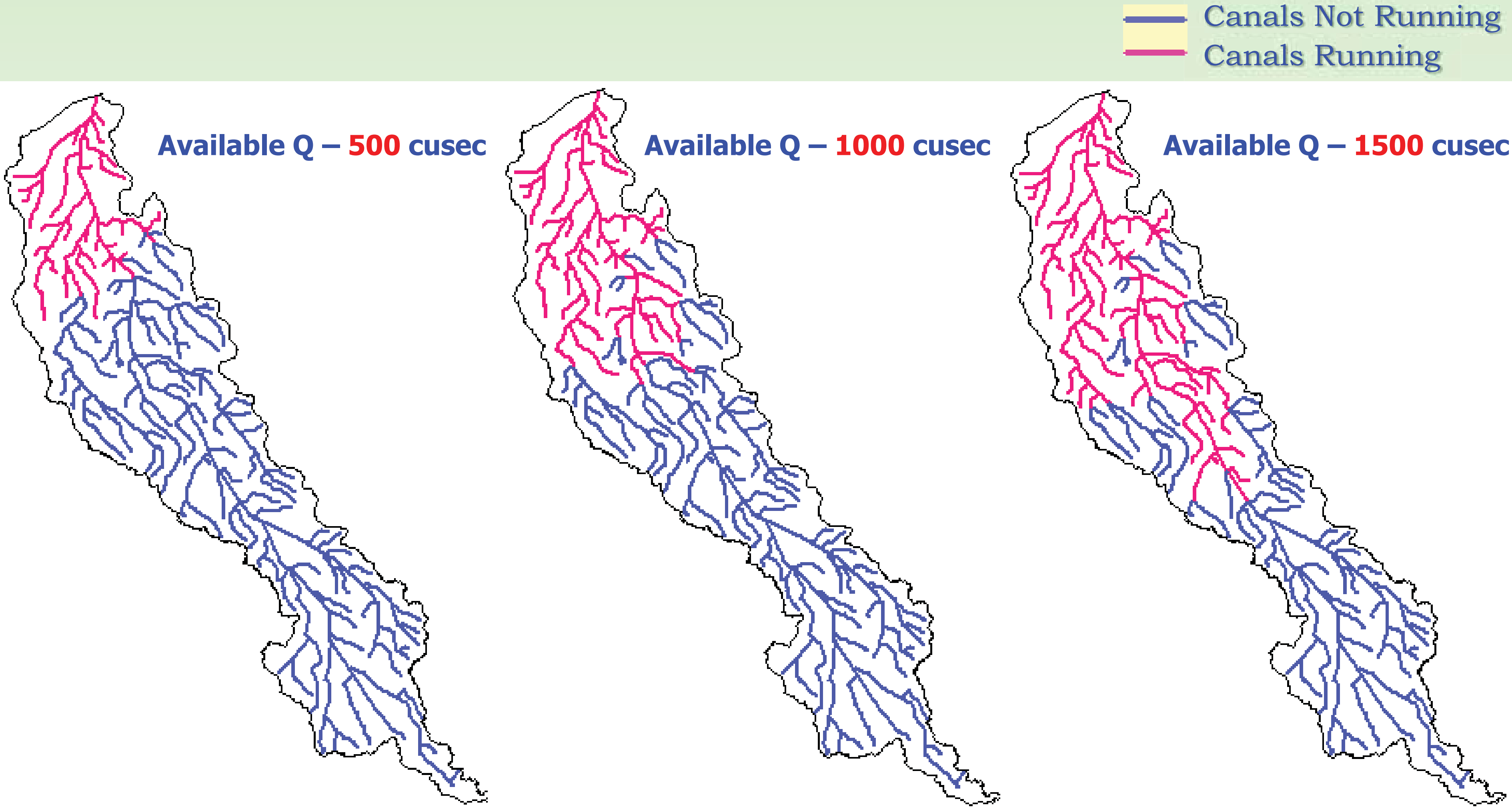


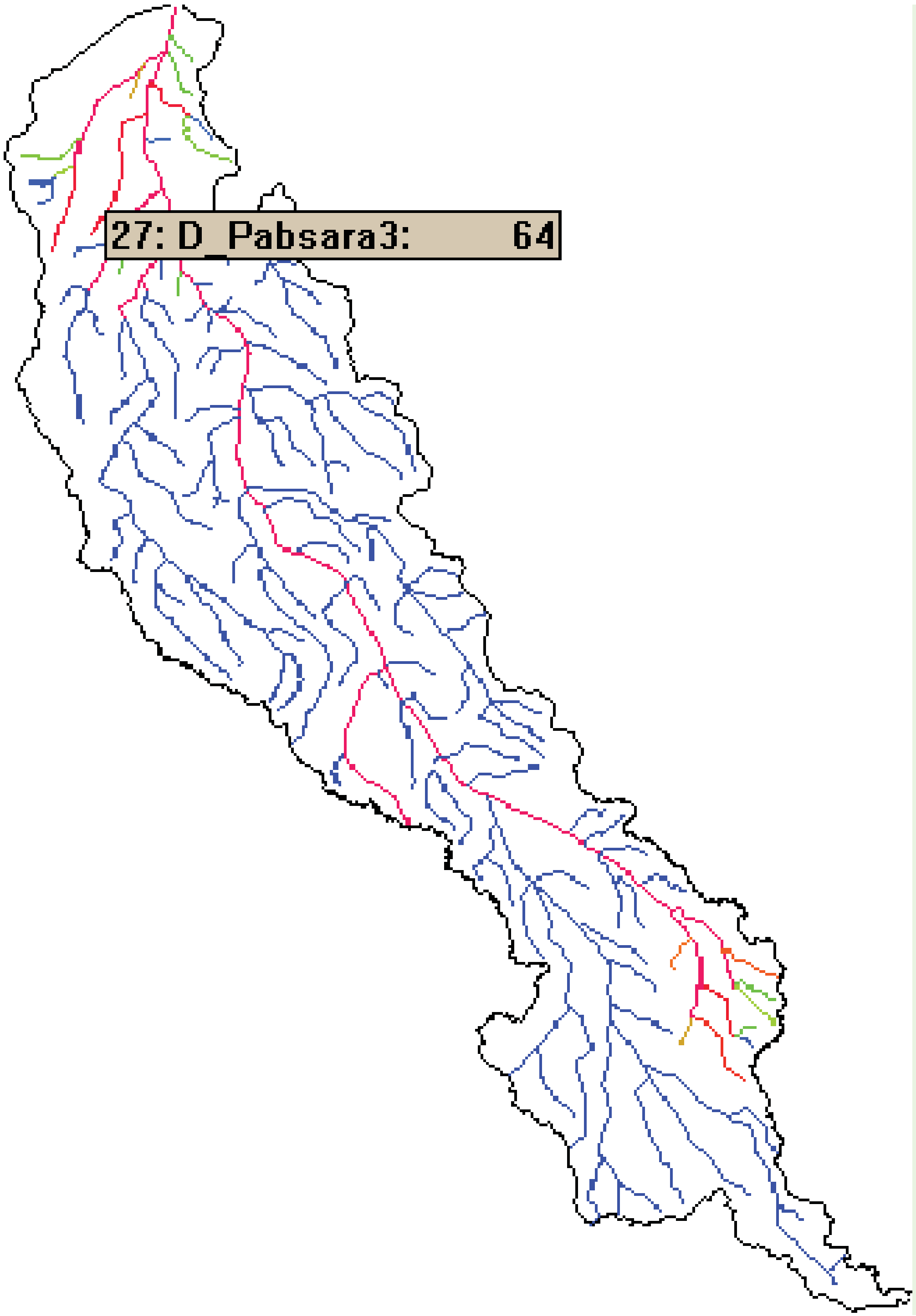
Concept of Prioritization

Various causes of assigning high priority:

- Socio/political constraints
- Crops under a segment are in “Stress”.
- Groundwater potential in a segment is not sufficient to meet its demands

Results of Head_Priority Policy with Different Available Discharges



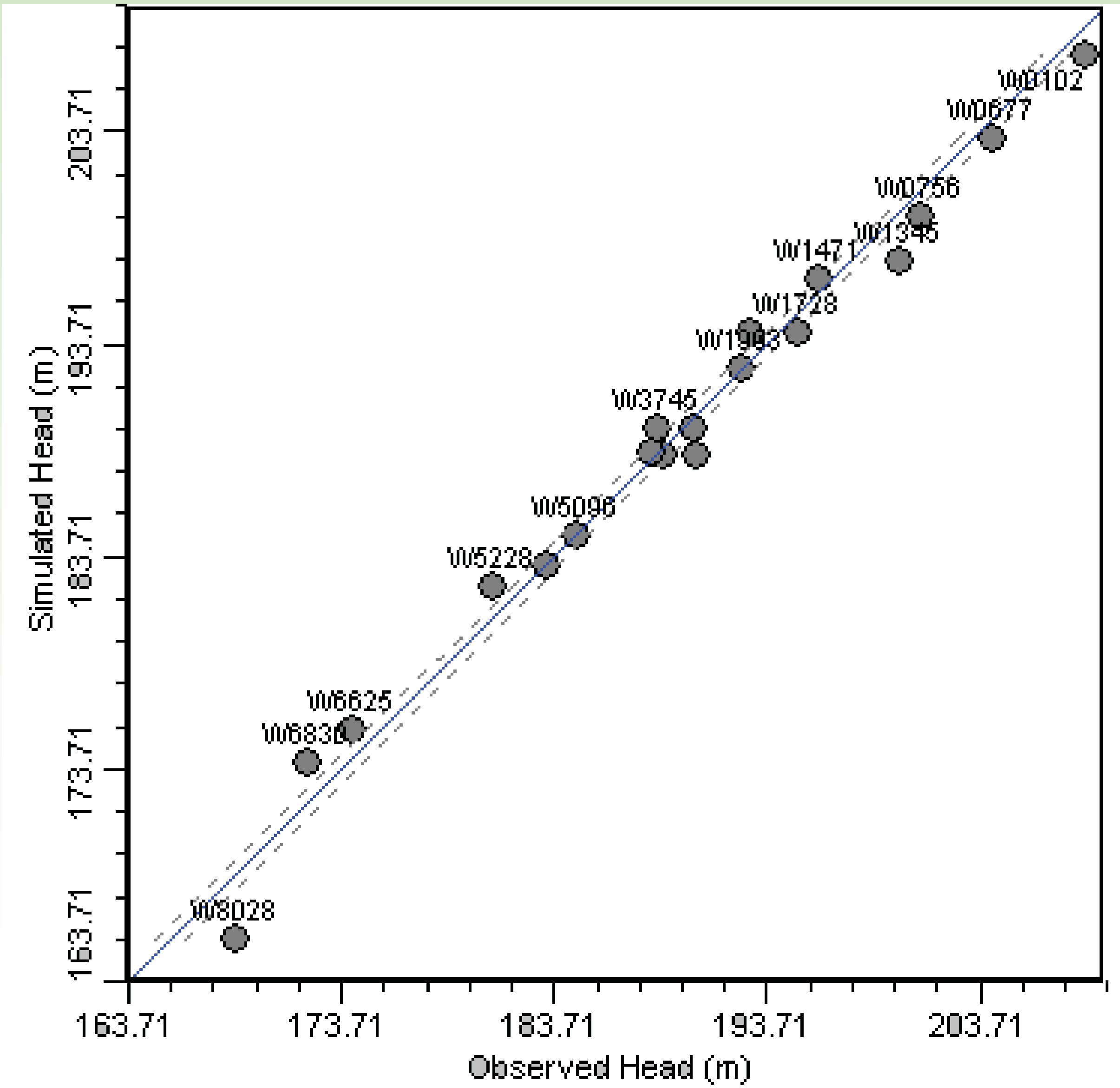


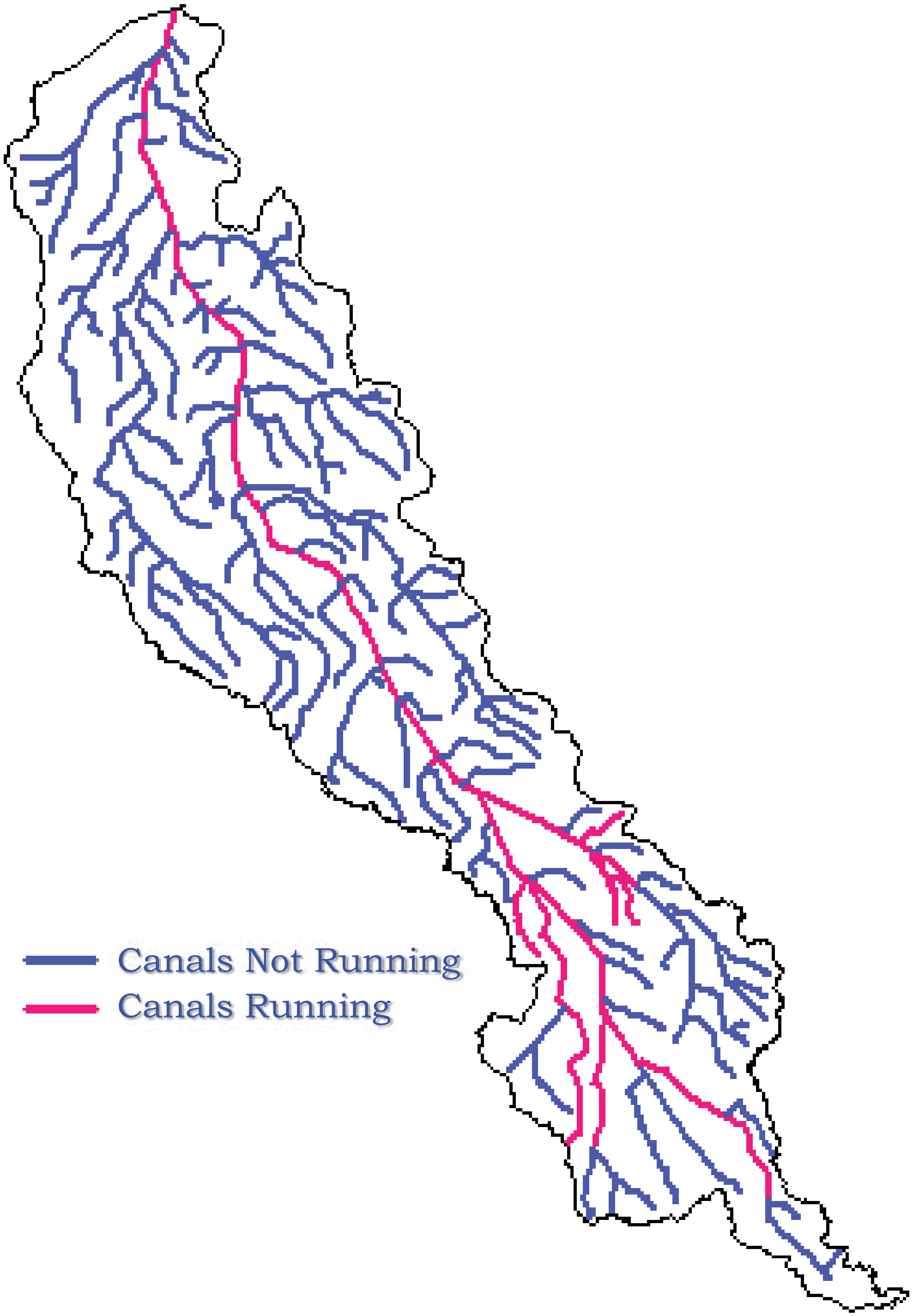
Representation of Results on the Map

Model Calibration

- Data for one year was used for model performance analysis
- To analyze different canal operation policies, hypothetical scarcity conditions were assumed
    - Rainfall reduced to 60% of actual values
    - Canal supply assumed to be 75% of planned
- The system was run from June 18 to October 14

Results of Calibration

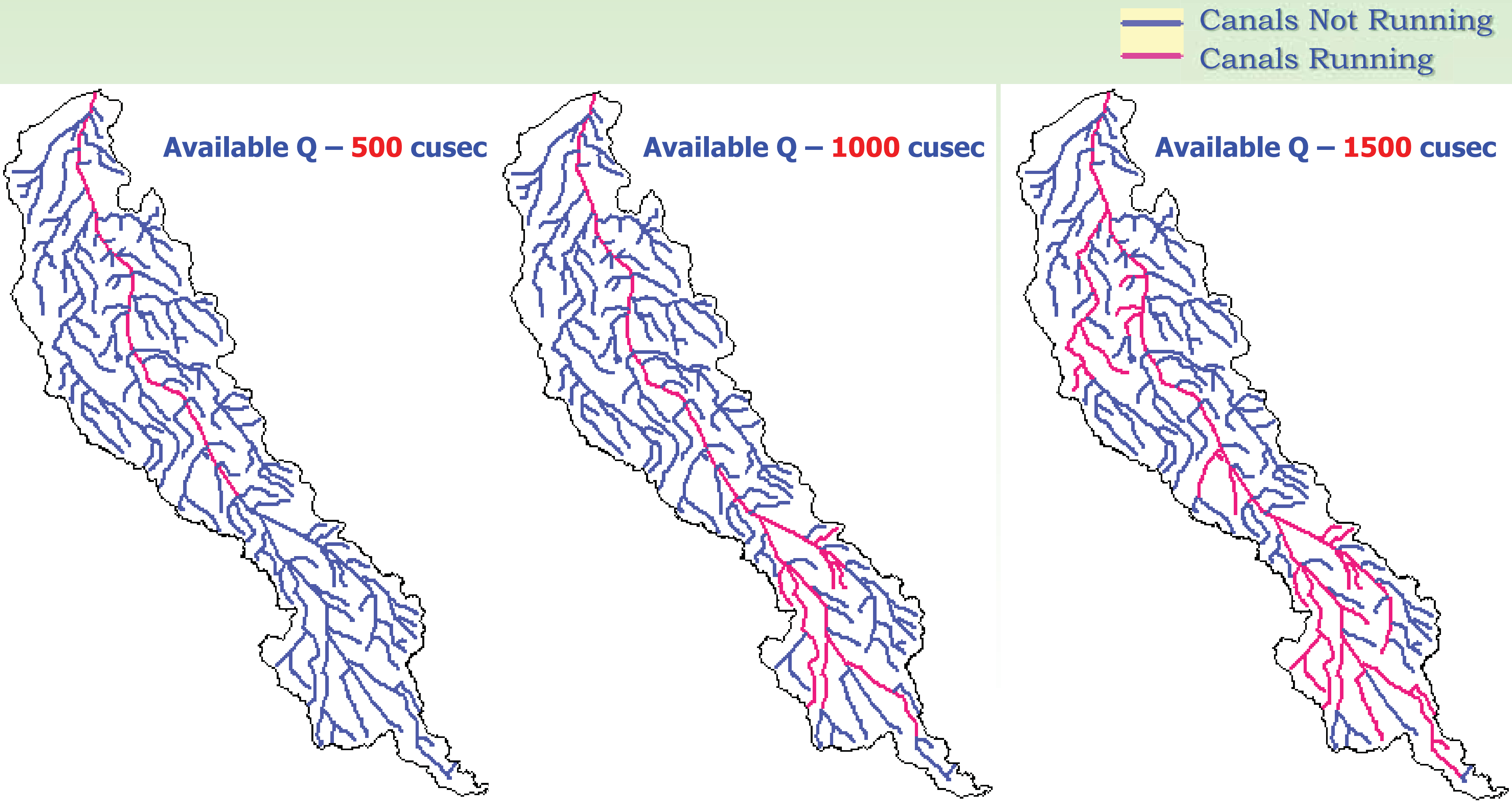


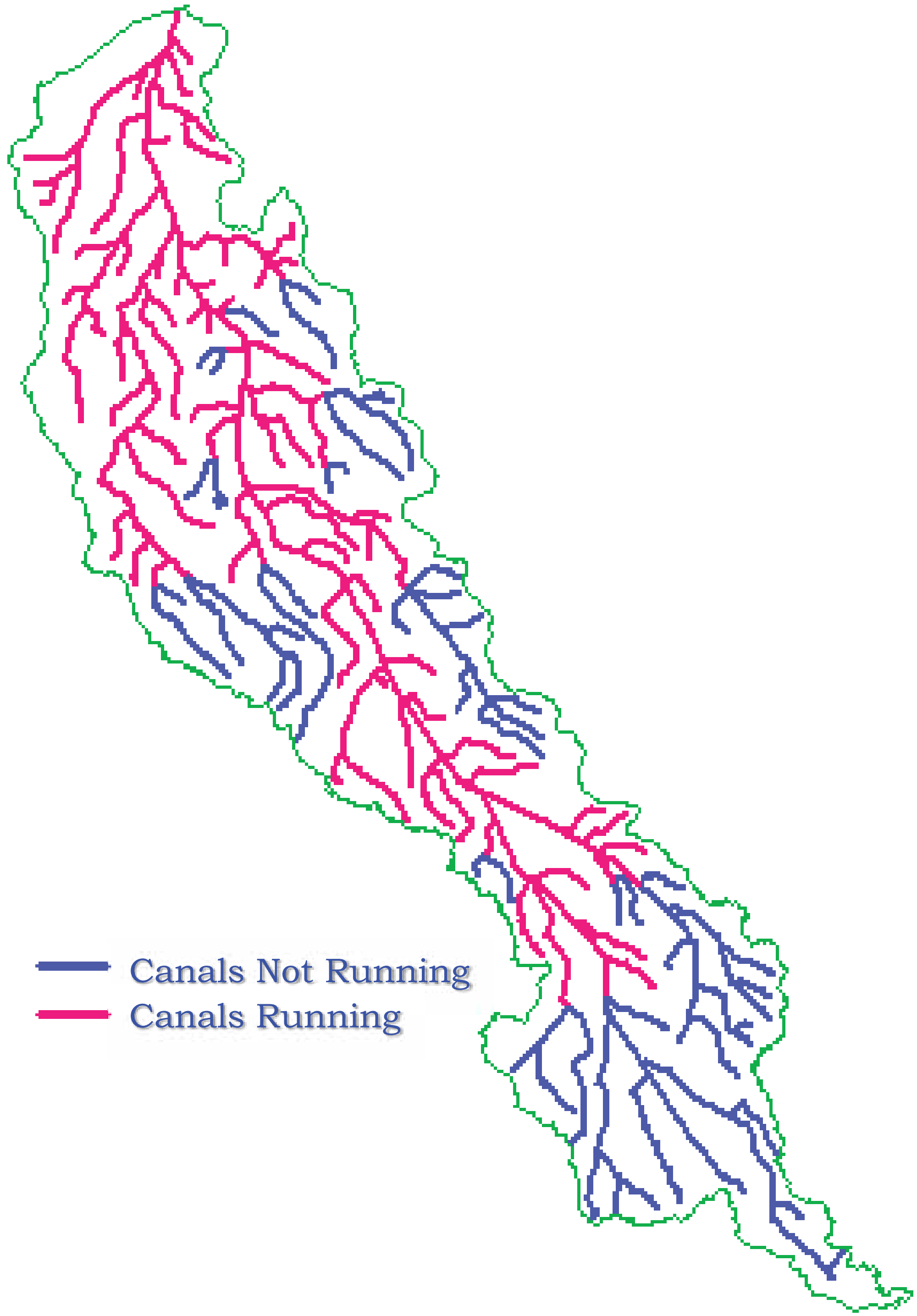


Results of Canal Operation with Policy of Conjunctive Use

Required Q – 2179 cusec
Available Q – 1000 cusec

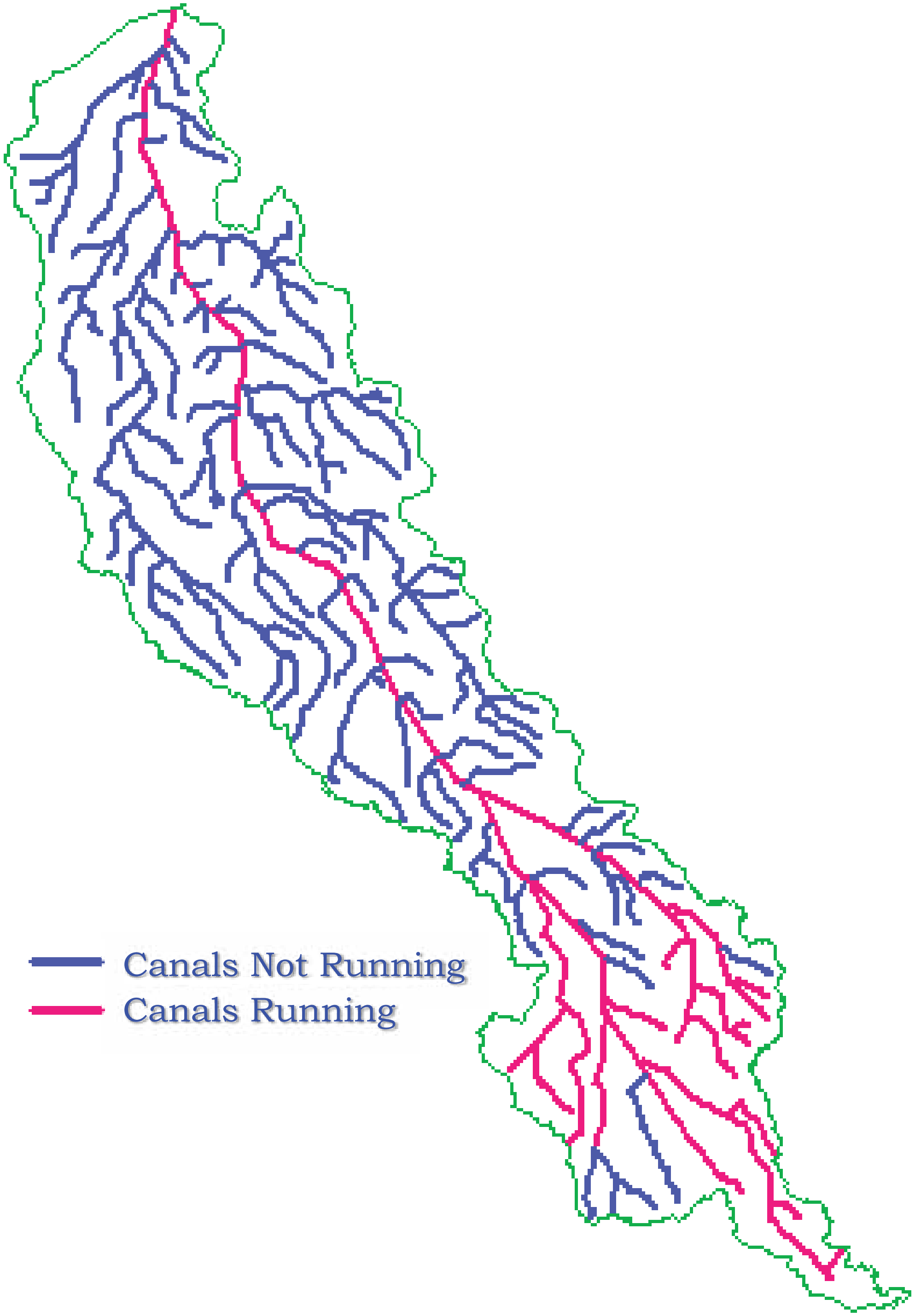
Results of Conj. Use Policy with Different Available Discharges





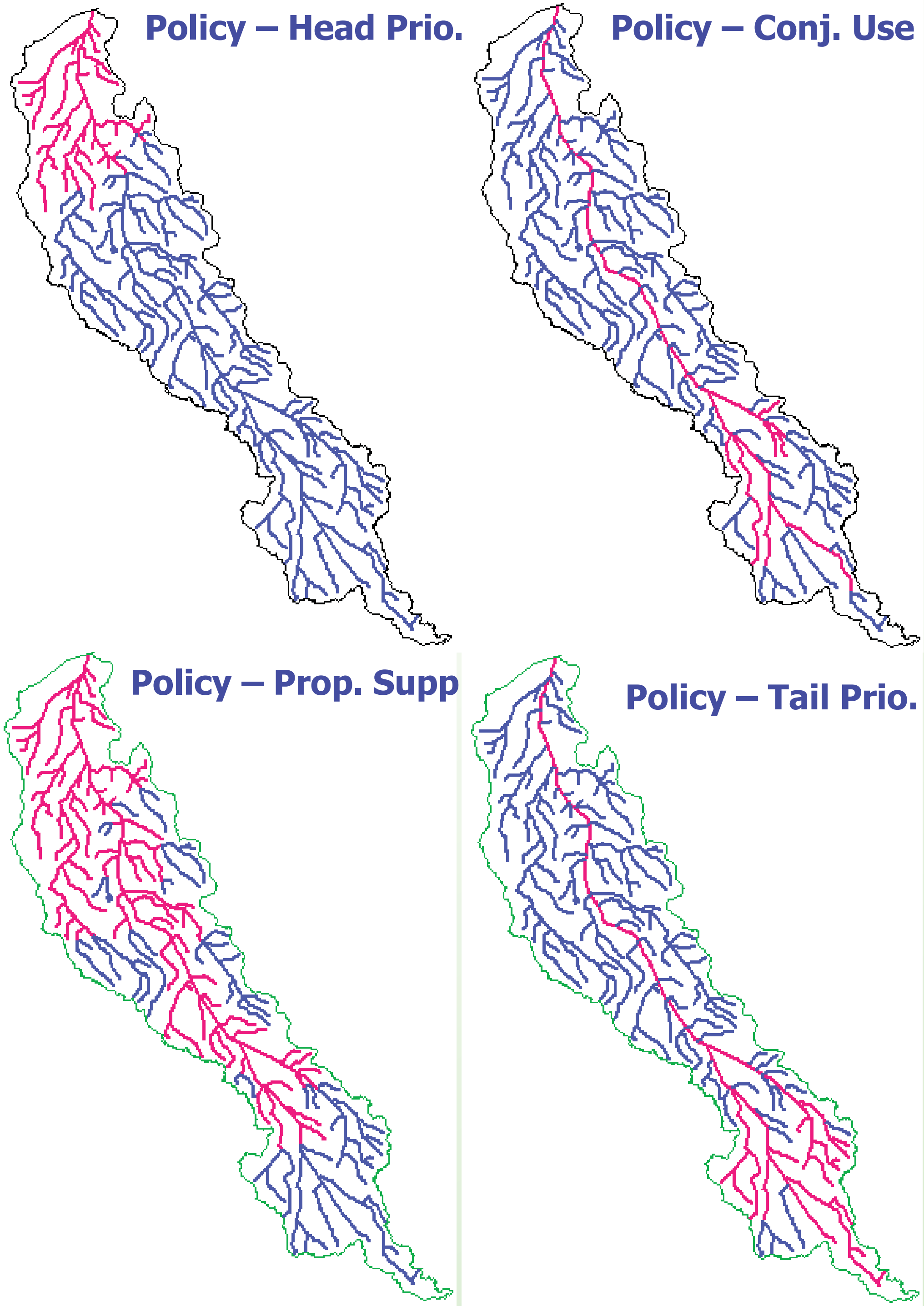
Results of Canal Operation with Policy of Prop_Sup

Required Q – 2179 cusec
Available Q – 500 cusec



Results of Canal Operation with Policy of Tail_Reach Priority

Required Q – 2179 cusec
Available Q – 500 cusec



Comparison of Different Operation Policies

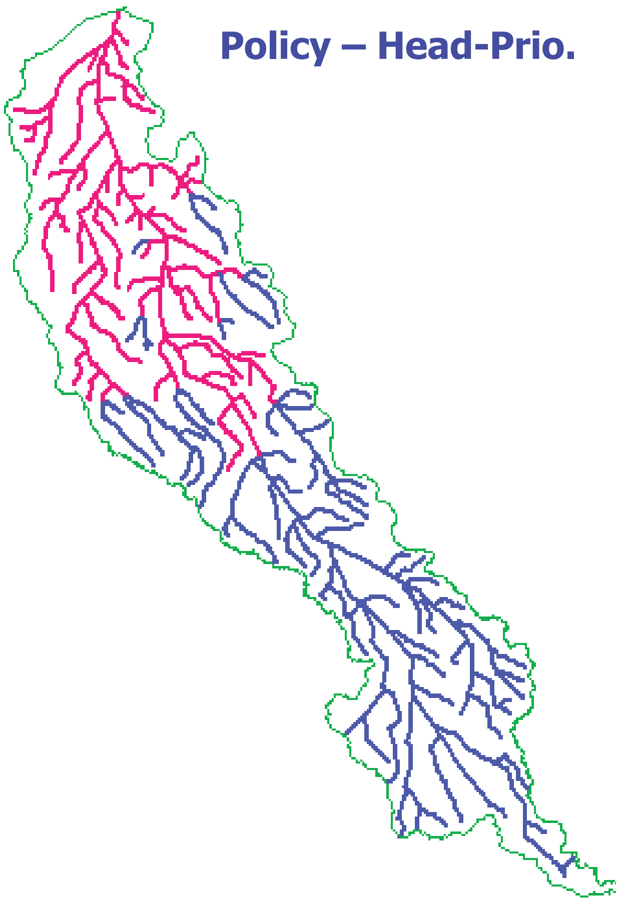
Canals Not Running
Canals Running

Results of Different Operation Policies

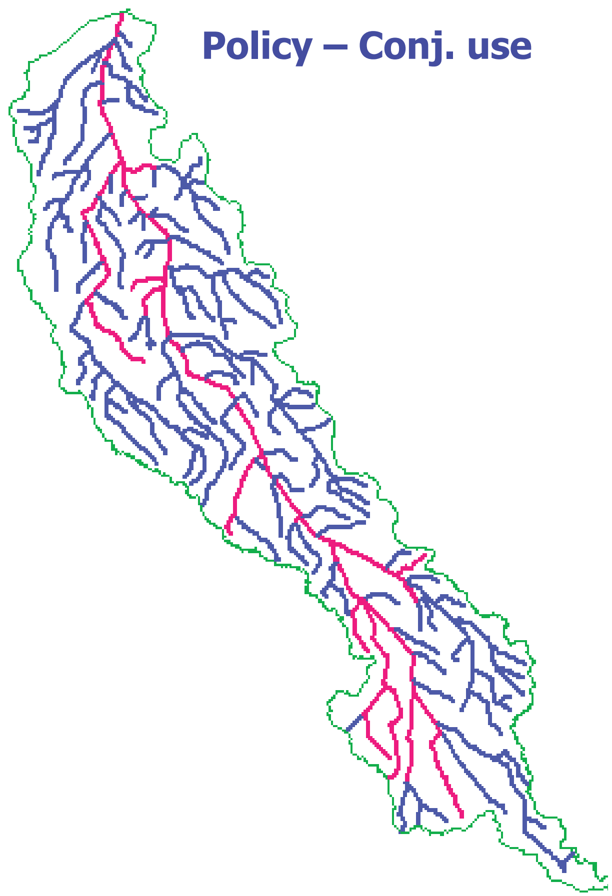
	Policy-1	Policy-2	Policy-3	Policy-4
Surface Water Available at Canal Head (Mm3)	24.19	24.19	24.19	24.19
Irrigation Demand at Head (Mm3)	50.75	50.75	50.75	50.75
Surface Water Utilized for Irrigation (Mm3)	18.84	16.50	17.37	14.40
Canal Seepage Loss (Mm3)	5.35	7.69	6.84	9.79
Groundwater Use in Command (Mm3)	31.91	34.37	33.38	36.25
Energy Demand in Canal-irrigable Area (MKwh)	1.2942	1.3269	1.3329	1.3706

Derivation of Optimal Policy

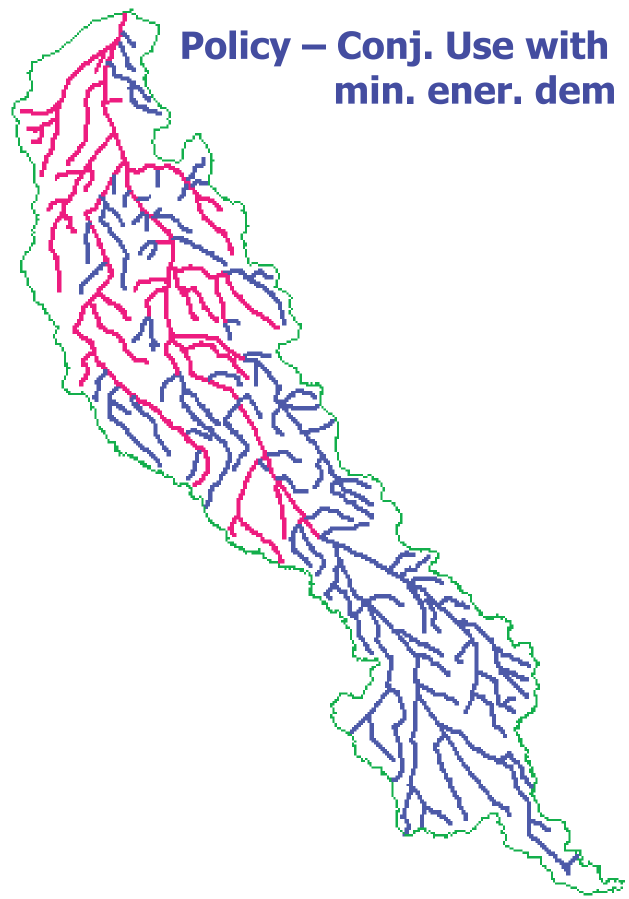
Policy – Head-Prio.



Policy – Conj. use



Policy – Conj. Use with min. ener. dem



Variation in Energy demand for different configurations

Results of Different Operation Policies

	Policy-1	Policy-2	Policy-3	Policy-4	Policy - 5
Surface Water Available at Canal Head (Mm3)	24.19	24.19	24.19	24.19	24.19
Irrigation Demand at Head (Mm3)	50.75	50.75	50.75	50.75	50.75
Surface Water Utilized for Irrigation (Mm3)	18.84	16.50	17.37	14.40	18.56
Canal Seepage Loss (Mm3)	5.35	7.69	6.84	9.79	5.62
Groundwater Use in Command (Mm3)	31.91	34.37	33.38	36.25	32.31
Energy Demand in Canal-irrigable Area (MKwh)	1.2942	1.3269	1.3329	1.3706	1.286

Results indicate that by adopting the policy of Conj. use with minimum energy demand, saving of the order of 27 MKwh can be made under similar conditions of water supply to the crops.

Thanks