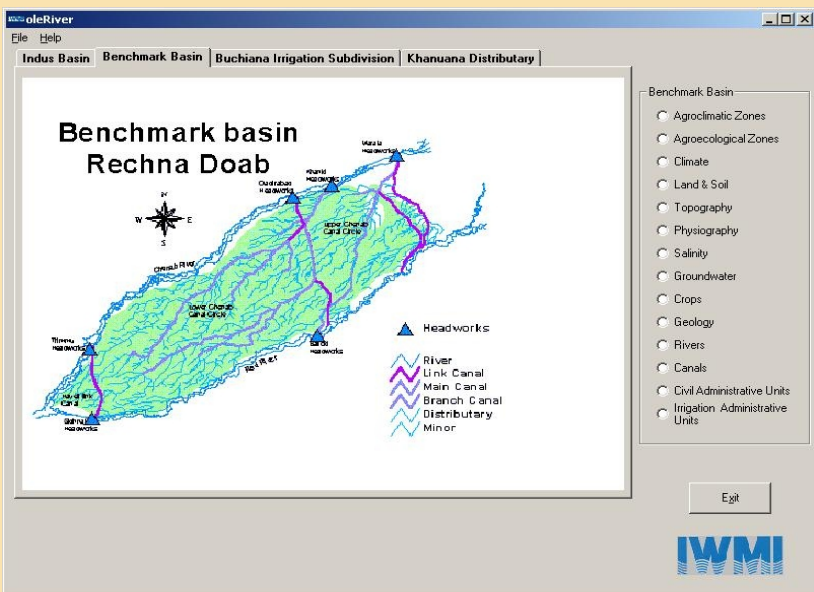


## WORKING PAPER 53

Pakistan Country Series No. 18

# Integrated Database Development for River Basin Management:

## An Example from Rechna Doab



Asad Sarwar Qureshi  
Asghar Hussain  
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Working Paper 53

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**International Water Management Institute**

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IWMI's mission is to improve water and land resources management for food, livelihoods and nature. In serving this mission, IWMI concentrates on the integration of policies, technologies and management systems to achieve workable solutions to real problems – practical, relevant results in the field of irrigation and water and land resources.

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# 1 BACKGROUND

The growing awareness of the interrelated nature of anthropogenic water uses and of the natural water cycle within a basin, together with the limitations of traditional approaches based on the augmentation of supply have led to the emergence of widely popular concepts such as Integrated Water Resources Management (IWRM), or Integrated River Basin Management (IRBM). Now-a-days, holistic and participatory approach recognizing water both as a social and an economic good is being advocated. While few oppose such general principles, there is evidence that real world situations rarely confirm to these ideal frameworks. As a result, one needs to go beyond such general concepts and get on-the-ground understanding and knowledge about how societies have effectively dealt with the problem of managing land and water resources at the basin level, and how coming challenges can be addressed.

The focus is, therefore, on documenting the development “trajectory” of river basins, showing how a particular society has grown, evolved and developed its productive activities within a given physical, climatic and ecological context. Such trajectories are marked by conflicts, shock events, crises, and compromises that need to be highlighted.

A basin perspective allows us to integrate upstream and downstream issues, to understand the interrelatedness of competing uses and users, to integrate other natural resources and human interventions with the management of water resources. Most of the existing basin-scale studies appear to be sectoral or discipline-oriented (hydrology, agriculture, environment, etc.) and aim at specific objectives. They lead to a series of different approaches, viewpoints, scales, and outputs. There is a need to carry out more comprehensive and comparable studies that integrate the behavior of all actors within a given specific physical and societal environment.

Most studies focus on the actual situation but do not provide a detailed picture of how “we got there”. Attitudes towards water and how it is shared and used, are historically grounded and that the past development of the basin, or its gradual anthropogenisation, must be reconstituted and factored into the analysis of both the present situation and future prospects. This is also why an in-depth approach of a few basins is preferred to an in-breadth analysis of a higher number of river basins. As most existing studies are partial, they do not lend themselves easily to comparisons. By adopting a common protocol for the study of river basins in different physical and socio-cultural contexts, a more generic understanding of both the commonalities and the importance of site-specific conditions must arise.

## 1.1 Objectives

- The main purpose of the basin case studies is to contribute in addressing IWRM challenges by generating, synthesizing and disseminating useful information and knowledge on basin level water management challenges, for use by practitioners, development agencies, policy makers and donors.
- To achieve this goal, the project will include an in-depth analysis and comparison of the historical development and present status of a number of selected basins. The resulting knowledge is specifically aimed at improving the understanding of basin level processes and their interactions, and identifying trade-offs. This will form the

basis for exploring, in a participatory manner, the alternatives and scenarios of the future sustainable management of water resources in the basin, and for deriving a set of contextualised options that may be used to address water management challenges.

- This multi-disciplinary and comparative investigation is expected to yield several building blocks of knowledge, as well as methodological lessons, that will contribute to the Comprehensive Assessment carried out within the framework of the Dialogue on Water, Food and Environment.

## **1.2 Need for Integrated Database Development**

Sustainable and equitable development has to be based on reliable and accurate information; hence application of geo-information technologies is becoming more and more significant. Decisions are influenced by geographic locations. Complex analyses require digital spatial data that define the characteristics of geographic space. Solving the complex problems of water resource management requires accurate, up-to-date information with an integrated spatial component, which is accessible and comparable with basic predictions.

Many organizations have used different methods for acquiring, storing, processing, analyzing, and viewing spatial data. Today, exchanging, sharing, and integrating spatial data from various sources have become increasingly important. This is a result of the growing environmental concerns and of pressures on governments and different sectors to perform more efficiently because of limited budgets. Due to the pressure for efficient use of limited resources, cooperation among different sectors is essential for the design and development of spatial databases. Such a need is now constantly expressed in various forums. It is therefore important to introduce a systematic approach to develop a spatial dataset for land, water and environment. There is a general consensus among various sectors that better datasets of the area are of prime importance for improving assessment, monitoring change, and implementing effective programs and policies.

Current handling of spatial information among line agencies is neither efficient nor effective. Spatial data are generally not available or are poorly maintained, out of date, and often inaccurate. Maps are on varying scales and have different coordinate systems, making it difficult to make overlays and integrate them. Also, maps on higher scales, which are needed for the type of urban management applications required, are not available. Spatial information is not defined in a consistent manner and naturally is of low standard. Data (metadata) are not documented, rendering them unavailable for future use.

There are no clear mandates and policies for the institution responsible for defining, maintaining, and revising such data. There is little or no interaction between the institutions or projects and often their mandates, authorities, responsibilities and functions overlap. Experience shows that to bring different sources of spatial data of the area together and to integrate them is very difficult, if not impossible.

The development of an efficient database plays a vital role for its productive use in the decision making for water resources management. The advantage of well established database is to access specific information in an organized and standardized format. The advent of information technology has altered the scope of information processing. Computers are now able to process maps (spatial data) and tabular data (non-spatial data) and merge them together to give an added value. Using GIS tools, a user interface can be developed

based on data available in different forms. The GIS based database is distinguished it from other information systems, and is useful for multi-sectoral analysis and planning strategies. The user interface will provide the information in friendly and easy format in the form of maps, tables, and charts. A conceptual framework for the development of integrated database is given in Figure 1.

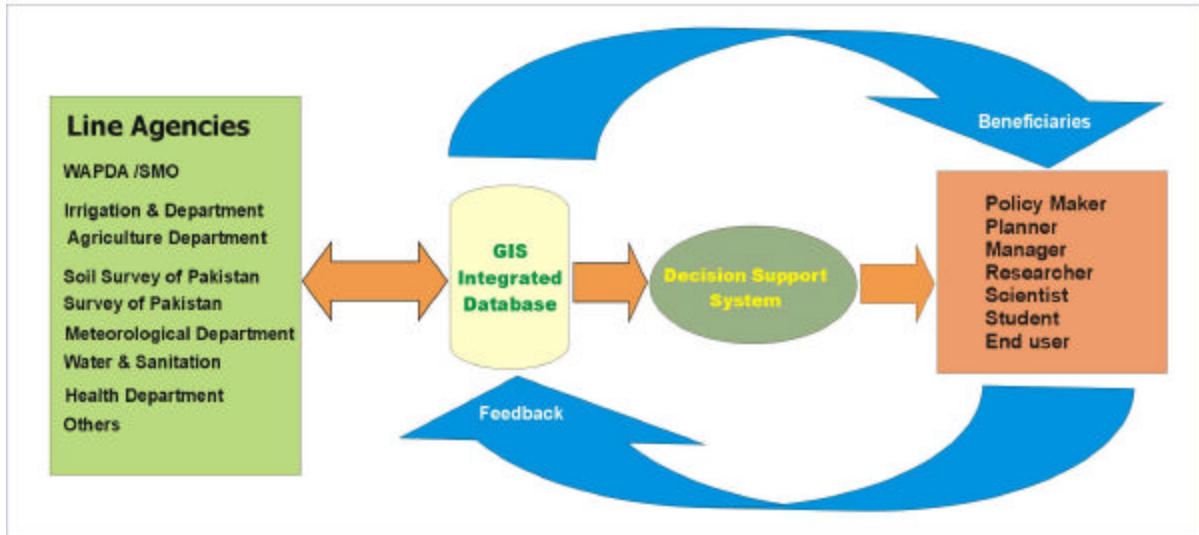


Figure 1. Conceptual framework for integrated database development and decision support system

### 1.3 Geo-Information Technology- An Integrated Tool

The advent of information technology has altered the scope of information processing. Computers are now able to process maps (spatial data) and tabular data (non-spatial data) and merge them together to give an added value. Geo-information technology has given added dimensions to the visualization of information. A geographic information system (GIS) is a computer-based tool for mapping and analyzing whatever exists and events that happen on earth. GIS technology facilitates the merging of map and tabular data quickly, thus processing spatial information. These abilities distinguish GIS from other information systems and make it useful for multi-sectoral analysis and planning strategies.

Presently, state-of-the-art, various tools like GIS/RS, EXCEL, SQL and other software like Visual Basic are available to establish the better and efficient database. IWMI in collaboration with partners intends to collect information at basin, system and farm levels on a regular basis through secondary sources, field measurements and farm household surveys. The collected information will be analyzed and synthesized using a four step approach.

- Physical, institutional and socio-economic characterization of the basin;
- Identification of data to be collected on hydrology, socio-economic condition, institutions, environment and health;
- Selection of performance indicators at basin level; and
- Establishing the procedures for data collection and related mapping and modeling.



The integrated database established through this combined activity will be accessible to various government organizations, research institutes and universities involved in the management of water resources within a river basin. This database will provide multi-disciplinary and comparative investigations that will yield meaningful information for practitioners, development agencies, policy makers, water resources managers and researchers to calculate different scenarios in order to extract generic knowledge and a range of contextualised options for river basin management.

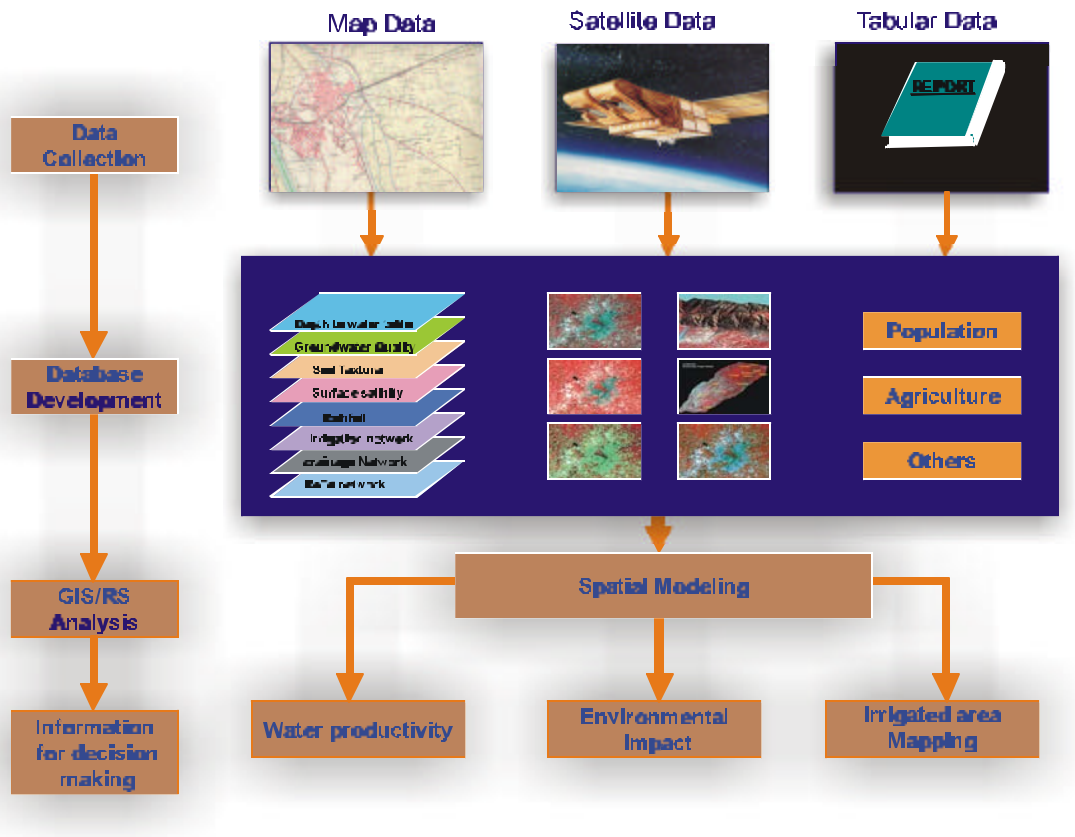


Figure 2. Methodology used in GIS for integrated database development

In order to advance this process, IWMI is establishing a series of benchmark basins. These basins will provide framework for piloting integrated water resource management. IWMI's target is to establish 10-12 Benchmark Basins by 2005. The Benchmark Basins, when viewed together, will provide a good cross-section of the major resource environments and water resources management characteristics in the developing world. Current Benchmark Basins are The Ruhana in Sri Lanka; Olifants-Limpopo in southern and eastern Africa, and Rechna Doab (Indus River sub-basin) in Pakistan.

## 2 THE RECHNA DOAB: BENCHMARK BASIN IN PAKISTAN

### 2.1 Physiography and Climate

The Rechna Doab is the interfluvial area between the Chenab and Ravi Rivers. It lies between longitude of 71° 48' to 75° 20' East and latitude of 30° 31' to 32° 51' North (Figure 1). The gross area of the Doab is 2.97 million ha and covers a maximum length of 403 Km and maximum width of 113 km including 2.3 million hectare of cultivable land. It is one of the oldest and most intensively irrigated areas of Punjab, Pakistan. The area falls in the rice-wheat and sugarcane-wheat agro-ecological zones of the Punjab. Rice, Cotton and Forage crops dominate summer season (*Kharif*), whereas wheat and forage are major crops for winter season (*Rabi*). In some parts sugarcane is also cultivated which is an annual crop.

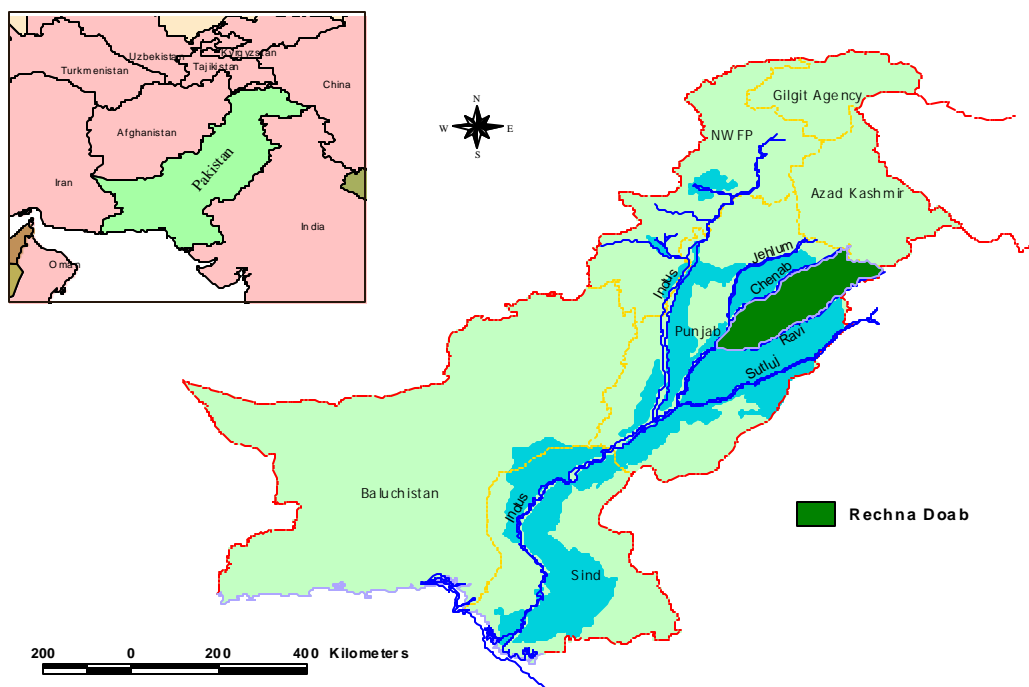


Figure 3. Location of the Rechna Doab in Punjab, Pakistan

Topographically, the Rechna Doab is flat with little natural drainage. The area trends southwesterly to a topographic relief of difference of 113 mm. The average slope of 0.37m/km across the 390 km length of the Doab decreases by about 25% in the lower reaches. The area is characterized by complete lack of well-defined natural surface drainage, and micro differences in elevations define the pathways for surface run-off during the monsoon season. The drainage problems are further aggravated by the construction of infrastructure like roads, railways, flood embankment and irrigation system. Due to flat topography, natural subsurface drainage through down-valley movement of groundwater is also restricted. Therefore, ponding of agricultural land, following intense rainstorm, with

consequent crop and property has become a recurrent phenomena in many parts of the Rechna Doab.

The area is subtropical, continental lowland, designated as semi-arid. The climate is characterized by large seasonal fluctuation of temperature and rainfall. Summer is long and hot, lasting from April through September with minimum daytime temperature ranging from 21<sup>0</sup>C to 49<sup>0</sup>C while in winter (December – February), it varies between 5 to 27 <sup>0</sup>C. The spring and fall months are more or less limited to March and October.

The mean annual precipitation varies from 350mm in the south to 1080 mm in the upper reaches of the Doab. The Doab area is located on the fringe of the monsoon belt, and about two third of the average annual rainfall occurs from June to September. One third falls in winter from January to March as low intensity fontal rains. Rainfall is generally scout and sporadic, and therefore, not a dependable source of water for agriculture production. Mean monthly rainfall, temperatures and reference evapotranspiration in the Rechna Doab is given in Figure 4.

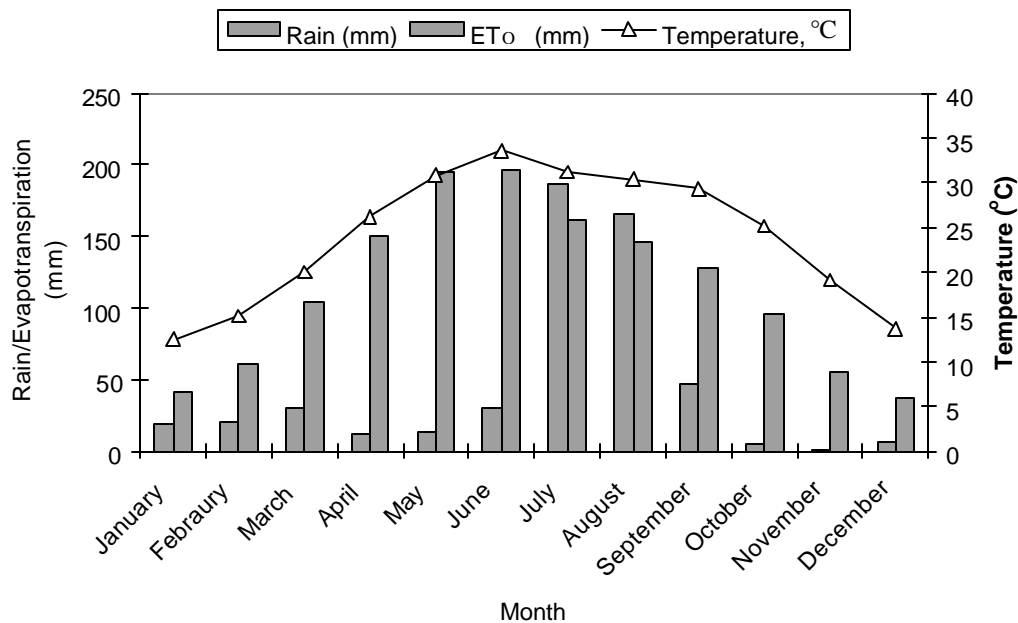


Figure 4. Mean monthly rainfall, temperature and reference evapotranspiration in the Rechna Doab, Punjab, Pakistan

## 2.2 Irrigation System and Practices

Without assured irrigation supplies, the arid and semi-arid areas of the Rechna Doab can not support any agriculture, as the evapotranspiration demand in high and rainfall is scanty and unreliable. In the Rechna Doab, this irrigation system typically consists of the main canals from which the water is distributed to branch canals. Much of the present day irrigation is commanded by two major canals: Upper Chenab Canal (UCC) covers the bulk of the upper over third of the system, where as Lower Chenab Canal (LCC) covers the rest (Figure 5). Along with the operation canal system in the Doab, a total of 2.39 Mha of land is under

perennial and non-perennial irrigation. Non-perennial irrigation is restricted to the upper Rechna in the command of upper Chenab and Marala Ravi linked canal.

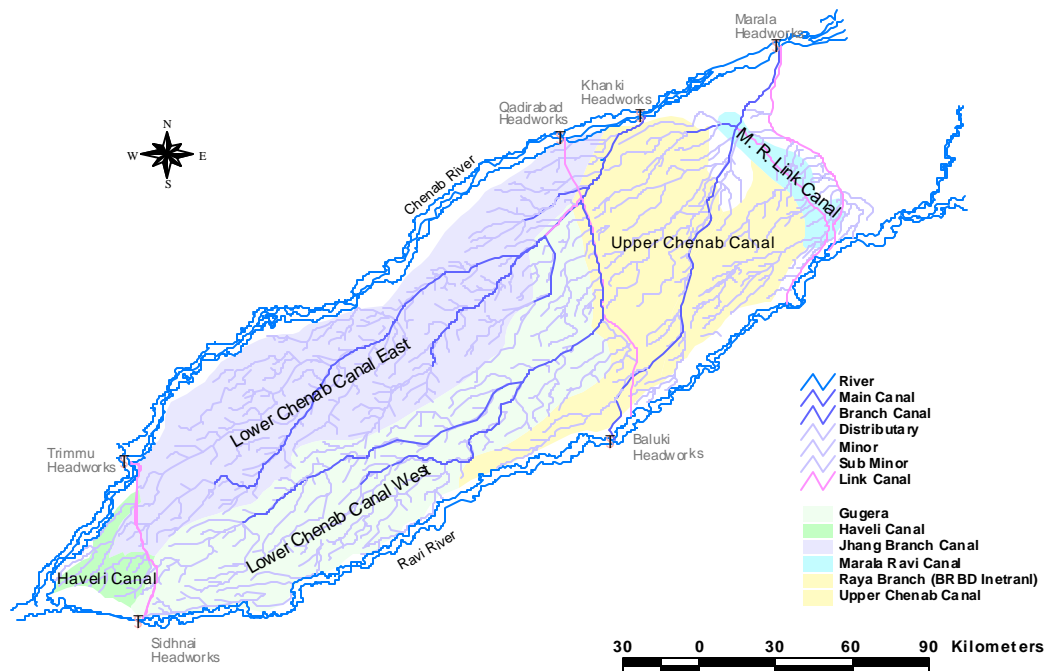


Figure 5. Network of irrigation system in the Rechna Doab, Punjab, Pakistan

The irrigation system typically consists of the main canals from which the water is distributed to branch canals. Secondary channels, called distributaries, take off from the branch canals. The distributaries and their branches, called minors are the main arteries for releasing water through outlet to small irrigation service areas (averaging 160 ha) called 'chaks'. The outlet discharge is a function of water level elevation in the supply canal. Due to the variations in the main canal discharges and the changes in the channel regime caused by siltation, it becomes difficult to achieve equity in water distribution. In times of water shortage, the water has to be rotated among secondary canals, the distributaries and minors.

The operation of this system is based on continuous water supplies and is not related to actual crop water requirements. Irrigation canals are mainly not allocated more than their design capacity, of which a typically value is about  $2 \text{ mmd}^{-1}$ . The distribution of water, from the canal outlets having mostly a capacity of  $30 \text{ to } 90 \text{ l s}^{-1}$ , to the group of farmers is performed on a fixed rotational system called Warabandi, being generally a weekly or 10-day cycle. This means that each farmer is allowed to take an entire flow of the outlet once in seven or 10 days and for a period proportional to his land holding. Due to age and poor maintenance, the delivery efficiency is low ranging from 35 to 40 percent from canal head to crop root zone. In Practical terms therefore, much surface water is currently lost enroute, which, if salvaged, could profitably be used by farmers.

The system was originally designed for an annual cropping intensity (i.e. yearly cropped area) of 75 percent with the intention to spread irrigation water over as large an area as

possible to expand the settlement opportunities. The main objective of irrigation development at that time was to prevent crop failure and avoid famine. Another designed feature was the low management and operational requirement, which is an advantage, with an internal disadvantage of inflexibility. Increasing demand for food has caused the annual cropping intensities to rise to about 150 percent. Moreover, many canals can no longer convey their officials design capacity, due to siltation and erosion of banks. From the scarcity by design and the intensified former practices, over time canal water availability per unit of irrigation land has become ever more limited.

Due to the inadequacy, variability and unreliability of the surface irrigation supplies, the farmers have turned more and more to the use of groundwater without a full awareness of the hazard represented by groundwater quality. This has resulted in a sharp increase in the tubewell population over the last two decades (Figure 6). The exploitation of useable groundwater provided an opportunity to the farmers of this area to supplement their irrigation supplies and to cope with the vagaries of the surface supplies. However, the present uncontrolled and unregulated use of groundwater is replete with serious consequences as it is depleting the fresh groundwater. This is causing extra lowering of groundwater and intrusion of saline groundwater into fresh groundwater aquifers. This is not only deteriorating the quality of groundwater but also increasing the pumping cost. This means more expensive and poor quality groundwater will have to be pumped for irrigation in future.

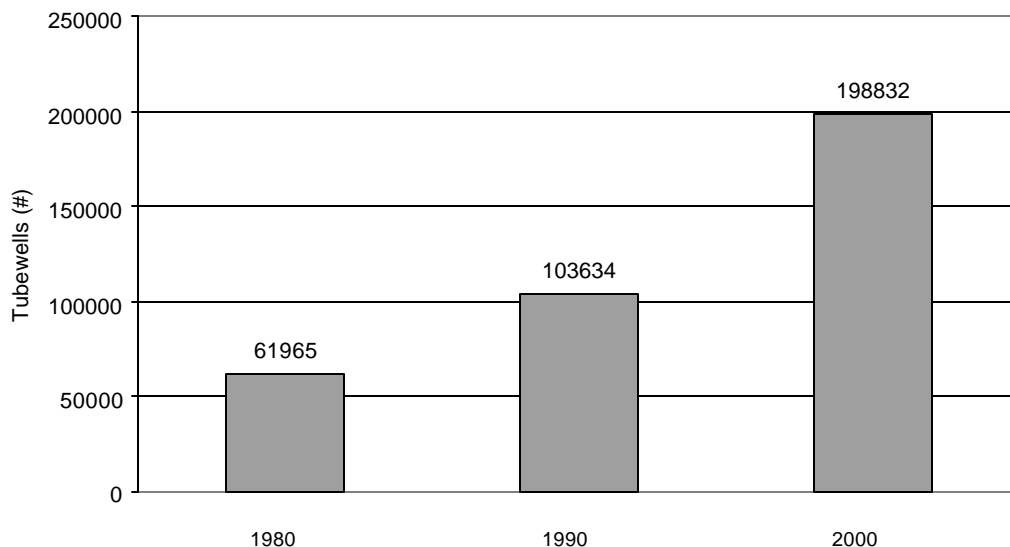


Figure 6. Development of tubewells in the Rechna Doab, Punjab, Pakistan

### 2.3 Soil and Soil Salinity

In early sixties, Water and Salinity Investigation Division (WASID) of WAPDA did a detailed soil survey of the Rechna Doab involving profile sampling to a depth of 180 cm. Based on the 15-180 cm of strata, the soils of the Rechna Doab have been classified into 5 series based on both vertical and horizontal textural variations. A brief description of these five soil series is given below.

*Jhang: Coarse (sand and loamy sand)*

These soils are very permeable, usually slightly calcareous, and seldom have a zone of lime accumulation. Owing to their coarseness, these soils are unlikely to build up higher levels of salinity or fertility.

*Farida: Moderately Coarse (sandy loam and fine sandy loam)*

These are the most extensive soils in the Rechna Doab. Derived from older alluvial deposits, they are generally found on smooth, nearly level topography. The surface is mildly calcareous, whereas the subsoils are moderately to highly calcareous. With a wide range of adaptation, the fertility levels and organic matter can be readily built up.

*Buchiana: Medium (loam, silt loam, and silt)*

These soils also have been derived primarily from the older sediments. Being moderately permeable, they contain good to high water holding capacities that make them the most favorable soils for farming. Kankar zones are frequent in the upper substratum, particularly in areas where the watertable has fluctuated within the soil crust.

*Chuharkana: Moderately fine (silty clay loam, sandy clay loam, clay loam)*

Occurring across depressional or semi-depressional areas, these soils have a compact substratum that supports a rather narrow range of crop adaptation. Because of limited drainability, the salinity hazard for these soils is much more pronounced, especially when accompanied by high watertables.

*Nokhar: Fine (sandy clay, silty clay, and clay)*

The substratum of these soils is commonly of moderately fine texture. The internal drainage is highly restricted and surface drainage features are unfavorable. Extent-wise, they are only a small fraction of the Rechna Doab.

Figure 7 shows the spatial distribution of the above-mentioned five soil series. Soil Survey of Pakistan (SSoP) has further classified the soils on the basis of porosity, structure, consistency and drainage. The distribution of these soils across the Rechna Doab in terms of associations and their constituting series has been given in Figure 8. Using these soil association in the database, IWMI has developed the crop suitability maps for four major crops grown in the Rechna Doab i.e. rice, wheat, sugarcane, and cotton (Figure 9).

The problems of soil salinity were first realized in 1927 in the upper regions of the Rechna Doab where the groundwater table was either at the surface or very close to it. The extent of the damaged area was estimated through a salinity survey (Thur Girdawari) started by the Waterlogging Enquiry Committee during the same year. It was initially confined only to those areas where the groundwater table was within 1.5 meters from the ground surface. Salinity was attributed to high watertable conditions and groundwater as the source of salts. Later, investigations revealed that salts were originally present in the soil crust, and their movement was accelerated to the surface by high watertables due to poor irrigation practices and inadequate drainage facilities. Figure 10 shows the distribution of surface salinity within the Rechna Doab. This salinity assessment was based on the visual salinity survey. The salinity was classified into four groups: non-saline ( $EC_e < 4$  dS/m, salts not visible), slightly-saline ( $EC_e$  4-8 dS/m, salts slightly visible), moderately saline ( $EC_e$  8-15 dS/m, salts fairly visible) and strongly saline ( $EC_e > 15$  dS/m, salts widespread).

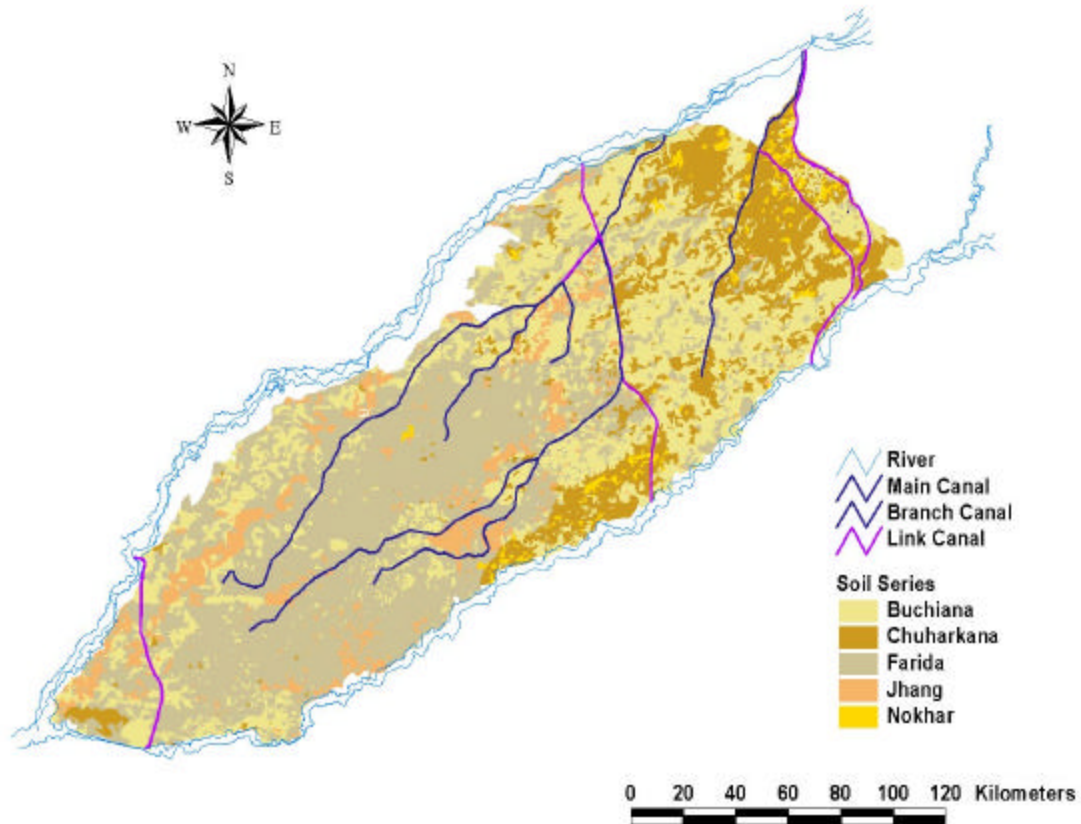


Figure 7. Spatial distribution of Soil Series in the Rechna Doab, Punjab, Pakistan

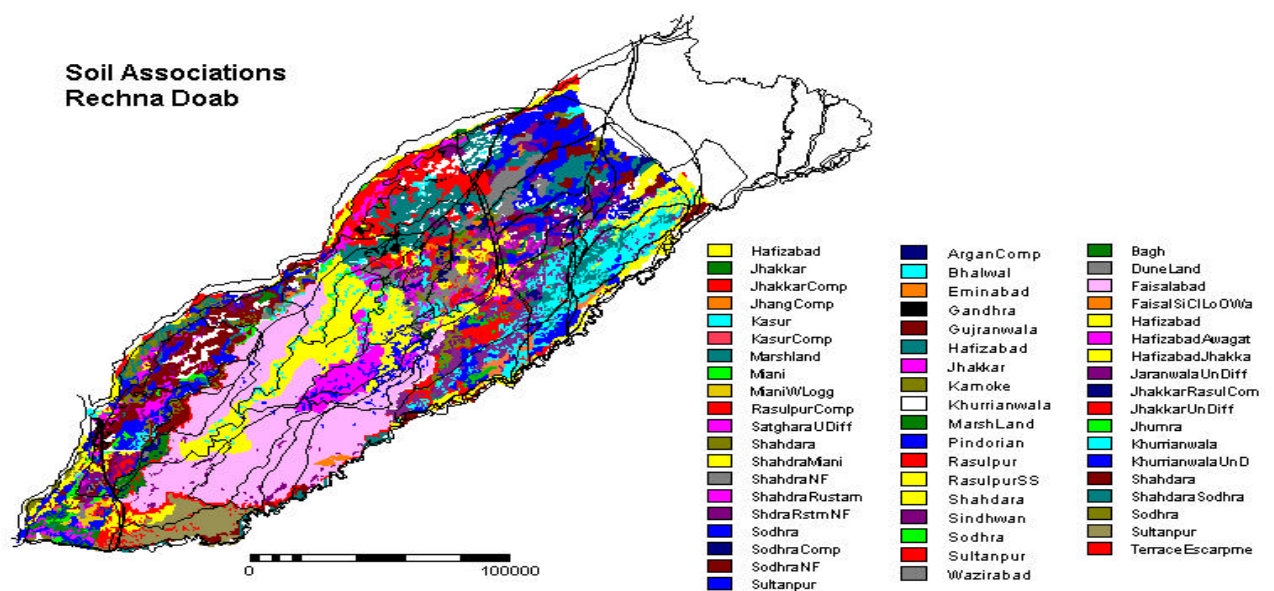


Figure 8. Soil associations within the Rechna Doab, Punjab, Pakistan



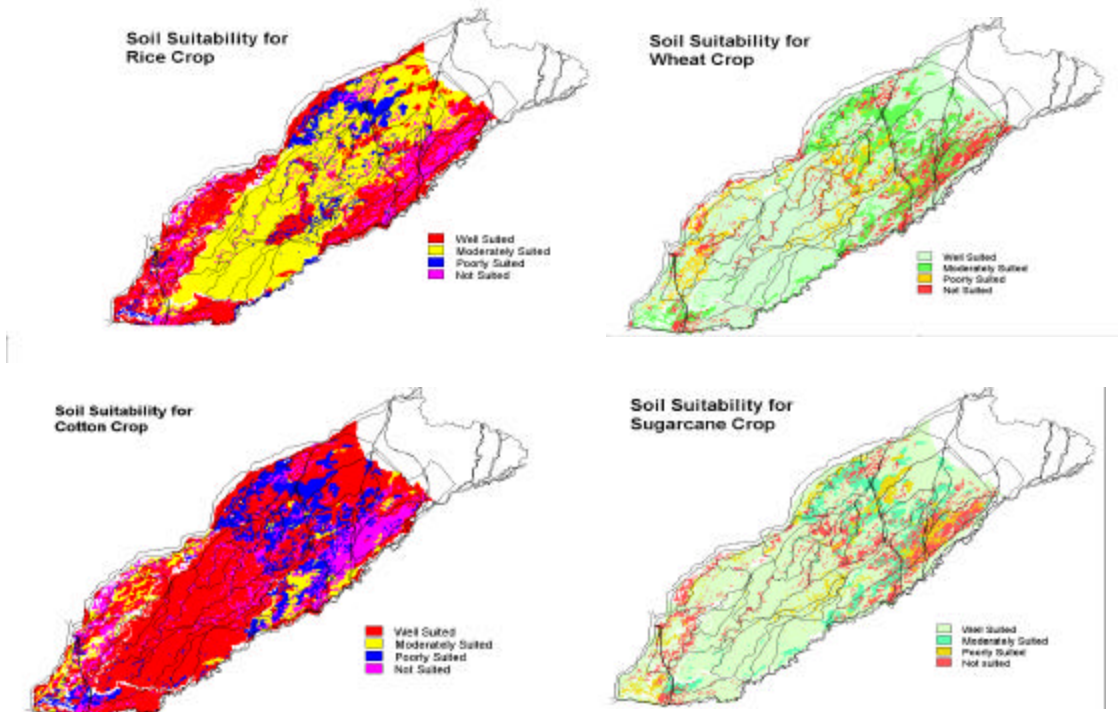


Figure 9. Soil suitability for major crop within the Rechna Doab, Punjab, Pakistan

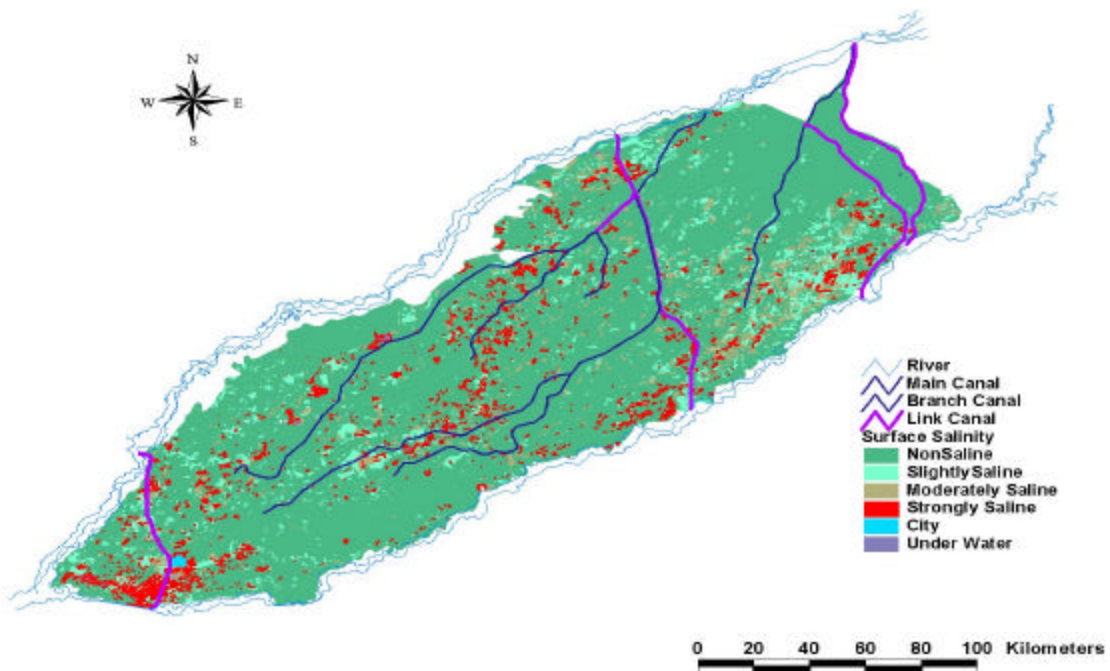


Figure 10. Distribution of surface salinity within the Rechna Doab, Punjab, Pakistan



There are large tracts of salinized land in the center of the lower Rechna Doab where the groundwater is also saline. For the remaining lands in the Doab, salinity can be described as 'patchy' and encountered almost everywhere. However, only 4.8 percent of land is highly saline and 82.5 percent is non-saline. The soil problems in the Rechna Doab are not only due to salinity but also of sodicity. This problem is becoming severe due to increasing trends of irrigation with tubewell water. According to an estimate, about 70 percent of tubewells are discharging sodic water. The sodicity problem is a serious threat to irrigated agriculture as farmers face difficulties in the reclamation of these soils.

## 2.4 Crops and Cropping Intensities

In terms of both output and employment, the major agricultural crops in the Rechna Doab are wheat, rice, sugarcane and cotton. Out of the total production of the wheat, rice, cotton and sugarcane in Punjab (i.e. 11.22 million tones (MT), 1.68 MT, 6.5 million bales and 24.51 MT, respectively), about 3.61 MT, 0.95 MT, 0.014 million bales and 10.38 MT, respectively, has been produced in the Rechna Doab during 1993-94. Rechna Doab is a major contributor to overall crop production in the Punjab province. Table 1 shows the share of four major crops to the overall production of Punjab in 1993-94. It is evident that about 32 percent of wheat and over 50 percent of rice produced in Punjab, came from the Rechna Doab.

Table 1. Production of four major crops in the Rechna Doab

Crops	Total production in Punjab	Total production from Rechna Doab	% share of the Rechna Doab
Wheat (million tones)	11.22	3.61	32.17
Rice (million tones)	1.68	0.95	56.5
Cotton (million bales)	6.5	1.4	21.5
Sugarcane (million tones)	24.5	10.38	42.4

The temporal analysis of the census data (1960-1995) shows the estimates of the cropping intensity for the Rechna Doab. The consistent increase in the cropping intensity is a clear evidence of rising trends in the irrigated agriculture. This also demonstrates the increasing demand for water to meet crop requirements (Table 2). The 1995 figure on aggregate cropping intensity was 134 percent, being highest on the small farms (150 percent) as compared to the medium and the large farms. The cropping intensity on the medium and large farms is estimated to be 131 percent and 135 percent, respectively. Table 3 shows the cropping intensities for major crops calculated at sub-division level. These estimates are based on the survey conducted by IWMI in 1998.

## 2.5 Groundwater Table Depth and Groundwater Quality

The Rechna Doab is underlain by a deep, unconfined, high yielding aquifer that is 300m thick, relatively homogeneous and highly anisotropic. The bulk of the alluvial is composed of silt and fine sand, or mixtures thereof, with an absence of thick layers of pure clay, except for a few meters thick local clay lenses. The material is highly porous and is capable of storing and transmitting water readily, the horizontal permeability being greater than vertical.

Recharge to the aquifer is principally seepage from the rivers and to a lesser degree precipitation. Seepage from the Chenab and Ravi Rivers generally moved towards the center of the Doab. Prior to canal construction, the water depth occurred at a depth of more than 10 meters, and in the center of the Doab at more than 30 meters. Because of relatively flat

topography, low hydraulic gradient, and poor drainage conditions, the watertables began to rise due to increased recharge through unlined irrigation channels and deep percolation remitting from croplands. Temporal and spatial variations of groundwater depth in the Rechna Doab are shown in Figure 11.

Table 2. Cropping intensity across farms in the Rechna Doab, (1960-95)

Farm Size	1960	1972	1980	1990	1995
1	105	152	160	174	
2	104	141	152	169	
3	107	132	146	161	
Small	105	142	153	168	150
4	108	129	139	15	
5	106	125	134	147	
6	101	116	126	140	
Medium	105	123	133	147	131
7	91	107	119	136	
8	67	100	110	128	
9	27	85	98	109	
Large	61	98	109	124	135
Over All	91	121	131	146	134

Table 3. Cropping intensity in different sub-divisions of the Rechna Doab

	CCA (ha.)	Kharif Crops						Rabi Crops		
		S-cane	Cotton	Rice	Maize	Fodder	Minor	Wheat	Fodder	Others
Bhagat	75167	8.9	27.4	10.4	3.9	12.2	2.4	53.7	12.3	2.4
Buchiana	64178	15	6	19	15	15	3	53	11	7
Chuharkana	70064	2.6	0.0	56.0	0.0	12.6	4.4	77.5	9.4	4.4
Dhauhar	66012	13.4	30.6	32.9	0.0	14.5	0.0	58.1	18.7	0.0
Gujranwala	233543	0.3	0.0	73.7	1.2	18.6	6.0	65.0	21.4	6.0
Shorkot	91582	15.0	25.9	15.5	0.0	14.7	0.0	54.6	16.8	0.0
Kanya	56114	19.5	3.4	24.2	0.0	19.5	1.4	45.8	11.0	1.4
Malhi	82666	0.0	0.0	85.5	0.0	10.2	2.6	72.2	18.5	2.6
Mangtanwa	165552	9.2	0.0	43.4	0.0	11.3	7.0	50.6	16.4	7.0
Muridke	182317	0.1	0.0	74.9	0.0	9.6	1.9	57.3	21.2	1.9
Naushera	167423	0.3	0.0	82.7	0.0	13.1	2.0	58.4	22.5	12.2
Nokhar	199494	1.7	0.0	67.4	0.0	15.0	5.3	71.2	16.9	5.3
Paccadala	71029	9.6	0.0	33.2	0.0	18.7	0.0	51.5	14.4	0.0
Sadhoke	170350	0.2	0.0	81.5	0.1	7.9	2.2	65.0	22.7	2.2
Sagar	96988	0.0	0.0	73.8	0.0	5.3	0.0	70.3	8.1	0.0
Sangla	40225	7.6	0.0	19.2	2.5	24.4	0.0	50.8	24.9	2.5
Shahdara	101036	0.5	0.0	61.3	5.4	10.7	6.9	55.7	22.7	6.9
Sheikhupura	116528	0.9	0.0	60.3	0.0	19.5	8.7	59.1	20.0	8.7
Sikhanwala	82256	0.0	0.0	67.6	0.0	17.7	1.2	52.3	27.2	1.2
Sultanpur	44524	18.2	17.3	53.0	0.0	7.9	0.0	71.9	7.8	0.0
Tandlianwal	84752	19.3	8.7	11.3	3.8	29.8	0.0	55.6	20.3	0.0
Tarkhani	67068	18.7	0.0	0.0	5.6	16.5	3.1	55.5	19.7	3.1
Uqbana	98322	15.9	4.9	0.3	13.7	29.5	2.1	47.1	22.5	2.1
Wer	63684	14.2	21.3	11.0	16.7	17.7	1.6	59.5	18.0	1.6
Kot Khudiyar	51289	6.0	3.1	16.7	6.9	23.8	4.4	59.7	16.3	4.4
Mohlan	89938	4.9	0.0	28.0	2.5	26.4	6.6	56.9	30.0	6.6
Veryam	94924	12.3	17.9	0.0	26.1	22.6	0.0	63.0	20.6	0.0

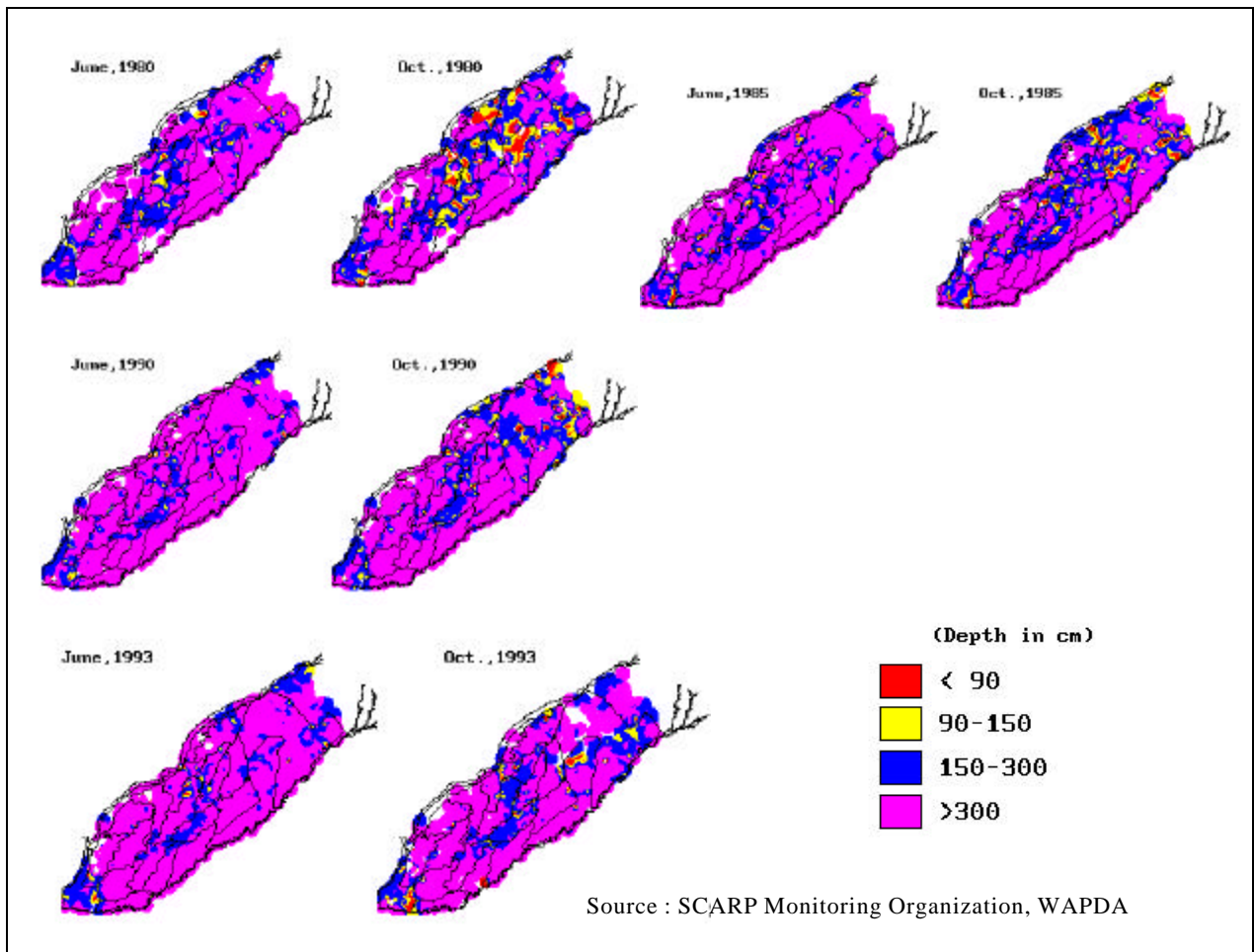


Figure 11. Temporal comparison of depth to watertable in the Rechna Doab, Punjab, Pakistan

Introduction of SCARP (Salinity Control and Reclamation Projects) and private tube wells decreased the waterlogged areas from a high of 0.96Mha in 1987 to 0.52 Mha in 1997. However, waterlogging combined with soil Salinization still occurs in fairly large areas. Salinization problems are further aggravated by the use of saline groundwater for irrigation.

Higher concentrations of dissolved salts are found in the groundwater than surface water because of the greater exposure of the GW to soluble material in geological strata. In most cases, upto the depth of 155 m, the GW is of good quality ranging from 500-1000 ppm. The underlying deep-water qualities are somewhat more hazardous than shallow water. The variation in the lithology of the aquifer imparts a wide range of hydraulic properties and different chemical characteristics to groundwater and consequently the wells may pump water of different chemical quality from different horizons. The differences in GW quality across the Doab in terms of the total salt concentration (measured as electrical conductivity) are shown in Figure 12.

Groundwater of low salinity is found in the areas along the rivers. The groundwater salinity increases with distance from the rivers as well as with depth. The saline groundwater areas also have a thin layer of fresh water overlying the saline water. Based on groundwater

salinity the area can be divided into two zones: useable groundwater zone and saline GW zone. The useable groundwater zone (TDS < 3000 ppm) upto the depth of 255m, the groundwater is generally of good quality ranging in salinity from 400 to 600 ppm.

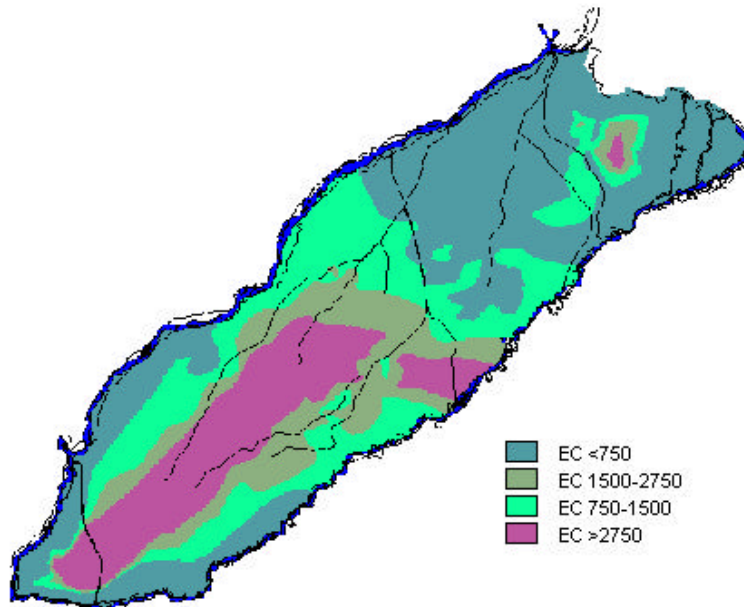


Figure 12. Spatial distribution of groundwater quality within the Rechna Doab, Punjab, Pakistan

In saline GW zone (TDS > 3000 ppm), saline GW starts even at shallow depths of 30m. Deeper water up to 110m are generally highly saline.

For groundwater in the Rechna Doab having TDS < 300 mg/l, the dominant ions in the solution are Ca, Mg and HCO<sub>3</sub>; for the TDS range 500-1000, its Na, HCO<sub>3</sub> or a mixture of HCO<sub>3</sub>, Cl and SO<sub>4</sub>. The dominant ions in TDS concentrations exceeding 300 mg/l are Na and Cl.

In the Rechna Doab, analysis of 2500 shallow water samples (6 to 18 cm below ground surface) shows that about 50% of the total samples contain salinity of 750 ppm, about 40% up to 1500 ppm and the rest goes up to 3000 ppm. In general, a vertical gradient exists within the GW aquifer that must be taken into account in GW studies.



### 3 CASE STUDY

The geographical extent of the Rechna Doab is too large and the information contained in the individual themes (soil texture, salinity, groundwater table depth and groundwater quality) is too diverse to result in a consolidated interpretation of issues regarding integrated water resources management. For such a large area, it is time consuming and expensive to develop such a detailed database. Therefore, it is advantageous to concentrate our initial efforts in a pilot area. The 28 irrigation sub-divisions of the Rechna Doab act as its building blocks of irrigation system. Each of these irrigation sub-divisions receives irrigation water through distributary with specific command area and discharge. The salient features of these 28 sub-divisions are given in Table 4.

For the development of prototype integrated database development, 'Buchiana' irrigation sub-division has been selected as a case study. This selection was made due to availability of large amount of data, which IWMI has collected over the past few years. The main objective of this exercise is to design and develop a spatially referenced digital database that will help all water resources managers, irrespective of their agencies, to take effective decision for sustainable management of water resources. This exercise also aims at identifying the gaps in present data collection and the data requirements for the development of an effective decision support system.

#### 3.1 Buchiana Irrigation Sub-division- A Building Block

Buchiana Sub-division is the first of the three sub-divisions comprising the Lower Gugera Branch of the LCC. The Branch traverses the entire length of the sub-division on its way to the Tarkhani Sub-division further south. The sub-division's gross area is 81,151 hectare of which 79 percent is CCA. Its irrigation network, off taking from either side of the Lower Gugera Canal, consists of 302 sanctioned outlets for an average of nearly 212 hectare of cultivated land per watercourse. The total length of the distribution network is approximately 195 kilometers corresponding to a density of about 3 kilometers per 1000 hectare.

The morphology of the sub-division is characterized by well-defined clustering of coarse to medium soils. The soils of this sub-division are well drained and suited for the growth of cotton, sugarcane and wheat. The tail reaches of this sub-division faces inter-seasonal watertable fluctuations but mainly they are confined to a narrow contiguous spread running north-south along the meander of the lower Gugera channel. According to IWMI's sample survey, nearly 78 percent of the soils are non-saline. A majority of the non-saline observations are occurring in the medium soils; however, with the increasing trend in salinity, the proportionate contribution of the clay loam is substantially increasing.

The Buchiana sub-division is very similar to the neighboring sub-divisions in terms of the equivalent land use, cropping and culturable waste intensities. The major crop intensities are favorably supported by useable groundwater across much of the sub-division. This sub-division lies in the medium net income category. The wheat yields are 2000-3000 Kg/ha.

Table 4. Salient characteristics of the irrigated sub-division, Rechna Doab, Punjab, Pakistan

Sub-division	Gross Area ( Ha )	Canal Command Area	Difference (ha)	Percentage of CCA within Gross Area	No. of Distributaries	No. of Minor	Sanctioned Water Courses	Direct Outlet	Average Area/Water course	Design Discharge (cumecs)	Length of Disty. System (Km)
Aminpur	92479	78104	14375	84	7	20	465	0	167.97	13.38	234.96
Bhagat	96394	75167	21227	78	6	13	389	0	193.23	17.33	255.47
Buchiana	81151	64178	16973	79	13	8	295	7	212.51	13.10	194.96
Chuharkana	97417	70064	27353	72	8	8	329	0	212.96	12.45	190.40
Dhauhar	98000	66012	31988	67	10	15	379	0	174.17	10.73	273.75
Haveli	98654										
GujranWala	109664	94757	14907	86		23	601			37.42	
Kanya	77473	56114	21359	72	8	7	302	0	185.81	13.04	178.21
Kot Khuda Yar	81252	51289	29963	63	15	12	405	0	126.64	13.81	177.80
Malhi	48998	33905	15093	69		21	325			23.02	
Mangtanwala	68167	60466	7701	89		10	314			34.05	
Mohlan	112694	89538	23156	79	10	15	437	0	204.89	17.59	270.64
Muridke	74548	73813	735	99		19	469			40.04	
Naushera		71299				18	402			26.96	
Nokhar	115705	80840	34865	70		14	450			45.91	
PaccaDala	78108	71029	7079	91	8	11	361	0	196.76	15.59	177.46
Sagar	114234			0							
Sadhoke	113288	64940	48348	57		24	648			31.53	
Sangla	51610	40225	11385	78	10	10	241	5	163.52	7.07	134.14
Shahdara	85545	42685	42860	50		17	405			25.29	
Sheikhupura	66761	46512	20249	70		14	321			31.53	
SikhanWala		41738				13	139			21.04	
SultanPur	60629	44525	16105	73	8	6	219	0	203.31	11.27	170.67
TandlianWala	110879	84752	26127	76	15	20	439	0	193.06	22.75	239.24
Tarkhani	88240	67068	21172	76	10	8	351	4	188.92	16.50	160.56
Uqbana	119053	98322	20731	83	16	4	520	0	189.08	22.27	248.95
Veryam	108122	94924	13198	88	11	15	382	0	248.49	24.39	137.83
Wer	93768	63684	30084	68	10	14	313	0	203.46	16.87	255.87

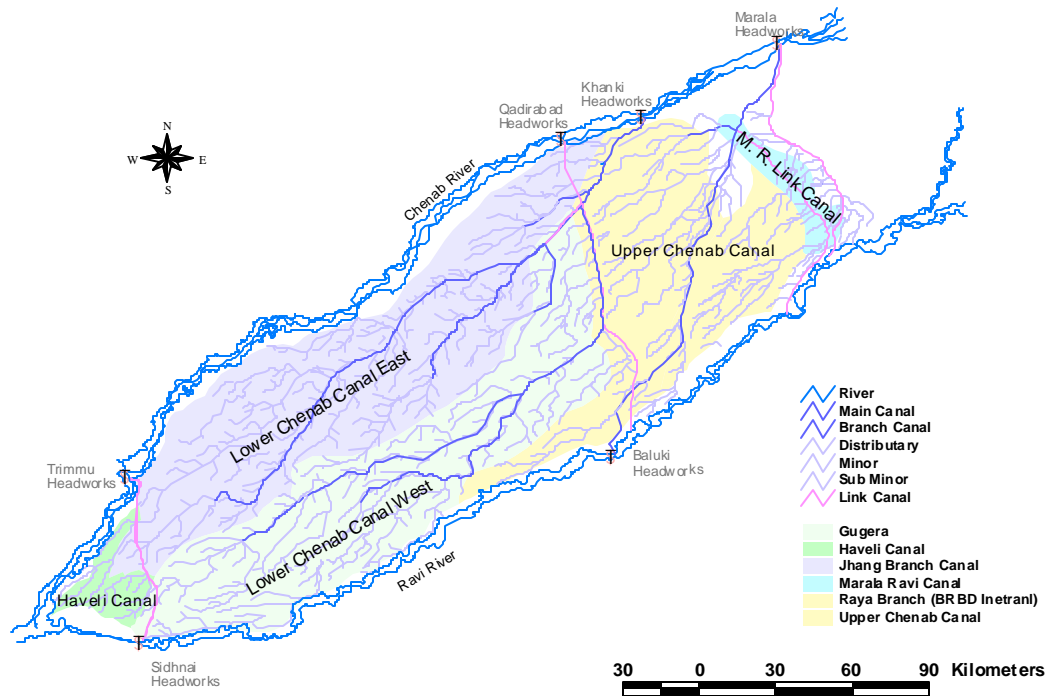


Figure 13. Location of Buchiana Sub-division within the Rechna Doab Benchmark Basin

### 3.2 Data Collection

The analysis presented in this report is based on a two-year (1999-2000) data of Buchiana Sub-division collected from different national organizations. The collected data was stored in the GIS format for in-depth analysis of various aspects of irrigated agriculture. Table 5 shows a complete inventory of the data set used for this analysis along with the departmental source.

### 3.3 GIS Database Design and Development

GIS database of the Buchiana irrigation division integrate map data, satellite data, and secondary sources data. In order to integrate these divergent datasets, all data was compiled in the GIS format. Extensive use of satellite imagery was made to get information on land use and environmental parameters. Therefore, the developed database clearly demonstrates the application of GIS and RS technologies in the planning and management of irrigated agriculture. The advancement of space technology made it possible to look at the possibilities of using different satellite imagery to complement spatial data. With the help of Landsat image data, the base map has been developed. Efforts were made to integrate attributed information from the irrigation and agriculture departments regarding flow, design of channels, yields, crop patterns and so on.



Table 5. Inventory of dataset used for the analysis of Buchiana Sub-division

Main Topic	Data Themes	Department
Physical and climate setting	Rainfall, ET, Temperature etc	Meteorological Department
	Soils	Soil Survey of Pakistan, WAPDA
	Topography	WAPDA
	Drainage network	Provincial Irrigation Department
	Mean and probable seasonal flow	
	Past extreme events	
	<b>Groundwater resources</b>	WAPDA
	Hydraulic conductivity	
	Specific yield	
	Depth to Watertable	
	SCARP Scheme	
	Aquifer conditions	
	Fresh and saline groundwater	
Main Ecosystem	Agriculture Ecosystem	WAPDA, Agriculture Department
	Cropping Pattern	
Water resources development	Canal tubewells etc	Health
	Water treatment	
	Desalinization	WAPDA
	Irrigated area (all size official or not)	Provincial irrigation Department
	Characteristics and maintenance status	
Infrastructure	Roads, rivers, transportation	Survey of Pakistan

Data for infrastructure like canal network, roads, railway, administrative units both irrigation and civil in the form of maps (vector format) were organized into database by digitizing maps. Satellite images or scanned data were organized into database by means of image processing, and the non-spatial data (attributed information) were organized into a Relational Database Management System (RDBMS).

For the development of a GIS database for Buchiana irrigation sub-division, the following secondary sources information was used.

- Irrigation department chak plans at the Scale of 6" = 1 miles.
- Map published by Soil Survey of Pakistan at scale 1: 250000
- WAPDA Master planning survey Atlas 1977 at the scale 1: 250000
- Survey of Pakistan GD sheet at scale of 1: 50000
- SMO, WAPDA depth to watertable maps at the scale of 1" = 4 miles
- WASID BULL; Soil Salinity maps at scale of 1" = 1 mile

Information from existing maps was extracted by manual digitization using ILWIS 1.4 software. These maps are digitized sheet-by-sheet and joined on GIS station using ILWIS software. Information on canal network, railway, road, drain, civil and irrigation administrative boundaries was extracted from 6" = 1 mile Chak plans: soils, surface salinity, soil crop suitability, drainability were extracted from 1: 250000 scale maps of Soil Survey

and WAPDA master planning Atlas; Soil Salinity maps are extracted from 1"=1 mile WASID BULL maps sheets; piezometer location, natural surface levels extracted from 1"=4 miles SMO, WAPDA depth to watertable maps; Landsat tm Image data used for base map. A complete listing of spatial database for Buchiana sub-division is given in Table 6.

All the basic and resulted layers are presented in annexure 1.

Table 6. List of the spatial database of Buchiana Irrigation Sub-division

Layer	Source	Scale	Date
Irrigation Administrative units	Chak plan	6"= 1 mile	1960
Irrigation Network	Chak plan	6"= 1 mile	1960
Surface Drainage Network	Chak plan	6"= 1 mile	1960
Civil Administrative Units	Chak plan	6"= 1 mile	1960
Soil Association	Soil Survey of Pakistan	1:250000	1967
Soil Drainability	Soil Survey of Pakistan	1:250000	1967
Soil Salinity	Soil Survey of Pakistan	1:250000	1967
Soil Crop Suitability	Soil Survey of Pakistan	1:250000	1967
Physiography	Soil Survey of Pakistan	1:250000	1967
Surface Texture	SMO, WAPDA	1:250000	1977
Profile Texture	SMO, WAPDA	1:250000	1977
Surface Salinity	SMO, WAPDA	1:250000	1977
Profile Salinity	SMO, WAPDA	1:250000	1977
Depth To Watertable	Depth to Watertable	1"= 4 miles	1980-19200
Metrological Data	Survey of Pakistan	1: 500000	
Satellite Image Data	LandSat Tm	30m/Pixel	August, 1999

### 3.4 Spatial Data Modeling and Decision Support System

The spatial database nurtures two independent but supportive sets of activities geared towards modeling and contextual support. The spatial data models are combinations of thematic extraction, prepared during the collection and formatting stage, to observe the interaction of one or more variables in space. A host of multi-thematic models was prepared for Buchiana irrigation sub-division with the overlay operations providing the point, linear, and delimited referencing in space for location and information, which leads to the decision support system. The process flow chart for GIS modeling exercise is in figure.

The spatial data modeling and decision support system diagram have four major steps:

1. Comprise the building block of this component whereby much of the data need for spatial modeling is extracted through multiple combinations of theses basic spatial themes provided by different organizations.
2. Spatial layers set, for which locational reference is provided through survey of Pakistan topo sheets and classified according to the respective criteria.
3. The GIS models are not just limited to logical interrelationships in space, but also provide the higher medium of interaction through linkages with predictive capabilities of other models towards a spatial view of the future with simultaneous examination of

alternative scenarios. For example, in the context of the exercise intended for the Buchiana irrigation sub-division, the cartographic deliverable from the GIS serve as the reference in space for the location of tubewells that have been identified for a degrading pattern in groundwater quality. Piezometers have identified the seasonal fluctuation depth to watertable and describe the subsurface gradients. There are three major derivatives of soil association: soil drainability, soil crop suitability and soil salinity.

4. The simulations constitute a multiple effect across the number of models with different results, with the spatial stratifications being the net against which the optimum selections are retained. The resulted layers, for example, Association of subsurface drainage impediments and groundwater quality versus seasonal fluctuation in depth to watertable leads to decisions.

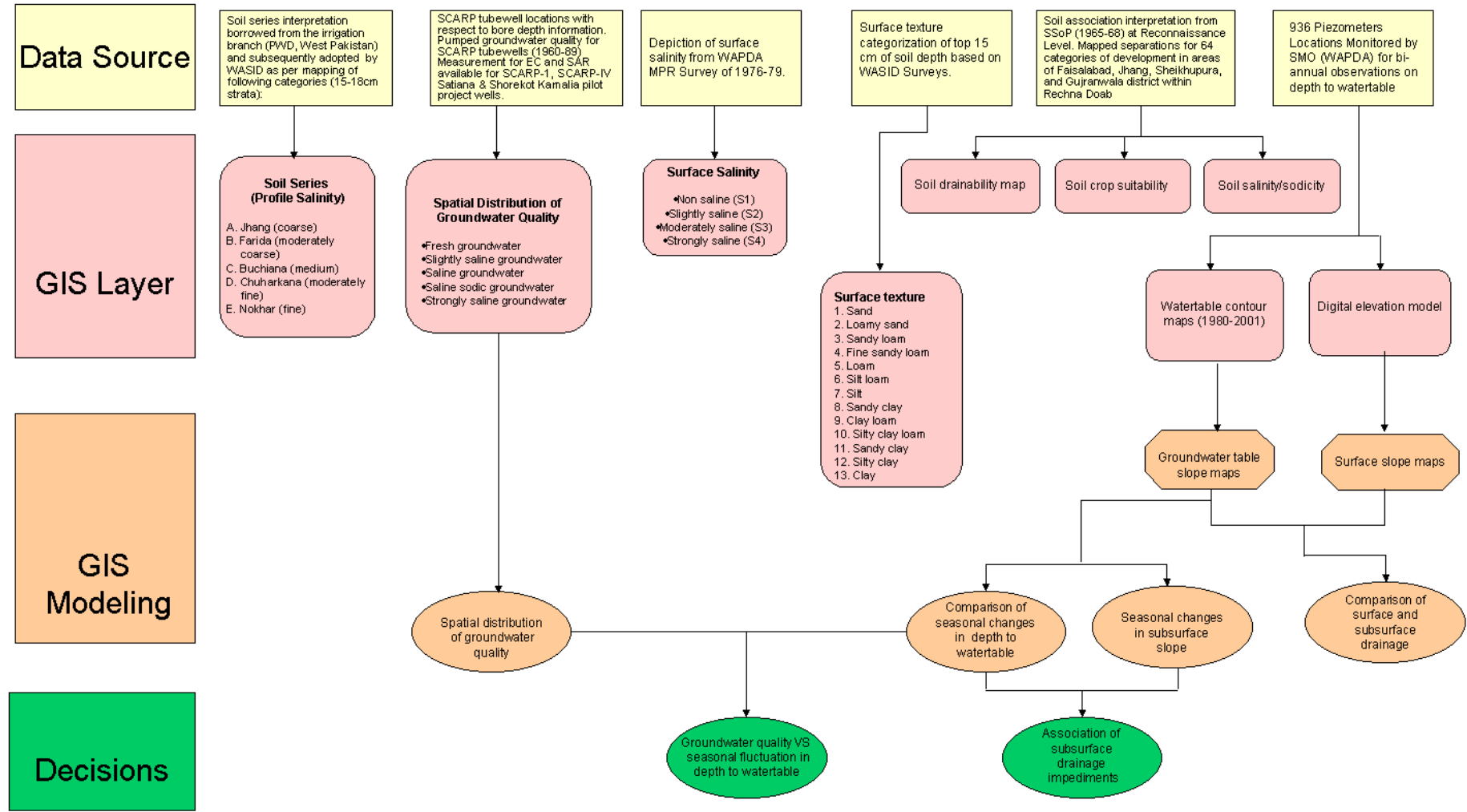
Typical examples of GIS developed and resulted layers are presented in the Annexure 1.

All the spatial layers are managed in to Arcview GIS software. The layout consists of view and the history of source organization, scale of source maps. The red box highlights the current displayed layer in the view and detail of legends.

A view is actually a collection of themes. It defines the geographic data that will be used and how it will be displayed. A theme represents a distinct set of geographic features in a particular geographic data source. For example, a view showing a base map of Buchiana and one theme representing cities, another representing roads, and one more is representing canals, etc. A view is an interactive map that lets you display, explore, query and analyze geographic data in ArcView. Views are saved in the ArcView project.

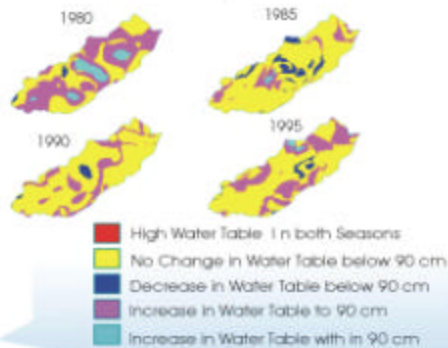
## ANNEXURE I

# Spatial Data Modeling and Decision Support System Buchiana Irrigation Sub-division



# Temporal and spatial analysis of depth to watertable

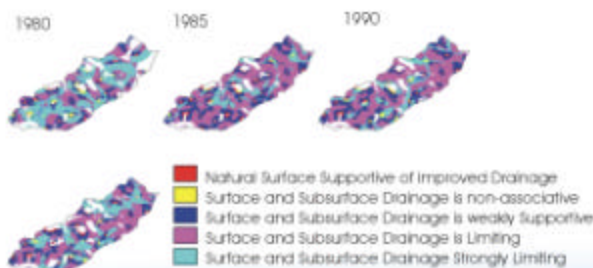
Seasonal fluctuation of Depth to Water Table



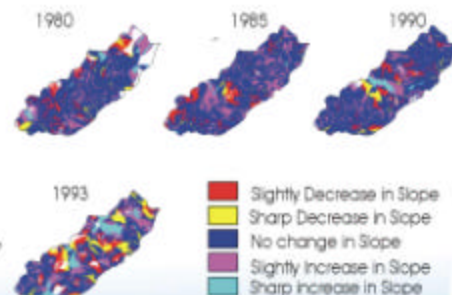
Topography



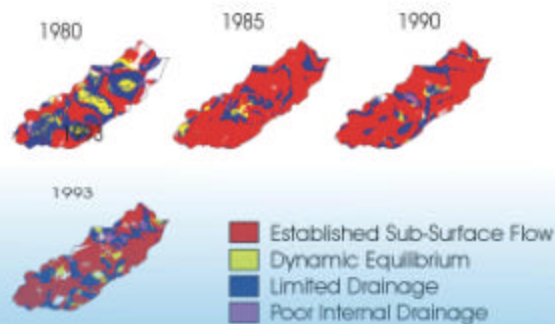
Comparison of Surface and Subsurface Drainage



Seasonal fluctuation of Subsurface Gradient

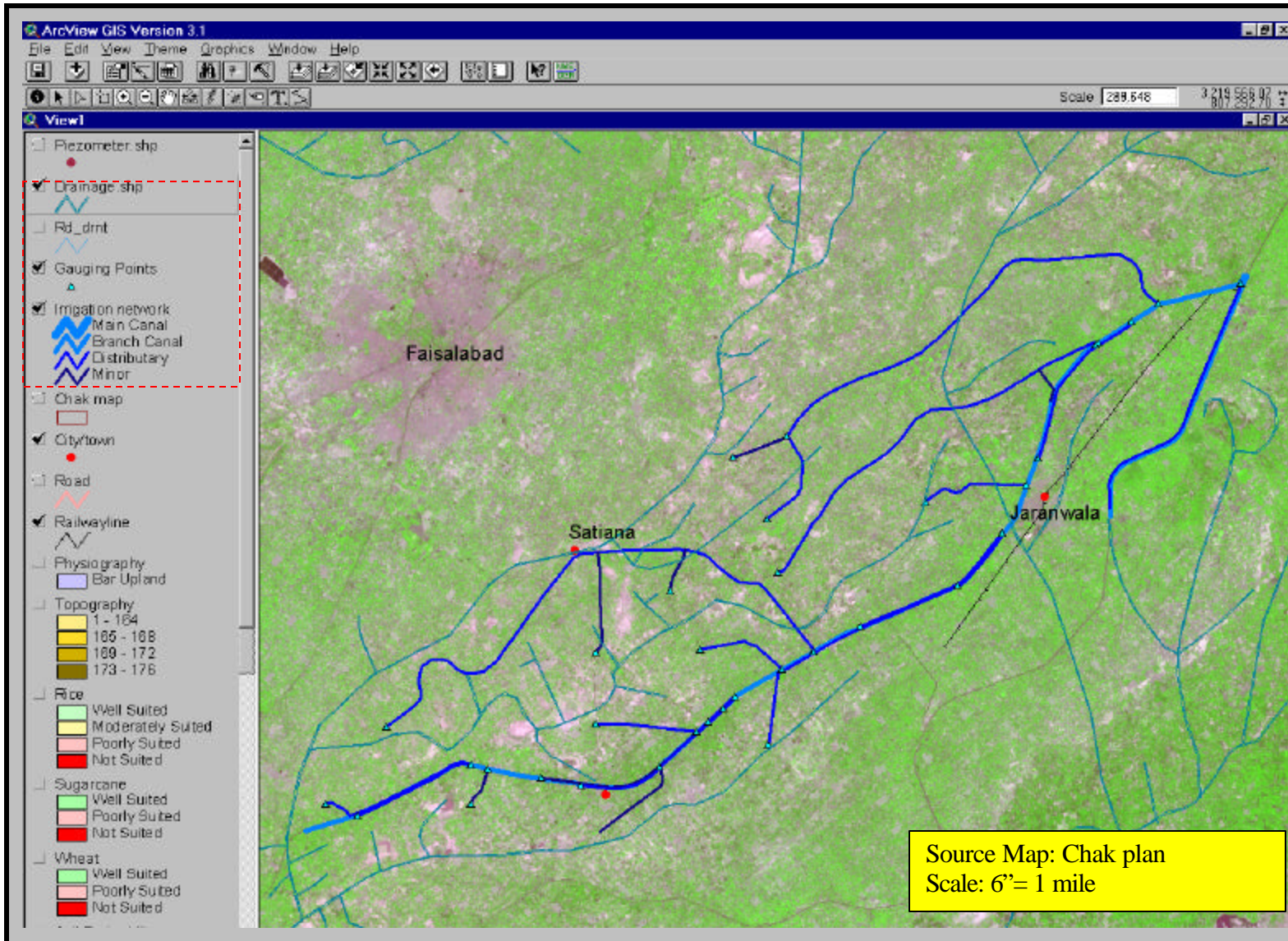


Association of Subsurface drainage impediment





# Irrigation and Drainage Network

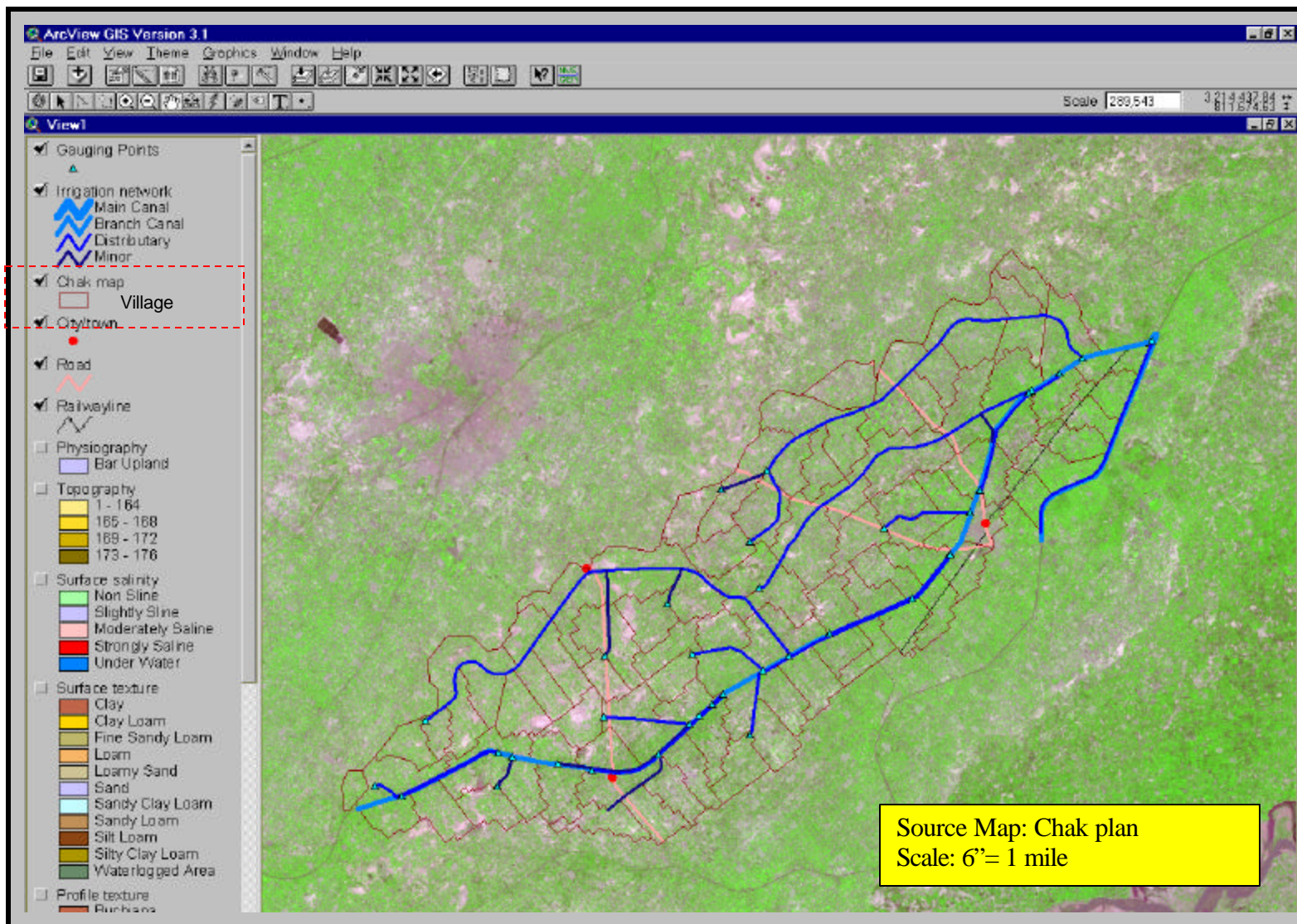


## Irrigation Department

Irrigation department has key role in distributing water and system management. Irrigation department has two major sections: Design section and Revenue section. Design section is responsible for topographic surveys, design of structures and flow measurements. Revenue section collects all the cadastral information. For example, crop assessment surveys, cropping intensities.



# Civil Administrative Units

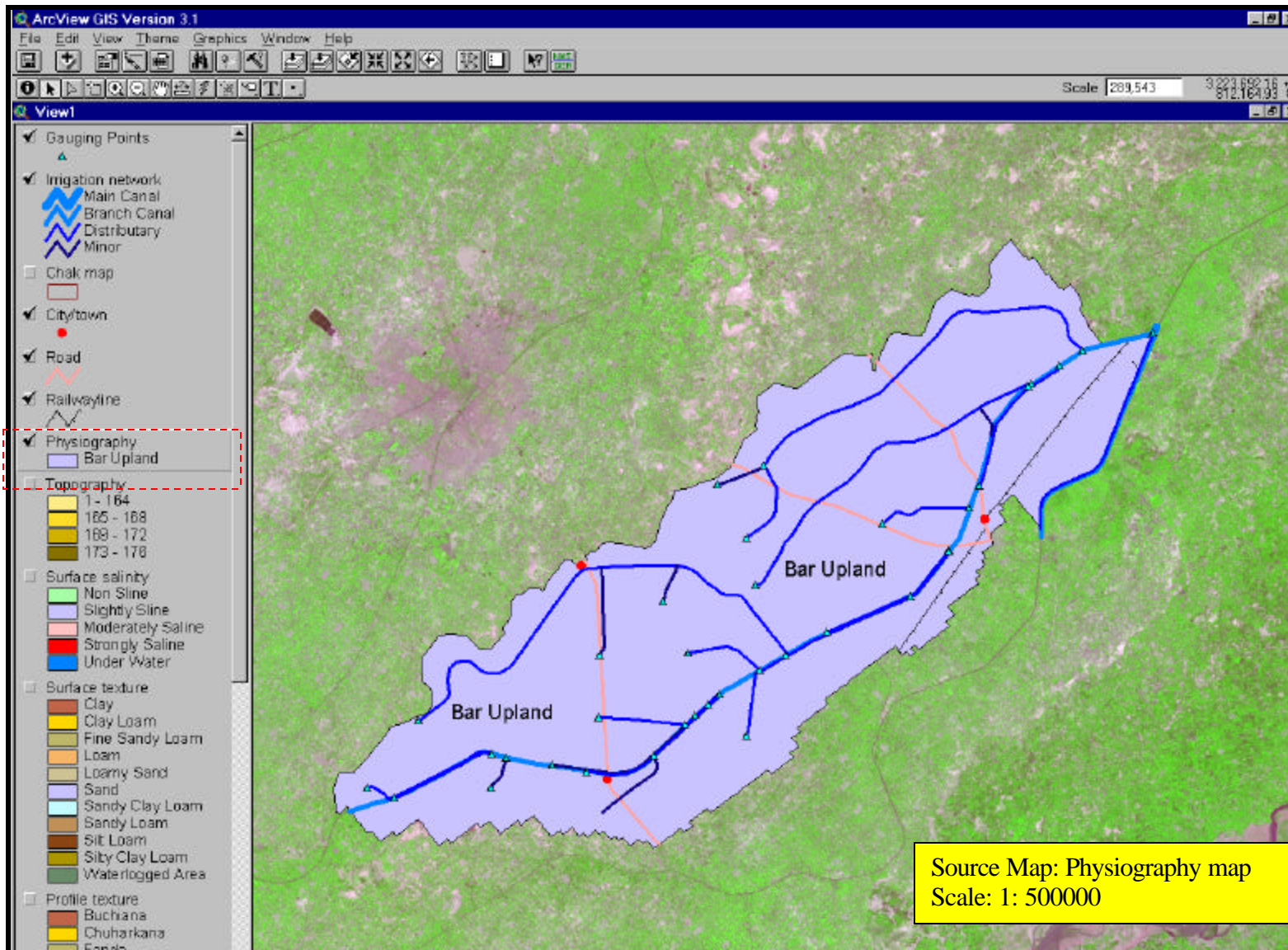


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# Physiography

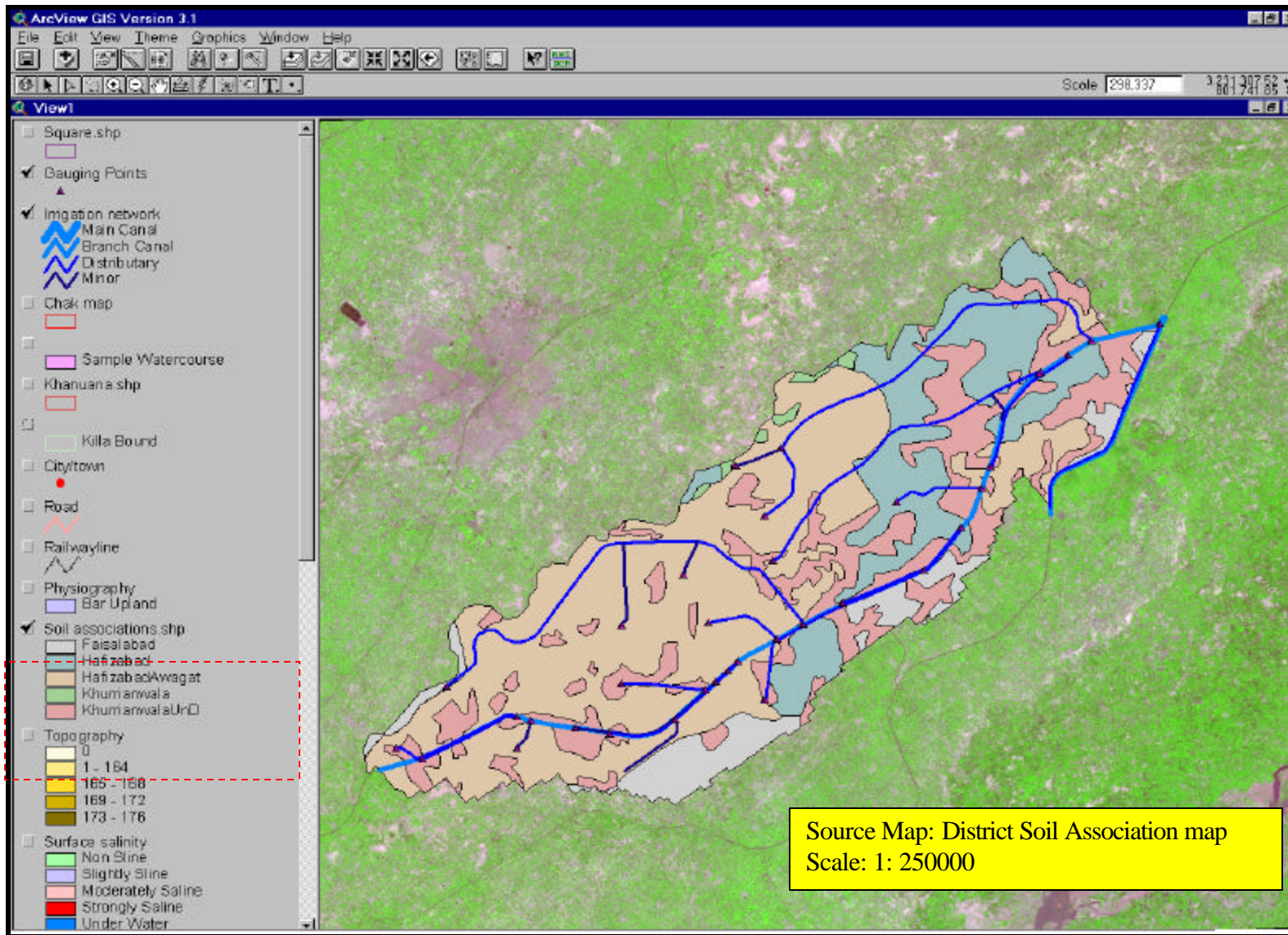


## Soil Survey of Pakistan

Directorate of Soil Survey of Pakistan (SSoP) conducted a survey in 1965-68. Based on the interpretation of the aerial photography available for the area, soils are classified on the basis of their generic characteristics at a reconnaissance level. More emphasis was given on factors like porosity, structure, consistency and drainability.



# Physiography

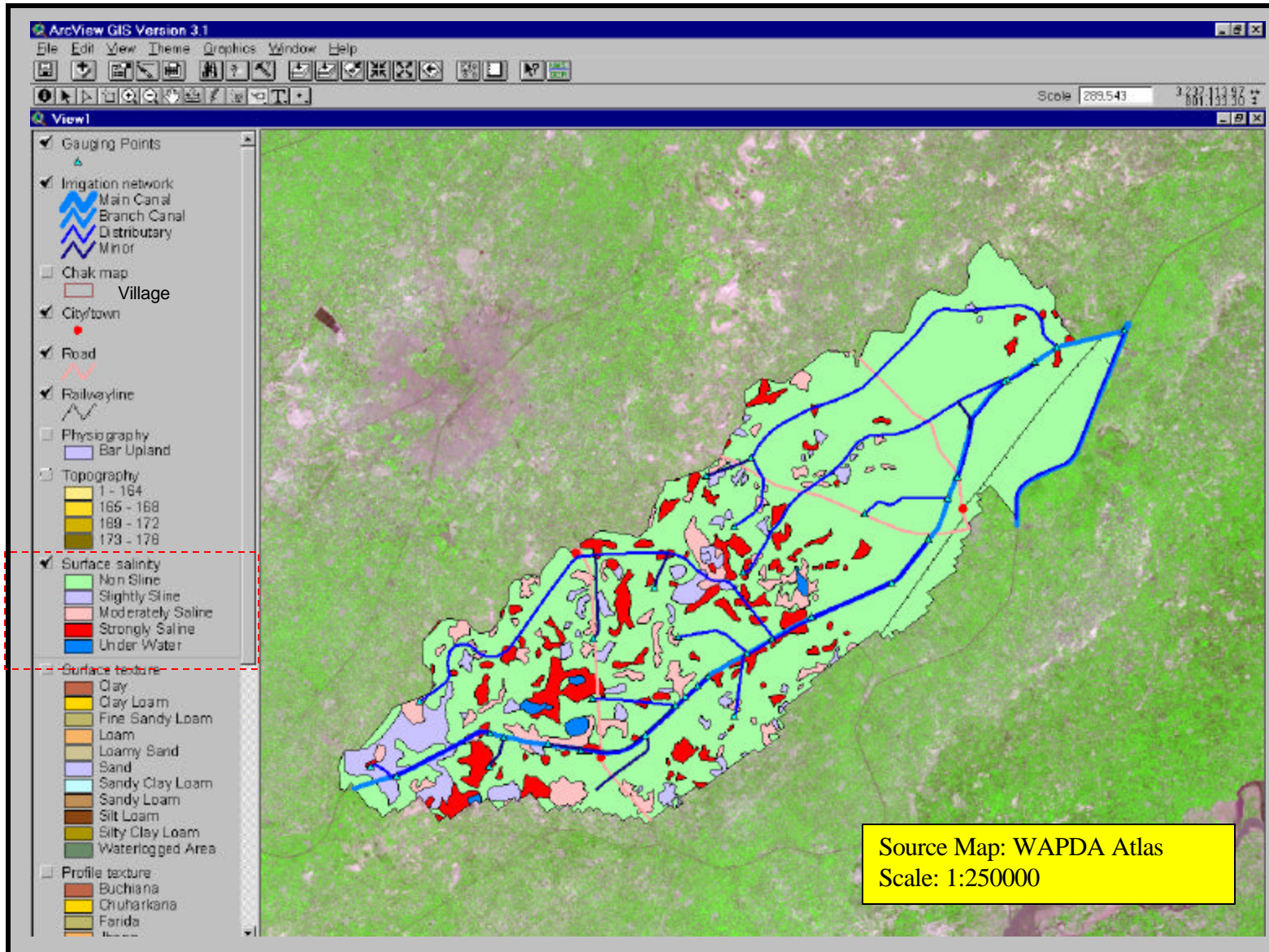


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# Surface Salinity

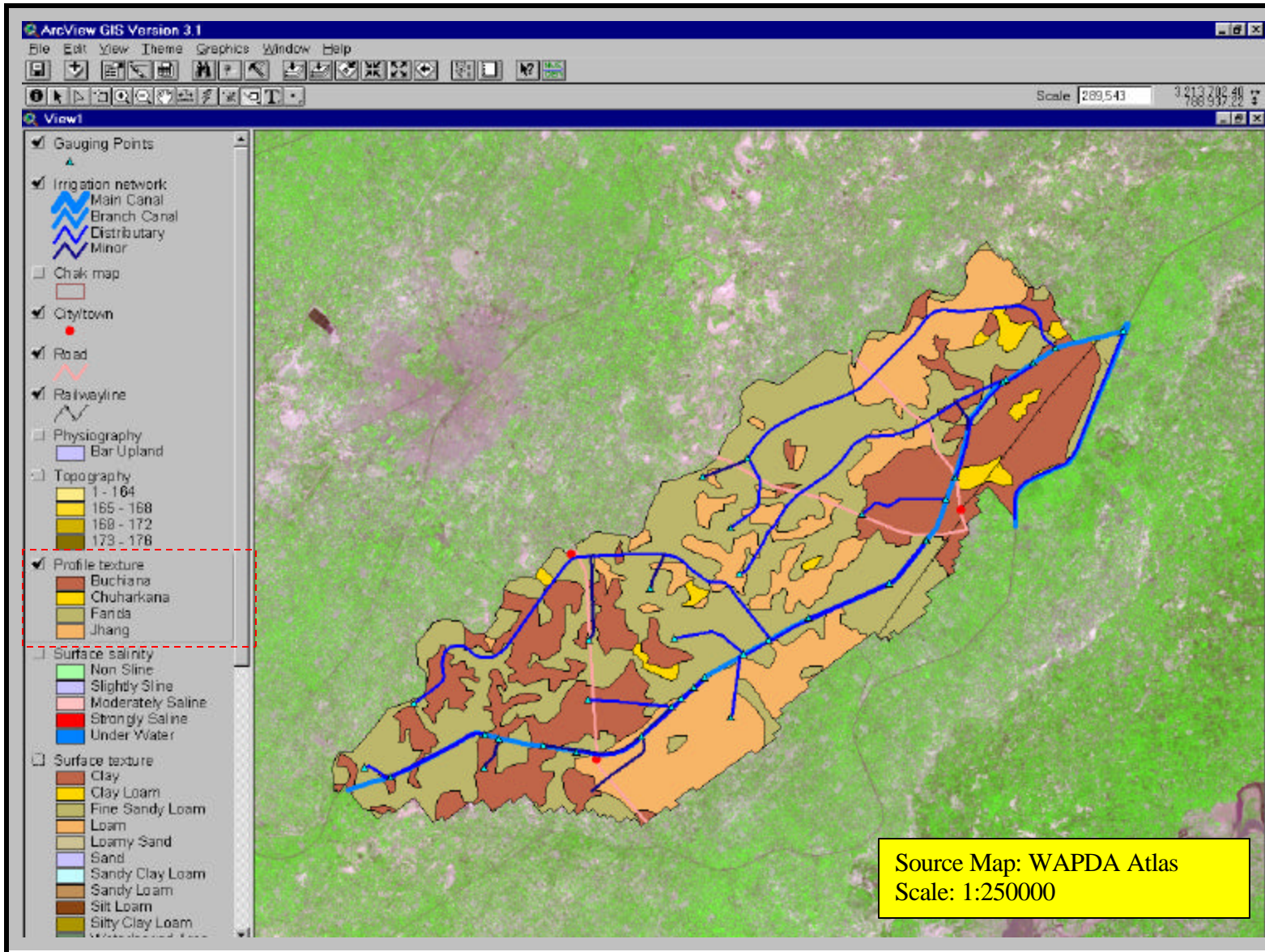


## SCARP Monitoring Organization (SMO), WAPDA

Salinity Control and Reclamation Project (SCARPs) were initiated by WAPDA in 1960. SMO was developed under the planning division to monitor depth to watertables and groundwater quality. SMO is also responsible for conducting soil salinity surveys and performing soil and water analysis.



# Soil Series



## SCARP Monitoring Organization (SMO) WPADA

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