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RESEARCH SUPPORT FOR FORDWAH EASTERN SADIQIA (SOUTH) IRRIGATION AND DRAINAGE PROJECT

SOIL SALINITY-SODICITY AND LAND USE SUITABILITY IN THE FORDWAH EASTERN SADIQIA (SOUTH) IRRIGATED AREA

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EXECUTIVE SUMMARY

In the present study, physiography and **soils,** as welll **as** waterlogging and salinity/sodicity, conditions in the Fordwah Eastern Sadiqia (South) Project area were investigated through a soils survey using satellite images dated December 1998, along with chemical analyses of soil samples and water samples taken from the study area. All of the available literature about the area generally pertaining to physiography and soils, waterlogging and soil salinity/sodicity were reviewed in order to determine trends of salinity/sodicity build-up by comparing the past and present salinity/sodicity research studies. Because suitability and development of land is vital for irrigated agriculture, the land use suitability classificaiton was also made in the present study. The various potential remedial measure are also proposed for mitigation of soil salinity/sodicity in the irrigated land of the project area.

The study area is comprised of **two** terraces; namely.' Pleistocene Terrace and Sub-recent Terrace, occupying **17.6** percent **(24,538** ha) and **82.4** percent (I 15,000 ha), respectively. of the total project area of 139,538 ha. The former terrace lies at a relatively higher elevation than the latter. The soils of the Pleistocene terrace are deeply developed and are of brighter colors (brown to yellowish-brown), while those of the Sub-recent flood plain are less deeply homogenized and of darker colors (brown to dark-brown). The soils of both terraces are predominantly coarse-loamy to loamy (sandy loams, fine sandy **loams** and loams) and are moderately calcareous. Secondary lime accumulation in the form of lime kankers (nodules) are also encountered in the sub-strata of some Pleistocene Terrace soils. The pH values of normal soils range from 8.0 **to** 8.2, while saline-sodic soils are around 8.8. The present configuration is due to wind/water action and ***gives*** rise to high sandy ridges/dunes associated with inter-dunal hollows locally called ***"dhar"***, and nearly level plains. **The** other contrasting features of the landscape are the abandoned, extremely saline, but moderately sodic, low-lying areas subject to accumulation of run-off and seepage water from the adjoining high, very permeable sandy areas, generally sown **to** high-delta crops.

The Pleistocene terrace consists of two physiographic units, namely, the dune land occupying **10.6** percent and level plains occupying about **7** percent of the project area. The Sub-recent terrace comprises three land form units, which are the Rasulpur Terrace, Haroonabad Terrace and Depressional Areas. The Rasulpur Terrace occupies about **7.8** percent, Haroonabad Terrace occupies 72.8 perceni and Depressional **Areas** occupy about 2 percent of the project area. Haroonabad terrace is the most extensive level landform of the area. In the affected areas, the major part of this landform is involved. The soils of this landform are level, deep, homogenized to 30 **to** 40 inches, well drained, non-saline, non-sodic, fine sandy **loams** approaching to loams. In the Haroonabad Terrace the normal hactareage is about **34.3** percent and waterlogged and salinity are 38.5 percent. The area is intensively cultivated, except areas that have been abandoned due **to** sevete waterlogging or salinity, or are partly under high delta crops (sugarcane and rice with moderate to poor yields).

The present study reveals that salinity existing in the area is associated with **a** high water table and covers **an** area of about **23.7** percent. Also, **its** efficacy **has** begun to manifest itself even in the middle reaches **of** the canals that were previously safe, **as** the farmers are replacing cotton with rice cultivation because the cotton-yields are decreasing gradually due to a high water table **in** the area. Presently, the areas appear normal (water table depth ranging between 150- I80 cm, without salinity), but are liable to be infested with the twin menace of waterlogging and salinity in the future. About **17.8** percent of the FESS area falls in this category. NESPAK in 1975-76 and WAPDA in 1986 figured the **salinity** to be **9.2** percent and 8.7 percent of the FESS area, respectively, and also hinted about **a** somewhat

downward trend/equilibrium state, but the present study revealed that at present. about 23.7 percent of the project area has been salinized.

Chemical analyses of soil samples mostly collected from saline soils showed that though the soils are saline, they contain leachable salts (chlorides, sulphates and bicarbonates of Na, Ca and Mg). These soils also have a sufficient quantity of gypsum for self-reclamation. Chemical analyses of groundwater from various sources and depths manifest clearly that it is marginal and hazard zone for irrigation purposes. but its residual sodium carbonate (RSC) and carbonates are nil and the pH values are below the dangerous value of 8.5. Therefore, the salts concentration created by tubewell irrigation is leachable with a few heavy irrigation turns of canal water. On the other hand, the soils are also permeable. Hence, canal water can be supplemented with groundwater.

According to the land use suitability classification, about 55,518 ha (39.79%) of the project area consists of highly suitable land with very high economic potential under irrigation. This land is capable of growing a wide variety of crops including fruit orchards, which are ecologically suited to the area. The groundwater is hazardous for irrigation in most of the area. However. canal water could be supplemented by installing skimming wells along the irrigation channels where shallow groundwater is not of bad quality.

An area of about 53,783 ha (38.54%) forms moderately suitable land with a high economic potential under irrigation. This land has moderate limitations for agricultural production due to high water table (120-150cm), slight to moderate salinity and moderately coarse textured soils. By improving the regional drainage system, installing skimming wells, using modem management practices and selecting low delta crops, very high crop yields could be assured.

Comparatively, a small area of about 12,698 ha (9.10%) constitutes marginally suitable land with moderate to poor economic potential under irrigation. This land is infested with moderate to strong limitations for agricultural production with a very high water table (60-120cm) associated with moderate to strong salinity, mostly accompanied with surface sodicity. This land can be rehabilitated agriculturally only by lowering the water table through lining the irrigation channels, installing skimming wells and banning the high delta crops, or by installing subsurface drainage. These lands have sufficient gypsum for self-reclamation. By adopting these remedial measures, good crop yields could be obtained.

Agriculturally unproductive lands consist of areas under water and stabalized sand dunes, which comprise about 17,539 ha (12.57%). A major portion, about 14,750 ha (10.57%), are sand dunes with 15 to 30 percent vegetative coverage, uneven topography, moderately coarse to coarse textured soils. A few patches of sand dunes are sown to oilseeds and barley as barani cultivation. Otherwise, they provide poor grazing and fuel wood. Depressional ponds could be practised as fish farms.

In the entire project area, salinity/sodicity is associated with the high groundwater table. To mitigate salinity/sodicity, lowering the groundwater table to below the capillary rise range should be the first priority. Therefore, the proposed potential remedial measures are mainly concerned with the emphasis on lowering the water table to below the capillary rise range, or at a depth where its deteriorating influence could be minimized by continuous cropping. The remedial measures include On-Farm Water Management, Canal Improvement, Groundwater Development, Farmers' Participation, Surface Drainage System, Subsurface Drainage System, Reclamation Approach, and Biological Approach.

1. INTRODUCTION

1.1. Location and Extent of the Study Area

The Fordwah Eastern Sadiqia (South) (FESS) Irrigation and Drainage Project falls in the Bahawalnagar District of the Punjab Province and partially covers the Bahawalnagar, Haroonabad and Chishtian Tehsils. Located about 200 km south of Lahore, it lies between longitudes 72-40 and 73-25 East and latitudes 29-25 and 30-00 North. The project area is triangular in shape and is bounded by the Malik Branch and its Murad Distributary in the north and north-west, Haran Minor in the west, the Hakra 6-R Distributary of the Hakra Branch in the south, and the Indian boundary in the east (Figure 1). This area covers about 139538 hectares (ha).

1.2. General Nature of the Area

The project area is nearly leveled, mostly medium to coarse-textured river alluvium plain with many scattered, stabilized, 10-50 ft. higher-than-general ground level sand dunes and depressional areas, 10-20 ft. lower-than-general ground level, where water stagnates throughout the year. The project area has been under perennial canal irrigation for more than 50 years, and only in the last 20 years has the effect of salinity been associated with a high-water table (groundwater table rises to the capillary rise range) in the soils, which has begun to affect the ecological agricultural production noticeably. There are now significant areas of abandoned farms due to excess salinity caused by the high water table. Presently, several agencies are engaged in restoring the previous agricultural productive potentiality mainly by lowering the water table. For example, WAPDA, through Mott MacDonald, is lining some irrigation canals, distributaries and minors to minimize water seepage, which goes to the groundwater and causes a high water table. EUROCONSULTANTS are also busy spreading a well-knit surface drainage system. and IWASRI is experimenting with a sub-surface drainage system. These efforts may salvage the agricultural lands of the project from the effects of waterlogging and salinity, regenerate the agricultural potential in deteriorated soils and save the remaining unaffected land.

1.3. Irrigation

1.3.1. Canal Supplies

The canal system for the project area begins with the diversion from the left bank of the Sulemanki Headworks to the Eastern Sadiqia Canal, which runs for a distance of some 46 miles (74 km) and then forks into the Hakra and the Malik Branch Canals at the beginning of the project area. Distributaries, minors and sub-minors off-take from each of the canals. The details of the canals system are shown in Table 1.

The design of the canal system is based on a water allowance of 3.6 cusecs per 1000 acres (0.085 cumec per 400 ha), which would permit a cropping intensity of about 80 percent (40% each season), The quality of the surface water is good (about 300 mmhos/cm). Following the 1960 Indus Water Treaty with India, the area receives its water supply through the Balloki-Sulemanki link, which brings it under the command of Mangla reservoir. Most of the channels are unlined and due to the previous nature of the soils, leak large quantities of water. This seepage is one of the major reasons for the waterlogging and salinization of soils in the project area.

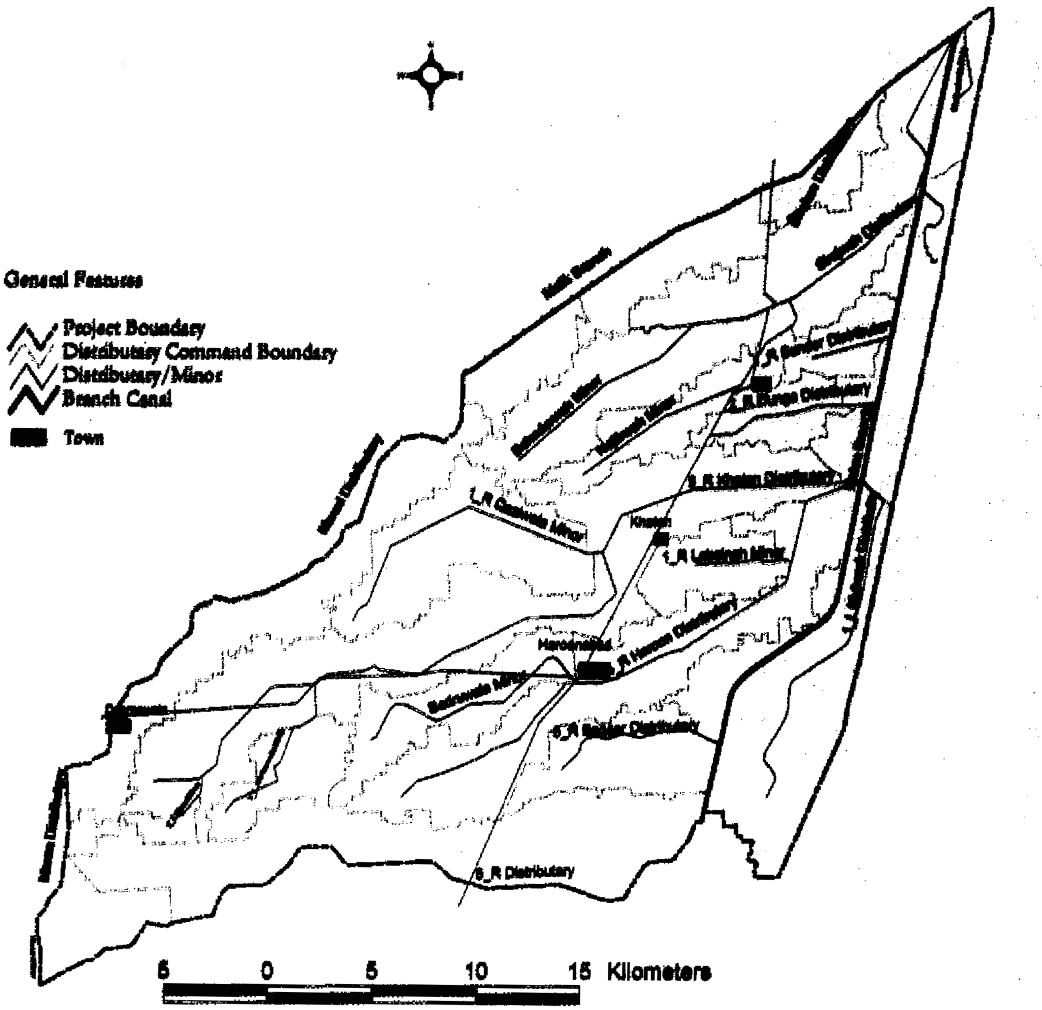

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Figure 1. Location Map of Fordwah Eastern Sadiqia South (FESS) Irrigation and Drainage Project.

Table 1. Details of the Canal System.

	Channel Type	GCA (Acres)	CCA (Acres)	Number of Watercourses	Authorized Discharge (Cfs)
Eastern Sadiqia (Total)	M	297604	258701	668	523016280
Girdariwala	DY	4033	3041	9	13
Sirajwah (Total)	DY	49176	44121	113	I97
Direct Outlets	WC	18081	15679	37	58
Najibwah	MR	9793	9473	27	39
Bahadarwah	MR	20363	18350	47	82
1-R/Bahadarwah	MR	935	917	2	3.6
Malik Branch (Total)	BR	48392	41302	89	1538
Direct Outlets	WC	15739	12465	22	47
Bhukan	DY	5369	3835	10	13
Murad	DY	22402	21002	46	595
Haran	MR	3940	3103	9	69
Shadab	SMR	942	897	2	3.5
Hakra Branch (Total)	BR	196003	I69937	457	2708
Direct outlets	WC	22240	19285	45	35
Bhaku Shah	DY	1569	1514	3	6
1-R Sunder	DY	5123	4990	11	19
2-R Dunga	DY	6764	5643	14	20
3-R Khattan (Total)	DY	81 195	70316	186	307
Direct outlets	WC	51365	45334	116	168
1-R Qaziwala	MR	19552	16779	46	66
1-L Jourkanwala	MR	8144	6408	19	27
2-L	MR	2134	1795	5	7
4-R Haroonabad (Total)	DY	49439	44307	I29	189
Direct outlets	WC	30064	27609	81	117
1-RA Labh Singh	MR	6967	6077	16	22
1-R Badruwala	MR	12408	10621	32	43
1-L Mubarak	DY	18861	14500	44	67
5-R Baghsar	DY	10812	9382	25	36
Total		297604	258701	668	
Say		298000	259000		
Total (ha)		121000	105000		

M = Main Canal; BR = Branch Canal; DY = Distributary; MR = Minor; SMR = Sub-minor; WC=Watercourse

Turnouts (*moghas*) into watercourses from all levels of the canals are operated and maintained by the farmers receiving water. On a fixed turn basis, each fanner is permitted to take the entire flow of the watercourse for a length of time that is proportional to the area of land he owns. The rotation of service is repeated each seven to ten days. The farmer then distributes the water over his fields to the extent he chooses for cropping with the limited water supply. Most frequently, he uses basin flooding to spread the water in the fields. The canal system is operated at near the full capacity for some eleven months in the year.

1.3.2. Groundwater

1.3.2.1. Depth to Water Table

Regular monitoring of the water table is not being carried out in the project area. WAPDA had prepared a depth to water table map in June 1987. According to the information provided in the World Bank staff Appraisal Report for the project, about 50 percent of the project area is presently considered waterlogged with a permanent water table within 5 ft. (1.5 m) of the surface. The estimate is that more than 45 percent of the supply from the canal head up to farms percolates to the groundwater. Waterlogging first appeared on lands in the upper reaches of the Hakra Branch and is gradually moving down stream channel affecting an additional 15,000 acres (6,000 ha) each year. Currently, 11 percent of the area has a groundwater table of less than 2.5 ft (0.76 m), 17 percent of 2.5-4 A (0.76-1.22 m) and 21 percent of 4-5 ft (1.22-1.52 m).

In the project area, the average EC of the deep groundwater is about 19000 micromhos/cm. The shallow water quality is also of a highly hazardous nature and the average electrical conductivity of the project area is 12900 micromhos/cm. However, water quality at a very shallow depth, tapped by hand pumps and along canals, is comparatively much better. Some water samples from hand pumps and tubewells located along canals were collected by NESPAK during December 1991. Results of these sampling indicate that water from these tubewells along the canals could be used for irrigation purposes.

2.3.2.2. *Groundwater Development*

Because of poor aquifer conditions and marginal to hazardous quality groundwater (generally above 1500 micromhos/cm), only limited groundwater development has taken place. Recently, some small private tubewells (*one* cusec or less) have been installed to provide supplemental irrigation water during periods of peak crop water requirements. These tubewells are mostly located close to irrigation channels because the groundwater quality around these channels is relatively better. due to excessive seepage.

1.4. Drainage

There is no natural drainage system; roads and the irrigation system have blocked most of the overland run-off. The project area was included as SCARP VIII in the regional development program for the Northern Indus Plains prepared by Tipton and Kalmbach, Inc. (consultants to WAPDA) in 1967. NESPAK redefined it in 1978, to cover a total of 1.67 million acres (676353 ha) on the left side of the Sutlej River in the Fordwah and Sadiqia Canal commands. Out of this total, a pilot project of 77800 acres (31509 ha), known as the Minchinabad Pilot Project, was implemented in the 1970s. In 1987, WAPDA further redefined the project area, excluding areas underlain by fresh groundwater and the area covered by the Command Water Management Project (CWMP) This project, named the Fordwah Eastern Sadiqia Remaining Phase-I (SCARP-VIII), covered about 618,500 acres (*250,500* ha). The most recent version of this project consists of two parts, the Northern and the Southern zones. An independent network of surface drains has been planned for each *tone.* The surface drains in the northern zone are to discharge *into* the Sutlej River below the Islam Headwork. The surface drains in the southern zone are to discharge into a series of evaporation ponds situated at the end of the natural slope in the southwest of the project area in the Cholistan Desert. The same evaporation ponds would be used to dispose of drainage effluent from the Hakra 6-R Distributary subproject of CWMP. All the planned surface drains in the southern zone fall in the area of the proposed Fordwah Eastern Sadiqia

(South) Project, Phase-1; therefore, these drains have now been included in the FESS Project with the mutual agreement of donors, WAPDA and GoP.

1.5. Objectives

The main objectives of the present study are:

- To study the physiography and soils of the study area:
- To investigate waterlogging and salinity/sodicity conditions in the project area:
- To map the location and extent of the waterlogged and salt-affected area;
- To determine trends of deterioration or amelioration by comparing past and present research studies;
- To determine the land use suitability classification; and
- To propose/recommend various remedial measures (feasible/practicable and economical) for managing waterlogging and salinity/sodicity in order to sustain agricultural productivity of the project irrigated area.

2. PREVIOUS STUDIES ON SALINITY/SODICITY IN THE FESS PROJECT AREA

Water And Power Development Authority (WAPDA); Soil Survey of Pakistan (SSP) and National Engineering Services Pakistan (Pvt.) Limited (NESPAK) conducted soil surveys of the project area and remained engaged in the land resources inventory in the past years. The results of investigations carried out by these agencies are briefly described below.

2.1. Studies by WASID, WAPDA (1962-63)

The Water and Soil Investigation Division (WASID) of WAPDA studied the soils of the project area in 1962-63 (WASID, 1963). The survey was carried out at a semi-detailed level, with 4 to 6 observations per sq. mile using airphoto enlargements (1:15840) of 1:40000 contact prints taken in 1952-54. Three soil series, namely, Farida, Buchiana and Chuharkana, were recognized and mapped mainly on the basis of textural appraisal of the upper 72 inches (180cm) of depth (sub-soil), except the texture of the plough layer. These series correspond to moderately coarse (Farida series), medium (Buchiana series) and moderately fine (Chuharkana series) textures. The results of this study are presented in Table 2. This means that in 1962-63, only 1.8 percent of the project area was infested with surface salinity.'

Table 2. Extent of Surface Salinity 'Classes by WASID, WAPDA (1962-63).

Salinity Class		Acreage	Percentage
Non-saline (SI)		256370	98.2
Slightly-saline (S2)		4165	1.6
Moderately-Saline (S3)		245	0 1
Strongly-saline (S4)		220	0.1
	Total	261000	100.00

The profile-salinity investigations indicate that 15.6 percent of the project area has been inflicted with different classes of salinity-sodicily in 1962-63. The percentage was calculated from the number of profiles investigated at the rate of one profile approximated at each grid of the G.T.SHEET.

2.2, Studies by Soil Survey of Pakistan (1971)

The Soil Survey of Pakistan carried out the soil survey of the Project area as a part of a reconnaissance soil survey of the Bahawalnagar area, with an average density of 2 auger holes per sq. mile (Ansari and Hamid, 1971). Airphotos taken at a scale of 1:40000 in 1952-54 were used as base maps and soils were examined up to I50 cm (5 ft) depth. The basic of soil identification used was the soil series. which were differentiated on the basis of significant differences in the sub-soil color. texture, structure, porosity, drainage, salinity/sodicity and thickness of the soil profiles. Soil series (two or more) occurring in the same physiographic unit and occupying certain predictable facets. in the landscape were grouped into soil associations, which constituted the mapping units shown on the published map of 1:50000 scale. A study of the map shows that six associations exist in the Project area. The associations. with brief descriptions are provided in Annexure 1.

These characteristics pertain to subsoil. All the soils are brown/dark brown to yellowish brown in colour. calcareous, massive to weakly structured. non-saline/non-sodic, except when otherwise stated. Textures are as per field appraisal; the pH was tested in the field using Thymol Blue indicator.

From the descriptions of the associations, it is revealed that only the Murad association is saline-sodic, but all other associations have saline-sodic soil as their components. By adding these saline-sodic acreage of the six soil associations, it is manifested that salinity exists in 5.9 percent (15,415 acres) of the total area. The texture-wise percentage and extent are details 4.3 percent (11,220 acres) as fine, 0.9 percent (2340 acres) medium, 0.0 % (1440 acres) coarse and 0.1 % (415 acres) moderately fine textured, The pH of saline-sodic soils ranges from 8.6 to 8.8. The intensity of the surface, as well as profile salinity. however, has not been mentioned by the survey agency.

2.3 . NESPAK Salinity Survey (October 1975 to March 1976)

NESPAK used the same airphotos of WASID at the 1:15840 scale and conducted a soil survey during October 1975 to March 1976 at a semi-detailed level, with 4 to 6 observations per sq. mile (NESPAK, 1978). The surface salinity visualized by NESPAK is presented in Table 3.

Table 3. NESPAK Salinity Classes.

Salinity Classes	Acreage	Percentage
Non-saline (S1)	2,362,466	90.6
Slightly-saline (S2)	16,545	6.3
Moderately-saline (S3)	6,140	2.4
Strongly-saline (S4)	1,215	0.5
Area under water	515	0.2
Total	2,60,881	100.00

NESPAK used the same air photos of WASID and studied 117 soil profiles in order to investigate profile salinity. Of these, 71 (60.7%) profiles were normal throughout the tested depth of 72 inches. The remaining 46 profiles (39.3%) were affected by saline and/or sodic conditions in some depths. This shows that both, surface as well as profile salinity has increased from 1.8 percent to 9.2 percent and from 15.6 percent to 39.3 percent, respectively, during the period of about 13 years (from 1962-63 to 1975-76).

2.4. Salinity Survey by Master Planning Division of WAPDA (1977-78)

Again, in 1977-78, the Master Planning and Review Division of WAPDA carried out a salinity-sodicity both surface and profile salinity survey of the project area and revealed the findings shown in Table 4. The survey was conducted at a semi-detailed level using the air photos at 1:30000 scale taken in 1976 (Review and Master Planning Division, 1979). Previously, all the salinity studies carried out by different agencies like SSP, WASID-WAPDA, NESPAK used the air photos taken in 1952-54.

Table 4. Salinity Extent by Master Planning Study.

Salinity Class	Acreage	Percentage
Normal (SI)	2,41,860	92.7
Slightly Saline (S2)	12,150	4.7
Moderately Saline (S3)	2,830	1.1
Strongly Saline (S4)	3,710	1.4
Area under water (U/W)	450	0.1
Total	2,61,000	100.0

Quite clear from the above table is that the total surface salinity is about 7.2 percent. Of this, 4.7, 1.1 and 1.4 percent was slightly, moderately and strongly saline, respectively.

2.5. WAPDA Updated Salinity Data (1986)

In 1986 the Planning Directorate (Water). Central, of WAPDA updated the soil classification and surface salinity studies carried out by WASID in 1962-63, and the Master Planning Division in 1977-78. The updated survey was conducted at a semi-detailed level using 1:30000 air photos taken in 1976. The findings of this study regarding surface salinity are provided in Table 5 (Planning Directorate Water Central, 1988). Again, surface salinity has increased from 7.2 percent in 1977-78 to 8.7 percent in 1985-86.

Table 5. Updated Areas of Surface Salinity Classes (1985-86).

Salinity Class	Acreage	Percentage
Non-saline (SI)	2,35,880	90.4
Slightly-saline (S2)	13,490	5.2
Moderately-saline (S3)	2,655	1.0
Strongly-saline (S4)	6,565	2.5
Area under Water (U/W)	2,410	0.9
Total	2,61,000	100.0

In summary, in 1962-63, only 1.8 percent of area were saline at the surface, which increased to 5.9 percent in 1971. According to the NESPAK survey in the winter months of 1975-1976, surface salinity was 9.2 percent. However, the Master Planning Division Survey of 1977-78 reduced the saline area to 7.2 percent, which increased to 8.7 percent by the Planning Directorate (Water), Central, WAPDA Survey in 1986. This indicates an increase of 1.5 percent within a period of about 10 years. There is reduction of about 2 percent (9.2 vs. 7.2%) between the NESPAK survey conducted in the winter months of 1975-76 and that of the Master Planning survey in 1977-78. This reduction is ascribed mainly to the exceptionally wet monsoon season of 1976, when there was 18" rainfall at Bahawalnagar, 21"in Gulab Ali, 18"at Faqirwali, 28"at Dahranwala and 13"at Chishtian. After such heavy rains, there must be some washing away of surface salts. as well as, especially, their partial leaching deep in the soil profile in low water table areas. this results in more sodification of the soils. Hence, the statistics of both, surface and profile salinity of 1977-78 are less than those of 1975-7G. However. the figure of the 1986 WAPDA survey is less by 0.5 percent (8.7 vs. 9.2%) than those of the NESPAK survey in 1975-76, which is also of little significance and is indicative of an equilibrium in the extent of surface salinity.

3. RESEAKCH METHODOLOGY

In order to determine recent soil conditions (waterlogging and salinity/sodicity) of the study area, the soil investigation survey was carried out during the months of February to April 1999 using satellite images at a scale of 1:440000 taken in December 1998 as a base map. Before going to the area in order to conduct the soil-salinity survey, the digitized soils association polygons (each association contains mote than two soil series) of the FESS area, mapped by SSP, were over laid on these images. Then, these images were taken to the field and were used as base maps to conduct soil and soil-salinity surveys in detail. By this procedure the soils association polygons were reshaped into soils consociation polygons, which were further mapped, where necessary, at a phase level because each soil/phase has a certain topographic position in the landscape, which are shown by tonal differences of the satellite images and can be delineated with the help of some additional ground truthing.

In the office, the satellite images of the area were thoroughly studied and their photo-patterns, tonal differences. land uses and parceling patterns, ctc. indicating landforms and different drainage designs were delineated. These marked differences were studied in detail in the field noting down the external (environmental) and internal (soil profile) salient characteristics that influence the ecological agricultural production potential of soils, directly or indirectly. Externally, these characteristics include land form, salinity. crop condition, management practices including mechanical cultivation and cropping intensities. Internally, these consist of texture. structure, color including mottles. sodicity (pH value with Thymol Blue indicator). consistence calcareousness, depth to groundwater, lime concretion zone (sometimes present) arid impervious layer, texurally-comprised fine-silty/clayey. These were noted in the field for all the augerholes and soil pits. But, some most representative augerholes and all the soil pits were sampled and the chemical determinations, such as ECe, cations (Ca, Mg, Na, K), anions (SO4, CO3, HCO3, Cl), pH, SAR, soil gypsum requirement per acre and lime percentage were made at the chemistry laboratory.

For this purpose, 106 augerholes to the dcpth ranging from 5 to 7 feet and 3 soil pits of 6x4x6 ft dimensions. or to the dcpth of sloughy soil material, or to the depth of groundwater table, were dug in the representative sites for a horizon-wise detailed study of each soil profile. Ten (10) representative sites of augerholes were sampled from the depths of 0—6, 6—18, 18—36, 36—72 inches or to the reach of sloughy soil material or to the depth of groundwater table. But, all the soil pits werc described in detail and sampled according to the horizon-wise depth (Annexure II). The total (41) of soil samples were collected and handed over to the laboratory staff, mostly for the determination of chemical properties. Twelve (12) water samples of (5 tubewells, 3 augerholes, 1 hand pump, 2 soil pits, 1 sub-surface drainage trial site I near to the Malik Branch Canal) were also collected and their detailed chemical analyses were conducted at the Soil and Water Testing Laboratory.

The soil association-imposed satellite image, after delineating various soils and phases boundaries were handed over to the GIS Section for digitizing the newly-drawn soil/phase boundaries. The soil legend was prepared and given to the same section for drafting. The Soil Salinity and Land Use Suitability niaps were derived out of the Soil Map using a similar scale of 1:200000 .The basic information about landforms and soils was taken from the Reconnaissance Soil Survey Report of the Bahawalnagar area (Ansari and Hamid, 1971). Approximately, all the available literature about the area generally pertaining to soil. soil salinity/sodicity and groundwater table. with its quality. were reviewed. These agencies were the Soil Survey of Pakistan, WASID-WAPDA, NESPAK, which actually remained busy preparing a soil inventory of the area at different times.

4. RESULTS AND DISCUSSION

4.1. Physiography and Soils

Based on genetic age and geomorphologic characteristics of the soils, the survey area comprises two distinct terraces: (1) Pleistocene Terrace and (2) Sub-recent Terrace. The parent material of both terraces is river alluvium, deposited in different periods. Pleistocene terrace (an oldest terrace) and Sub-recent flood plain occupy 17.6 percent (24538 ha) and 82.4 percent (115000 ha), respectively. The former terrace lies at a relatively higher elevation than the latter. The soils of the Pleistocene terrace ate deeply developed and are of brighter colors (brown to yellowish-brown). while those of the Sub-recent flood plain are less deeply homogenized and of darker colors (brown to dark-brown). The soils of both terraces are predominantly coarse-loamy to loamy (sandy loarns, fine sandy loams and loams) and are moderately calcareous. Secondary lime accumulation in the form of lime kankers (nodules) are also encountered in sub-strata of some Pleistocene terrace soils. The pH values of normal soils range from 8.0 to 8.2. while those of saline-sodic are around 8.8, The present configuration is due to wind/water action that has partly modified it and gives rise to high sandy ridges/dunes associated with inter-dunal hollows locally called "dhar", and nearly level plains. The other contrasting features of the landscape are the abandoned, extremely saline. but moderately sodic, low-lying areas subject to accumulation of run-off and seepage water from the adjoining high, very permeable sandy areas, generally sown to high-delta crops. The physiography and soil, with their phases found in the project area, are presented in the Physiography and Soils Map (Appendix A) and also being discussed below.

4.1.1. Pleistocene Terrace (24538 ha, 17.6%)

This is an oldest plain and is located mostly along the eastern side of the Project area toward the Indian border. .Occupying higher elevation than the Sub-recent plain, these two plains are separated by an escarpment. which was characteristically cut at the edges and is easily distinguishable on both ground and the air photos taken in 1952-54. But, at present. most of such cuts have been leveled and sown to crops, and vivid tonal differences on the satellite images taken in December 1998 are not distinguishable. This terrace consists of two physiographic/land form units, namely. "Dune land" and "Level plain".

4.1.1.1. Dune Land (14750 ha, 10.6%)

Dune land contains wind-resorted stabilized sand dunes at 10 to 50 ft higher than the general ground level and are scattered in the entire FESS area, but its main and continuous occurrence is along the Indian border and in the south-western corner of the area. The sand dunes have a sparsely vegetative cover of about 20 to 30 percent of the surface area. Texturally, they are sandy loams approaching loamy sands, deeply homogenized and a sufficient acreage of these sand dunes are sown to oil-seeds (Taramira and Sarsoon), and barley as barani cultivation. Along the Indian boarder, lift-irrigation covers almost the whole area comprising such land. The over-grazed and devegetated portions of these sand dunes become prone to wind erosion, therefore, such actions must be avoided to save the adjacent good lands.

4.1.1.2. Levd Plains (9788 ha, 7.0%)

Envisaged, are both, wind-resorted and water-laid sandy materials that, with age, developed into level to nearly level, deep, well-drained, non-saline, non-sodic, deeply homogenized with lime concretions at a 4-ft depth of loamy (loams) soils (Hafizabad soil series and its saline and waterlogged phases). Of this, about **5.6** percent are normal Hafizabad soil, and the remaining 1.4 percent belongs to its saline/waterlogged phases. Approximately, the whole area under this soil type is under intensive **irrigated** cultivation, except areas, that **have** been abandoned due ***to* strong** salinity associated with the high water table.

4.1.2. Sub-recent Plain (1 15000 ha, 82.4%)

This terrace occupies a comparatively low topographic position that resulted in **the** major deteriorated hectarage of this plain. Comprising mainly three physiographic/landform units, generally due **to** their topographic difference, are Rasulpur terrace, Harunabad terrace **and** third represents depressional areas where water stagnates.

4.1.2.1. Rasulpur Terrace (10932 ha, 7.8%)

Comparatively, it is higher in this landscape and proportionately less affected by **the** high water table and salinity. The soils of this landform are nearly level, deep, homogenized up **to** 30 **to** 36 inches, somewhat excessively drained, partly non-saline, non-sodic sandy loams/light sandy loams (Rasulpur Soil Series with its saline and waterlogged phases). Approximately, **6.1** percent are normal Rasulpur **sods,** while the remaining **1.7** percent are its saline and waterlogged phases. Approximately, the whole area under this soil type is under irrigaied cultivation.

4.1.2.2.. Harunabad Terrace (101279 ha, 72.8%)

This is the most extensive level landform of the area. In the affected areas, the major part of this landform is involved. The soils of this landform are level, deep, homogenized to 30 ***to* 40** inches, well drained, non-saline, non-sodic, fine sandy loams approaching to **loams** (Harunabad soil series with its saline and waterlogged phases). The normal hactareage is about **34.1** percent and those affected **are** 38.5 percent **The atea** is intensively cultivated, except areas, that have been abandoned due to severe waterlogging or salinity, or are partly under high delta crops (sugarcane and **rice** with moderate to poor yields).

4.1.2.3. Depressional Areas (2789 ha, 2.0)

These areas are quite different from inter dunal **valleys** locally known as "dhars" that mostly exist in the Pleistocene Terrace and are generally level to the general ground level. Being situated at higher terrace, **water does** not stand on their surfaces throughout the year. But, the areas under mention are the special feature **of** the Sub-recent flood plain and are quite below the general ground level where water stagnates throughout the year. In central parts. which remain under water during the whole year, remained unexplored texturally, but the margins where the water depth fluctuates between 0 to 2 ft. were investigated In texture, they range from fine sandy **loams to** Ioams. strongly saline, moderately sodic (pH ranges from 8.5-8.8) and mostly gypsiferous. Such areas have been placed under the U/W (area under water) category. They are devoid of any vegetation. and the wind-blown salts of these areas may be affecting the surrounding areas adversely. Figure 2 presents percentages of various phases of soils of the project area. Table 6 presents the total area of each soil with its phases, and Table **7** provides FESS soil mapping units with their areas and percentages.

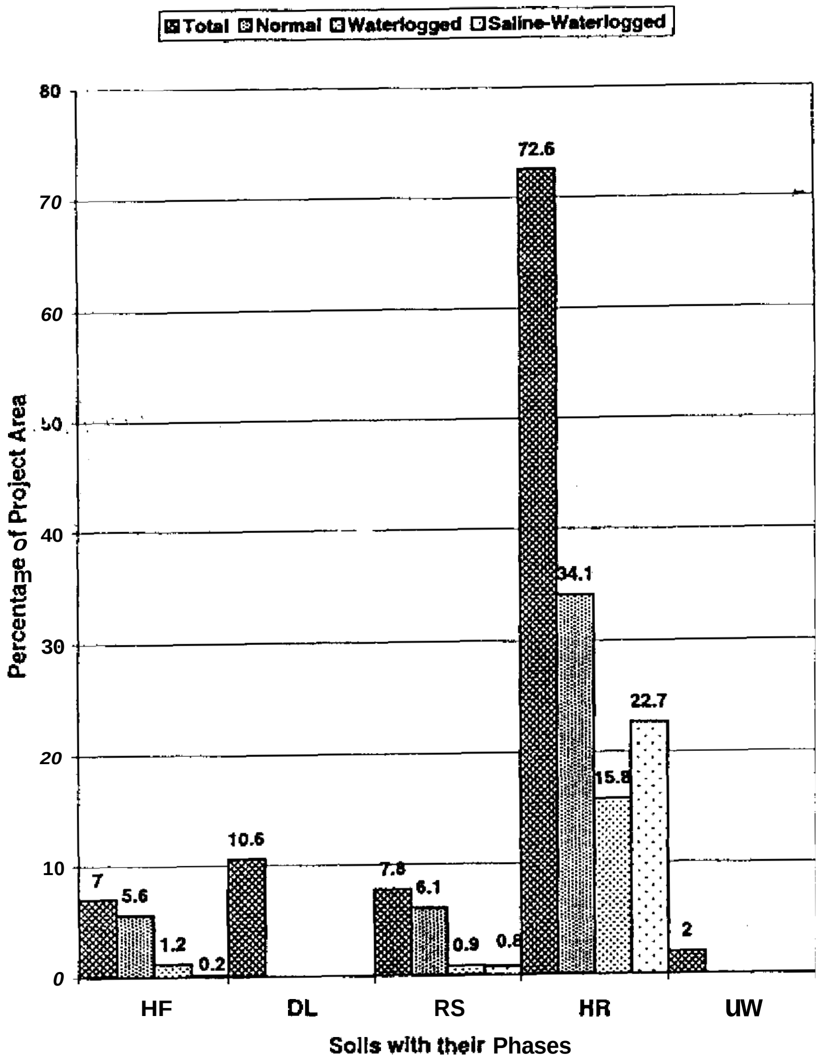

Figure 2. Percentages of **Various** Phases **of Soils of** the FESS Project **Area (HF=Hafizabad Soils; DL=Dune Land: RS=Rasulpur Soils; HR=Haroonabad Soils; UW=Area under Water).**

Table 6. Total Area of Each Soil with Phases (ha/percentage).

S. No.	Soil	Ha/Percentage (total)	Normal/ Percentage	Waterlogged Percentage	S-W-Loggedl Percentage
1.	Hafizabad	9788/7.0	7888/5.6	1647/1.2	25310.2
2.	Dune Land	14750/10.6			
3.	Rasulpur	10932/7.8	8517/6.1	1212/0.9	1203/0.8
4.	Harunabad	101279/72.6	47630/34.1	21970/15.8	31679/22.7
5.	Area under water	278912.0			

S = Saline; W = Water

Table 7. FESS **Soil** Mapping Units **with their Areas** (Hectares) **and Percentage.**

S. NO.	Map Unit	Map unit description	Area	Percentage
1.	Hf	Hafizabad well-drained	7888	5.65
2.	Hf/wII	Hafizabad moderately well-drained (watertable at 120-150 cm)cm)	1647	1.18
3.	Hf/wIIs	Hafizabad moderately well-drained, slightly to moderately saline	68	0.05
4.	Hf/wIII	Hafaizabad imperfectly drained (w-table at GO-120 cm), moderately to strongly saline	185	0.13
5.	DL	Undulating stablized sand dunes	14750	10.57
6.	RS	Rasulpur somewhat excessively-drained	8517	6.10
7.	Rs/wII	Rasulpur moderately well-drained	1212	0.87
8.	Rs/wIIs	Rasulpur moderately well-drained, slightly to moderately saline	1203	0.86
9.	Hr	Harunabad well-drained	47630	34.14
10.	Hr/wII	Hamnabad moderately well- drained	21970	15.74
11.	Hr/wIIs	Harunabad moderately well-drained, slightly to moderately saline	19166	13.74
12.	Hr/wIII	Harunabad imperfectly-drained water table at (60- I20 cm), moderately to strongly saline	12513	8.97
13.	U/W	Area under water	2789	2.0
		Total	139538	100.00

4.2. Soil Conditions

In the present study, a range of soil conditions for the study area has been devised, which is briefly described below.

- Condition WI. In this condition, the groundwater table is below 5 feet from the surface and without salinity/sodicity (S1 level of salinity).
- Condition WII. Here the groundwater table is within 4 to 5 feet depth with S1 level of salinity.
- Condition WIIs. In this case, the groundwater table is within 4 to 5 feet, but with slight to moderate salinity (level of salinity ranges from S2 to S3).
- Condition WIII. The groundwater table of this condition lies between 2 to 4 feet, with a moderate to strong salinity (level of salinity ranges from S3 to S4).
- Condition WIV = U/W (under water). This is the most deteriorated condition where water stagnates within 0 to 2 feet depth throughout the year with severe salinity (level of salinity is S4 for the whole year).

4.3. Soil Salinity/Sodicity

43.1. Kinds and Causes of Salinity/Sodicity in the Project Area

- Genetic salinitylsodicity is caused due to weathering of the parent soil material;

- Primary salinitylsodicity occurs generally on the margins of depressions and low-lying areas where rain and flood water accumulates;

- Secondary salinitylsodicity is caused due to a rise in the groundwater table by seepage from the irrigation system and over-irrigation. Also, excessive water applications for reclamation and replacing the cultivation of low delta to high delta crops displace the salts and bring them into the root zone or onto the soil surface through capillary rise;

- Insufficient leaching of salts due to the shortage of irrigation water (insufficient to leach the salts from the root zone) also causes soil salinity; and

- Present salinity/sodicity is caused due to watering the crops with poor quality groundwater.

- During the 1999 IIMI soil survey, a most important pedological feature of occurrence of compact and calcareous silty/clayey non-continuous layers at varying depths in the sub-soil, which restrict the downward flow of water and act as a barrier to drainage was observed. This phenomenon helps in raising the groundwater to the capillary rise range and aggravates the salinity/sodicity problem. It encounters in the entire Sub-recent Flood Plain that forms about 90% of the Project area, exclusion consists of sandy alluvial deposits of Pleistocene period including Dune Land (sand dunes scattered in the whole Project area) and a small continuous part of Cholistan Desert, occupying the south-western corner of the Project area.

In the project area, secondary salinitylsodicity dominates.

4.3.2. Classification of Soil Salinity

Four classes of salinity, namely, S1, S2, S3 and S4 were recognized on the basis of visual appraisal in the field and subsequently, confirmed by the chemical anatyses of the representative soil samples in the Chemistry Laboratory. These classes are defined as under:

SI: Non-saline: In this case, ECe is less than 4 dS/m at 25 ^{0}C. In the field, salts are not visible on the surface and no adverse effects are seen on the plant growth;

S2: Slightly-saline: The ECe varies from 4 to 8 dS/m at 25 ^{0}C. In the field, less than 20 percent of the surface area has salinity patches where plant growth is also adversely affected;

S3: Moderately-saline: The ECe varies from 8 to 16 dS/m at 25 ^{0}C. In the field, 20 to 75 percent of the surface area is infested with salinity and its adverse effect on the plant growth in that area is quite visible; and

S4: Strongly-saline: The ECe is more than 16 dS/m at 25 "C. In the field, more than 75 percent of the surface area has been inflicted by such salinity. and plant growth is seen only in patches. The fanners usually leave such lands/fields (un-ploughed) because these areas do not return even the seed of the sown crop.

4.3.3. Classification of Soil Sodicity

Soils become sodic when the exchange surfaces of clays become dominated by sodium instead of calcium ions. And mostly, it is classified in terms of the Sodium Adsorption Ratio (SAR) of the soil saturation extract in the laboratory. In the field, it is checked with the pH value; if the pH value reaches *8.5* or above, the soil is sodic (in FESS area the Thymol Blue indicator was used to determine the soil pH value). Four classes, recognized by the USDA , of soil sodicity in terms of SAR are given in Table 8.

Table 8. Classes of Soil Sodicity.

Sodicity Class	SAR
Non-sodic	Less than 15
Slightly-sodic	15 to 25
Moderately-sodic	25 to 45
Strongly-sodic	More than 45

Classifications for salt-affected soils considering both. ECe and SAR. is provided in Table *9.*

Table *9.* Classification of Salt-affected Soils.

Normal	ECe is less than 4dS/m and SAR is also less than 15
Saline	ECe is more than 4dS/m and SAR is less than 15
Saline-sodic	ECe is more than 4dS/m and SAR is also more than 15
Sodic	ECe is less than 4dS/m but SAR is more than 15

Saline and saline-sodic soils are generally found in the project area.

4.3.4. Water Qualities

Water quality classifications based on measurements of electrical conductivity (EC). sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) is provided below in Table 10.

Table 10. Irrigation Water Quality Criteria of WAPDA.

Classification	EC(dS/m)	SAR	RSC (meq/l)
Useable	<1.5	<10	<2.5
Marginal	1.5 to 3.0	10 to 18	2.5 to 5.0
Hazardous	>3.0	>18	>5.0

Twelve water samples (of 5 wells, 3 augerholes, I handpumps. 2 soil pits. I sub-surface drainage trial site-I near that Malik Branch Canal) were analyzed and their results are provided in Annexure 111. According to WAPDA water quality criteria, the groundwater samples analysis reveals that the overall water quality for irrigation purposes is useable to marginal and somewhat hazardous *(25%* useable ; **58.3%** marginal and **16.7 %** hazardous). But, cations and anions in dominant sequence arc Na. Ca+Mg and Cl, HCO, and SO,, respectively. The laboratory results also indicate that ***RSC*** and CO, are nil/traces, and the pH value ranges between 7.6 to 8.3, well below the hazardous pH value of 8.5. This manifests clearly that salts in the water are dominantly Cl, SO_4 and HCO_3 of Na, Ca and Mg in the sequence of dominance. These are all leachable and their accumulation in the soil profile by tubewell irrigation can be rectified by two heavy irrigation turns of about 4 inches each year.

4.4. Present Salinity-Sodicity Status

In order to conduct the present salinity survey, the most recent satellite images taken in December 1998 were used as a base map. The 6-R Distributary of the Hakra Branch was taken as the south-westem boundary of the project area to where joins the Haran Minor (command-wise), thereby increasing the study area from 261000 acres (105668 ha) to 344658 acres (139538 ha). Forty-one (41) soil samples consisting of thirty (30) from ten (10) augerholes and eleven (11) from three (3) soil pits, were collected. Their laboratory analysis (Annexure IV) reveals that all the salt-

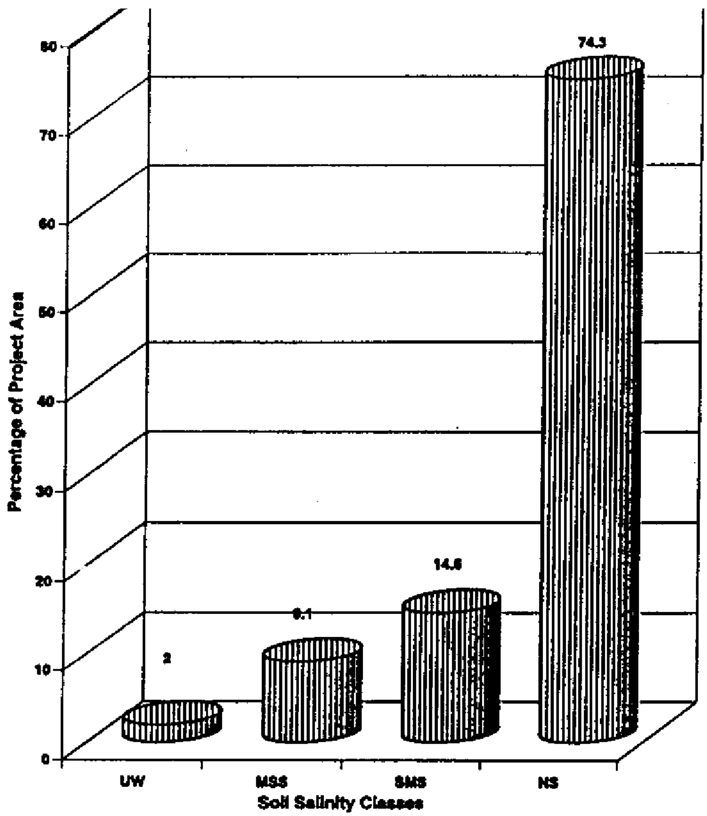

Figure 3. Percentages of Total Project Area under Various Salinity Classes (UW=Area under water; MSS=Moderately to strongly saline; SMS=Slightly to moderately saline; NS= Normal soils).

associated with the high water table) that decreases with increasing depth from the surface, about one-third (mostly surfaces) is moderately sodic with pH values ranging from 8.5-8.8 that very seldom rises above these values. The area and percentage of the total project area under various soil salinity categories are presented in Table II.

Table **11.** Salt-affected Area in FESS during **1999.**

Salinity Class	Hectares	Percentage
Non-saline(SI)	**103614**	**74.3**
Salightly to moderately saline **(S2/S3)**	**20437**	**14.6**
Moderately to strongly saline **(S3/S4)**	**12698**	**9.**I
U/W (area under water)	**2789**	**2.**
Total	**139538**	**100.0**

This means that presently, about **23.7** percent of the project area is infested with salinity and sodicity though sodicity is rare (mild to moderate), and generally on the surface. Figure **3 shows** the percentages of the total project area under various classes of salinity found in the study area. The soil salinity map given in Appendix B shows various *soil* types found in the project area under different soil salinity classes.

4.5. Comparison of Salinity/Sodicity Findings

4.5.1. Surface Salinity/Sodicity

As found earlier, extensive information is available about the status of surface and profile salinity studied by WAPDA, SSP and NESPAK. The areal extent of the surface salinity mapped by the above agencies is chronologically presented in Table **12.** Evident, is that in **1962-63**, only **1.8** percent of area was saline at the surface, which increased **to 5.9** percent in **1971**. According to the NESPAK survey in the winter months of **1975-1976,** surface salinity was **9.2** percent. However, the Master Planning Division Survey of **1977-78** reduced the saline area to **7.2** percent, which increased to **8.7** percent **by** the Planning Directorate (Water), Central. WAPDA Survey in **1986.** This indicates an increase of **1.5** percent within a period of about 10 years. The IIMI salinity survey conducted on satellite images of December **1998** (most recent photos) indicates the increase of salinity from **8.7** percent in **1986** to **23.7** percent in **1999.** an increase of **15** percent. About **17.8** percent of the non-saline area is potentially risky for saliniwtion as the water table in this area has risen to about **120-180** cm. The farmers of such areas are replacing rice with cotton because the cotton yield is decreasing gradually. mainly due **to** the high water table. This whole cultivation phenomenon manifests that the process of sanlinization has not attained an equilibrium, and that rapid and efficient remedial measures are required mainly to lower the water table, or at least to check the rising trend. The summary of surface salinity reported by different agencies is presented in Table **12.** Figure **4** presents the comparison of salinity findings by various agencies.

Table **12.** Summary of Surface Salinity Reported by Survey Agencies in Different Years.

SIA	Y***IS***	T/F/M	Salinity Classes/Extent (Acres)				
			Normal (S1)	Sl/Sal (S2)	Mod/Sal (S3)	St/Sal (S4)	T/Sal
W/WAPDA	1962-63	**1952-54**	**256370**	**4165**	**245**	**220**	**4630**
		ap l: 40000	**(98.2)**	**(1.6)**	(0.1)	**(0.1)**	**(1.8)**
SSP	1971	**1952-54**	**245385**				**15415**
		ap l: **40000**	**(94.I)**				(5.9)
NESPAK	Oct. ***751***	**1952-54**	**236585**	**16545**	**6140**	1215	**23900**
	Mar **76**	ap l: **40000**	**(90.6)**	**(6.3)**	**(2.4)**	**(0.5)**	**(9.2)**
M/P/D WAPDA	1977/78	**1976.**	**241860**	**12150**	**2830**	**3710**	**18690**
		ao 1:30000	**192 7)**	**(4.7)**	11.1)	(1.4)	**17.2)**

S/A	Y/S	T/F/M	Salinity Classes/Extent (Acres) Normal (S1)	Sl/Sal (S2)	Mod/Sal (S3)	St/Sal (S4)	T/Sal
P/D/W/C	1986	1976,	235880	13490	2665	6565	22710
WAPDA		ap 1:30000	(90.4)	(5.2)	(1.0)	(2.5)	(8.7)
IIMI-PAK	1999	Sat/image	25592	S2/S3	S3/S4		
		Dec. 1998	(74.3)	50479	31364		81843
				(14.6)	(9.1)		(23.7)

S/A = Survey Agency; Y/S = Year of Survey; T/F/M = Type of Field Maps used; ap=Airphotos W/WAPDA = WASID/WAPDA; SSP = Soil Survey of Pakistan; M/P/D = Master Planning Division; P/D/W/C = Planning Directorate (Water) Central; Sl/Sal = Slightly Saline; Mod/Sal = Moderately Saline; St/Sal = Strongly Saline; T/Sal = Total Salinized; Sat = Satellite

Numbers in parentheses are percentages with respect to the gross area of 2,61,000 acres, except for IIMI, for which the gross area is 344658 acres. Areas mapped under water (515 acres by NESPAK, 4450 acres by the Master Planning and 2410 acres by the Planning Directorate (Water) Central have not been included in the above statistics). The Soil Survey of Pakistan (SSP) did not map the saline areas in terms of SI, S2, S3 and S4 categories.

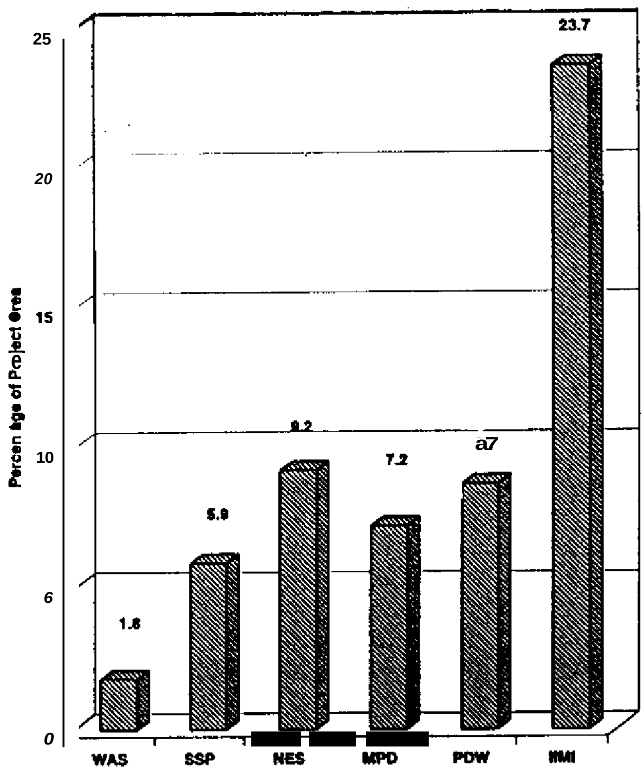

Figure Surface salinity reported by Survey Agencies in different years (WAS= WASID/WAPDA; SSP=Soil Survey of Pakistan; NES = NESPAK; MPD= Master Planning Division; PDW = Planning Directorate Water Central; IIMI= International Irrigation Management Institute).

There is reduction of about 2 percent (9.2 vs. 7.2%) between the NESPAK survey conducted in the winter months of 1975-76 and that of the Master Planning survey in 1977-78. This reduction is ascribed mainly to the exceptionally wet monsoon season of 1976, when there was 18" rainfall at Bahawalnagar, 21"in Gulab Ali, 18"at Faqirwali, 28"at Dahranwala and 13"at Chishtian. After such heavy rains, there must be some washing away of surface salts, as well as, especially, their partial leaching deep in the soil profile in low water table areas, this results in more sodification of the soils. Hence. the statistics of bath, surface and profile salinity of 1977-78 are less than those of 1975-76. However, the figure of the 1986 WAPDA survey is less by 0.5 percent (8.7 vs. 9.2%) than those of the NESPAK survey in 1975-76, which is also of little significance and is indicative of an equilibrium in the extent of surface salinity. However, within the last 37 years (1962-63 to 1999), the extent of surface salinity has registered an increase of about 22 percent (1.8 to 23.7%). The increase is relatively more pronounced in S2 and S4 categories as a result of an increasing high water table and the abandonment of already deteriorated land. Therefore, it is concluded that whether there is equilibrium or progression of the soil salinization with time, the existing situation of soil deterioration especially, the rising water table is looming large and hence, there is a dire need of suitable remedial measures for the rehabilitation of the deteriorated lands of the project area.

4.5.2. Profile Salinity/Sodicity

The number of saline and/or sodic profiles is presented in a chronological sequence in Table 13. In 1962-63, there were only 16 percent saline and/or sodic profiles, which increased to 39 percent in 1975-76. This figure reduced to 28 percent in 1977-78. The reasons for this reduction have already been discussed. WAPDA explored each grid. while NESPAK did the same job but at distances of 2 miles apart. The samples were collected in sections of 0-6, 6-18, 18-36 and 36-72 inches depths for the appraisal of the saline and/or sadic status of the profiles.

Table 13. Saline and/or Sodic Profiles reported hy Survey Agencies in Different Years.

S/A	Y/S	No. of Profiles Investigated	Percentage of Deteriorated Profiles and/or Sodic
W/WAPDA	1962-63	225	16
SSP*	1971		
NESPAK	October 75-March 76	117	39
M/P/D WAPDA	1977/78	462	28
P/D/W/C WAPDA*	1986		

*Did not conduct separate profile-salinity study
S/A = Survey Agency; Y/S = Year of Survey; W/WAPDA = WASID/WAPDA; SSP = Soil Survey of Pakistan: M/P/D = Master Planning Division; P/D/W/C = Planning Directorate (Water) Central

4.6. Land Use Suitability Classification

Suitability and development of land is vital for irrigated agriculture. The interpretation of the physico-chemical characteristics and qualities of the soils in terms of land use suitability classification is an integral component of the appraisal to assess their ecological production potential under the ultimate development conditions. The land use suitability classification made in the present is mainly based on the system described by Gil (1979).

4.6.1. Suitability Classification

4.6.1.1. Orders

There arc two main orders of suitability classification, which arc described below.

- Found suitable for a specific use, expressed by the **major** symbol S; and
- Found nut suitable for a specific use, expressed by the major symbol N.

4.6.1.2. Classes

Classes in these two orders express the grade of suitability and non-suitability as follows:

- Class SI means highly suitable without significant limitations for a given use;
- Class SII means moderately suitable with moderate limitations for a given use;
- Class SIII means marginally suitable with severe limitations for a given use;
- Class NI means currently not suitable with limitations to a given use, which may, however, he overcome by adopting practices to convert such land to an "S" suitability class; and
- Class NII means permanently not suitable with severe limitations that make it impossible to change the conditions to an "S" class for a given use.

For land usc suitability classification, the main external/areal characteristics like surface salinity, cropping intensity, crop conditions and land use, and internally (soil profile features) like texture, structure. consistence (dry, moist, wet), color including mottles, sodicity by noting the pH value (with Thymol Blue Indicator) and the depth to groundwater table were recorded. The land use suitability classification of the FESS Project area is greatly influenced by a high groundwater table, especially when it reaches within the capillary-rise range, and is the main cause of various types of root zone/surface salinity (root zone salinity, depth-wise ranges from 0-150 cm). The other major factor of the project area, that affects the suitability for various agricultural crops is its moderately coarse/coarse-textured soils, which have low water and nutrient holding capacities. Also, these lands arc low in inherited fertility. These coarse textured soils are also moderately to moderately rapid permeable. which result in a huge loss of costly irrigation water through seepage from the whole irrigation system. By interpreting these properties, the FESS Project area has been classified into four (4) classes, which have further been divided into eight (8) sub-classes because of their different kinds of hazards, their effectiveness, and corrective measures to be taken for their removal (Appendix C). These classes are described in detail below.

SI. This class fornis highly suitable medium textured land (Fine sandy loams/light loams and loams/heavy loams) with no limitations to grow a wide variety of crops, including vegetables and fruit orchards, that are ecologically suited to the area. This class responds very well to modern management and produces high to very high yields under balanced inputs. Such soils must be kept under intensive cultivation, especially for cash crops of the area. Extending over about 55518 ha (39.8%), mostly occupies the south-western part of the project area along the left bank of the Murad Distributary of the Malik Branch Canal. A small area of its hectarage also lies along the Indian border.

SIIc. This sub-class constitutes moderately suitable land due to its moderately coarse texture (Sandy loams). These soils have low water and nutrient holding capacities and moderately to moderately rapid permeable. Such soils can produce high yields, including vegetables and deep-rooted crops like cotton, by adopting the following suggestions. Covering about

8517 ha (6.10%) of the project area, scattered patches are present throughout **the** area, mostly adjacent **to** low sand dunes.

- Precise levelling and small fields;
- Split doses of chemical fertilizers;
- Light, but frequent irrigations;
- Addition of organic matter in any form; and
- Avoid high-delta crops.

SIIWII. This group of soils comprises **a** medium-textured class and forms moderately suitable land due to a high water table (120-150cm). This hazard limits the choice of crops, especially deep-rooted crops and fruit orchards. Such soils need an efficient regional drainage system (surface or sub-surface or vertical). In these soils the cultivation of high-delta crops like rice and sugarcane shoud be avoided. This group of soils covers about **23617** ha **(16.93%)** and encompasses mostly the area situated between the Hakra Branch and the Bahawalnagar-Fort Abbas railway track. Some scattered patches along the western side of the railway track also exist.

SIIcWII. This sub-class consists of moderately suitable coarse-textured lands. The main limitations comprise **a** coarse texture (Sandy loams) and a high water table (120-150cm) that limit the choice of crops. The first hazard demands similar suggestions as already mentioned for the subclass SIIc. For the latter, the regional drainage system must be improved. The areal coverage of this sub-class **is** about 1212 ha (0.87%).

SIIWIIs. **This** group **of** soils is medium-textured. slightly **to** moderately saline (S2/S3) and a water table within 120-150 cm, classifying it as moderately suitable lands. The main limitation that causes salinity and reduces the selection of crops and their yields is its high water table condition. The deep-rooted crops/fruit orchards are sensitive to salinity crops, like pulses, which will not produce desired results. By lowering the water fable through an efficient regional improved drainage system and applying a few extra heavy irrigations, **this** land could be reverted to SI land. The areal extent group of soils is about **19234** ha (13.78%).

SIICWIIs. This moderately suitable sub-class has many limitations like its coarse **texture,** high water table and slight to moderate salinity that restricts the selection **of** crops. **The** root-hazard is the high water table that needs **to** be lowered urgently. The salinity problem can be overcome by applying a few extra canal water irrigations after lowering the water table. In order to obtain a **good** return, the measures mentioned in the sub-class SIIc must be adopted. This sub-class encompasses **a** small extent of about **1203** ha **(0.86%).**

SIIIWTII. This forms **a** marginally suitable medium-textured sub-class due **to** the **severe** limitations **of** salinity (moderate to strong; S3/S4) associated with the **very** high water table (60-120cm). These limitations have restricted the choice of crops to rice and sugarcane (high delta crops), with little wheat cultivation. **A** considerable area of this sub-class formerly under cash crop has been abandoned in the recent past. Lowering the water table is a very urgent priority because the other reclamation procedures are dependent upon it. In **certain cases,** a small quantity of **gypsum** may be required during reclamation. The hectarage of this sub-class is about 12698 ha (9.10%).

NIIW. This land is permanently not suitable due to a very severe limitation of water that stagnates permanently. and consists of about **2789** ha (2.0%).

NIIIC. These are stabilized sand dunes that have severe limitations of topography, without access to irrigation system, and also contain coarse-textured mil material. These severe hazards have made it permanently *not* suitable land, which covers about 14750 ha (10.57). Figure 5 shows the area under each land use suitability class as a percentage of the total project area. The area under each class end its sub-classes, with the percentage *of* the total project area of 139538 ha, is presented in Table 14.

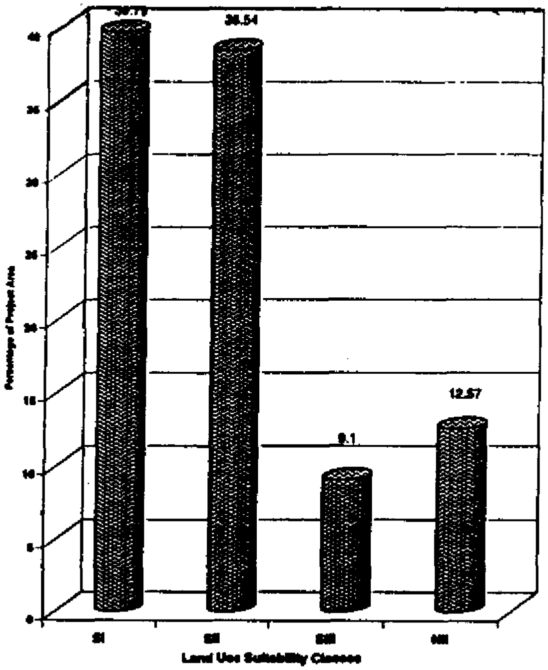

Figure 5. Percentages of Total Project Area under Various Land Use Suitability Classes (SI= Highly suitable; SII = Moderately suitable; SIII = Marginally suitable; NII = Permanently not suitable).

Table 14. FESS Area Land Use Suitability Classes/Sub-classes with their Areas[(ha)/Percentage].

Sub-Classes	Suitability Classes			
	SI	SII	SIII	NII
SIIc		8517/6.10		
SIIWII		23617/16.93		
SIIcWII		1212/0.87		
SIIWIIs		19234113.78		
SIIcWIIs		1203/0.86		
SIIIWIII			12698/9.10	
NIIW				*278912.0*
NIIIC				14750/10.57
Total area (ha)	55518	53783	*12698*	17539
percentage	39.79	38.54	9.10	12.57
Total Project Area (ha)				139538

5. POTENTIAL REMEDIAL MEASURES

All soils and irrigation waters, including very good irrigation canal water (with a salinity concentration of 150-250 mg/l) contain a mixture of soluble salts, all of which are not essential for plant growth. The salt concentration in the soil solution is usually higher than that of applied water (Total salts = soil salts + water salts). The continuous transpiration from the plants and the soil surface evaporation of water (only in arid and semi-arid climate) loads the remaining soil solution/soil water with various kinds of salts; if this concentration reaches a harmful level for crop production by increasing the osmotic potential of the soil, the soil will be named as saline soil. This concentration mostly occupies the surface layer of the soil and has a direct effect on the seed germination and plant roots development.

In order to keep the soil solution below a harmful concentration of salts, it is necessary to remove a portion of it from the crop root zone by leaching. Salts will be leached down whenever the water application exceeds evapotranspiration. This means, that more salts are being added to the soil through irrigation water. Actually, the salts concentration in the soil solution is being mitigated and not totally freed from salts; and therefore, a continuous process of leaching is required in order to keep soil salts below a harmful level.

But, the leaching process becomes less effective when the groundwater that contains a comparatively higher concentration of soluble salts reaches within the capillary rise range (depth to capillary rise is different for different textural classes). The groundwater rises mainly due to the seepage from the irrigation system, over-irrigation, excess water applications for reclamation and shining the cultivation from low to high delta crops. Such areas must have a groundwater table below the capillary rise range by an improved drainage system (horizontal or vertical) prior to leaching.

When the soil complex contains more Na than Ca and Mg, the soil is termed as sodic soil. Such soils require chemical amendments like gypsum or sulphuric acid (H_2SO_4), along with leaching, for their reclamation.

In all these reclamation processes, a less concentrated soluble salt solution is used to dilute and leach highly concentrated, or approximately of the same concentration, solution. This means that the omission of one is dominance of the other. Therefore, salinization and its reclamation are never-ending processes (especially in the irrigated areas of the arid and semi-arid climate) and need continuous efforts.

In the entire project area, salinity/sodicity is associated with the high groundwater table. To mitigate surface or root zone salinity/sodicity by leaching, lowering the groundwater table to below the capillary rise range should be the first priority. Therefore, the following measures are mainly concerned with the emphasis on lowering the water table to below the capillary rise range, or at a depth where its deteriorating influence can be minimized by continuous cropping, with the exclusion of some very sensitive crops to salinity/sodicity or deep rooted crops.

5.1. On-Farm Water Management (OFWM)

This programme can have very positive results in reclaiming the saline-sodic-waterlogged soils, provided it is operated properly under the guidance of relevant experts, because it focuses mainly on the conservation of water arid there are possibilities of reducing the need for sub-surface drainage, or even eliminating that need altogether. Both, the OFWM and sub-surface drainage system have a similar objective of limiting the wastage of irrigation water, or the water allocation must be according to the needs of presently growing crops, thereby restricting the addition to the groundwater or eliminating the groundwater rise. The water saved by OFWM can enhance the cropping area, cropping intensities and their yields, while the effluent of the used subsurface system, that is generally saline and definitely has more soluble salts than the previously used irrigation water, will spread salinity on the soil surface, whether drained into disposal tanks or mixed with canal or river waters. The following efforts of OFWM need immediate and special attention:

- **Watercourse lining ;**
- Precise land levelling;
- Small fields or small parceling pattern, especially in coarse-textured (sandy loam/fine sandy loam) soils;

The farmers must be persuaded to:

- Light. but frequent irrigation events, mainly in coarse-textured soils;
- Application of chemical fertilizers in split doses formed mainly in coarse-textured soils; and
- Addition of organic matters in any form.

As most of the project area texturally consists of sandy and loamy (sandy loams, fine sandy loams, loams and rarely silty/fine silty) and have quite permeable sub-soil, hence, the above suggestions will prove economically beneficial. The project area is located in an and to semi-arid climatic zone where evapotrnspiration always exceeds the applied irrigation water results in the accumulation of salts within the root zone and on the soil surface. To get rid of it, two heavy irrigation tours of about 4 inches each, when the crop water requirements are minimal, will prove very beneficial.

5.2. Canal Improvement

Lining of canals, distributaries and minors would result in reduced drainage requirements of waterlogged lands in the project area and also water savings through seepage losses control. It would also improve delivery efficiency and equity of water distribution in the project area. Lining of Malik Branch and Hakra Branch would have tremendous impact in terms of lowering water table in the command areas and also water savings through seepage losses control which are about 9.10 and 17.89 cfs/msf, respectively. Those portions of the irrigation channels, which pass either through very sandy soils or flow much higher than the surrounding areas must be lined, only to avoid heavy expenditures to line the whole length. Water User Associations with some authority and responsibility must be formed for the longevity of this lined canal system; and

5.3. Groundwater Development

According to WAPDA water quality criteria, the groundwater samples analysis reveals that the overall water quality fot irrigation purposes is useable to marginal and somewhat hazardous (25% useable; 58.3% marginal and 16.7 % hazardous). But, cations and anions in dominant sequence are Na, Ca+Mg and Cl, HCO_3 and SO_4, respectively. The laboratory results also indicate that RSC and CO_3 are nil/traces and the pH value ranges between 7.6 to 8.3, well below the hazardous pH value of 8.5. This manifests clearly that salts in the water are dominantly Cl, SO_4 and HCO_3 of Na, Ca and Mg in the sequence of dominance. These are all leachable and their accumulation in the soil profile by tubewell irrigation can be rectified by two heavy irrigation turns of about 4 inches each year. And, on the other hand, the majority of soils are rapid to moderately rapid permeable sandy to loamy soils, Therefore, the following suggestions are advised primarily to combat the waterlogging condition that is the root cause of most of salinity presently prevaifing in the project area.

- Sinking skimming wells at 30 to 90 feet depths along the canals by the private sector, with some subsidy from Government;
- The water from buried interceptor drains already complete may be returned to irrigation channels; further, this costly procedure may be reconsidered;
- As the distance increases from the recharge source (in the Project area, canals are the recharge source), the groundwater may surpass a reusable stage that can be minimized by placing gypsum stone lumps in watercourses, or mixing with canal water;
- These skimming wells may only be pumped in case of emergencies; and
- Deeper aquifer generally contains bad quality water and may not be pumped or tested from the water testing laboratory for suitability to irrigation purposes.

5.4. Farmers' Participation

The involvement of farmers is necessary due to the following reasons:

- Firstly, the constraints farmers face need to be understood, since government irrigation and drainage interventions attempt to develop a physical environment that is more conducive for farmers to cultivate drops without adverse environmental effects. Only then can appropriate interventions, which effectively help farmers to cope with the adverse effects of irrigation, be formulated;
- Secondly, the life-long experiences that farmers have had in coping with salinity-sodicity-waterlogging can be beneficial for devising interventions; and
- Finally, there is a large range in farmers' socio-economic backgrounds. These backgrounds will determine, to a large extent, whether farmers can or want to take advantage of the opportunities that are offered to them.

5.5. Surface Drainage System

The well-knit surface drainage system is being spread to drain the topographically uneven area with low-lying depressions and high sand dunes. The depressional areas with permanently stagnated water have been connected by these drain channels; presently, these areas are usually inundated instead of drying. And, also seeing the conditions of the old drains, which are choked, full of water-weeds/reeds and have become very shallow depth-wise, it is doubted that its maintenance may not meet the same fate, Characteristics (physical and chemical) of the soils at the depth of drain greatly influence the drainability-efficiency and sustainability of the drain, hence, the durability of this system is questionable or require special types of engineering devices that must be feasible and economical. Due to the following reasons special maintenance arrangements are needed.

- Approximately, the substratum approximately of the entire project area is sandy/fine sandy and very unstable in the presence of water, especially when drained/water in the drains flows at a tower level when compared to the water to be drained from the adjacent irrigated areas, which contain sandy sub-stratum or run-off from the adjacent catchment areas. Depth-wise maintenance of this system seems a cumbersome job. The sloughy soil mass will cave in and its depth will be reduced to near the surface after a short period. Thus, its working capacity will be minimized because it will not be able to lower the water table below 5 to 10 feet of the adjacent areas, and will be unable to carry the sub-surface drainage effluent, water from the depressional areas and torrent water;

- This system may not be able to drain depressional areas due to its depth-wise maintenance problem, where water accumulates through different resources and the deteriorated surrounding areas;

- The brackish effluent in surface drains passing through the shallow sweet groundwater zone will induct its brackishness, making it unfit for irrigation purposes; and

- Special inlets will be required for secondary drains. and also for draining the surface run-off.

5.6. Subsurface Drainage System

This is a very costly system and should be considered as a last resort. After lining the irrigation channels and sinking skimming wells, monitor drainage for 1-2 years and then install this system in Condition WIII (water table at 2-4 feet with moderate "S3" and strongly "S4" salinity) only; if still present anywhere, at 5-8 A depth and maintain it at WII (water table at 4 to 5ft without any salinity) condition. Otherwise, the ideal depth varies from crop to crop and soil to soil the (the shallower the depth, the lower the cost). In addition, the effluent at this depth is partially reusable, while a deeper depth is generally not fit for reuse and its disposal also requires a well-knit, efficient surface drainage system with depth-wise maintenance already mentioned as "questionable". Dropping the shallow, reusable effluent of condition WIII may increase the canal supply that can be used at the tails of the irrigation channels where the nearby Cholistan area remains barren.

5.7. Reclamation Approach

Pre-requisites for the reclamation of salt-affected soils are presented below.

- Land leveling and proper <u>bunding</u> of fields (OFWM Department can do it);

- The provision of an adequate quantity of good quality water and drainage system;

- Infiltration rates depend upon texture, porosity and the sodic condition of the soil. The soils of the Project area ate coarse-textured, porous and rarely sodic, which is mostly confined to the surface. The average basic intake of the compact layers is 0.2 cm/hr, while that of the surface soils is 0.63 cm/hr (NESPAK and HARZA, 1990);

- The nature of salts is an important factor that influences the pace of the reclamation of salt-affected soils. An analysis of the soil samples taken from the salt-affected soils of the project area reveals that Na and Cl ions dominate in the saturated extracts of the soils. The other soluble cations like Mg and Ca, and anions such as SO, and HCO_3, are next in sequence of dominance. As all the above salts are easily soluble, their leaching will not be problematic;

- The gypsum requirement, if needed can be determined quantity-wise from laboratory. But, the detailed examination of saline/sodic soil-profiles of the project area revealed the existence of greyish-brown gypsum specks; its presence was also confirmed by testing the soil pH using the "Thymol Blue" indicator in the field. To begin with, the pH value of the affected soil was high (9.0 or more), but after the lapse of a few seconds, when the gypsum reacted, it dropped to below 8.0. The presence of gypsum in the saline-sodic soils was further confirmed by tests carried out in the laboratory with acetone; sometimes, so much of gypsum is present in the soil that a higher gypsum requirement was reported as nil. Hence, these soils are called self-reclamable. They do not require the addition of amendments;

- Phosphatic fertilizers may be preferred the use of chemical fertilizers to augment tlie nutrient deficiency caused during the leaching operation; and

- Green manuring for further amelioration of the leached soils

The basis of the reclamation approach is the use of small-scale interventions to improve soil conditions. The soils, which are saline porous, can bc reclaimed by applying a few heavy irrigations of good quality water and adding organic wastes. Tlic soils, which are saline-sodic and have low water infiltration rates require additional chemical amendments like gypsum, sulphuric acid or kallar grass fur their amelioration. But, if the water table is within 1.5 m (5 ft), i.e., within the capillary rise range, the sustainability of tlie reclaimed-phase of soil becomes vulnerable. For durable reclaniation, an improvement in the regional drainage systcin is very essential. The best, quickest and most durable results can be obtained using combinations of methods. In the project arca, priority must be given to lower the groundwater table to below the capillary rise range (improvement in regional drainage system). Reclamation claims individual efforts, while the drainage system requires integrated endeavors hy both, the Government and the farmers. for its longevity.

5.8. Biological Approach

This is based on the principle that if the common plants do not grow well in the prevailing environmental conditions, it would be desirable to find plants that can grow under adverse soil and irrigation water conditions. Severely salt-affected soils arc mainly devoid of any type of vegetation cover, therefore, salts from tlie bare surface carried by wind or watcr can cause great damage to tlie adjoining good lands. All these moderate to severely salt-affected soils have a high water table ranging from a 0-5 foot depth (within the capillary rise range). Such soil can be sown to kallar grass. Eucalyptus, Janter, Frash and Mesquite. After some reclamation, rice, oilseeds and barley should be grown and land should not bc left fallow.

5.9. Impact of Chishtian Sugar Mill

The Chishtian Sugar Mill is also aggravating the problems of waterlogging and salinity in the area. including the project arca, due to the following reasons:

- About 90-95 percent of the sugarcane supply arca comprise (remaining 5 to 10% constitute the flood-plain of the Sutlej River) a moderate to moderately rapid permeable sandy arca (sandy loams approaching to loamy sands; fine sandy loams; and light loams). with sandy sand-dunes. Simple-minded farmers of the arca wcrc lured to grow more profitable, high delta sugarcane crops indiscriminately. Thus, an enormous amount of seepage water from the irrigation system and from high delta crops grown in rapidly permeable soil results in a water table rise, thereby greatly damaging greatly the agricultural production through waterlogging and salinity;

- Farmers were not demonstrated that to grow such a crop on rapidly permeable land requires small fields to minimize the addition to the groundwater through seepage that causes waterlogging associated with salinity; or to confine its production to the Sub-recent flood plain of the Sutlej River where comparatively less permeable, coarse silty, fine silty and clayeye soils are present. Additionalty. the plentiful good quality groundwater, if exploited, can meet the full requirements of high delta crops like sugarcane and rice. Also, its close proximity to the Sutlej River, which acts as a drain, will never cause waterlogging;
- By dismantling the sugar mill, the land users will automatically turn on low delta cotton – wheat rotation crops that will be sustainable, even with presently-adopted measures for the mitigation of the twin menace of waterlogging and salinity;
- *Otherwise,* a huge amount from the Government must be earmarked yearly to maintain this big surface and subsurface drainage system; and
- Water saved by this measure (closing the Sugar Mill) could be utilized at the tails of distributaries, where the shortage of irrigation water is a common phenomenon, and also where more good agricultural potential of the Cholistan area adjacent to irrigation channels, can be brought under cultivation.

6. CONCLUSIONS

The main conclusions that could be derived from the research findings of the present salinity/ sodicity study are provided below.

- All types of salinity/sodicity are associated with a high water table. Lowering the water table is the main job to be done to rehabilitate the agricultural potential of the area. Economically, it can be achieved by lining the irrigation channels phase-wise, and with skimming wells. Canal lining will minimize seepage, but deep percolation from the cropland with enhanced canal supply after lining will continue, and recharge to aquifer may not turn sour;

- NESPAK in 1975-76 and WAPDA in 1986 figured the salinity to be 9.2 percent and 8.7 percent of the FESS area, respectively, and also hinted about its equilibrium state, but the IIMI root-zone salinity survey revealed that at present, about 23.7 percent of the project area including miscellaneous areas and 27.2 percent excluding them, has been salinized; additionally, 17.8 percent of the Project area is potentially risky for salinity as the water table in this area has risen to 150 to 180 cm;

- Most of the cultivated area (more than 90%) texturally comprises coarse loam and sandy (loam. fine sandy loams, sandy loam and loamy fine sands), which have rapid to moderately rapid perneability, In order to use them to their production potential level without deteriorating them, the lands requite special management practices regarding irrigation, parcelling pattern, manuring (chemical. farmyard, green, etc.) and the selection of crops;

- Chemical analyses of groundwater from various sources and depths manifest clearly that it is marginal and hazard zone for irrigation purposes. but its RSC and CO_3 are nil and pH value is below the dangerous value of 8.5. Therefore, the salts concentration created by tubewell irrigation is washable and can easily be leached with a few heavy irrigation turns with canal water. On the other hand, the soils are also permeable, Hence, canal water can be supplemented with groundwater;

- Chemical analyses of soil samples mostly collected from saline soils showed that though the soils are saline. they contain leachable salts (chlorides, sulphates and bicarbonates of Na, Ca and Mg). These soils also have a sufficient quantity of gypsum for self-reclamation;

- Surface drainage may not perform well due to the fine sandy soil mass in the substratum in most of the project area, which is usually unstable in the presence of water;

- Farmers must be included, consulted and educated for all the remedial measures to be undertaken in their lands for good agricultural production;

- High-delta crops must be banned as has been done in the Khairpur Distict of the Sindh Province; and

- The Chishtian Sugar Mill must be dismantled in order to save the area from waterlogging and saliznity.

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ANNEXURE I. BRIEF DESCRIPTION OF SOIL ASSOCIATIONS.

Mapping Unit No.	Soil Association and Extent	Component Soil Series/Extent	Physiographic Position	Identification Characteristics
5	Harunabad 1,96,550 acres 75.3 percent	Harunabad 65 percent 1,27,755 acres	Nearly level Sub-recent flood plain	Loams and fine sandy loams marginal to loam underlain by silty clay at about one-metre depths, average pH 8.4
		Rasulpur 15 percent 29480 acres	Gentty sloping levees. Sub-recent flood plain	Fine sandy loams approaching loamy fine sands, average pH 8.3
		Dahranwala 10 percent 19655 acres	Nearly level, old terrace Pleistocene remnants	Clay loams underlain by silty clays at about 60-cm depths, average pH 8.3
		Hafizabad 5 percent 9830 acres	Nearly level, old terrace remnants	Deep loams. average pH 8.3
		Inclusions 5 percent 9830 acres	Nearly level, old terrace remnants	Saline-sodic silty clays, average pH 8.8
7.	Rasulpur 14350 acres 5.5 percent	Rasulpur 70 percent 10040 acres	Gently undulating levees. Sub-recent flood plain	Deep sandy laoms. average pH 8.3
		Jhang IS percent 2 I50 acres	Gently undulating, stabilized levees	Brown to pale brown loamy sands and fine sands, average pH 8.4
		Harunabad 5 percent 720 acres	Nearly level, Sub-recent flood plain	Loams and fine sandy loams marginal to loam, underlain by silty clay at about one-metre depths, average pH 8.4
		Mariala 5 percent 720 acres	Gently undulating channel levee remnants. Sub-recent flood plain	Saline-sodic sandy loams underlain by silty clay at about one-metre depths, average pH 8.6
		Inclusion 5 percent	Gently undulating. Sub-recent flood plain	Saline-sodic, sandy loams, average pH 8.6

Mapping Unit No.	Soil Association and Extent	Component Soil Series/Extent	Physiographic Position	Identification Characteristics
23.	Dune land-Khatan complex 44410 acres 17.0 percent	Dune land 75 percent 33310 acres	Undulating and rolling Pleistocene Terrace	Fine sands of shifting nature
		Khattan 15 percent 6660 acres	Gently undulating, stabilized dunes of Pleistocene terrace	Fine sandy loam, average pH 8.2
		Hafizabad 5 percent 2220 acres	Nearly level, Pleistocene terrace	Deep loam, average pH 8.3
		Inclusions 5 percent 2220 acres	Nearly level, old terrace remnants	Saline-sodic loams and clay loams, average pH 8.6
24	Hafizabad-Harunabad 1100 acres 0.5 percent	Hafizabad 40 percent 440 acres	Nearly level, Pleistocene terrace	Deep loams, average pH 8.3
		Harunabad 25 percent 275 acres	Nearly level, Sub-recent flood plain	Loam and fine sandy loam to loam underlain by silty clay at about one-meter depths, average pH 8.4
		Murad 10 percent 110 acres	Nearly level. eroded Pleistocene terrace remnants	Saline-sodic silty clays with lithologic discontinuity below a one-metre depth. average pH 8.8.
		Lakhewala 10 percent 110 acres	Nearly level eroded Pleistocene terrace remnants	Pale brown, mottled silty clays up to 50 cm depth, stratified below, average pH 8.4
		Gajiana 5 percent 55 acres	Nearly level raised parts of eroded Pleistocene terrace remnants	Saline-sodic silty clay loams, average pH 8.8
		Inclusions 10 percent 110 acres	Nearly level, Pleistocene terrace	Loamy soils, average pH 8.2
25	Lakhewala 2210 acres 0.8 percent	Lakhewala 55 percent 1220 acres	Nearly level eroded Pleistocene terrace remnants	Pale brown, mattled silty clays upto 50 cm depth, stratified below, average pH 8.4.
		Murad 15 percent 330 acres	Nearly level, eroded Pleistocene terrace remnants	Saline-sodic silly clays with lithlogic discontinuity below a one-metre depth, average pH 8.8
		Harunabad	Nearly level Sub-recent flood	Loams and fine sandy loam marginal to loam

Mapping Unit No.	Soil Association and Extent	Component Soil Series/Extent	Physiographic Position	Identification Characteristics
		15 percent 330 acres	plain	underlaid by silty clay at about one metre depth, average pH 8.4
		Dahranwala 10 percent 220 acres	Nearly level, old terrace remnants	Clay loams underlain by silty clay at about 60 cm depth, average pH 8.3
		Hafizabad 5 percent 110 acres	Nearly level. Pleistocene terrace	Deep laoms, average pH 8.2
26	Murad 2380 acres 0.9 percent	Murad 40 percent 90 acres	Nearly level, eroded Pleistocene terrace remnants	Saline-sodic silty clays with lithologic discontinuity below one metre depth, average pH 8.8
		Dahranwala 15 percent 360 acres	Nearly level old terrace remnants	Clay loams underlain by silty clay at about 60 cm depth. average pH 8.3
		Gajiana 15 percent 360 acres	Nearly level, raised parts of eroded old terrace remnants	Saline-sodic silty clay loams, average pH 8.8
		Lakhewala 10 percent 235 acres	Nearly level eroded old terrace remnants	Pale brown, mottled silty clay up to 50 cm, stratified below, average pH 8.4
		Haroonabad 10 percent 235 acres	Nearly level. Sub-recent flood plain	Loams and fine sandy loams marginal loams underlain by silty clay at about a one-niche depth, average pH 8.4
		Hafizabad 5 percent 120 acres	Nearly level. old terrace remnants	Deep loams, average pH 8.2
		Inclusions 5 percent 120 acres	Nearly level, old terrace remnants	Saline-sodic loamy soils, average pH 8.8

ANNEXURE II. HORIZON-WISE DESCRIPTION OF SOIL PITS

SOIL PIT 1

Location:	Chak No. 100/6-R; Sq. No./Ac No.=9/25
Dated:	April 2,1999
Parent Material:	River alluvium of Sub-recent period
Physiography	Sub-recent level plain
Topography:	Level to nearly level; sloping to south-west
Source of moisture:	Perennial canal supply
Drainage:	Imperfectly drained
Watertable depth:	90 cm
Salinity/Sodicity:	Moderately to strongly
Land use:	Sugar-cane. rice, wheat are major crops grown

The ares falls in the wheat-cotton rotation ecological zone, but moderate "S3" to severe"S4" salinity associated with the high water table (2-4 A) have changed the crop rotation totally.

Soil Profile Description

Ap 0-12 cm	Brown to dark-brown (10YR4/3) moist; sandy loam; massive; slightly sticky, slightly plastic/gritty when wet, friable when moist, slightly hard when dry; few fine interstitial and tubular pores; moderately calcareous; common fine and very fine roots; clear smooth boundary; pH 8.5 (salt crust pH 9.0).
AB12-18 cm	"Plough Pan" Dark brown (10YR3/3) moist common fine faint, but distinct in root channels, grey mottles; sandy loam; massive to very weak coarse sub-angular blocky structure; slightly sticky, slightly plastic when wet, friable when moist, slightly hard when dry; few fine tubular pores; moderately calcareous; common fine and very fine roots; (some decayed roots with greying surrounding are present), clear smooth boundary; pH 8.4.
Bw1 18-40 cm	Dark-yellowish-brown (10YR4/4) moist; fine sandy loam; weak coarse and medium sub-angular blocky structure; slightly sticky, slightly plastic when wet, very friable when moist, slightly hard when dry; common fine and very fine tubular pores; moderately calcareous; few fine and very fine roots; gradual smooth boundary; pH 8.4.
Bw2 40-90cm	Dark yellowish-brown (10YR4/4) moist, common fine faint grey mottles; loam; weak coarse and medium sub-angular blocky structure; slightly sticky, slightly plastic when wet, friable when moist, hard when dry; common fine and very fine tubular pores; moderately calcareous; few fine and very fine roots; pH 8.2.

SOIL FIT 2

Location:	Chak Kot Bahawal Bux (Bukkan) Sq. No./AC No. = x/8
Dated:	April 3,1999
Parent Material:	River alluvium of Pleistocene period
Physiography:	Pleis-tocene level plains
Topography:	Level to nearly level; sloping toward southeast
Source of Moisture:	Perennial canal supply
Drainage:	Moderately well drained
Watertable depth:	120 cm
Salinity/Sodicity	Nil
Land use:	Sugarcane, wheat with little cotton, and few mango gardens are grown, but plants are not healthy and show the adverse effects of the high water table, i.e., with dried tips.

Soil Profile Description

Ap 0 - 15 cm	Brown to dark-brown (10YR4/3) moist. greyish brown (10YR5/2) dry; loam; massive; slightly sticky. slightly plastic when wet, friable when moist, slightly hard dry; few fine interstitial pores; moderately calcareous; many fine, very fine and when few medium mots; clear smooth boundary; pH 8.4.
Bwl 15-50 cm	Dark greyish-brown (10YR4/4) moist; loam (heavy): weak coarse sub-angular blocky structure; sticky. slightly plastic when wet, slightly firm moist, hard when dry; common fine and very fine tubular pores; moderately calcareous; common fine, very fine and few medium mots; worm activities; gradual smooth boundary; pH 8.3.
Bw2 50-80 cm	Brown to dark-brown (10YR4/3) moist; clay loam; weak coarse and medium sub-angular blocky structure; sticky, slightly plastic when wet, slightly firm moist, hard when dry; common fine and many very fine tubular pores; moderately calcareous; common fine, very fine and few medium roots, clear smooth boundary; pH 8.2.
Bw3Ca 80-120 cm	Brown to dark-brown (1oYR4/3) moist, few gleyed spots; clay loam/silty clay loam; weak medium, sub-angular blocky structure; sticky, plastic when wet, firm when moat, very hard when dry; few fine and very fine tubular pores; strongly calcareous; common fine and few medium lime nodules; few fine and very fine roots; pH 8.3.

The water table was 120 cm at the time of the soil profile description, but no visible surface salinity was **present.**

SOIL PIT 3

Location:	Chak 38/3-R, Sq. No./AC No. = 30/2
Dated	**April 4, 1999**
Parent materia	**River alluvium** of **Sub-recent period**
Physiography	**Sub-recent Level plain**
Source of moisture	**Perennial canal supply**
Topography	**Level to nearly level, sloping to south-east**
Drainage	**Well drained**
Watertable depth	<150 cm
Salinity/Sodicity	**Nil**
Land use	**Wheat, cotton, some sugarcane, mango garden; all the crops ecologically suited to the area can be grown profitably**

Soil Profile Description

Ap 0-15 cm	**Drown** to **dark-brown** (10YR4/3) **moist, brown** (10YR5/3) **dry;** sandy loam; **massive; slightly sticky,** slightly **plastic/gritty when** *wet,* **very friable when** moist, **slightly hard** when dry; **few** tine **interstitial pores; moderately calcareous; many fine** and very fine **roots; clear smooth boundary:** pH 8.4.
AB 15-28 cm	**Brown to dark-brown** (10YR4/3) moist, sandy loam; **massive** to very **weak** coarse **sub-angular** blocky structure; **stightly sticky, slightly plastic** when **wet,** friable **when** moist, slightly **hard when dry; few fine tubular pores; moderately calcareous;** few fine **and** very **fine roots; clear** smooth **boundary;** pH **8.4.**
Bw1 28-80 cm	**Dark yellowish-brown** (10YR4/4) moist; **fine** sandy loam; **weak coarse sub-angular blocky** structure; **slightly sticky, slightly plastic when wet, friable when moist,** slightly hard when dry; **common fine and** *very* **fine tubular pores; moderately calcareous; common fine and many very fine roots;** worm **activities,** lime mycelia; **gradual smooth boundary;** pH **8.2.**
Bw2 80-118 cm	**Brown to dark-brown** (10YR4/3) **moist;** loam; **weak coarse sub-angular blocky structure; slightly sticky, slightly plastic when wet, friable when moist, slightly** hard **when dry;** common **fine and very fine tubular pores; moderately calcareous; few fine and very fine roots; worm activities; clear smooth** boundary; pH 8.2.
Cca 118-150 cm	**Pale brown** (10YR6/3) **moist;** loam; **massive;** slightly **sticky, slightly plastic when wet, slightly firm when moist, hard when dry; few fine and very fine tubular** pores; **strongly calcareous; few** fine **lime nodules; few** very fine **roots;** pH **8.2.**

ANNEXURE III. CHEMICAL ANALYSIS OF WATER SAMPLES COLLECTED BY IIMI DURING THE 1999 SURVEY.

S. No.	Depth(ft)	Ca+Mg	Na	Cl	CO_3	HCO_3	SO_4	pH	EC	SAR	RSC(meq/l)
		(meq/l)							(dS/m)	$(meq/l)^{1/2}$	
1	190	4.38	9.78	5.00	Nil	3.50	0.36	8.3	1.29	6.6	Nil
2	90	8.70	9.56	2.50	Nil	6.40	0.42	8.3	1.46	4.5	Nil
3	90	15.94	39.13	13.20	Traces	5.88	1.63	8.2	4.26	13.9	Nil
4	70-90	3.45	2.17	0.70	Traces	3.92	0.07	8.3	0.44	1.7	0.47
5	27	32.08	83.69	40.60	Traces	9.62	2.55	7.9	8.23	20.9	Nil
6	3-4	14.20	20.86	5.50	Traces	10.46	0.81	7.7	2.60	7.8	Nil
7		18.95	31.52	18.70	Traces	7.60	0.90	8.1	3.80	10.2	Nil
8		41 20	21.95	2.00	Traces	6.96	2.13	7.6	3.94	4.90	Nil
9		17.20	49.62	13.30	Traces	9.40	1.89	7.8	4.72	16.90	Nil

ANNEXURE IV. RESULTS OF PHYSICAL AND CHEMICAL ASALYSES OF SOIL SAMPLES COLLECTED BY IIMI DURING 19!).

S. No.	Detail Hole No.	Depth (Cm)	EC (dS/m)	pH	G.R. (T/acre)	$CaCO_3$ (%)	Texture			
							Sand (%)	Silt (%)	Clay (%)	Textural Class
1	6	00-15	19.2	8.2	Nil	7.3	81	16	3	Loamy Sand
2		15-45	11.4	8.3		9.3	74	11	15	Sandy Loam
3		45-90	11.1	8.3		14.3	67	10	23	Sandy Clay Loam
4	8	00-15	4.9	8.8	2.8	4.1	87	3	9	Loamy Sand
			3.0	8.4		2.3	92	1	7	Sand
6		45-90	0.9	8.4		5.5	87	4	9	Loamy Sand
7	13	00-15	15.3	8.9	2.3	3.4	93	2	5	Sand
8		15-45								
9		45-90								
10	17	00-15	40.1	8.6	Nil	2.5	86	4	10	Loamy Sand
11		15-45	11.0	8.3		7.5	84	2	14	Loamy Sand
12		43-90	10.3	8.6		3.4	88	4	8	Loamy Sand
13		90-180	21.4	8.3		14.1	32	44	24	Loam
14	24	00-15	64.7	8.4	Nil	2.7	84	8	8	Loamy Sand
15		15-45	9.8	8.6		3.5	91	4	5	Sand
16		45-90	5.4	8.4		7.9	85	6	9	Loamy Sand
17	39	00-15	59.5	8.7	Nil	5.3	85	10	5	Loamy Sand
18		15-45	8.6	8.7		7.8	87	6	7	Loamy Sand
19		45-90	4.9	8.3		11.1	91	2	7	Sand
20	43	00-15	10.4	8.6	Nil	4.3	85	4	11	Loamy Sand
21		15-45	1.7	8.4		6.7	89	4	7	Sand
22		45-90	1.1	S.3		9.7	87	6	7	Loamy Sand
23	46	Surface	245.9	8.3		1.2	57	6	37	Sandy Clay
24	55	00-15	40.6	9.0	6.5	3.7	85	4	11	Loamy Sand
25		15-45	3.3	10.3		2.1	91	2	7	Sand
26		45-90	2.3	9.0		4.7	89	2	9	Sand
27	60	00-15	9.2	8.3	Nil	8.5	79	8	13	Sandy Loam
28		15-45	4.0	8.6		9.1	81	8	11	Loamy Sand

S. No.	Detail Hole No.	Depth (Cm)	EC (dS/m)	pH	G.R. (T/acre)	$CaCO_3$ (%)	Texture			
							Sand (%)	Silt (%)	Clay (%)	Textural Class
29		45-90	4.1	8.3		9.5	87	4	9	Loamy Sand
30		90-180	3.8	8.2		13.4	59	22	19	Sandy Loam
31	1	00-15	1.3	7.9	Nil	2.6	73	10	17	Sandy Loam
32		15-40	1.2	8.1		2.3	63	16	21	Sandy Clay Loam
33		40-90	12.1	8.2		2.0	61	18	21	Sandy Clay Loam
34	2	00-15	2.0	8.1	Nil	2.9	63	16	21	Sandy Clay Loam
35		15-50	4.5	8.0		2.4	63	18	19	Sandy Loam
36		50-80	5.4	8.0		3.5	65	20	15	Sandy Loam
37		80-110	6.7	8.0		10.4	59	34	7	Sandy Loam
38	3	0-28	2.0	8,1	Nil	2.0	84	10	6	Loamy Sand
39		28-80	4.4	8.0		4.8	82	12	6	Loamy Sand
40		80-118	1.7	8.3		7.7	82	12	6	Loamy Sand
41		118-150	6.8	8.1		14.0	62	12	16	Sandy Loam

Annexure IV Continued.

S. No.	Detail Hole No.	Depth (Cm)	CA+Mg	Na	K Exch.	CO_3	HCO_3	CI	SO_4	SAR
			(meq/l)							
1	6	00-15	105	198	11.4	Nil	53	225	68.7	27
2		15-45	61	109	11.6	Nil	27	105	58.7	19
3		45-90	37	96	8.4	Nil	22	95	41.2	22
4	8	00-15	35	61	4.4	Nil	29	80	25.6	15
5		15-45	18	37	3.1	Nil	22	25	12.5	12
6		45-90	16	20	2.8	Nil	15	25	5.6	7
7	13	00-15	16	239	5.8	Nil	26	85	43.7	85
8		15-45	15	52	5.1	Nil	30	40	7.5	19
9		45-90	18	41	4.4	Nil	25	25	15.0	14
10	17	00-15	30	739	5.4	Nil	15	325	70.6	191
11		15-45	17	122	4.8	Nil	89	350	34.4	42
12		45-90	35	122	3.7	Nil	37	50	24.9	29
13		90-180	82	187	6.1	Nil	30	200	27.5	29
14	24	00-15	73	783	5.4	Nil	46	550	138.0	130
15		15-45	45	91	3.3	Nil	27	60	30.6	19
16		45-90	21	61	3.2	Nil	18	45	24.4	19
17	39	00-15	112	1217	14.0	Nil	26	215	146.0	163
18		15-45	56	61	8.7	Nil	20	50	45.0	12
19		45-90	31	33	6.4	Nil	47	65	20.6	8
20	43	00-15	34	98	3.0	Nil	39	15	49.3	24
21		15-45	37	24	3.1	Nil	30	90	8.7	6
22		45-90	23	15	2.7	Nil	30	15	2.5	4
23	46	Surface	383	4348	15.2	Traces	52	450	196.0	314
24	55	00-15	26	1196	7.1	74	23	50	155.0	332
25		15-45	25	70	3.8	Nil	26	25	21.9	20
26		45-90	19	33	4.0	Nil	27	20	7.5	121
27	60	00-15	34	139	14.1	Nil	26	75	58.7	34
28		15-45	17	57	8.2	Nil	24	25	23.7	20
29		45-90	30	44	4.6	Nil	21	25	19.4	11

S. No.	Detail Hole NO.	Depth (Cm)	CA+Mg	Na	K Exch.	CO_3	HCO_3	Cl	SO_4	SAR
			(meq/l)							
30	I	90-180	29	39	5.1	Nil	18	25	21.2	10
31	1	00-15	19.1	26.1	5.2	Nil	39	20	5.0	8.4
32	I	15-40	10.7	26.1	4.5	Nil	41	20	4.1	11.3
33	I	40-90	57.3	156.5	15.0	Nil	29	60	25.9	29.3
34	2	00-15	27.9	26.1	3.2	Nil	30	20	4.5	7.0
35		15-50	66.3	28.2	3.8	Nil	29	30	20.7	4.9
36		50-80	80.8	37.0	4.2	Mil	36	25	17.9	5.8
37		80-110	92.7	52.2	6.4	Nil	36	25	23.8	7.7
38	3	0-28	15.7	30.4	3.1	Nit	34	20	8.6	10.9
39		28-80	29.6	41.3	3.0	Nil	29	10	10.7	10.8
40		80-118	53.2	31.3	2.6	Nil	29	55	4.7	6.1
41		118-150	49.6	67.4	3.3	Nil	32	60	15.2	13.5

I[MI-PAKISTAN PUBLICATIONS
RESEARCH REPORTS

Report No	Title	Author	Year
R-1	Crop-Based Irrigation Operations Study In the Norlh West Frontier Province of Pakistan Volume I: Synthesis of Findings and Recommendations	Carlos Garces-R D.J. Bandaragoda Pierre Strosser	June 1994
	Volume II: Research Approach and Interpretation	Carlos Garces-R Ms. Zaigharn Habib Pierre Strosser Tissa Bandaragoda Rana M. Alaq Saeed ur Rehman Abdul Hakim Khan	June 1994
	Volume III: Data Collection Procedures and Data Sets	Rana M. Afaq Pierre Strosser Saeed ur Rehman Abdul Hakim Khan Carlos Garces-R	June 1994
R-2	Salinity and Sodicity Research in Pakistan - Proceedings of a one-day Workshop	J.W. Kijne Marcel Kuper Muhammad Aslam	Mar 1995
R-3	Farmers' Perceptions on Salinity and Sodicity: A case study into farmers' knowledge of salinity and sodicity, and their strategies and practices to deal with salinity and sodicity in their farming systems	Neeltje Kielen	May 1996
R-4	Modelling the Effects of Irrigation Management on Soil Salinity and Crop Transpiration at he Field Level (M.Sc Thesis - published as Research Report)	S.M.P. Smets	June 1996
R-5	Water Distribution at the Secondary Level in the Chishtian Sub-	M. Amin K. Tareen Khalid Mahmood Anwar Iqbal Mushtaq Khan Marcel Kuper	July 1996
R-6	Farmers Ability to Cope with Salinity and Sodicity: Farmers' perceptions, strategies and practices for dealing with salinity and sodicity in their farming systems	Neeltje Kielen	Aug 1996
R-7	Salinity and Sodicity Effects on Soils and Crops in the Chishtian Sub-Division: Documentation of a Restitution Process	Neeltje Kielen Muhammad Aslam Rafique Khan Marcel Kuper	Sept 1996
R-8	Tertiary Sub-System Management: (Workshop proceedings)	Khalid Riaz Robina Wahaj	Sept 1996
R-9	Mobilizing Social Organization Volunteers: An Initial Methodological Step Towards Establishing Effective Water Users Organization	Mehmoodul Hassan Zafar Iqbal Mirza D.J. Bandaragoda	Oct 1996
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R-12	Modeling of Sediment Transport in Irrigation Canals of Pakistan: Examples of Application (M.Sc Thesis published as Research Report)	Gilles Belaud	Oct 1996
R-13	Methodologies lor Design, Operation and Maintenance of Imgation Canals subject to Sediment Problems: Application to Pakistan (M.Sc Thesis published as Research Report)	Alexandre Vabre	Oct 1996

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R-14	Government Interventions in Social Organization for Water Resource Management: Experience of a Command Water Management Project in the Punjab, Pakistan	Waheed uz Zaman D.J.Bandaragoda	Oct 1996
R-15	Applying Rapid Appraisal of Agricultural Knowledge Systems (RAAKS) for Building Inter-Agency Collaboration	Derk Kuiper Mushtaq A. Khan Jos van Oostrum M. Rafique Khan Nathalie Roovers Mehmood ul Hassan	Nov 1996
R-16	Hydraulic Characteristics of Chishtian Sub-division, Fordwah Canal Division	Anwar Iqbal	Nov 1996
R-17	Hydraulic Characteristics of Irrigation Channels in the Malik Sub-Division, Sadiqia Division, Fordwah Eastern Sadiqia Irrigation and Drainage Project	Khalid Mahmood	Nov 1996
R-18	**Proceedings of National Conference on Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan**	M. Badruddin Gaylord V. Skogerboe M.S. Shafique (Editors for all volumes)	Nov 1996
R-18.1	Volume-I: Inauguration and Deliberations		
R-18.2	Volume-II: Papers on the Theme: Managing Canal Operations		
R-18.3	Volume-III: Papers on the Theme: Water Management Below the Mogha		
R-18.4	Volume-IV: Papers on the Theme: Environmental Management of Irrigated Lands		
R-18.5	Volume-V: Papers on the Theme: Institutional Development		
R-19	Detailed Soil Survey of Eight Sample Watercourse Command Areas in Chishtian and Hasilpur Tehsils	Soil Survey of Pakistan IIMI-Pakistan	Nov 1996
R-20	Unsteady Flow Simulation of the Designed Pehur High-Level Canal and Proposed Remodeling of Machai and Miara Branch Canals, North West Frontier Province, Pakistan	Zaigham Habib Kobkiat Pongput Gaylord V. Skogerboe	Dec 1996
R-21	**Salinity Management Alternatives for the Rechna Doab, Punjab, Pakistan**	Gauhar Rehman Waqar A. Jehangir Abdul Rehman Muhammad Aslam Gaylord V. Skogerboe	May 1997
R-21.1	Volume One: Principal Findings and Implications for Sustainable Irrigated Agriculture		
R-21.2	Volume Two: History of Irrigated Agriculture: A Select Appraisal	Gauhar Rehman Hassan Zia Munawwar Asghar Hussain	Jan 1997
R-21.3	Volume Three: Development of Procedural and Analytical Liniks	Gauhar Rehman Muhammad Aslam Waqar A. Jehangir Abdul Rehman Asghar Hussain Nazim Ali Hassan Zia Munawwar	Jan 1997
R-21.4	Volume Four: Field Data Collection and Processing	Gauhar Rehman Muhammad Aslam Waqar A. Jehangir Mobin Ud Din Ahmed Hassan Zia Munawwar Asghar Hussain Nazim Ali Faizan Ali Samia Ali	Jan 1997
R-21.5	Volume Five: Predicting Future Tubewell Salinity Discharges	Muhammad Aslam	Jan 1997

Report No.	Title	Author	Year
R-21.6	Volume Six: Resource Use and Productivity Potential in the Irrigated Agriculture	Waqar A. Jehangir Nazim Ali	Feb 1997
R-21.7	Volume Seven: Initiative lor Upscaling: Inigation Subdivision as *the* Building Block	Gauhar Rehman Asghar Hussain Hassan Zia Munawwar	Apr 1997
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