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# SALINITY MANAGEMENT ALTERNATIVES FOR THE RECHNA DOAB, PUNJAB, PAKISTAN

## Volume Seven

## Initiative for Upscaling: Irrigation Subdivision as the Building Block



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# SALINITY MANAGEMENT ALTERNATIVES FOR THE RECHNA DOAB, PUNJAB, PAKISTAN

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## I. INTRODUCTION

A key benefit in the use of the spatial information systems is in the integration of thematic information across a common coordinate reference. Such a consolidation is a pre-requisite to the use of the conventionally available GIS tools whereby not only discontinuities in space are identified, but also the remissions in data collection over time are exposed. Beyond the essentials of this integration, lies the need for subsampling which is necessitated when a larger geographic extent is too diverse to manipulate towards productive assimilations and modeled appropriations. This is particularly true when a substantial number of information units (points, lines, polygons, etc.) and types (legend-wise separations) are contained within a theme; the situation is compounded further if these spatial constitutions have a wide scattering. Granted this complexity in rendering, it is difficult to comprehend the significance of this information in relation to the externalities associated with its composition into a map. While it may be an achievement in itself to put several disparate spatial entities together, the seclusion of such an assemblage towards a meaningful inference necessitates recourse to information partitioning in space. The current study on the Rechna Doab is cited as an example wherein not only the geographic extent of 2.9 Mha is too large for a collective inference in space but the information pieces contained in the individual themes (like soil texture and its affiliated attributes of drainability, crop suitability, and salinity, along with quality of groundwater and subsurface water level fluctuations) are too diverse and discontinuous in time to result in a consolidated interpretation. Hence, towards ease of interpretation, the irrigated regime is partitioned into the administrative units at the subdivisional level (Figure 15, Volume Two, reproduced here as Figure 1(a)). The significance of this delimitation is already explained under Section II. B (3) of Volume Three.

Additional reference is made to the Section II. C of Volume Three whereby it is argued that, considering the mass of thematic information gathered for this study, it would be both prudent and logical to avoid a digression on the significance of the combinations made possible by the GIS analysis. Instead, a description of the locational concurrence of all modeled and survey data within each of the subdivisions is deemed to suffice for subsequent realizations on resource potential through selective application of the production function models derived under Table 10 of Volume Four. This descriptive process, appearing under *Descriptive Summary* in the Process flow chart (Figure 1, Volume Four), not only overcomes

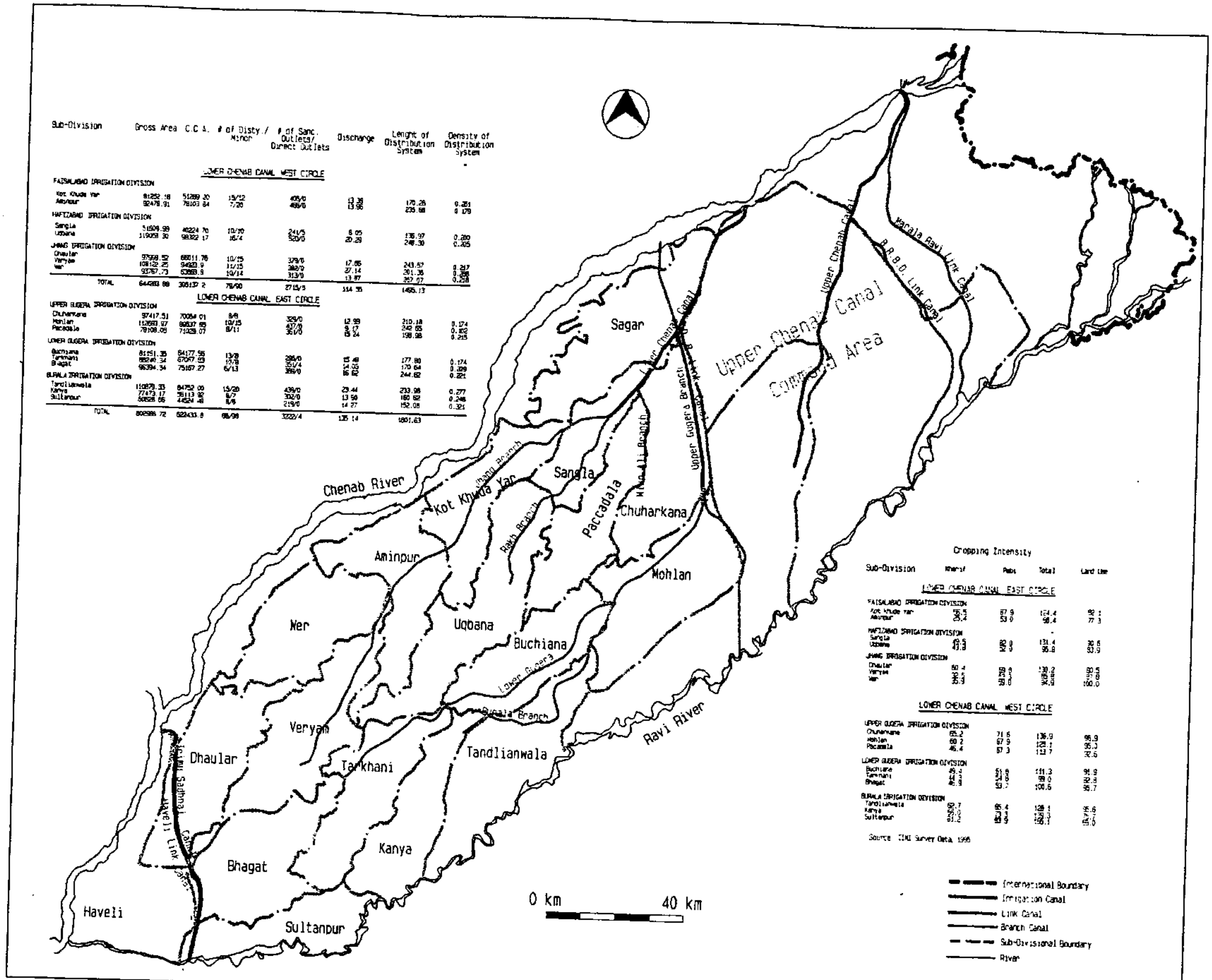



Figure 1(a). Administrative Units in the Lower Chenab Canal System Rechna Doab, Punjab, Pakistan problems in missing data but also relates well with the *Overlay Operations* support available to the *Subdivisional Stratifications* stage.

Specific reference to the deployment of the GIS generated themes for inclusion in the *Subdivisional Stratifications* stage is provided under the Analytical Flow Chart of Figure 13 in Volume Three. From amongst the seven thematic models, described there under numbered boxes 35, 36, 38, 47, 48, 49, & 50, items 48 and 50 were excluded from the stratifications at the subdivision level due to the limited extent of the groundwater quality data. Instead, some additional physical themes on soil texture/association, drainability, and crop suitability were included to facilitate the descriptive process.. An example of this physical summary of the regime at the subdivision level has already been given under Figures 4-12 of Volume Three. The following discussion highlights the characteristics of the physical and economic regime specific to each of the subdivisions considered for this study. This discussion is meant to provide an introduction to the location-specific constraints most likely to be encountered within the subdivisions, and facilitate the appraisal towards the choice and applicability of the production functions conforming to these constraints.

The discussion on IIMI's questionnaire related data on farm level economics draws extensively on the compendium of information given in Appendix H of Volume Four. The sequence of presentation relates to the salient farm level characteristics and gross farm inputs/returns (macro level indicators of farm economics and cost distributions) for the major crops. The purpose is only to introduce and compare the relative significance of the farming trends across the subdivisions while keeping in mind the physical description provided prior to such a discourse. The discussion on Kanya, Sagar, Sangla, Sultanpur and Wer Subdivisions has been omitted due to the small number of sample farmers.

The opening discussion for each of the subdivisions relates to the characteristics of the hydrologic regime. The information pieces critical to this understanding have been obtained from the most recent updates to the inventory of the irrigation system by the Punjab Irrigation Department. The records for the Sagar Subdivision (at the head of the LCC system) and Haveli Subdivision (comprising the commands of the main Haveli Canal, Lower Gugera and the Koranga Feeder from across the Sidhnai Headworks) at the very tail of the Rechna Doab were not centralized and hence were not available at the time of writing this report. The essential information pertaining to the hydrologic inventory appears under Table 1. Two specific parameters pertaining to the design of the secondary level irrigation network listed in this table are the *density of the distribution network* and the *design allocations per thousand hectares of the irrigated command.* When plotted together in the context of the *increasing size of the commanded area per watercourse* (taken here as a reference), the results from Figure 1(b) indicate haphazard variations in the respective magnitudes of the two variables, though they may be mutually related across the higher averages for the watercourse sizes. Assuming no physical alterations to the system, the line of maximum design allocations would then constitute the potential reference to the perceived shortages in the surface irrigation supplies. Table 2 lists the derived modifications table 1

Table 1. Salient Characteristics of the Hydrologic Regime in the Administrative Units of the Lower Chenab Canal System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Gross Area (ha) | Canal Command Area (ha) | Difference (ha) | Percentage of CCA within Gross Area | No. of Distributories | No. of Minors | Sanctioned Watercourses | Direct Outlets | Average Area/Watercourse | Design Discharge (cumecs) | Length of Disty. System (Km) | Qd/1000 ha CCA | Density of Distribution System (Km/1000 ha CCA) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aminpur | 92479.00 | 78103.84 | 14375.16 | 84 | 7 | 20 | 465 | 0 | 167.97 | 13.3780 | 234.96 | 0.1713 | 3.01 |
| Bhagat | 96394.00 | 75167.27 | 21226.73 | 78 | 6 | 13 | 389 | 0 | 193.23 | 17.3300 | 255.47 | 0.2306 | 3.40 |
| Buchiana | 81151.00 | 64177.56 | 16973.44 | 79 | 13 | 8 | 295 | 7 | 212.51 | 13.1000 | 194.96 | 0.2041 | 3.048 |
| Chuharkana | 97417.00 | 70064.00 | 27352.99 | 72 | 8 | 8 | 329 | 0 | 212.96 | 12.4540 | 190.40 | 0.1778 | 2.72 |
| Dhaular | 98000.00 | 66011.76 | 31988.24 | 67 | 10 | 15 | 379 | 0 | 174.17 | 10.7320 | 273.75 | 0.1626 | 4.14 |
| Haveli | 98654.00 | | | | | | | | | | | | |
| Kanya | 77473.00 | 56113.91 | 21359.08 | 72 | 8 | 7 | 302 | 0 | 185.81 | 13.0460 | 178.21 | 0.2325 | 3.17 |
| Kot Khuda Yar | 81252.00 | 51289.20 | 29962.80 | 63 | 15 | 12 | 405 | 0 | 126.64 | 13.8070 | 177.80 | 0.2692 | 3.46 |
| Mohlan | 112694.00 | 89537.65 | 23156.35 | 79 | 10 | 15 | 437 | 0 | 204.89 | 17.5880 | 270.64 | 0.1964 | 3.02 |
| Pacca Dala | 78108.00 | 71029.07 | 7078.93 | 91 | 8 | 11 | 361 | 0 | 196.76 | 15.5960 | 177.46 | 0.2196 | 2.50 |
| Sagar | 114234.00 | | | | | | | | | | | | |
| Sangla | 51610.00 | 40224.70 | 11385.30 | 78 | 10 | 10 | 241 | 5 | 163.52 | 7.0700 | 134.14 | 0.1758 | 3.33 |
| Sultanpur | 60629.00 | 44524.49 | 16104.51 | 73 | 8 | 6 | 219 | 0 | 203.31 | 11.2700 | 170.67 | 0.2531 | 3.83 |
| Tandlianwala | 110879.00 | 84752.00 | 26127.00 | 76 | 15 | 20 | 439 | 0 | 193.06 | 22.7480 | 239.24 | 0.2684 | 2.82 |
| Tarkhani | 88240.00 | 67067.83 | 21172.17 | 76 | 10 | 8 | 351 | 4 | 188.92 | 16.5000 | 160.56 | 0.2460 | 2.39 |
| Uqbana | 119053.00 | 98322.00 | 20731.00 | 82 | 16 | 4 | 520 | 0 | 189.08 | 22.2700 | 248.9500 | 0.1719 | 1.92 |
| Veryam | 108122.00 | 94923.90 | 13198.10 | 88 | 11 | 15 | 382 | 0 | 248.49 | 24.3910 | 137.83 | 0.2570 | 1.45 |
| Wer | 93768.00 | 63683.80 | 30084.20 | 68 | 10 | 14 | 313 | 0 | 203.46 | 16.8696 | 255.87 | 0.2649 | 4.01 |

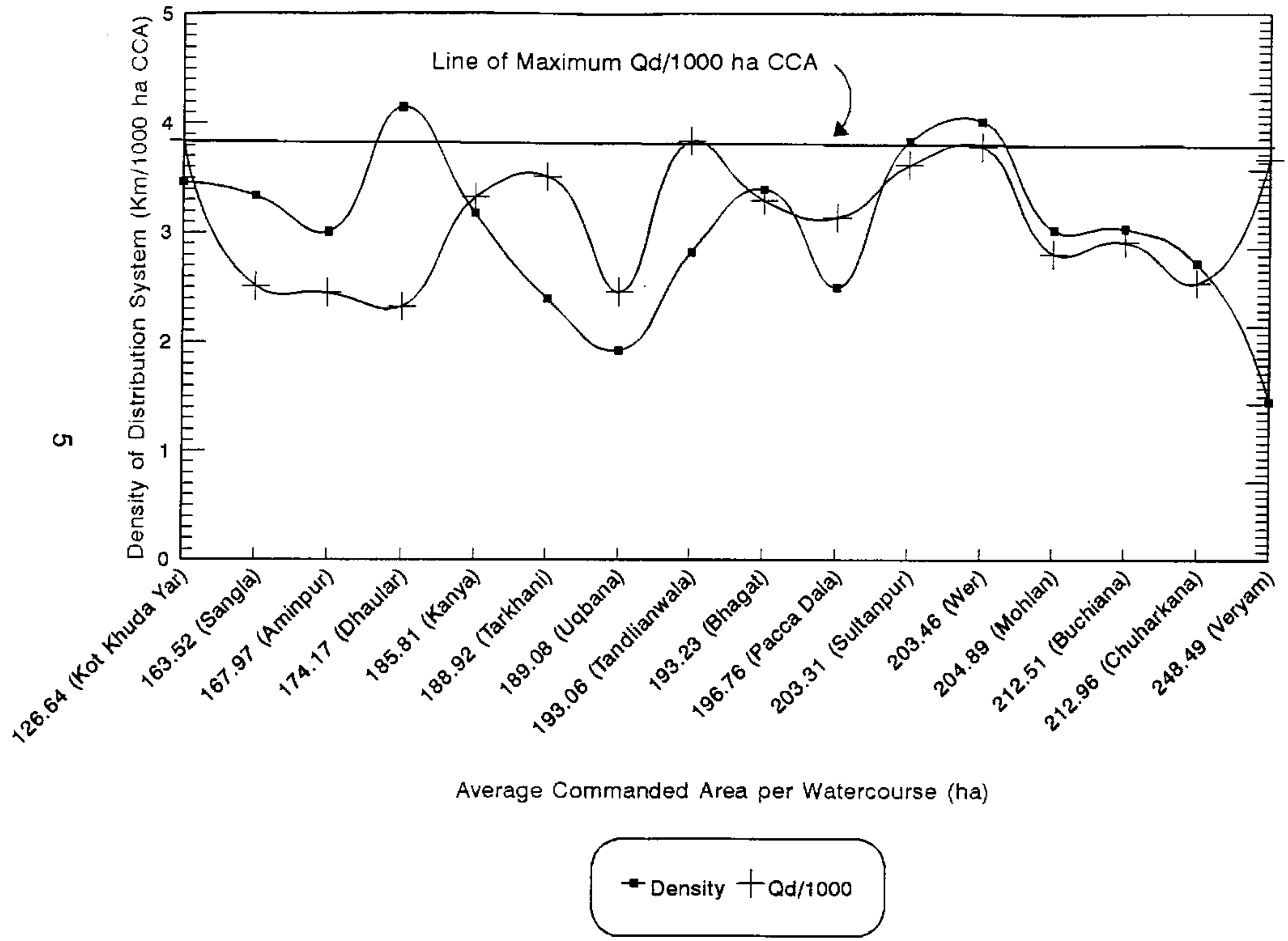



Figure 1(b). Design Allocation for Surface Irrigation in relation to the existing Hydrological Network and Tertiary Level Commanded Regime, LCC Irrigation System, Rechna Doab, Pakistan.

Table 2. Derived Modifications to the existing Hydrological Characteristics of the Irrigation System within the Administrative Units of the Lower Chenab Canal System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Canal Command Area (ha) | Design Discharge (cumecs) | Derived Qd (cumecs) | Qd/1000 ha CCA | Qd/1000 ha (Derived) | Length of Disty. System (Km) | Derived Length of the Disty. System (Km) |
|---|---|---|---|---|---|---|---|
| Aminpur | 78103.84 | 13.38 | 21.09 | 0.17 | 0.27 | 234.96 | |
| Bhagat | 75167.27 | 17.33 | 20.30 | 0.23 | 0.27 | 255.47 | |
| Buchiana | 64177.56 | 13.10 | 17.33 | 0.20 | 0.27 | 194.96 | |
| Chuharkana | 70064.00 | 12.45 | 18.92 | 0.18 | 0.27 | 190.40 | |
| Dhaular | 66011.76 | 10.73 | 17.82 | 0.16 | 0.27 | 273.75 | |
| Haveli | | | | | | | |
| Kanya | 56113.92 | 13.05 | 15.15 | 0.23 | 0.27 | 178.21 | |
| Kot Khuda Yar | 51289.20 | 13.81 | 13.85 | 0.27 | 0.27 | 177.80 | |
| Mohlan | 89537.65 | 17.59 | 24.18 | 0.20 | 0.27 | 270.64 | |
| Pacca Dala | 71029.07 | 15.60 | 19.18 | 0.22 | 0.27 | 177.46 | 191.78 |
| Sagar | | | | | | | |
| Sangla | 40224.70 | 7.07 | 10.86 | 0.18 | 0.27 | 134.14 | |
| Sultanpur | 44524.50 | 11.27 | 12.02 | 0.25 | 0.27 | 170.67 | |
| Tandlianwala | 84752.00 | 22.75 | 22.88 | 0.27 | 0.27 | 239.24 | |
| Tarkhani | 67067.83 | 16.50 | 18.11 | 0.25 | 0.27 | 160.56 | 181.08 |
| Uqbana | 98322.00 | 22.27 | 26.55 | 0.23 | 0.27 | 248.95 | 265.47 |
| Veryam | 94923.90 | 24.39 | 25.63 | 0.26 | 0.27 | 137.83 | 256.29 |
| Wer | 63683.80 | 16.87 | 17.19 | 0.27 | 0.27 | 255.87 | |

to the original cumulative design discharge and the design surface allocations per thousand hectares of the commanded regime.

To accommodate the above increases in design flows within the existing secondary level distribution network, two options are available; one, to remodel the current carrying capacity of the channels; or, else broaden the irrigation network. Assuming more bias in favor of the remodeling option in a manner that minimizes expansion of the existing network, the choice of the per unit carrying capacity of the channel ($Q_d$/km length) lends useful insight to the subdivisional level differentiations across the LCC system. The higher this ratio, the less need there is expand the network. From Figure 1(c), even if this ratio is selected as 0.1, a value that exceeds the calculations for all subdivisions except Veryam, the net impact (last column, Table 2) towards extensions to the existing network is significant for four out of the 16 units considered for this purpose. In reality, the modified $Q_d$/km ratio would necessitate some adjustments to the irrigaiton network; however, the intent here is to show only the most serious shortcomings in the existing densities of the distribution system at the subdivision level.

Finally, Table 3 provides a comparison of the targeted deficiencies in the design discharge $Q_d$ , with respect to the increases in flows realized as a result of the channel remodeling. Achieving modest increases in channel capacities *within design allocations* is not unusual, such as through desiltation for which process documentation studies by IIMI for the Lagar Distributary in 1989 indicate expected improvements of 25% or more in the allocations along the distribution system (see Figures 56(a) & 57, Volume Two). The impact of the respective increases in the flows, realized through remodeled increases of upto 25% beyond the existing design limits, appears in the last column of Table 3 wherein the deficits still remaining are indicated. It is this sum quantum of flows that would necessitate selective remodeling of the system to arrive at uniform levels of allocations ($Q_d$/1000 ha CCA) across all the subdivisions targeted under the current study. Again, the 25% figure of a remodeled increase is only presented as a reference against which likely adjustments to the channel capacities could be facilitated.

The above calculations are intended to be broad indicators of the deficiencies in the hydrologic regimes of the subdivisions; the extent of modifications represent the *maximum* with respect to the design level appropriations of the system (as per original record of the Irrigation Department). An added degree of pragmatism to the desirable overhauls may lie in the context of such additional information as the current levels of cropping intensities directly observed by IIMI during its field and farm level surveys in 1995 (Figure 1(d)), or better still, on the basis of the potential reliance on groundwater supplies.

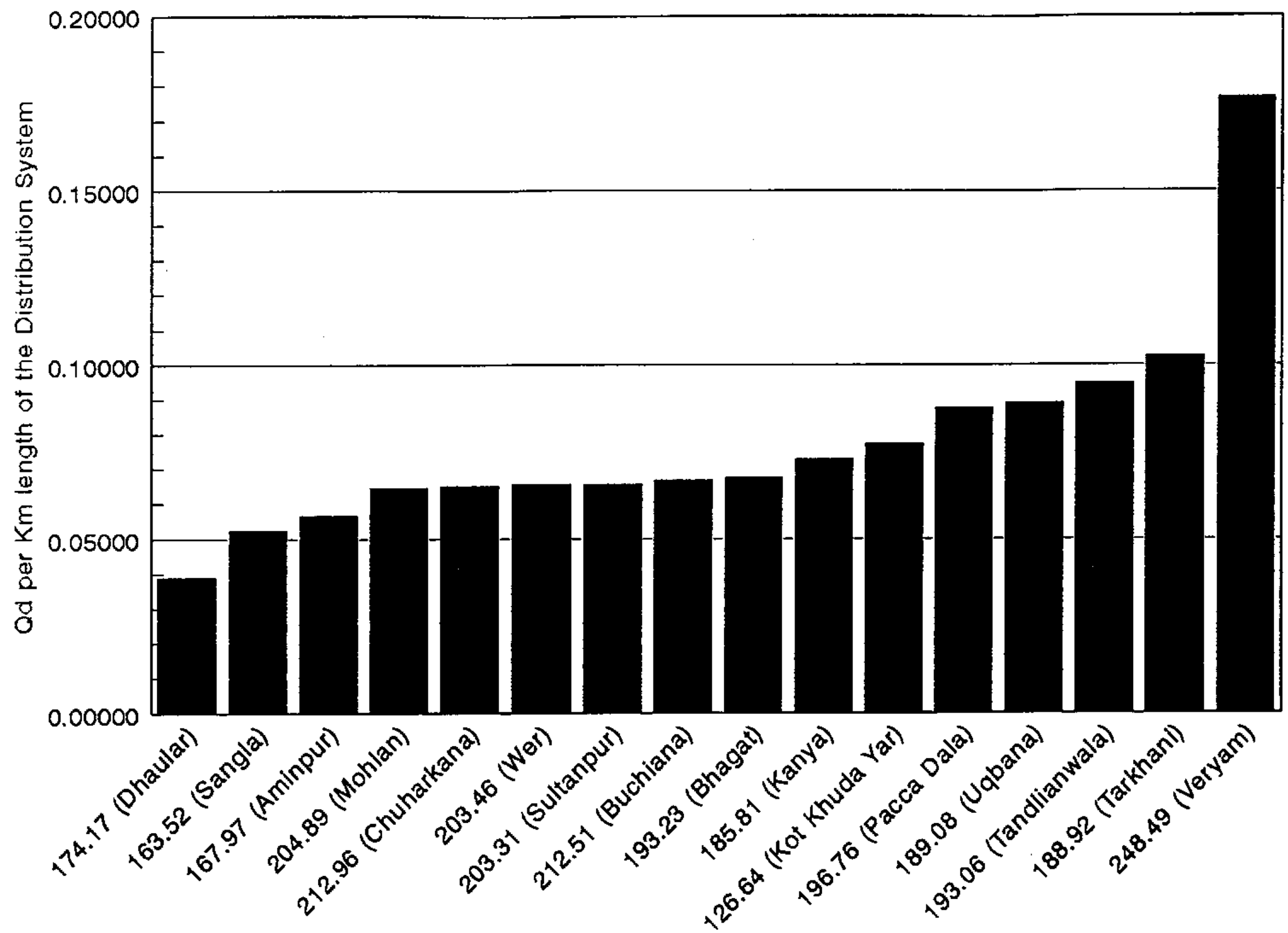



Figure 1(c). Distribution of the existing Surface Irrigation Flows per unit length of the Secondary Level Network within the Irrigation Subdivisions of the LCC System, Rechna Doab, Pakistan.

Table 3. Calculated Deficiencies in System Flows for the Irrigation Subdivisions of the LCC System, Rechna Doab, Pakistan.

| Subdivision | Design Discharge (cumecs) | Derived Qd based on Observed Maximum (cumecs) | Targeted Increase (cumecs) | Target met by assumed 25% Operation above Qd (cumecs) | Excess of Target (cumecs) | Deficit Remaining after Desiltation (cumecs) |
|---|---|---|---|---|---|---|
| Aminpur | 13.38 | 21.09 | 7.71 | 3.35 | | -4.36 |
| Bhagat | 17.33 | 20.30 | 2.97 | 4.33 | 1.36 | |
| Buchiana | 13.1 | 17.33 | 4.23 | 3.28 | | -0.95 |
| Chuharkana | 12.45 | 18.92 | 6.47 | 3.11 | | -3.36 |
| Dhaular | 10.73 | 17.82 | 7.09 | 2.68 | | -4.41 |
| Haveli | | | | | | |
| Kanya | 13.05 | 15.15 | 2.10 | 3.26 | 1.16 | |
| Kot Khuda Yar | 13.81 | 13.85 | 0.04 | | | |
| Mohlan | 17.59 | 24.18 | 6.59 | 4.40 | | -2.29 |
| Pacca Dala | 15.6 | 18.18 | 2.58 | 3.90 | 1.32 | |
| Sagar | | | | | | |
| Sangla | 7.07 | 10.86 | 3.79 | 1.77 | | -2.02 |
| Sultanpur | 11.27 | 12.02 | 0.75 | 2.82 | 2.07 | |
| Tandlianwala | 22.75 | 22.88 | 0.13 | | | |
| Tarkhani | 16.5 | 18.11 | 1.61 | 4.13 | 2.52 | |
| Uqbana | 22.27 | 26.55 | 4.28 | 5.57 | 1.29 | |
| Veryam | 24.39 | 25.63 | 1.24 | 6.10 | 4.86 | |
| Wer | 16.87 | 17.19 | 0.32 | | | |

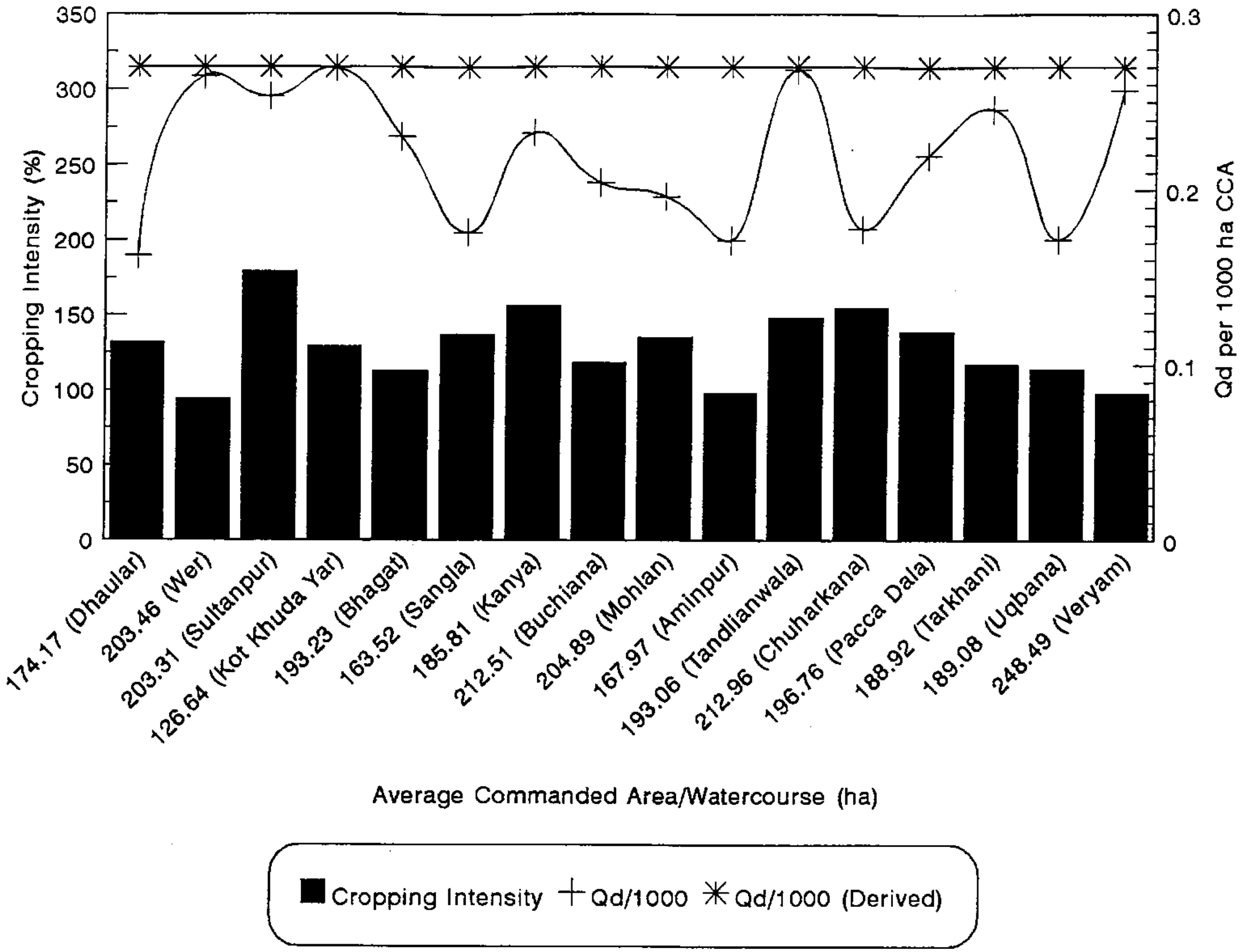



Figure 1(d). Derived Alterations to the Design Surface Flows in the Context of IIMI Sample Data for Average Cropping Intensities in the Irrigation Subdivisions of the LCC System, Rechna Doab, Pakistan.

## II. DESCRIPTIVE PROFILE OF THE SUBDIVISIONS

### A. Aminpur Subdivision

*Hydrologic Regime*: Aminpur Subdivision, comprising a gross area of 92479 ha, lies in the Lower Chenab Canal (West) Circle (Figure 2(a)) and is dependent on the Jhang Branch for its share of supplies to the 27 hydrological units (7 distributaries and 20 minors) irrigating a total of 465 sanctioned outlets (Table 1). The number of these tertiary units is the second highest across the entire LCC and Haveli system after the neighboring Uqbana Subdivision. However, given the nearly equal sanctioned allowances for the surface irrigation supplies, comparisons for the density of the secondary distribution network reveal Aminpur to have a more than 50% advantage over the Uqbana. From Figure 1(b), the sanctioned allowances for the Aminpur are one of the lowest against the maximums observed elsewhere in the system. Calculations in Table 3 show that these deficiencies are not going to be overcome through desiltation related enhancement of the existing carrying capacity. However, more significant is the fact that these modest gains can be realized without resorting to an extension of the existing irrigation network as the modified Qd/km ratio of 0.07 would still be less than the maximum assumed figure of 0.1 (Figure 1(c)) beyond which the carrying capacities of the channels would be exceeded. Figure 1(d) shows that the net impact of these enhanced surface allocations would be most significant for the Aminpur Subdivision where the existing cropping intensities are already very low (in fact, much of it is sustained by the wheat crop as more than 50% of the area is fallow during kharif).

The total topographic relief across the Aminpur Subdivision is between 15-17 meters; the slopes are much sharper on the right side of the Jhang Branch and correspond to an average of 0.00043 in comparison to the left side where the terrain along the long run of the Nasrana Distributary corresponds to an average of 0.00028.

*Soils*: According to the earliest soil series surveys conducted in the period 1958-63 by the then Water and Soils Investigation Division (WASID), the soils in the Aminpur irrigation subdivision are predominantly moderately coarse comprising constituents of fine sandy loam to sandy loam texture (Figure 2(b)). Variations from this occurrence are restricted only to the upper reaches of the Subdivision, in the commands of the several minors issuing from the Chiniot Distributary, where the scatters form part of the Buchiana soil series (see page 39, Volume Two).

The textural differentiation provided by the Soil Survey of Pakistan (SSoP) is more comprehensive than the one given by WAPDA, and consequently extolls upon a greater spatial diversity. From Figure 2(c), the regime is partitioned by the main Jhang Branch into the medium textures of the Faisalabad and Hafizabad associations to the south and the significantly finer intermixtures comprising Miani, Shahpur, Sultanpur and Shahdara soil associations to the north. There could be a broad agreement in the textural interpretations offered by the SSoP and WASID if the latter's distinctly coarser ranking of the soil textures

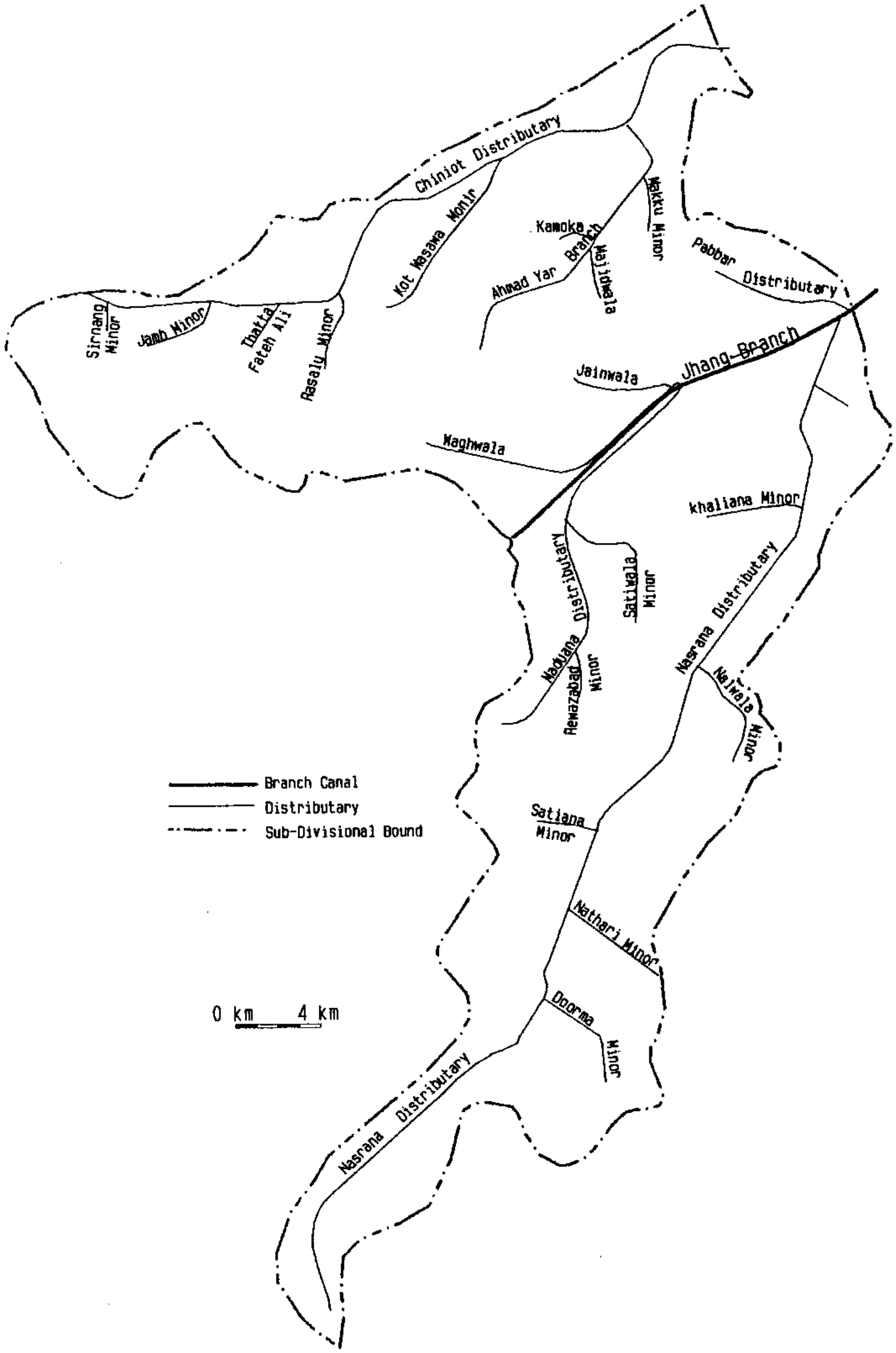
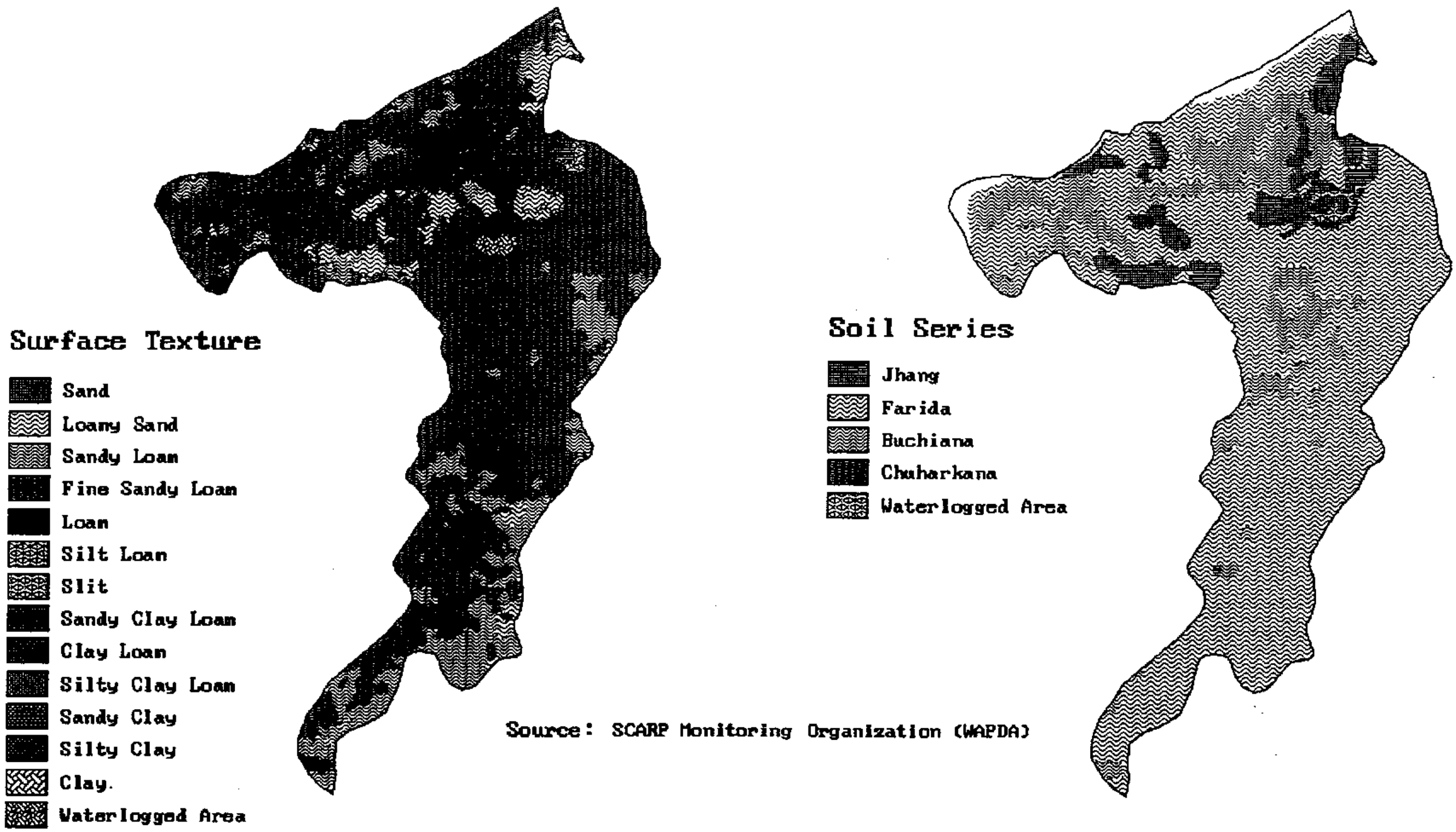



Figure 2(a) Aminpur Irrigation Subdivision in the Lower Chenab Canal (west) Circle, Rechna Doab, Punjab, Pakistan




Source: SCARP Monitoring Organization (WAPDA)

Figure 2(b) Surface and Profile Texture of the Soils in the Aminpur Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

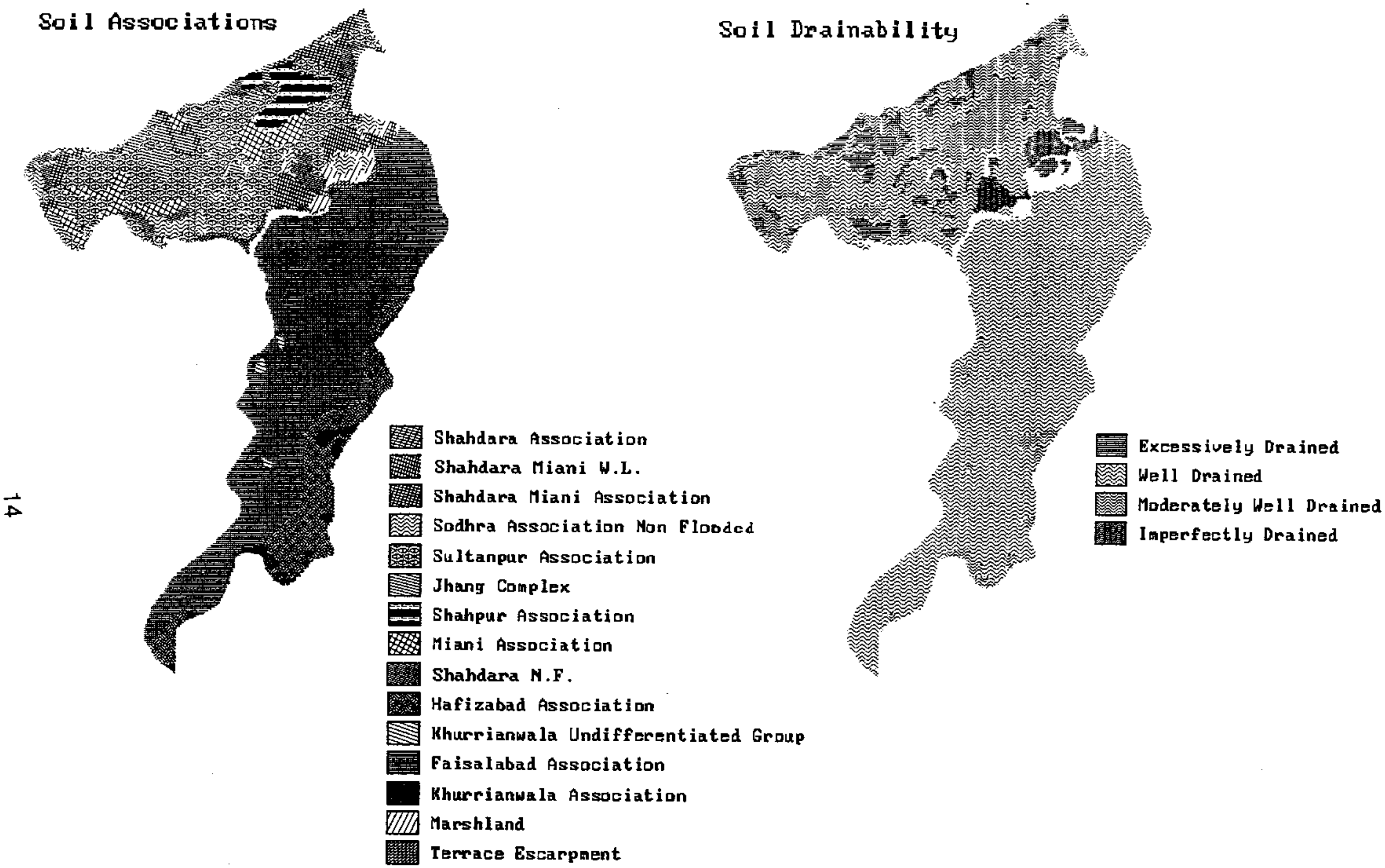



Figure 2(c) Associative Classification of the Soils and their Drainability Charactristics in the Aminpur Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

is ignored in favor of the more subtle variations offered by the former. In the upper reaches of the Subdivision, this difference is obvious in the direct spatial correspondence between the Sultanpur association (loam) and the fine sandy loam across the minor commands of the Chiniot Distributary. Similarly, further south, the loams of the Hafizabad association are mismatched against the sandy loams in the minor commands of the Nasrana Distributary.

*Soil Drainability and Crop-Suitability*: The drainable potential of the soils, as extracted from the descriptions provided under the SSoP associations, appears in Figure 2(c). Except for some excessively drained patches of the Jhang Complex and Sodhra associations, the rest of the regime is predominantly well drained; the phenomenon is overwhelming in areas southwards of the Jhang Branch. However, the immediate reaches of the Jhang Branch itself are waterlogged and comprise the Shahdara Miani and Shahdara non-flooded associations. Additional exceptions to the well drained extents occur in the right bank command of the Ahmed Yar Branch offtaking from the Chiniot Distributary where the predominance of the strongly calcareous silty clay loams of the Shahpur association (with intermixtures of the Sultanpur silt loams) make for moderately well drained conditions that are particularly suitable for the growth of wheat, rice and sugarcane crops. Overall, commands to the south of the Jhang Branch are well suited for the growth of wheat, cotton and sugarcane, whereas the well drained profiles are only moderately suited for growing rice (Figure 2(d)). The coarser fractions of Jhang and Sodhra soils occuring in the command of the Chiniot Distributary, opposite the offtake locations for Thatta Fateh Ali and Rasalu minors, are largely unsuitable for the growth of all the major crops mentioned above.

*Soil Salinity and Waterlogging*: WAPDA's Master Planning and Review surveys (1976-79) indicate the soils in the Aminpur Subdivision to be largely free of the effects of salinity. Varying degrees of salinity are mostly localized along the path of the Jhang Branch where, as already indicated, the effects of waterlogging are quite siginificant and localized (Figure 2(e)). Additionally, wide scatters of salinity are also present in the command of the Nasrana Distributary beyond the offtake location of the Nalwana Minor; however, this seems largely restricted to the uncultivated trcats. Presence of these patches is linked to the strongly saline Khurrianwala association identified earlier (1965-68) by the SSoP. WAPDA's profile soil salinity sampling supplements the SSoP assessment in that a visibly higher concentration of sodic soils has been identified in the tail reaches of the Nasrana Distributary.

The data available from WAPDA's SCARPs Monitoring Organization (SMO) for the pre- and post-monsoonal fluctuations in subsurface water levels indicates insignificant changes below the root zone in recent years (Figure 2(f)). The benchmark data of 1980 shows the middle reaches of the Nasrana Distributary to have experienced a decrease in water levels following the monsoon related recharge. Over the years, and up to the year 1993, an increase in water levels has been recorded but remained restricted to depths below the root zone; the progressive shift in these seasonal increases being continually towards the tail reaches of the Nasrana Distributary.

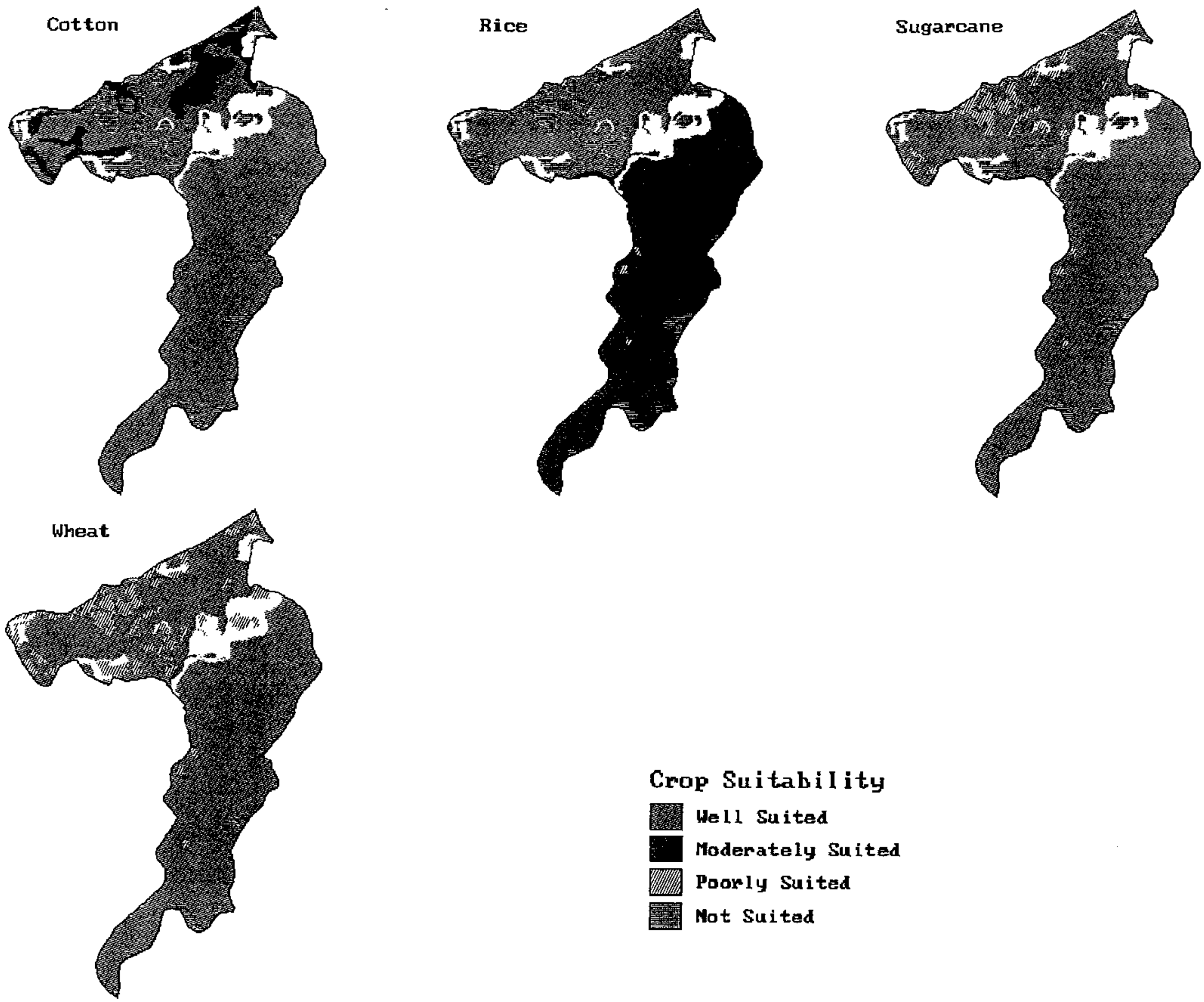



Figure 2(d) Soil Suitability for Major Crops in the Aminpur Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

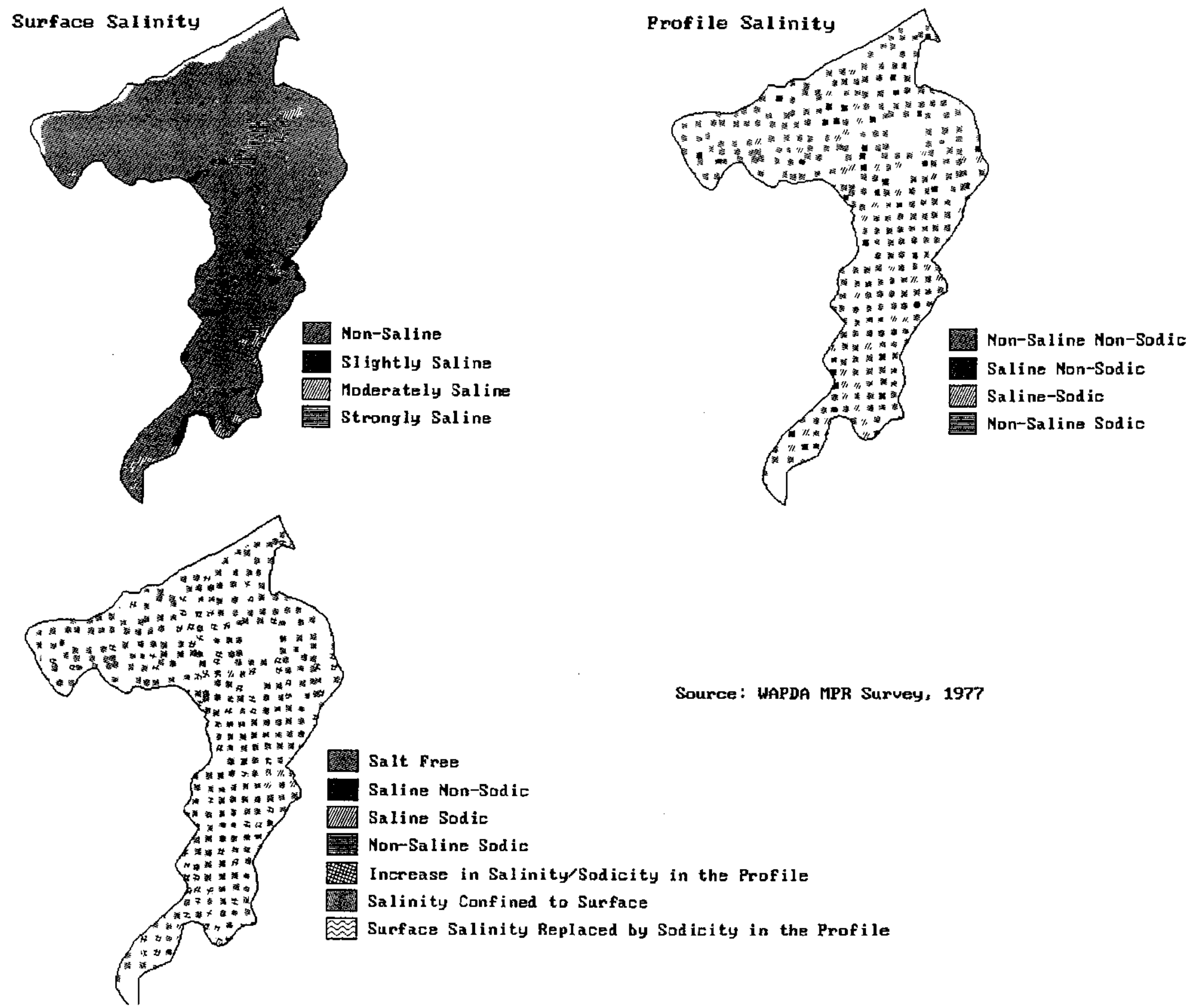



Figure 2(e) Surface and Profile Salinity in the Aminpur Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

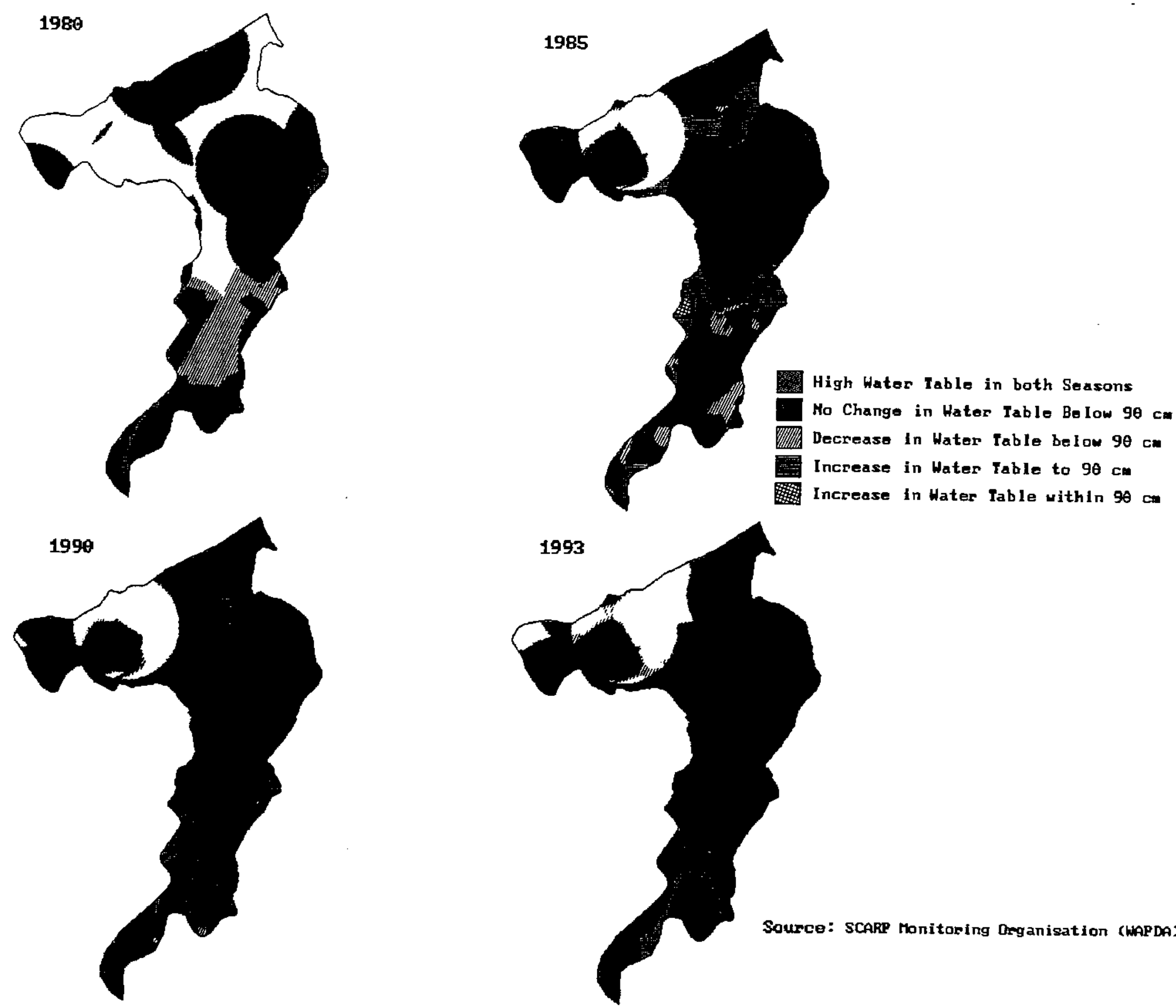



Figure 2(f) Temporal Variations in the Aminpur Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

Based on the internal flow regime, whereby the preferred flow paths within the stratum partly affect the subsurface levels, the subterranean slopes in the period 1985-90 indicate the Subdivision to be largely non-responsive to any recharge related activity (Figure 2(g)). However, from 1990 onwards, there are indications that the water levels, though remaining below the root zone, are experiencing reductions in the slopes of the outflow nets. Initially, it was restricted to the head reach of the Nasrana Distributary and its minor commands of Nalwala and Nathari minors; however, by 1993 the gradual loss in subsurafce slope was also visible in the head reach of the Chiniot Distributary. Interestingly, areas that have experienced an increase in the subsurface slopes are overwhelmingly either in the minor commands or constitute the tail portions of the distributaries. Considering the highly localized nature of such regimes, the inference is mostly likely drawn to the groundwater abstractions occurring during the high consumptive use period of the kharif season.

*IIMI Sampling for Soil Salinity and Texture*: From Table 7, Volume Four, a total of 834 sample observations on apparent soil salinity were made (through the EM38 device) in the commands of the Nasrana and Maduana distributaries of Aminpur Subdivision (Figure B1, Volume Four). The preceding discussion has already shown that it is in these areas that the majority of the salinity patches, identified through earlier surveys, are located. The results across nearly 11,000 ha of sample domain indicate that approximately 86% of the cultivated area is non-saline. From Figure B1, Volume Four, most of these non-saline observations belong to the loam/silt loam soil texture; higher levels of salinity predominate the silt loams and the somewhat coarser sandy loams that would generally correspond to the charateristically saline Khurrianwala association identified earlier by the SSoP.

Crop-wise preference for soils across all levels of salinity in the Aminpur Subdivision is shown in Figure C1 of Volume Four. Except for the barren category (included in the sampling because of its immediate proximity to the cultivated fields), all other patterns of land use are overwhelmingly on non-saline soils. Loam predominates all other soil textures by virtue of the Faisalabad Association; patterns of non-saline soil textures are similar across ploughed and fallow land categories (most likely to be cultivated for the wheat crop during the rabi season). Sugarcane has been observed to be dominating the medium textures and moderately fine textures; this preference coincides in space with the crop-suitability rankings provided by the SSoP in Figure 2(d) above. There were no observations for the rice crop since the sample domain was entirely limited to the well drained soils south of the Jhang Branch; the SSoP ranking being only moderately suitable for the growth of rice in this area. The 'S3' and 'S4' classes of salinity in the barren lands category closely match the textural composition provided earlier in Figure B1 of Volume Four, thereby confirming the comparatively higher incidence of salinization in silt loams/sandy loams.

*IIMI Farm Level Sampling*: A total of 17 sample farmers were interviewed across the Aminpur Subdivision where the reported cropping intensity, based on the cultivated area, was about 100%. This area is known predominantly for wheat and sugarcane crops that constitute almost 75% of the total cropping intensity. Despite the fact that over 84% of the gross area of the Subdivision is CCA, the on-farm cultivation intensity does not exceed 80%.

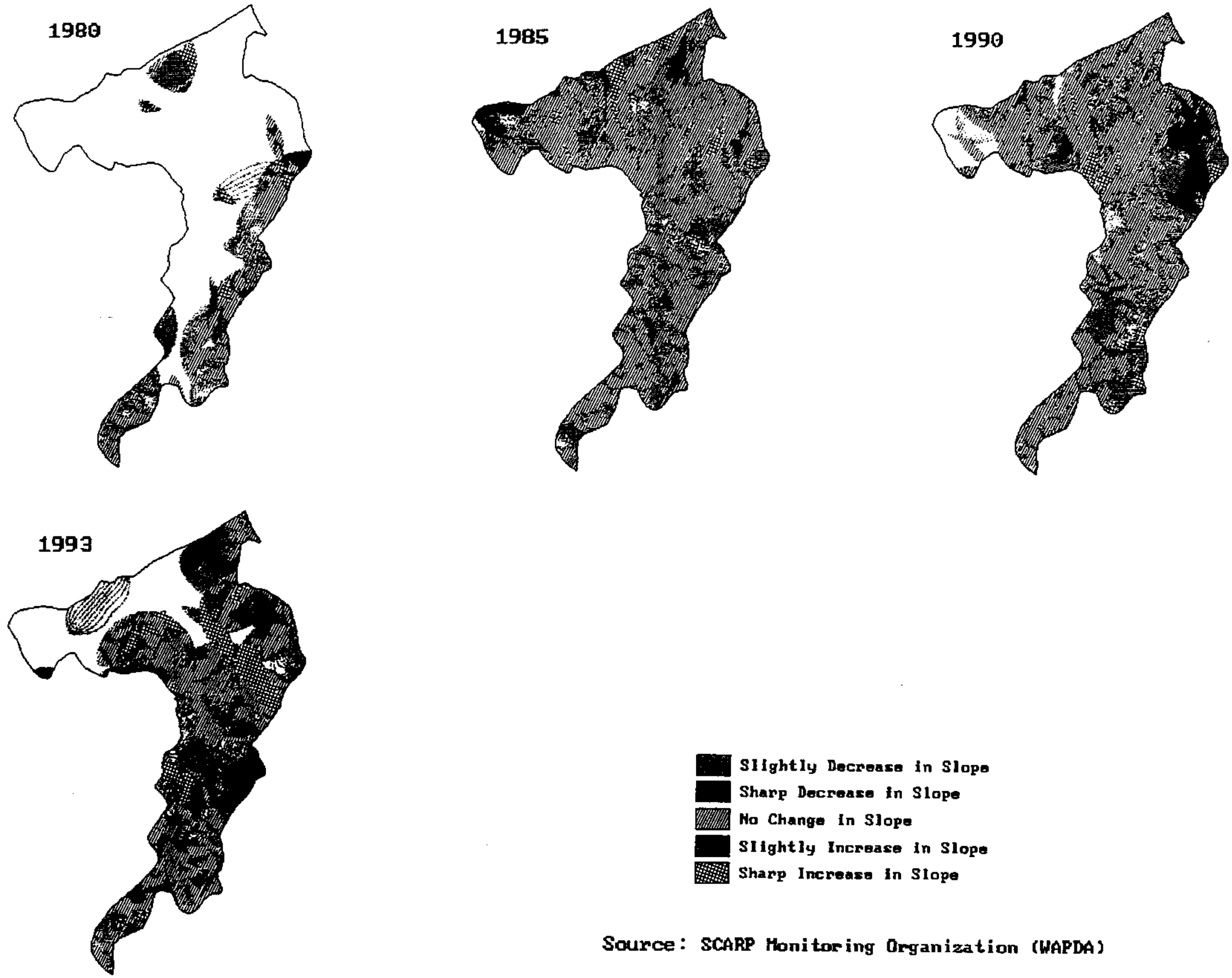



Figure 2(g) Interseasonal Slope Variations in the Subsurface Flows, Aminpur Irrigation Subdivision, Lower Chenab Canal (West) Circle. Rechna Doab. Punjab. Pakistan.

For reasons of scarcity of water and incidence of land degradation due to salinity/waterlogging (Figure H3, Volume Four), between 30-40% of the farmers are seasonally constrained to keep their lands fallow. Moreover, a majority of the farmers also cite poor quality of groundwater as an additional constraint towards boosting the cultivation intensity. Hence, over 20% of the regime has been classified as a culturable waste, i.e. lands fit for cultivation but not being cropped due to a shortage of irrigation supplies. Despite the foregoing, the farming community has been able to achieve comparatively higher gross incomes (and profits) for the wheat crop (Figure H6, Volume Four). The average yield of this crop is also high and ranks fourth in comparison to the other subdivisions of the LCC system. The same would be true for the sugarcane crop, however, the limited sample of only seven farmers reporting its cultivation prevents any generalized conclusions.

### B. Bhagat Subdivision

***Hydrologic Regime***: Located in the tail reaches of the Lower Gugera system, Bhagat covers a gross area of 96394 ha and comprises 8 secondary channels and 12 minors/subminors for a total cumulative canal command of 75167 ha (Figure 3(a)). For a total of 389 sanctioned outlets across the CCA, the average per outlet command is about 193 hectares. Incidently, IIMI's watercourse level activities in the past have focussed on some of the principal distributaries of this Subdivision including Khikhi, Pir Mahal, Dabanwala, and Junejwala Minor. The total topographic relief across the Bhagat Subdivision is 24 meters from head to tail, for which the average slope is 0.00041. The upper half of the system has a slope of 0.00038, whereas southwards of the town of Pir Mahal, it is slightly higher at 0.00048. In general, slopes are much sharper towards the west along the length of the Yakkar and Dabbanwala distributary commands.

Based on Figure 1(b), the hydrologic regime within Bhagat is very similar to the Kanya Subdivision that is commanded by the Burala Branch of the Gugera channel. Both require between 2-3 cumecs of additional supplies to cover for the difference against the maximum allocations within the system. However, given the already high levels of cropping intensity within the Kanya Subdivision (Figure 1(d)), the anticipated benefits from the higher water allowances would be reflected more appropriately within Bhagat. It is in Bhagat that these higher allowances could be utilized to the advantage of the less consumptive use crops like cotton, whereas the potential gains within Kanya would be largely consumed by a high delta crop, like sugarcane, which is very popular amongst the farmers.

*Soils*: Soil conditions are predominantly medium textured (fine sandy loam to loam) in the surface and moderately coarse in the profile (Figure 3(b)). While there is little change in the surface and profile texture in the upper 2/3rds of the Subdivision, the patchy nature of the increasingly finer variations across the stratum further south indicate conditions more suitable for intensive crop growth. These variations, predominantly medium textured, occur across the commands of Baggiwala, Darkhana, Shorkot, and Bachrianwala minors of Khikhi

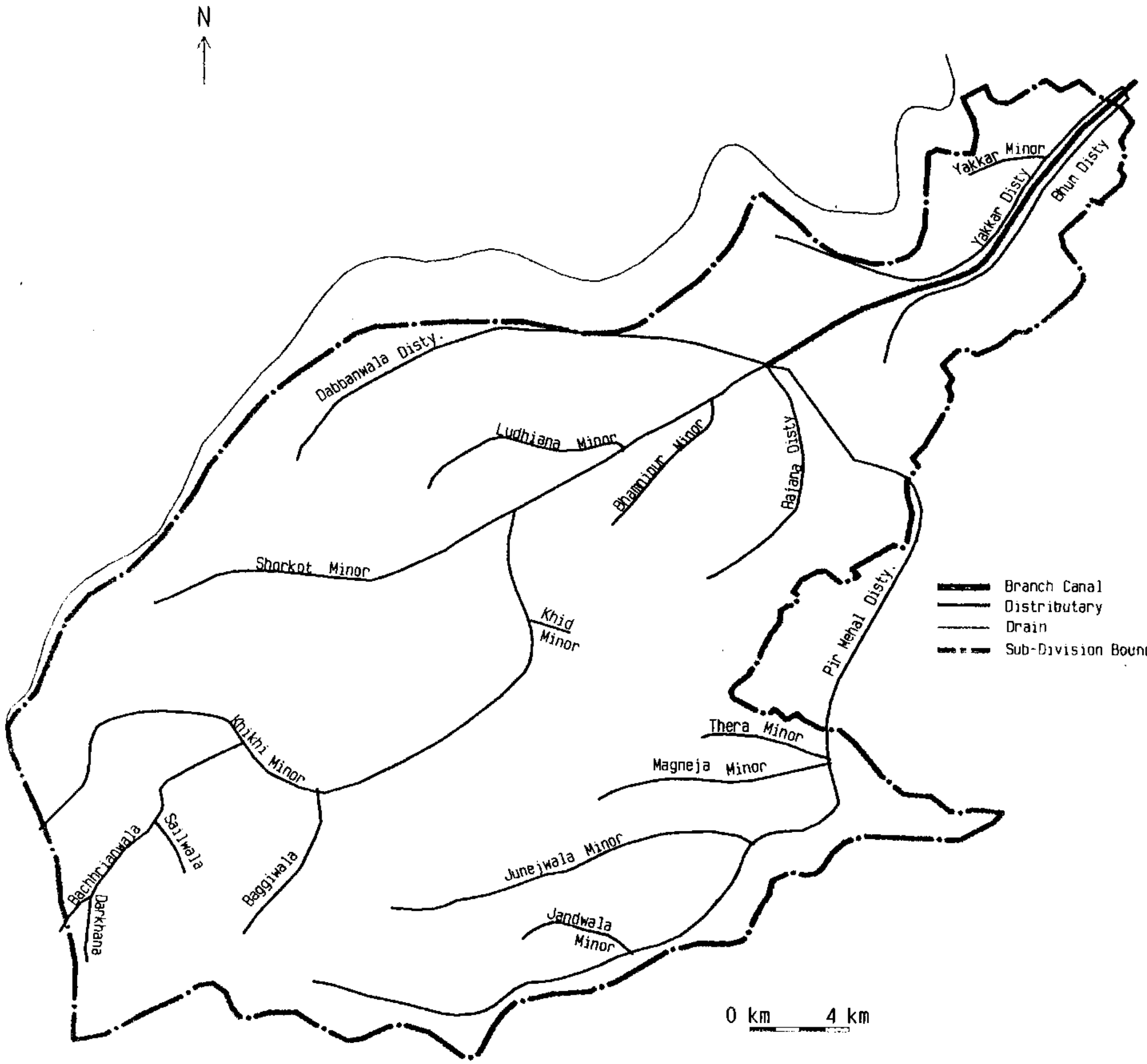



Figure 3(a) Bhagat Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

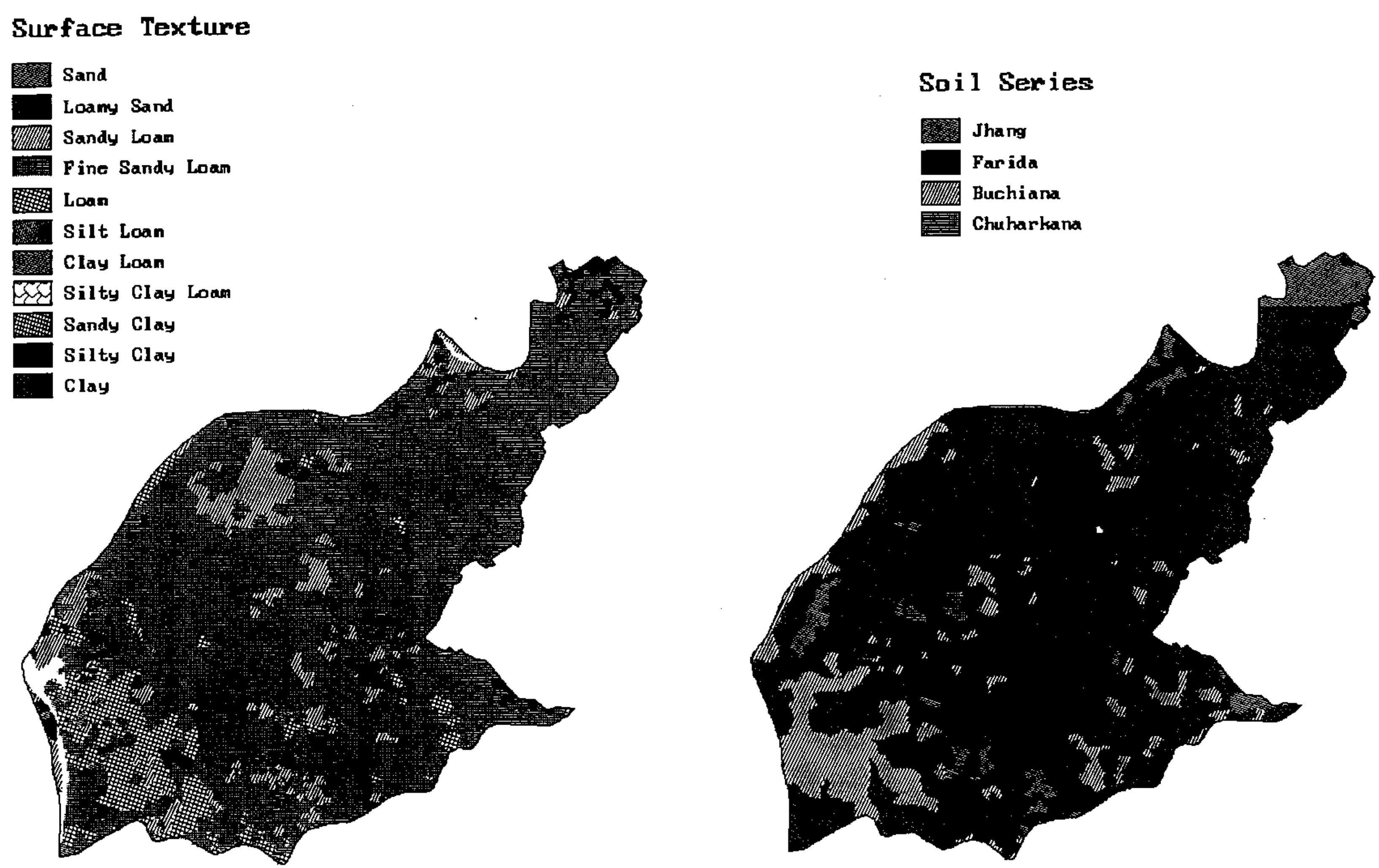



Figure 3(b) Surface and Profile Texture of the Soils in the Bhagat Irrigation Subdivision, Lower Chenab Canal (East) Circle. Rechna Doab. Punjab. Pakistan.

Distributary. To a somewhat lesser extent, these patches also frequent the commands of the Thera, Junejwala, and Jandwala minors of Pir Mahal Distributary to the east.

According to the SSoP, these medium soils in the lower reaches of the system (Figure 3(c)), and part of the level to nearly level old flood plain, are characterized by the Hafizabad-Jhakkar association and the Jhakkar Undifferentiated Group. The former is susceptible to high water table conditions and salinity across very deep calcareous loams with weak subsoil structure. The calcareousness is highlighted by the presence of a well defined kankar zone at a depth of 1.5 meters. The Jhakkar Undifferentiated Group is also similar to the Hafizababd-Jhakkar association but has the added problem of strong alkalinity and resultingly imperfect drainage. For the remainder of the entire Subdivision, with the exception of the commands of Shorkot Minor and Dabbanwala Distributary, where the soils are somewhat restricted in drainage with mottling in the A horizon, the subdivision has no limiting conditions in the substratum. These favorable drainage conditions are supported in the system head reaches by the Hafizabad soils (kankar zone below 120 cms), in the middle by a very large contiguous extent of Faisalabad soils (very fine sandy loam to silt loam upto a depth of 75-120 cms), and by the most suitable soils of Sultanpur across the lower 2/3rds of the Pir Mahal Distributary command. These deeply calcareous silt loam soils are relatively free of kankars however, the subsoil structure is weak. Below 75 cm depth, the texture may change to silty clay loam.

Entirely restricted within the confines of the Faisalababd association are the very significant patches of the Jaranwala Undifferentiated Group with its indistinct humps in the nearly level topography. These areas, showing signs of erosion through rill channels and scattered kankars on the surface, vary in texture from very fine sandy loam to silt loam.

*Soil Drainability and Crop Suitability*: From Figure 3(c) above, the Bhagat Subdivision is a well drained environment due to the dominance of the Faisalabad, Hafizabad-Jhakkar and Sultanpur loams/silt loams. This is somewhat contrasted by the periodically imperfectly drained soils of the Bagh association that are limited to the tail reaches of the Shorkot Minor and the Khikhi Distributary. Crop suitability-wise, the Subdivision is most suitable for the growth of sugarcane and wheat; however, for cotton the tail commands of Junejwala and Baggiwala as well as the scatterings of the Jaranwala Undifferentiated Group further north are not well suited (Figure 3(d)). The Faisalabad and Hafizabad soils moderately favor the growth of rice across much of the central and northern parts of the Subdivision; the more productive regimes for this crop are in the tail command of the Dabbanwala Distributary and the high and level areas of Sultanpur soils in the Pir Mahal command. IIMI's farmer questionnaire data indicates that wheat is the dominant rabi crop across the Subdivision with up to 40% cultivation intensity. For kharif, there is less than 25% cultivation each for rice and cotton.

*Soil Salinity and Waterlogging*: The soil salinity status described for the Subdivision by the SSoP survey of 1967 shows areas of concern extending in a wide swath along the left bank of the TS Link and upto its outfall into the Ravi. Additionally, to the west, the command

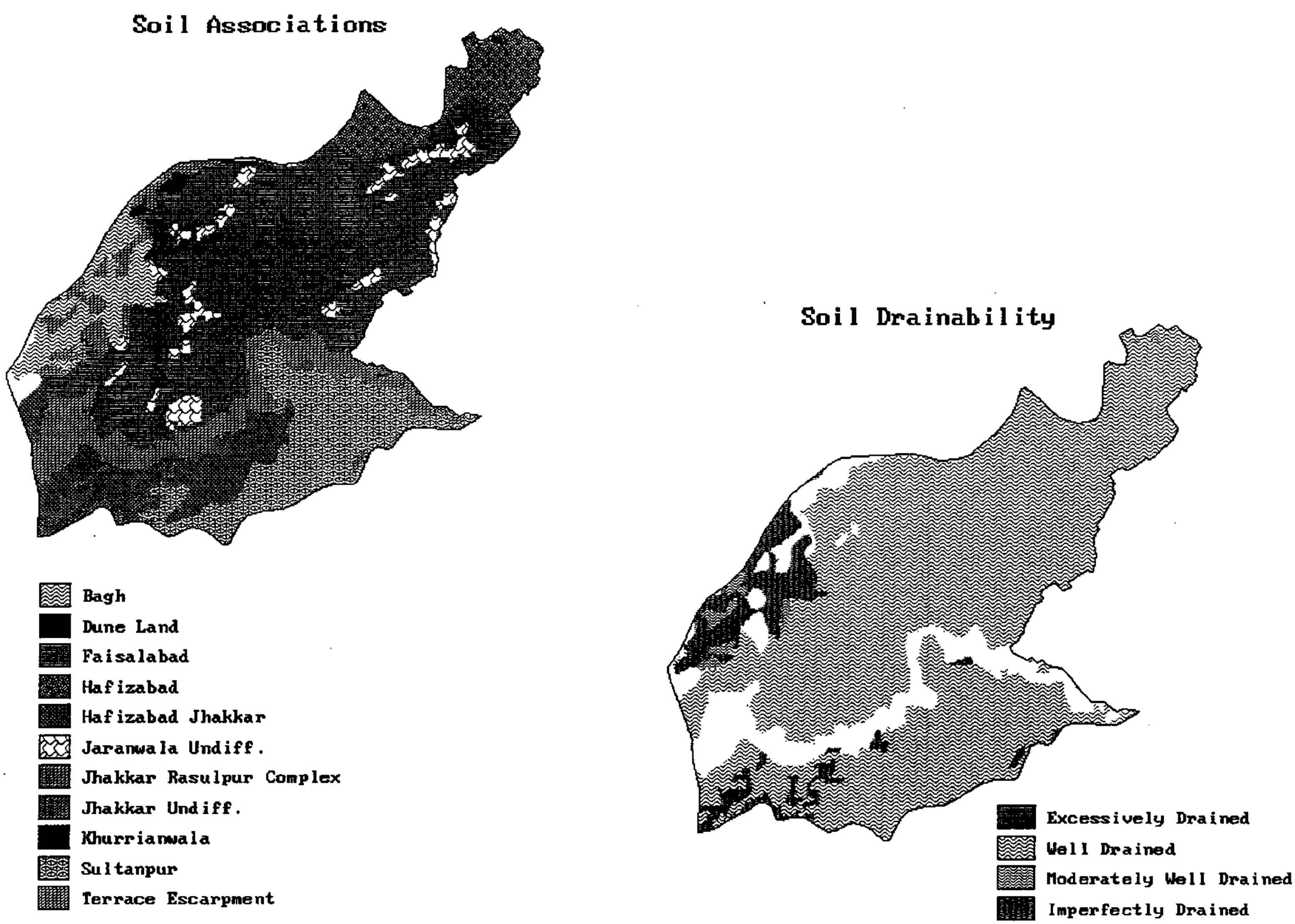



Figure 3(c) Associative Classification of the Soils and their Drainability Characteristics in the Bhagat Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.


Figure 3(d) Soil Suitability for Major Crops in the Bhagat Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab Pakistan.

of the Junejwala Minor also shows a significant concentration of surface salinity patches. These results are confirmed by the subsequent salinity survey by WAPDA 10 years later, whereby patches of strong salinity and alkalinity were observed (Figure 3(e)). In particular, the command of the Junejwala Minor showed a strong presence of saline sodic conditions on the surface as well as the profile. The dominant Faisalabad and Hafizabad soils in the central and head reaches of the system appeared to be free of these adverse effects; however, the patches of the Jaranwala Undifferentiated Group, characterized by convex lenses in the topography, indicated increasing salinity and sodicity in the profile.

WAPDA SMO data for the seasonal variations in water table indicates that the Subdivision has not had adverse water table conditions. The entire area has water tables below the 90 cm depth, i.e. the root zone and the June-October fluctuations are fairly constant across the standards for depth classification defined by WAPDA (Figure 3(f)). In fact, for the period 1993, the entire stretch along the TS Link, conventionally thought to be a seepage zone, has recorded a decrease in water table in the strata below the root zone.

The subsurface variations in slopes across the June-October comparison indicate that for most of the Subdivision the situation is largely static for the period 1980-93; however, the pockets of change are more frequent as compared to the evidence of change in the water table (Figure 3(g)). In general, the head reaches show a restriction in the subsurface flow conditions; the middle reaches, for which the subsurface flowout had much reduced in the period 1980-85, seem to have bounced back by 1993; and the tail reaches, that were initially quite stable, are experiencing a clogging in subsurface activity with increasing proximity to the TS Link. Overall, there is no evidence to suggest that the system could respond in equal measure to a substantial increase in recharge, and would at best rank as a limited drainage environment in the vadose zone. Otherwise, the subsoil and stratum conditions indicate adequate drainability of the root zone. This may, to a small measure, be also supported by the general topographic relief in the central reaches of the Subdivision; a weak but persistent correlation also exists within the Bhun Distributary and the lower half of the Rajiana distributary command. However, for the most part, there is little evidence to suggest a positive relationship between the topography assisting the subsurface drainage conditions.

***IIMI Sampling for Soil Salinity and Texture***: IIMI's sample survey in the Bhagat Subdivision indicates that for a total of 883 EM38 observations across 8870 ha of sample regime, nearly 94% are non-saline. A majority of these observations are in the silt loam and loam soils (Figure B2, Volume Four) which is the dominant textural component of the soil associations existing within the area. For salinized tracts, the soil texture is very much limited to the silt loam and silty clay loam. This is primarily due to the Jhakkar Undifferentiated Group soils aligned northeasterly away from the TS Link outfall where localized patches of high water table and salinity were observed by IIMI staff in the commands of the Baggiwala and Jandwala minors and tail reaches of the Pir Mahal Distributary. Jhakkar and Sindhelianwali series are the principal constituents of this Group, and the latter is known to be a strongly alkaline silty clay loam with visible salt crusting. These soils occur in the depressional areas

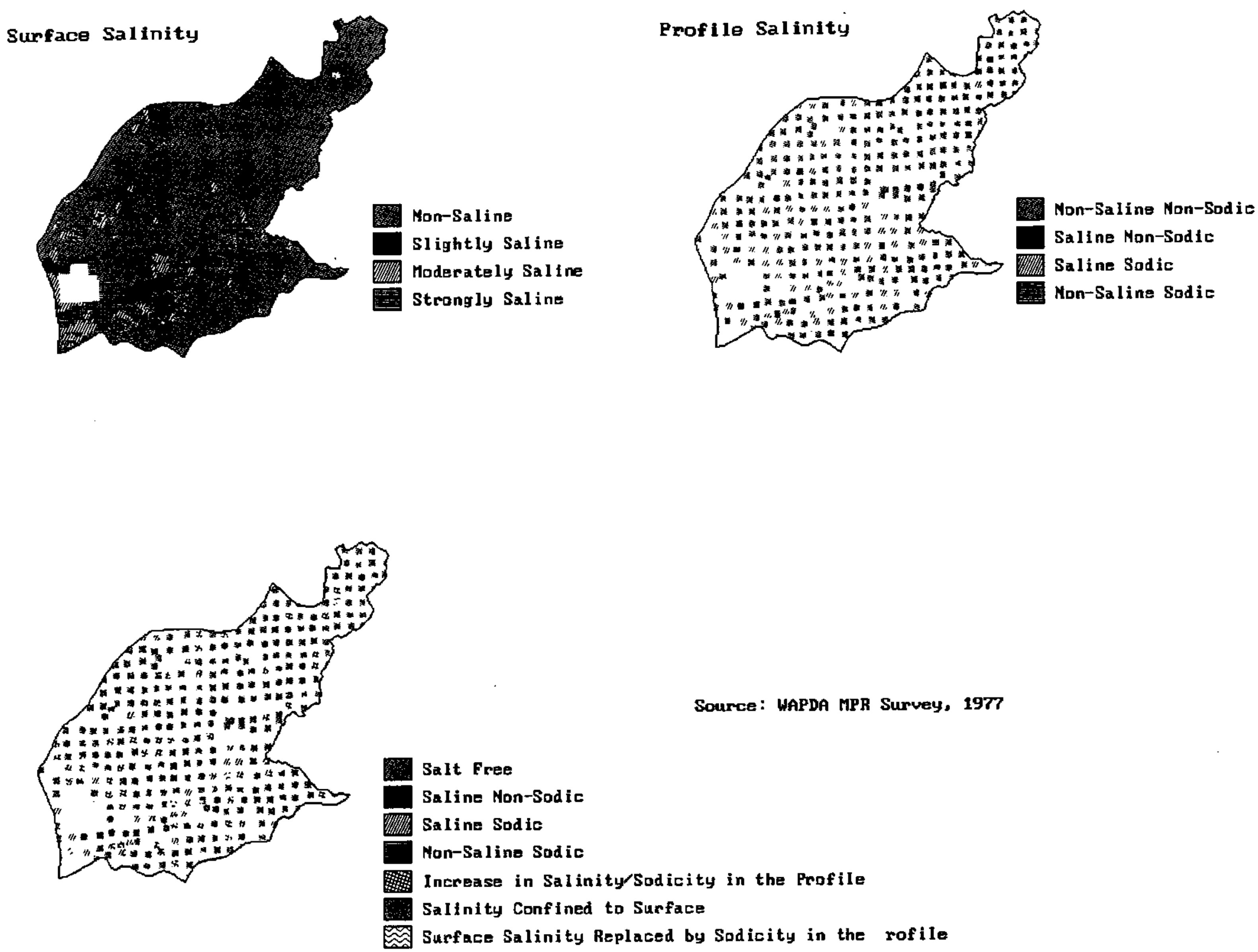
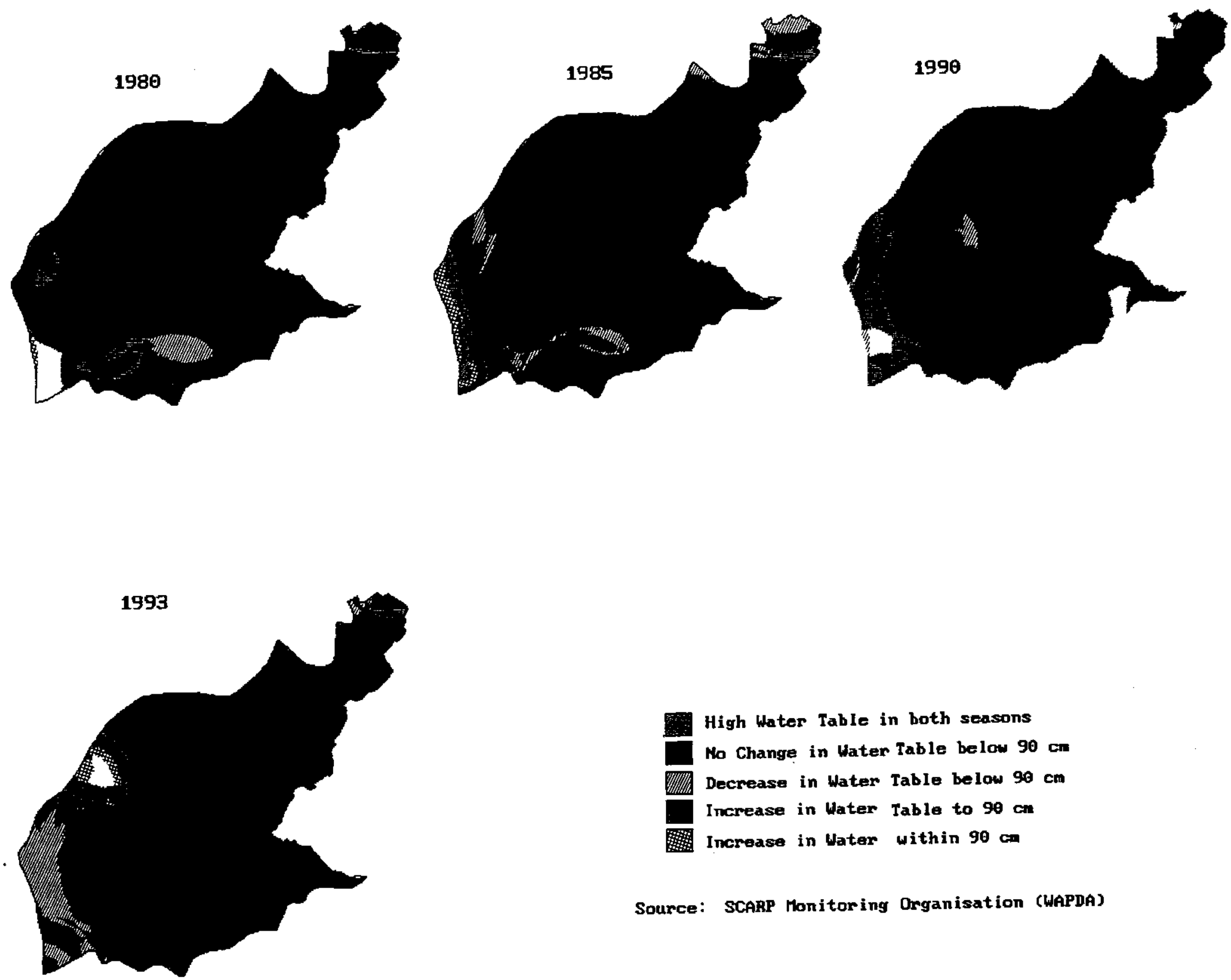



Figure 3(e) Surface and Profile Salinity in the Bhagat Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organisation (WAPDA)

Figure 3(f) Temporal Variations in the Depth to Water Table, Bhagat Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab Pakistan.


Source: SCARP Monitoring Organization (WAPDA)

Figure 3(g) Interseasonal Slope Variations in the Subsurface Flows, Bhagat Irrigation Subdivision, Lower Chenab Canal (East) Circle. Rechna Doab. Punjab. Pakistan.

of the old channel fills in the level to nearly level old cover flood plain. For the Jhakkar series alone, silty clay loam may be encountered below 135 cm depth, otherwise, it is basically a silt loam with weak structure. Additionally, a few patches of the Jaranwala Undifferentiated Group were also observed to be barren in the predominantly silty clay lom and silt loam soils occurring within the head reach of the Pir Mahal Distributary.

IIMI's survey of the cultivated land indicated that the crops were being grown overwhelmingly on non-saline tracts with loam to silt loam texture (Figure C2, Volume Four). The still finer fractions of clay loam and silty clay loam were encountered mainly in the ploughed category, whereas none of the areas under rice, the second most dominant crop in the area, showed any cultivation over these soils. Interestingly, a significant number of rice fields were being grown on fine sandy loam soils; this may be because of its cultivation on Sultanpur, Jhakkar Undifferentiated, and Jaranwala Undifferentiated Groups. All of these soils have very fine sandy loam in varying fractions that is usually underlain by the much finer silty clay loam soils between the depths of 75-135 cms.

*IIMI Farm Level Sampling*: IIMI's questionnaire on economic data sampled 20 farmers across the Subdivision. Its above average CCA to gross ratio has one of the highest intensities of land use; however, the benefits of the available productive lands are not justifiably reflected in the 114% overall cropping intensity within the cultivated commands. The major reason for this loss of productivity is the high degree of fallowing reported by the farmers (Table H1, Volume Four). Although the 74% fallow intensity is almost equal in both of the growing seasons, the competition for the scarce water supplies during the kharif season necessitates lower intensities of the major crops like cotton and rice in favor of the minor crops (other than fodders, as their intensities also remain unchanged from season to season). Given the less than adequate reliance on useable groundwaters and the acute shortage of surface supplies, the major crop intensities within Bhagat are higher than many of the subdivisions in the upper reaches of the Gugera system. Its profits from the wheat crop would increase substantially if the rather large investments in irrigation costs are curtailed. This would be quite justifiable given the high yields of wheat being realized in this Subdivision. Cotton would also stand to gain from reduced irrigation costs as it already shows profits and yields that are fourth overall across the LCC system. However, for the high delta crops of rice and sugarcane, the costs of irrigation are prohibitively high (Tables H4 & H5, Volume Four) due to extensive reliance on groundwater supplies @ Rs. 740 per ha per irrigation. In the absence of cheaper access to sources of irrigation, it is very unlikely that increases in the current levels of their respective yields could be realized to match the ones in the typical rice growing areas further north in the system. Perhaps, it would be far more advantageous for the farmers to substitute the existing intensities of these crops (between 5-7% each for the rice and sugarcane) to comparable increases in the cultivation of cotton so as to match those in the neighboring Haveli Subdivision.

## C. Buchiana Subdivision

*Hydrologic Regime*: Buchiana Subdivision is the first of the three subdivisions comprising the Lower Gugera Branch of the LCC. The Branch traverses the entire length of the Subdivision on its way to the Tarkhani Subdivision further south (Figure 4(a)). The Subdivision's gross area is 81,151 hectares of which 79 percent is CCA. Its irrigation network, offtaking from either side of the Lower Gugera channel, commands a total of 302 sanctioned outlets for an average of nearly 212 hectares of cultivated land per watercourse. The total length of the distribution network is approx. 195 kilometers corresponding to a density of about 3 kilometers per 1000 hectares. From Figure 1(b), the density of this distribution and the sanctioned allowances for the Buchiana Subdivision would compare well with the Mohlan and the Chuharkana Subdivisions upstream. All of these irrigated environments are drawing less irrigation supplies from the maximums observed elsewhere. If these maximums on allowances were to be accommodated across these subdivisions, then Table 3 shows that the enlargement or remodeling of the current channel capacities would be a prerequisite. In fact, from amongst these three subdivisions, Buchiana would be the most in need of improvement as its existing cropping intensities are already below that of Mohlan and the Chuharkana (Figure 1(d)).

The topographic relief across the Buchiana Subdivision is 15 meters from head to tail, for which the average slope is 0.00033. In the upper reaches of Buchiana Subdivision, from Buchiana head to the head of Jassuana Distributary, the slope is 0.00048, whereas the lower reaches of the subdivision are comparatively flat with a slope of 0.00032.

*Soils*: The Subdivision's morphology is characterized by well defined clusterings of coarse to medium soils (Figure 4(b)). The commands of Buchiana and Jaranwala distributaries have medium soil in the subdivision with a scattering of moderately fine texture. Towards the west, the commands of Awagat and Pauliani distributaries become successively coarser. In fact, the head reach of Pauliani is a mix of sand to loamy sand soil both in the surface and sub-surface stratum. However, the middle to tail reaches of both Awagat and Pauliani are made up of sandy loam to fine sandy loam. An equivalent proportion of coarse soil is also evident across the commands of Satiana Distributary and Talyara Minor below the left bank of the Lower Gugera main channel.

The tail reaches of the subdivision comprise a complex interweave of medium texture loam to fine sandy loam overlying deep sections of moderately coarse soil. The commands of the Khanuana, Bhartiana, and Kaluana distributaries in the middle of the subdivision are mostly made up of sandy fractions comprising loamy sand to very fine sandy loam.

The predominantly medium soils of Buchiana and Jaranwala channels have been described as Hafizabad/Hafizabad-Awagat by the Soil Survey of Pakistan (Figure 4(c)). The stretch of Hafizabad soils begins from head reaches of the system and continues longitudinally across to the tail reaches of Jassuwana Minor to the east. It is paralleled to the west by the dominating extent of the Hafizabad-Awagat association in a south-westerly direction to the

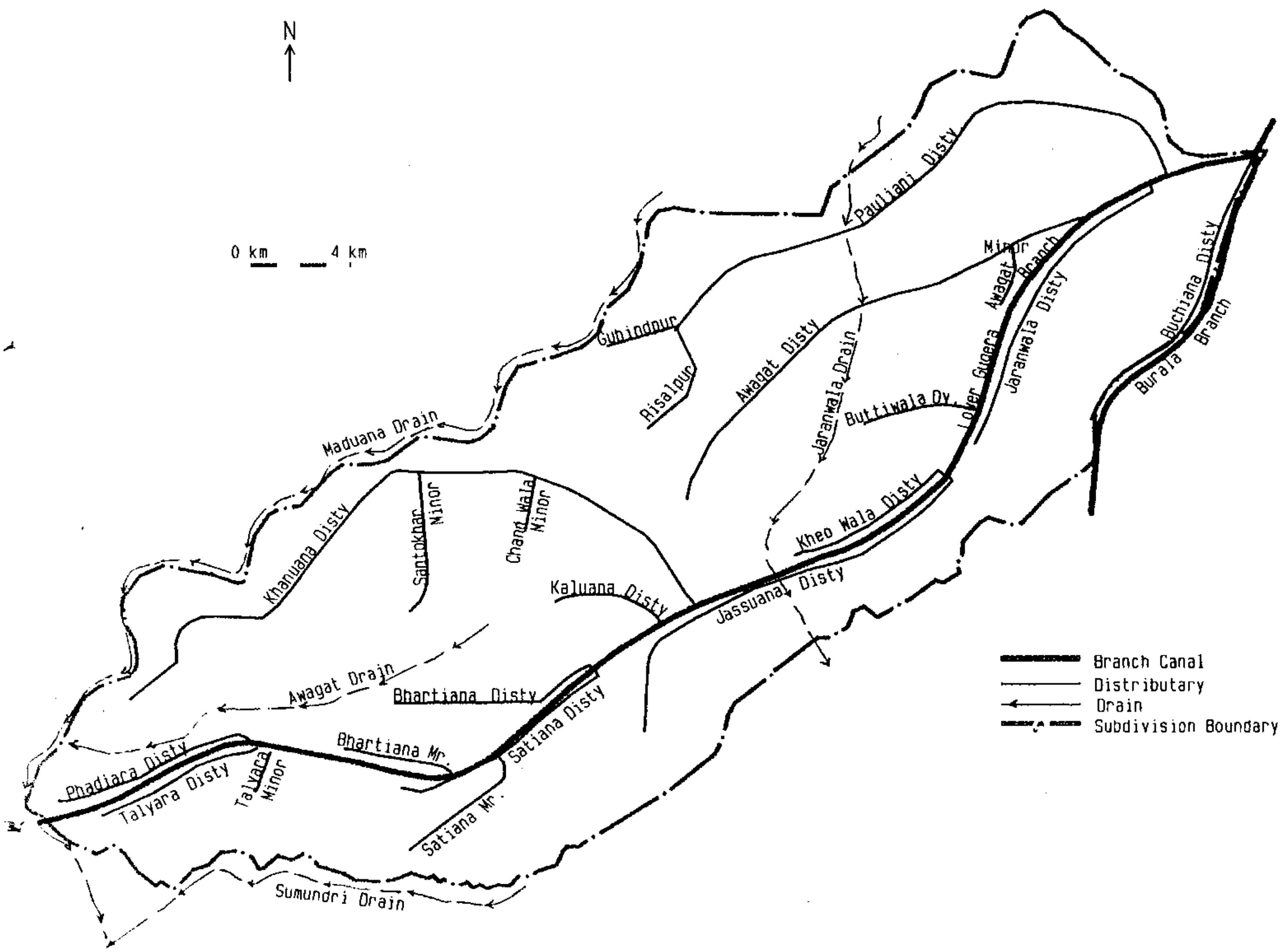



Figure 4(a) Buchiana Irrigation Subdivision in the Lower Chenab, Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

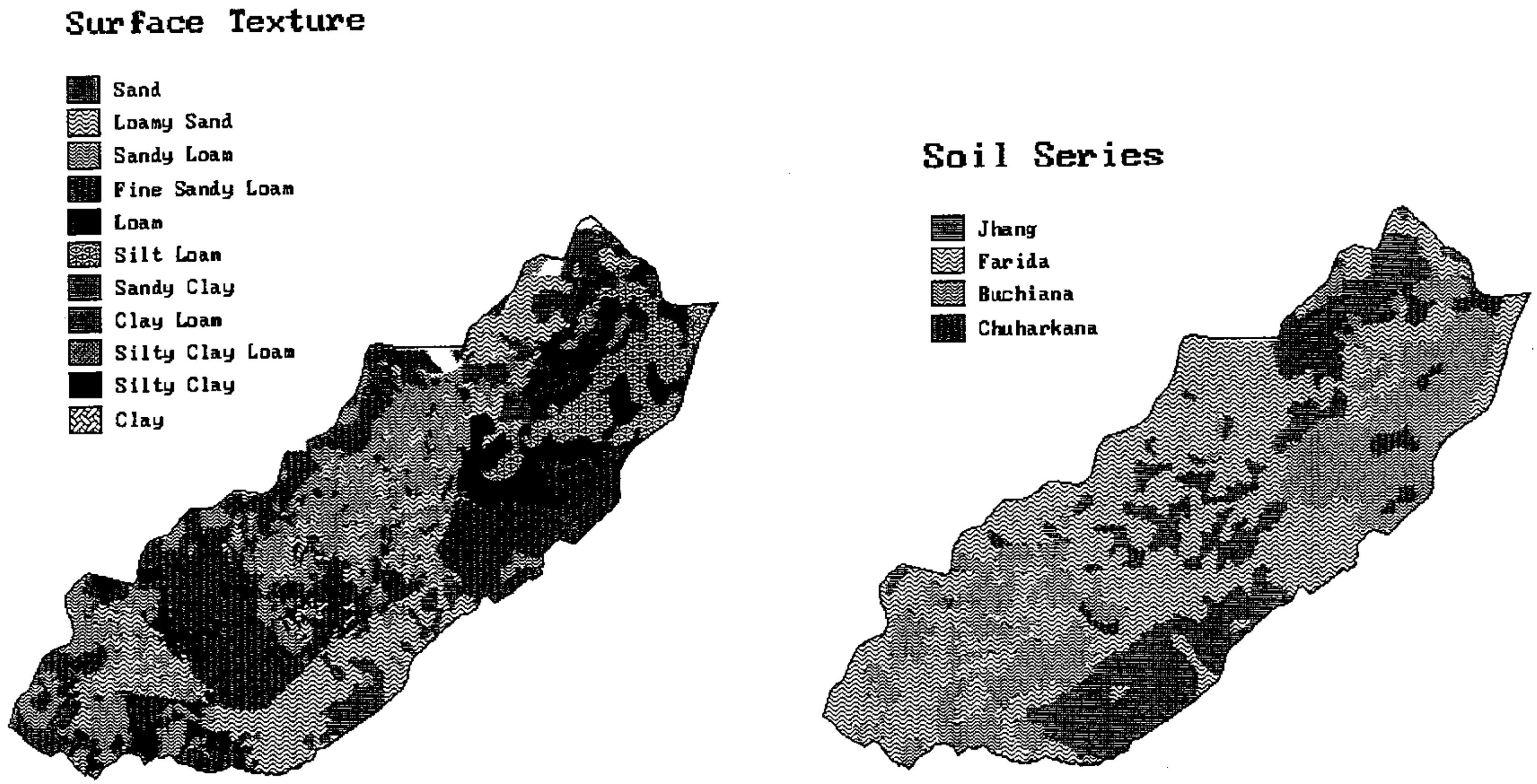



Figure 4(b) Surface and Profile Texture of the Soils in the Buchiana Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

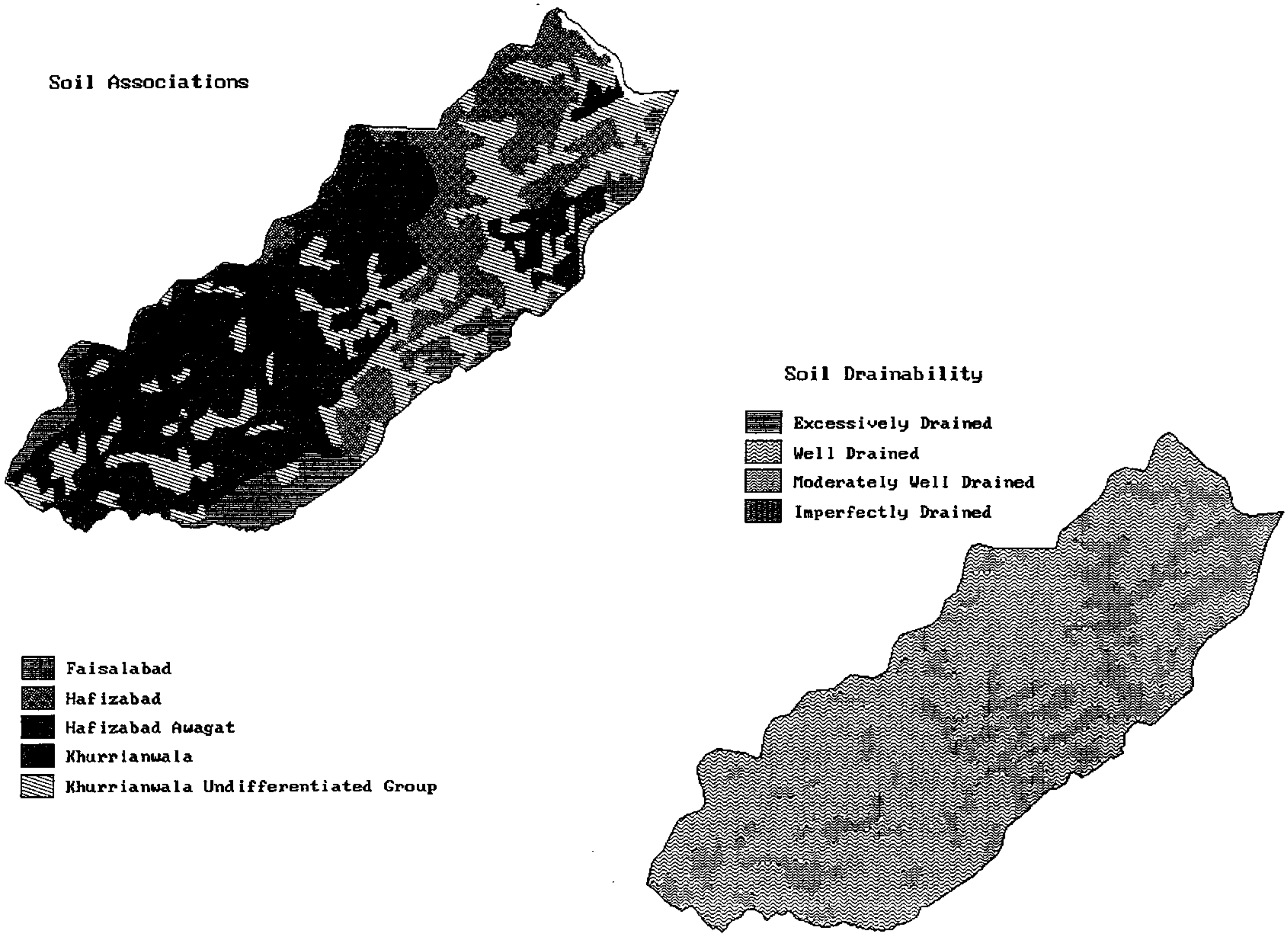



Figure 4(c) Associative Classification of the Soils and their Drainabilty Characteristics the Buchiana Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

tail reaches of the system. Barring a few exceptions of Faisalabad association at the fringes of the sub-division, and mostly to the east, the forementioned associations comprise the largest chunk of soil types within the Subdivision.

*Soil Drainability and Crop Suitability*: Figure 4(c) shows Buchiana Subdivision to have well drained soils. The exceptions pertain to the moderately well drained soils of the Khurrianwala Undifferentiated Group that have a very large scattered presence across the entire Subdivision. The soils of this subdivision are well suited for the growth of cotton, sugarcane and wheat (Figure 4(d)). For rice, the kankar zone deep in the stratum of the Hafizabad soils, that are nearly exclusive to the areas north of the Jaranwala Drain, offers a more suitable environment than areas further south.

*Soil Salinity and Waterlogging*: Scattered all across the length of the system are the patches of the Khurrianwala Undifferentiated Group. These soils are characterized by well defined salinity contents as per the SSoP survey of 1966-67. These patches, with imperfect drainage, are too numerous to be localized, however, their magnitude is most well defined within the Hafizabad Association near the head reaches of the system. This unit includes, besides Khurrianwala series, the saline-alkali phases of Sindhwan, Faisalabad and Jaranwala series. These soils are characterized by a kankar zone at shallow depths and are strongly saline and alkali with a deeply calcareous weak structure. In the subsequent WAPDA survey of 1977, the occurrence of salinity across the head reaches of the subdivision is almost non-existent with the exception of a few saline-sodic soils indicating a localized increase in salinity and sodicity (Figure 4(e)). However, the remaining scattering of the Khurrianwaala Undifferentiated Group across Hafizabad-Awagat association retains moderately to strongly saline characteristics. Some of the profiles studied by WAPDA indicate the previous salinity patches to be quite persistent. However, there is spatial evidence to suggest that in some areas the salinity is confined to the surface.

At the time of WAPDA MPR survey, the tail of the Buchiana Subdivision faced high water tables with the accompaniments of the saline/alkali hazard in the soils. Data for 1980 suggests that these conditions were particularly severe in the central reaches of the subdivision, i.e. the area buttressed between Kaluana and Bhartiana distributaries (Figure 4(f)). By 1990, there was no evidence of water table affecting the root zone, and the magnitude of the seasonal fluctuations remained confined to a narrow contiguous spread running north-south along the meander of the Lower Gugera channel from the head of the Subdivision to the tail of the Satiana Distributary. As late as 1993, the interseasonal water table fluctuations were beginning to approach the root zone, not only in the head reaches of the Jaranwala and Awagat distributaries, but also along the reach of the main Lower Gugera channel starting from the head of the Khewana Distributary to the tail of the Satiana Distributary.

*IIMI Sampling for Soil Salinity and Texture*: IIMI sample survey in the Buchiana Subdivison indicates that for a total of 620 EM38 observations across 7550 ha of sample regime, nearly 78% were non-saline. A majority of the non-saline observations are occuring in the medium

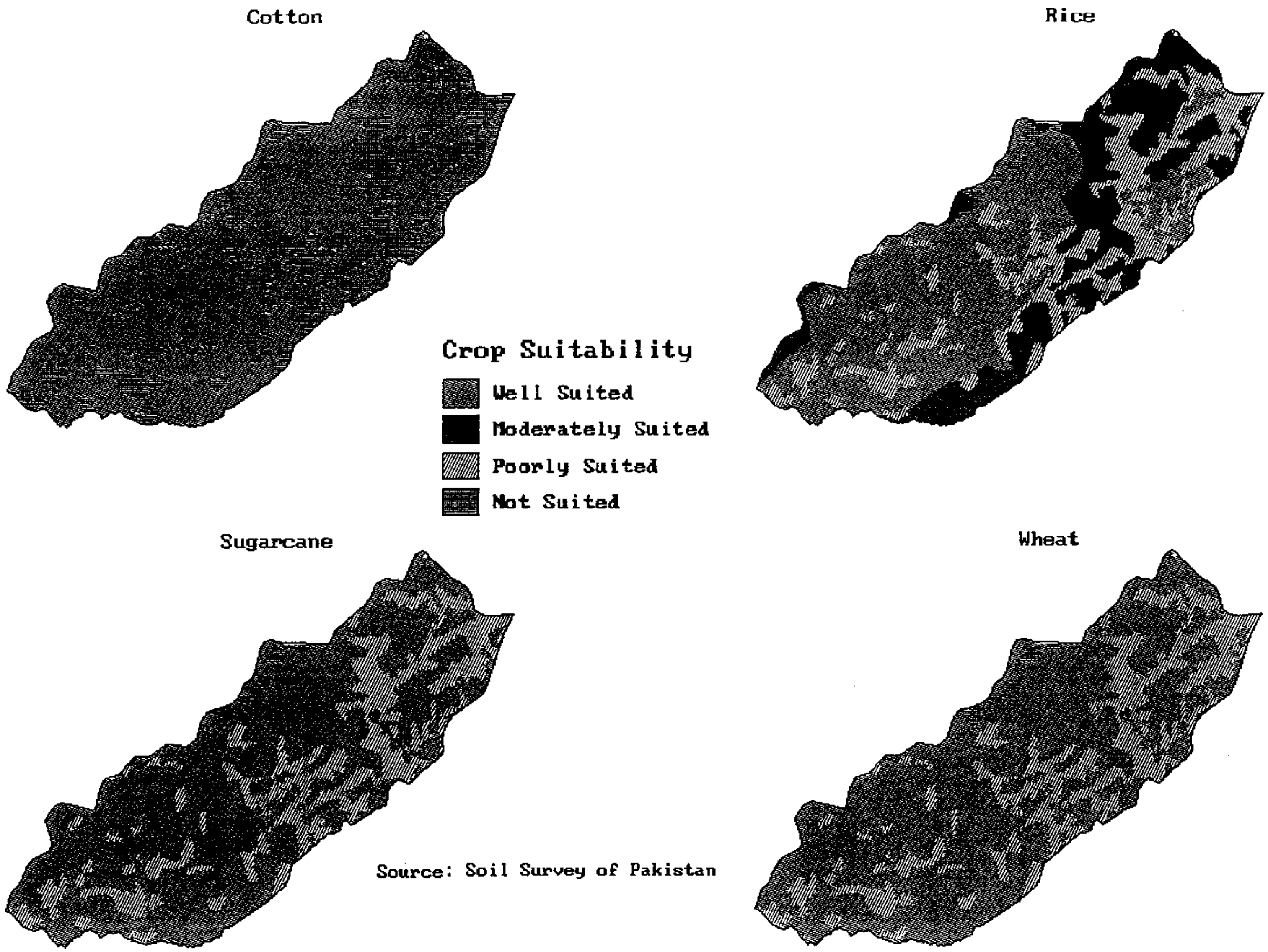



Figure 4(d) Soil Suitability for Major Crops in the Buchiana Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

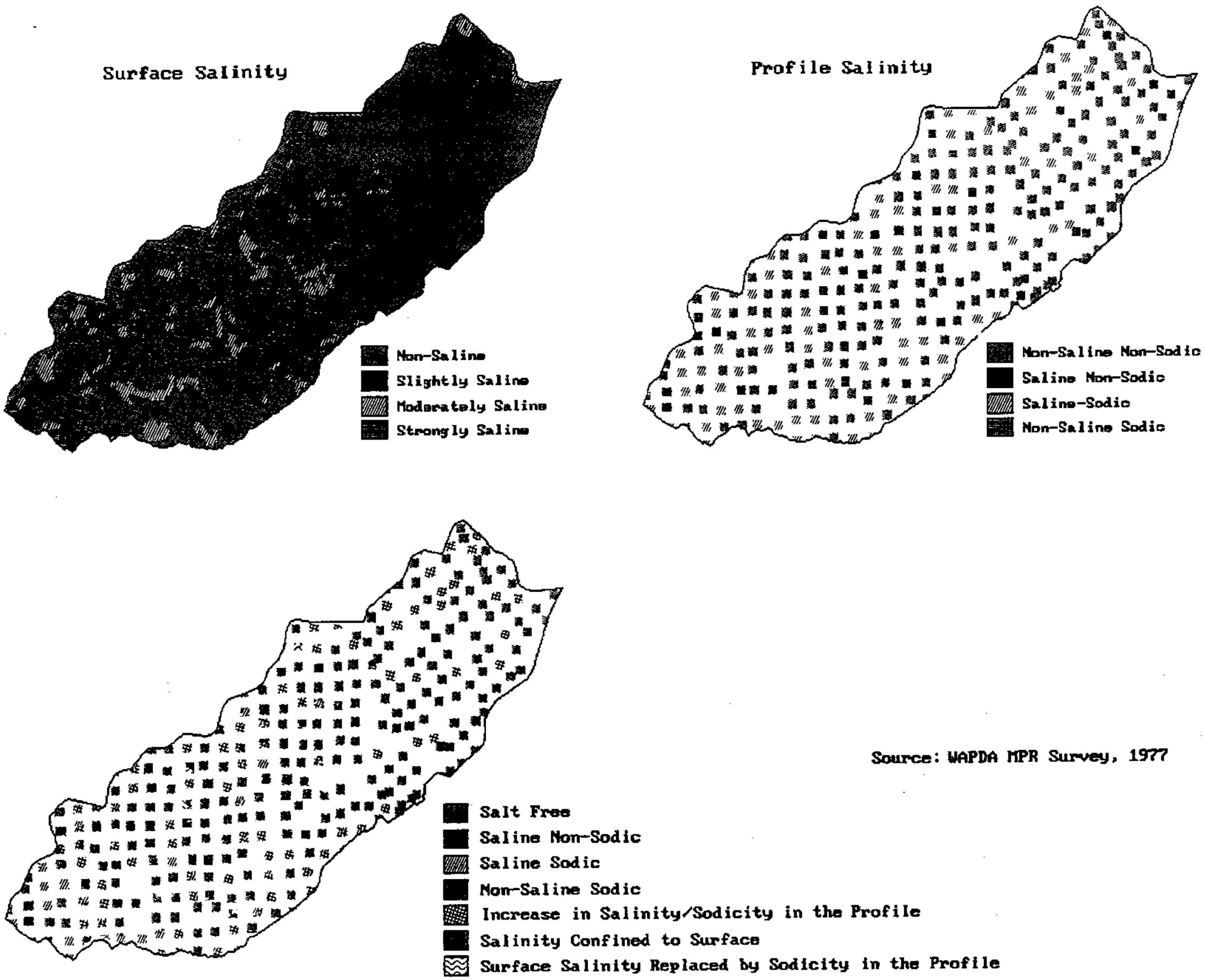



Figure 4(e) Surface and Profile Salinity in the Buchiana Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

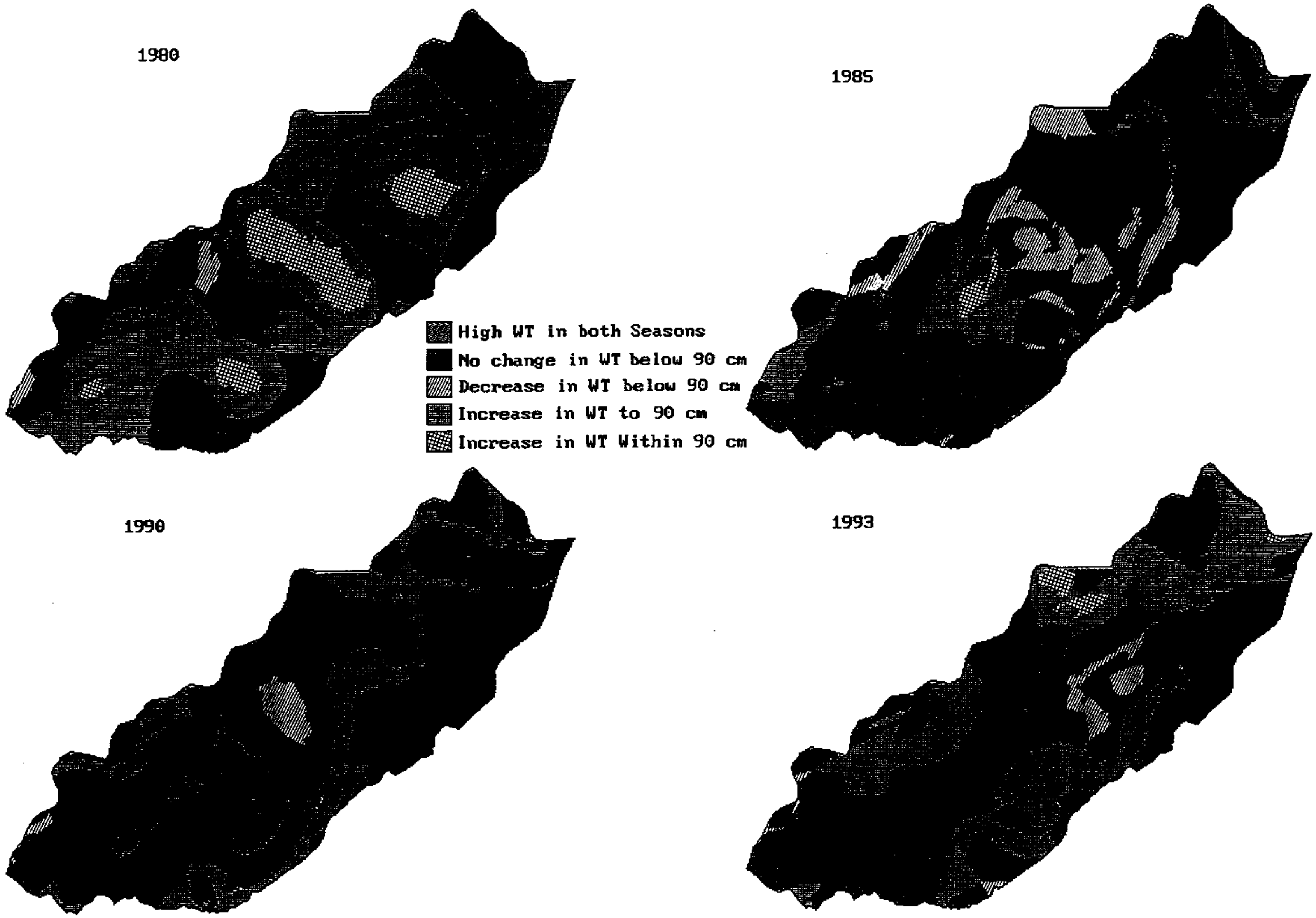



Figure 4(f) Temporal Variations in the Depth to Water Table, Buchiana Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

soils (Figure B3, Volume Four); however, with the increasing trend in salinity, the proportionate contribution of the clay loam shows a substantial increase. Loam/fine sandy loam is the most dominant soil type in the area, but with increasing salinity the silt loams exceed the loams due to its occurrence within the Khurrianwala Undifferentiated Group. This Group also includes the saline/alkali phases of Faisalabad series and is characterized by a shallow kankar zone.

A substantial extent of the Subdivision comprises the Hafizababd-Awagat association for which SSoP estimated between 20-25% of the area to be saline. This probably explains the persistence of loam in the higher salinity classes. This is also true for the sandy fractions of the Hafizabad association (Rasulpur series constituents), especially the local depressions, where the sandy loam soils have been observed to be moderately saline.

Figure C3, Volume Four, indicates that, excepting for the rice fields, loams are the most cultivated soils in the area. Moreover, almost all of the cultivated fields are non-saline. A higher proportion of the clay loams are being devoted to the growth of the traditional crops like cotton, fodder, and rice because of higher water retention capacity; however, for the high delta crop like rice, the preference for silt loam is obvious in the context of the highly calcareous shallow kankar zone in an otherwise seasonally imperfect drainage environment. It would be less suitable in a loam environment, such as Hafizabad association, that has a relatively deeper kankar zone (1.5 meters) and well drained environment. Such a situation would be well suited for growing sugarcane that prefers a loam/fine sandy loam.

The IIMI survey also confirms the existence of much of the previously recorded salinity observed by the SSoP and WAPDA, especially in the barren land category. Though WAPDA's observations on the surface texture categorization may not be entirely correct, the occurrence of the salinity patches across medium soils like silt loam only substantiate the earlier classification by the SSoP as the Khurrianwala/Khurrianwala Undifferentiated Group.

For the EM38 observations across the barren lands, the proportions of the silt loam soils are predominant across all salinity class differentiations and even exceed the still finer soil fractions of clay loam and clay. The strongly saline class has silt loam by itself, thereby indicating a combination of drainage and alkali related land degradation.

***IIMI Farm Level Sampling***: IIMI's questionnaire on economic data sampled 21 farmers across the Buchiana Subdivision. As part of the lower Gugera command, its share of the CCA within the gross area is typical of the situation in the other two downstream subdivisions of the Tarkhani and Bhagat. The Buchiana Subdivision is quite similar to the neighboring Tarkhani in terms of the equivalent land use, cropping and culturable waste intensities. However, the important difference lies in the intensity of fallowing that is about one-third higher within Buchiana. Additionally, wherein Tarkhani has more area under cotton, Buchiana has an equivalent advantage under the sugarcane crop. These major crop intensities are favorably supported by useable groundwaters across much of the Subdivision, although previous data in Figure 1(b) and Table 3 indicate that surface irrigation allowances are much less than the maximum in design observed values elsewhere.

The average yield of the wheat crop is about 200-300 kg/ha less than the comparable values in the downstream reaches of the Gugera command. However, the low overall costs allow it be reckoned at par with the other subdivisions of the Lower Gugera, which is in itself unique for any canal command within the LCC system.

## D. Chuharkana Subdivision

*Hydrologic Regime*: Chuharkana Subdivision, also known as the Farooqabad Subdivision, covers the head reaches of the Upper Gugera Irrigation Division. It has 16 irrigation channels, half of which are at the distributary level (Figure 5(a)). To the east, it is bounded by the parallel run of the Upper Gugera Branch and the Qadirabad Balloki Link canals and to the west by the LCC Main and its offtake---the Mian Ali Branch. For a gross to cropped area percentage of 72%, this Subdivision is one of the most productive agricultural regimes across the doab. It also has remained as the focal point for much of IIMI's past research on soil salinity and irrigation management during the 1989-93 period. For the sample watercourses of the Lagar and Mananwala distributaries, extensive information has been collected on groundwater quality, cropping pattern, and variations in surface water flows that constitutes an authentic record of irrigation related constraints to productivity.

The irrigation units within the Subdivision sustain an annual cropping intensity of 140% (Rabi 75%, Kharif 65%), and much of it is owed to the contributions from the groundwater that range between 50-75% of the total. While there is some restriction on the use of shallow groundwater, especially in the low surface recharge zones near the tail reaches of the distributaries, the WAPDA SMO data for SCARP-I tubewell pumpage indicates that the deep groundwater quality is mostly below 1500 microsiemens/meter. While many of the SCARP-I tubewells are inoperative or disused, IIMI's analysis of the private tubewells data for the Mananwala Distributary indicates that he number of tubewells per watercourse is increasing and in some localized pockets the quality is marginal to poor. An exclusive reliance on the use of these brackish waters may hinder the maintenance of a favorable salt balance in the root zone.

Since the Mananwala Distributary, with a GCA of nearly 31200 ha, constitutes a significant fraction (44.5%) of the Subdivision's commanded regime, IIMI's findings on secondary salinization are fairly representative of the dominant situation emerging within the area. The major conclusions drawn therein include:

- the use of groundwater is particularly important when farmers grow crops with higher water requirements and where tubewell owners have installed electric tubewells with relatively low O&M costs. This is much the situation in the head reaches of the system, where not only an inequitably higher share of surface supplies is consumed,

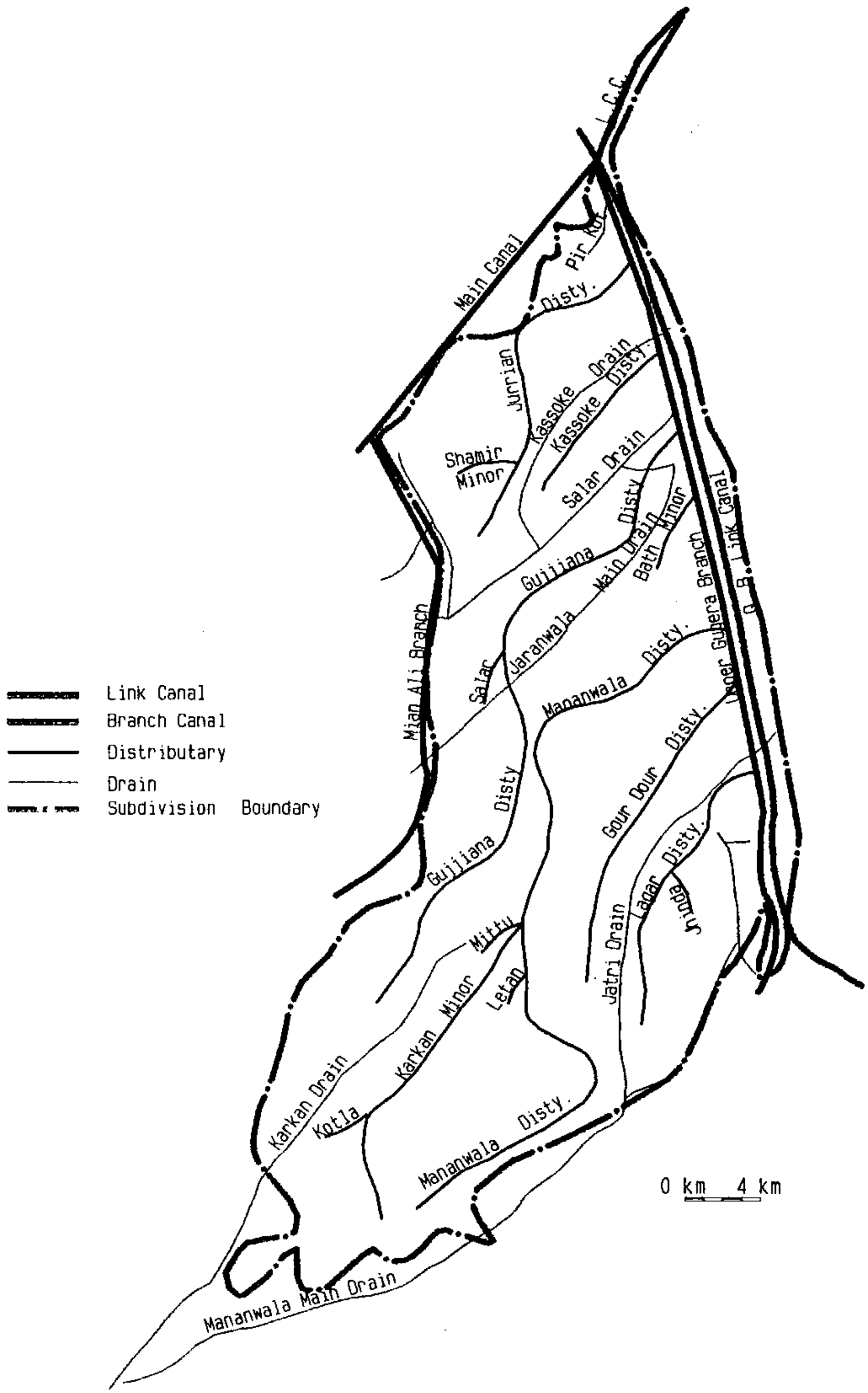



Figure 5(a) Chuharkana Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

but also, because of a relatively fresh groundwater regime, a high density of private electric tubewells exist. Towards the middle reaches, these higher densities are superceded by the diesel powered tubewells that have become the preferred choice in the absence of reliably available electric supply, or when the consumptive use is less.

- The contribution from private tubewells may exceed 80% in the kharif season; if public tubewells are also taken into account, then the cumulative contributions may reach 90% of all irrigation water during kharif. However, in general, the groundwater contribution is about 70% of the total irrigation water used. Also, farmers with access to a higher share of surface water also pump more groundwater than farmers who have less surface water.

- There is no evidence to suggest that farmers are substituting groundwater for declining surface water supplies; ground water is used as an additive to surface water rather than a substitute source of water.

- In water short environments, such as the tail-ends of distributaries and many watercourses, there are scant opportunities to practice the recommended mixing of the canal and 'marginal' quality groundwater in a 1:1 ratio.

- Due to the problems of inequity in canal water distribution and lower quality of groundwater, the dependence on groundwater supplies at the tail has caused secondary salinization. IIMI's 10% spatial sample coverage for the appraisal of surface salinity across the entire Mananwala Distributary indicates that the higher incidence of salinity is mostly concentrated in the lower one-third of the command, especially the tail watercourses of the main Distributary and its Minor, Karkan. A synoptic corroboration of the above is provided by the analog interpretation of satellite image data available for the area where larger tracts of wasteland are seen to be more frequent in the tail areas.

*Soils*: The occurrence of wasteland is also a result of the topographic limitations that have rendered these areas inaccessible to canal water supplies. Some of these areas have a predominantly coarse to moderately coarse profile, e.g. the tail reaches of the Mananwala and Karkan, and along the length of the Kassoke Drain in the head reach of the Subdivision. According to the WASID classification of soil profiles, the upper half of the Subdivision is predominantly medium to moderately fine soils overlain by loam, silt loams, and sandy loams, whereas the lower half comprises the coarser Farida series (with fine sandy loam in the subsoil) (Figure 5(b)). The variation in surface texture is quite frequent between the moderately coarse and medium soils, however, with respect to the underlying series, this differentiaiton is homogeneous. For the moderately finer textures of sandy clay loam, clay loam, and silty clay loam, the distribution is limited to the head reaches of the Jurian and Mananwala distributaries.

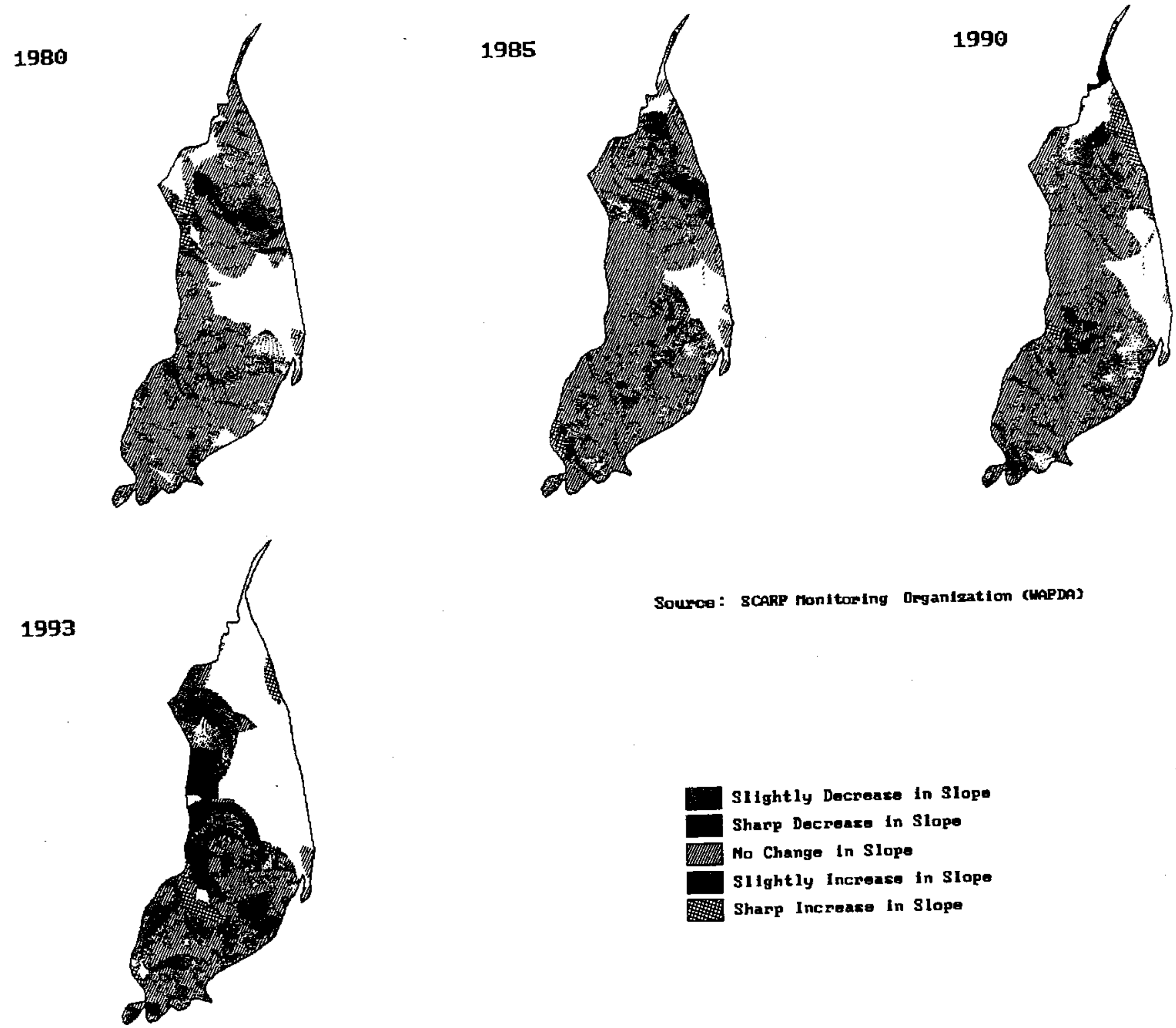



Figure 5(b) Interseasonal Slope Variations in the Subsurface Flows, Chuharkana Irrigation Subdivision, Lower Chenab Canal (East) Circle. Rechna Doab. Punjab. Pakistan.

The Soil Survey of Pakistan has identified a wide scattering of a host of soil associations within the Chuharkana Subdivision (Figure 5(c)). The head reach of the system, northwards of the Salar Drain, is primarily a mix of Rasulpur, Wazirabad (along the drain), and Hafizabad associations. There also are significant patches of the Khurrianwala soils in close proximity to the Rasulpur soils. Elsewhere, the area between the Salar and Jaranwala Main drains is a complex distribution of moderately fine to fine textured saline-alkali soils. Along the left bank of Mananwala Distributary and extending from the head to the middle reach, the medium to moderately fine textures of Pindorian and Bhalwal associations mix with the texturally similar saline-alkali patches of the Gajiana. The non-calcareous clay loams of the Pindorian association are more extensive further south in the Ghordour Distributary command where they circumscribe a significant presence of the Rasulpur soils. The course of the Karkan Minor follows the sinuous pattern of distribution of the Hafizabad soils that are replaced in the tail reaches with the strongly saline-alkali mix of Gandhra, Firoz, and Khurrianwala soils.

*Soil Drainability and Crop Suitabilitiy*: With the exception of the Gajiana and Bath distributary commands, where the soils are seasonally imperfectly drained, the drainability varies between well to moderately well drained conditions; in some cases it is excessively drained, as in the commands of the Kassoke Distributary and along its namesake drain (Figure 5(c)).

From the loamy Hafizabad soils in the command of the Jurian Distributary to the Hafizabad/Bhalwal mix predominating the command of the Mananwala Distributary, the soils are well suited for the growth of cotton (Figure 5(d)). The rest of the Subdivision has a complex mix of finer textures and salinity/sodicity that restrict its growth to mostly marginal conditions.

Since sugarcane favors medium to moderately fine textures like loam/silt loam/clay loams, its preferred suitability is largely within the commands of the Jurian and Mananwala distributaries. This would exclude the lower half of the Lagar and the tail reaches of the Mananwala and Karkan commands due to incidence of salinity in the soil profile. There is little soil-related restriction pertaining to the wheat crop and , except for the salinity patches cited above, the rest of the Subdivision has soils that are well to moderatelly well suited for its cultivation.

*Soil Salinity and Waterlogging*: WAPDA MPR data for 1976-78 indicates Chuharkana Subdivision to be largely free of salinity, both in the surface and the profile (Figure 5(e)). In areas where the salinity does manifest itself, the scatter is quite large and mostly discontinuous, thereby indicating peculiar constraints local to the area. In general, these localized patches are somewhat larger in the upper half of the Subdivision, especially along the middle to tail reach of the Jurian Distributary and its Minor, Shamir. The surface salinization is disproportionately higher within the Gajiana Distributary command. In fact, the strongly saline patches are almost exclusively limited to the hydrological divisions mentioned above. What is surprising is that the largely unculturable waste in the tail

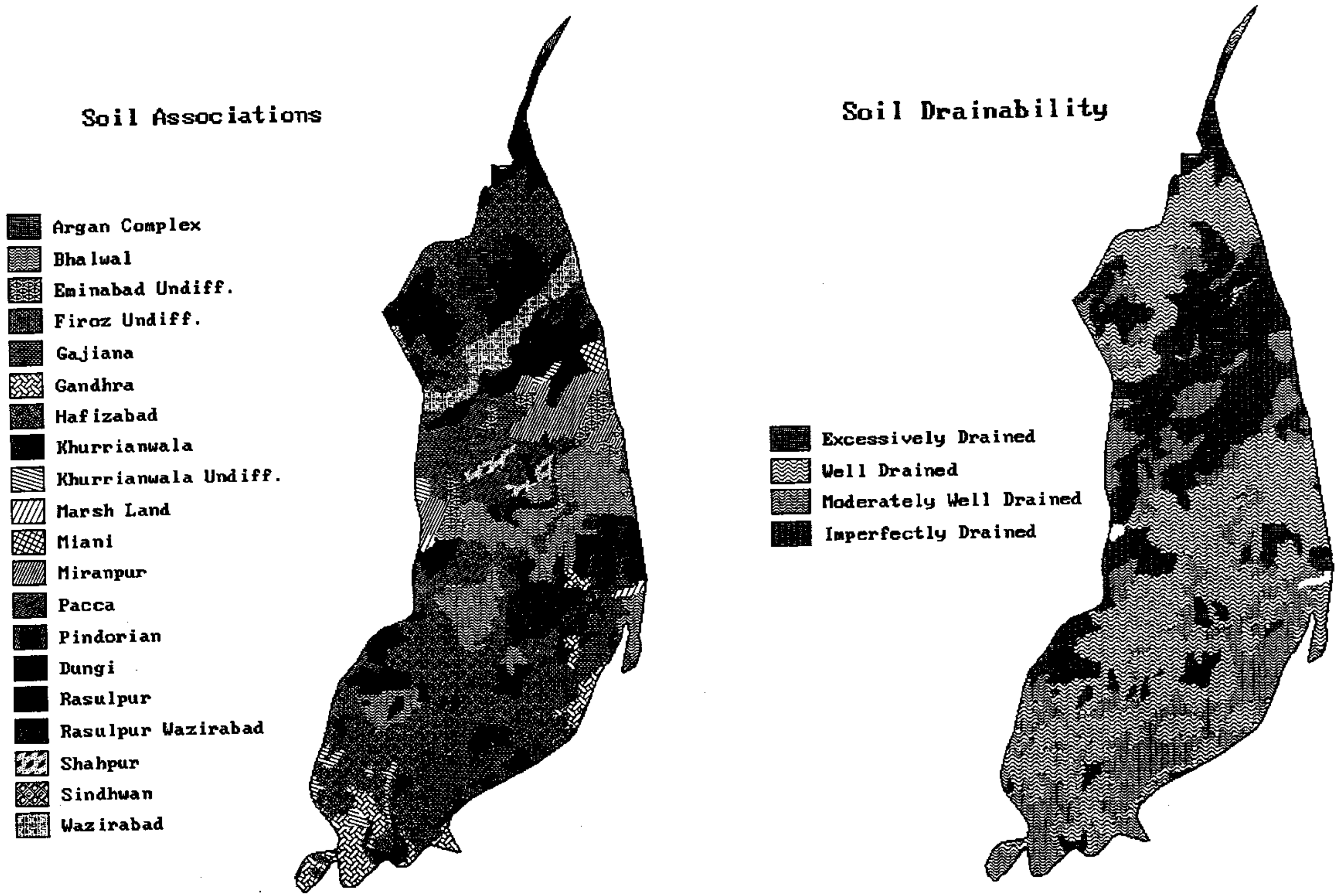



Figure 5(c) Associative Classification of the Soils and their Drainability Characteristics the Chuharkana Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.


Figure 5(d) Soil Suitability for Major Crops in the Chuharkana Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

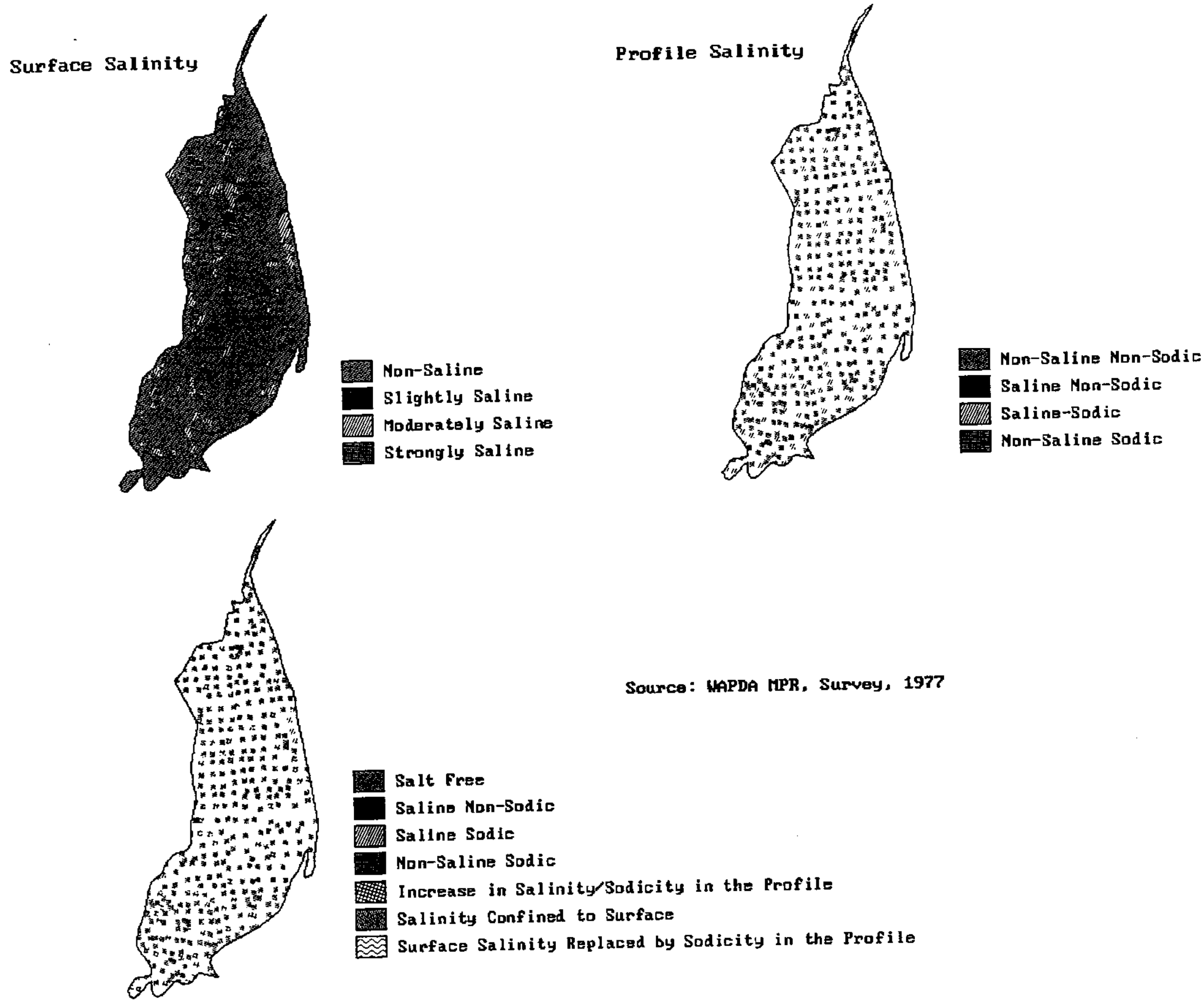



Figure 5(e) Surface and Profile Salinity in the Chuharkana Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

portions of Mananwala and Karkan commands, commonly observed to be strongly affected by salinity, is not emphasized as such by the WAPDA survey. However, the profile sampling conducted for these tail areas does show evidence of salinity/sodicity buildup that is similar to the situation in the Gajiana command. Elsewhere, WAPDA data shows subdued spatial correlation with the Gajiana and Dungi soil association related salinity/alkalinity identified earlier by the SSoP. In fact, the most dominant presence of salinity in large spatial tracts is shown under the SSoP's Gajiana association that is poorly correlated to the salinity incidence reported by WAPDA. The discrepancy in the mapped delineation of the permanently affected regimes is reduced towards the very tail commands of the Gajiana Distributary (and a few scatters within the Karkan Minor command) where the strongly saline alkali silty clay loams of the Firoz Undifferentiated Group have been confirmed by the succeeding WAPDA survey.

The well defined patches of soil salinity and alkalinity shown by the SSoP under Gandhra and Khurrianwala Undifferentiated associations in the commands of the Lagar and Karkan channels have been confirmed by IIMI's field surveys during 1989-93. In addition to these soils, the SSoP also identified Dungi/Gajiana associations related salinity in the head and tail reaches of the Gajiana Distributary. In fact, throughout the Chuharkana Subdivision, Gajiana Distributary has the most affectation due to salinization processes occurring across a selection of medium to moderately fine texture soils. Resultantly, farmers prefer to grow rice in this command due to its salinity tolerance and higher water retention capacity of the soils. Additionally, within the Distributary command, the cultivation of rice also takes place in the non-saline associations of Pacca, Miranpur, and Shahpur that represent ideal conditions for its growth.

Biannual measurements on water table fluctuations indicate that while in 1980 much of the upper half of the Subdivision had problems close to the root zone, by 1993 these had been greatly reduced to localized regimes within the head reaches of Ghordour and Lagar distributaries (Figure 5(f)). The decrease in the post-monsoonal rise in water levels coincides with the phenomenal increase between 1980-1990 in the number of private tubewells within the area. IIMI research data in sample watercourses of the LCC system indicates that the private tubewell development has been extensive over the past decade and that densities of 5-14 tubewells/100 ha. are rather common. These private tubewells, as well as the existing public tubewells, are used effectively to sustain high crop water requirements of less drought tolerant crops during the peak kharif season. The evidence suggests that the aquifer exploitation already may exceed recharge, at least locally if not over larger areas.

This increased pumpage has had its repercussions on the lateral subsurface flows, whereby areas with previously established flow regimes, such as along the head reaches of the Mian Ali Branch (suited to sugarcane and wheat crops), have responded with reduced outfllows in the post-monsoon period (Figure 5(g)). Contrastingly, the areas paralleling the length of Upper Gugera Branch in the head reach of the Subdivision have developed rather sharp slopes indicative of a steep seepage gradient between the main channel and the adjoining


Figure 5(f) Temporal Variations in the Depth to Water Table, Chuharkana Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

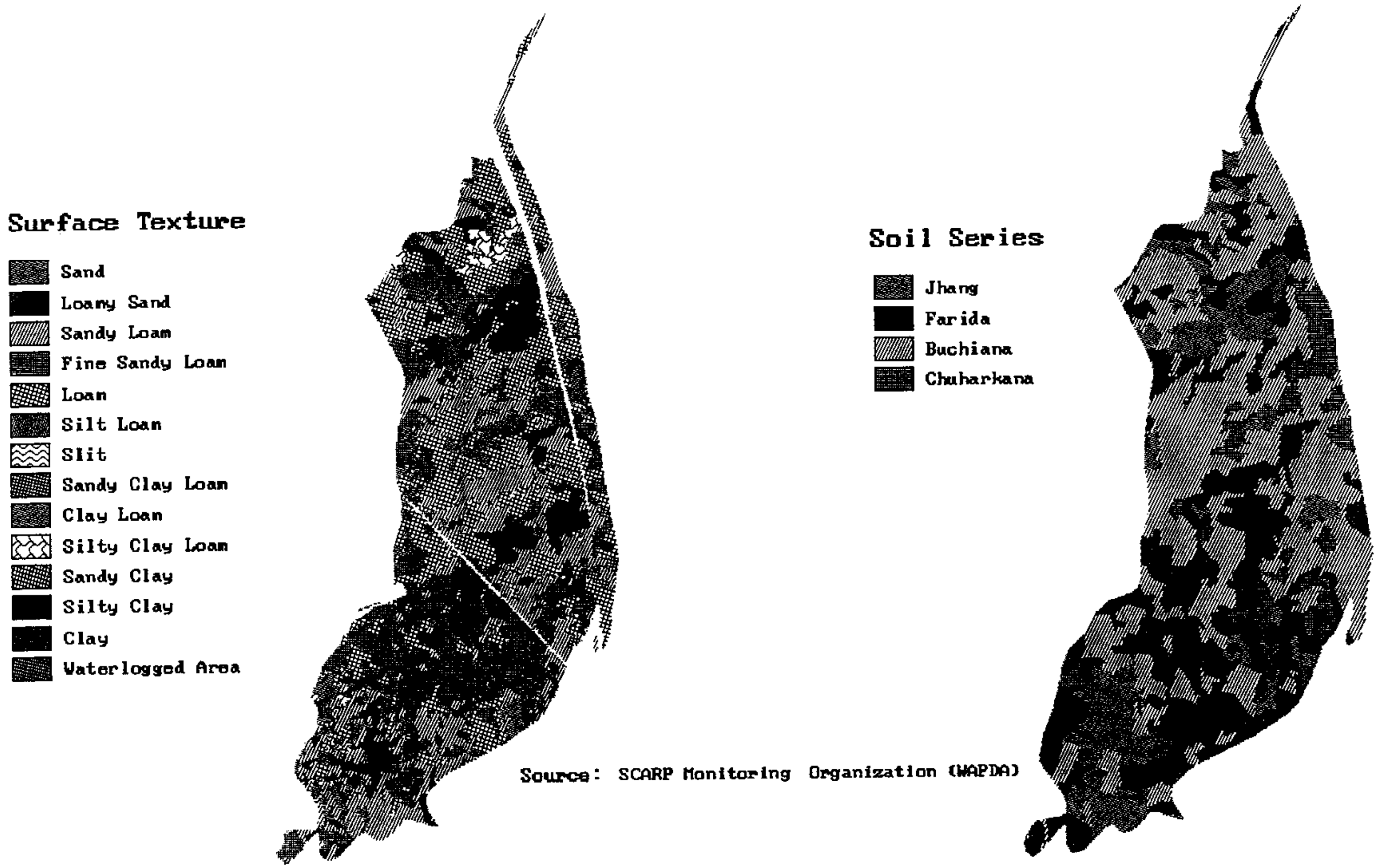



Figure 5(g) Surface and Profile Texture of the Soils in the Chuharkana Irrigation Subdivision, Lower Chenab Canal (East) Circle. Rechna Doab. Punjab. Pakistan.

vadose zone. Areas in between these two extremes first changed to higher lateral flow regimes by 1985, and then receded back to an even larger spatial restriction on subsurface outflows, especially along the entire length of the Mian Ali Branch. One explanation could be that the recharge reaching the water table has been augmented abnormally due to seepage from rice/sugarcane fields that are quite extensive in this area. This could also be related to the local densities of the tubewells in different areas with different extraction rates and hence large variability in uniform movement of subsurface flows. In general, given the available data for the 1980-93 period, if it is assumed that decreasing slopes correspond to the rise in water tables (or less groundwater extraction), and vice versa for an increase in slopes, then

- The upper one-third of the subdivision indicates comparatively lesser exploitation by the tubewells (due to fewer areas satisfying soil suitability for high delta crops, like rice).

- The lower third of the Subdivision, with relatively favorable soil conditions for the cultivation of rice and sugarcane, relies heavily on groundwater extractions. This disproportionate reliance on pumpage is due to the inequity of distribution of surface supplies in these tail areas.

- In the middle reaches of the system, the rise in the watertables is quite evident for areas with known incidence of salinization, e.g. the Gajiana Distributary command and areas along the Mian Ali Branch. It is in these areas of finer soils that the rice cultivation is most extensive. The rice crop is not only more resilient to the detrimental effects of salinity but also contributes, through seepage, to the rise of the subsurface water levels.

*IIMI Sampling for Soil Salinity and Texture*: The thirteen IIMI sample sites, comprising nearly 9,900 ha, for soil salinity assessment were distributed mostly at the fringes of the Subdivision. A total of 1544 EM38 observations were collected that showed almost 95% of the cultivated regime to be non-saline. This compares well with the 97% agricultural land use intensity as reported in the IIMI questionnaire for the sample domains. The irrigated area (CCA) is 72% of the gross area of the Subdivision, a figure that is lower than the average due to comparatively higher urban land use.

Comparison of the soil texture vs soil salinity (Figure B4, Volume Four) indicates an near equal reliance on moderately coarse to moderately fine soils when cultivating under non-saline conditions. For upto moderately saline levels, the farmers prefer to grow crops either on the loams or better still on the coarser loamy sand to sandy loam fractions. This may be indicative of the purposeful avoidance of the difficulty in leaching away the salts in the finer textures where pore spacing is further restricted in the presence of the sodic salts.

Crop-wise differentiation shows overwhelming preference for the sugarcane cultivation on the medium textured soils, although its presence on the finer soils is also significant. For a still higher consumptive use crop like rice, the trend is reversed whereby the finer textures dominate the medium and the moderately coarse categories. The cultivation intensity of cotton is much less as compared to the rice and sugarcane; accordingly, its lower cash value is exploited on the moderately coarser soils that are not well suited to meet its crop water requirements. Here again, in an effort to minimize field seepage, its cultivation has also been extensive on the clay loams ahead of the loams commonly observed elsewhere.

In lieu of greater proximity to population centers, farmers have tended to grow a larger share of the vegetables, mostly on the sandy loam to loam/clay loam type of soils. From amongst the ploughed/fallow land, the proportion of the land amongst the sandy loam, loam/clay loam is not too different from the land use under vegetables during kharif. One inference, based on IIMI's past observations through a cropping census of Lagar and Mananwala distributaries, is that these soils are likely to be brought under a higher cultivation intensity of vegetables during rabi. By far, the highest land use is bracketed under the category of ploughed/fallow land followed by fodder. While the former has predominantly medium and somewhat lesser moderately coarse soils being readied for the impending rabi cultivation (higher by 10% over the kharif cropping intensity of 65%, mostly wheat/sugarcane), the latter is heavily favored for the medium soils which is not unlike the situation in other subdivisions of the Gugera. In fact, fodder is also being grown on fine textured soils thereby indicating the unavoidable need for its cultivation even in soils not entirely suited for its growth.

*IIMI Farm Level Sampling*: IIMI's economic survey for the Chuharkana Subdivision comprised interview data for 31 farmers that have reported cultivation (land use) intensities more than 90% of the available farm acreage (Table H1, Volume Four). These values are quite representative of the higher landuse within the Upper Gugera commands. This intensity of land use is complemented by one of the highest cropping intensities across the entire LCC system. The opportunities for higher production are reflected in the share of the major crops in the total cropped area---40% for wheat and 32% for rice. Resultantly, this shows up in the comparatively fewer areas devoted to fallow activity (28% in kharif and 23% in rabi) as compared to the subdivisions in the Lower Gugera. Of the farmers reporting fallow practices, less than 20% attribute it to presence of salinity on their farm lands, whereas the majority reported a scarcity of surface supplies to be the principal contributing factor (Figure H3, Volume Four). The groundwaters remain useable across much of the Subdivision; however, about one-third perceived it to be unfit for irrigation.

Despite higher levels of investment in land preparation and irrigation, the profits from the wheat crop are less than in the neighboring Pacca Dala due to low overall yields (Table H2, Volume Four). However, given the more than double cropping intensity of the rice crop within the Chuharkana Subdivision (duly aided by higher investments in all areas of critical inputs), the profits exceed those in the Pacca Dala Subdivision. In any case, in the higher consumptive use category, Pacca Dala is known more for the cultivation of the sugarcane crop than rice, which partly explains the difference in the profitability patterns due to these farm level preferences in cultivation..

## E. Dhaular Subdivision

*Hydrologic Regime*: Dhaular Subdivision represents the tail command of the Jhang Irrigation Division. Its irrigation supplies are from the principal channels; namely the Dhaular Distributary and the Bhangu Branch, both of which offtake from the tail reaches of the main Jhang Branch that itself ends in the Veryam Subdivision (Figure 6(a)). Out of the gross area of 98,000 ha, a little over two-thirds is commanded, which is very similar to the situation in the neighboring Wer Subdivision to the north, but with one important exception, i.e. in the number of watercourses. Dhaular has 379 watercourses to 313 for Wer, meaning its average of the commanded area per watercourse is much less in comparison to Wer. This comparison is particularly useful in the context of the proportion of the culturable waste and the resultant impact on the cultivation/cropping intensities. In the absence of IIMI's sample data on cultivation and cropping intensities for the Wer Subdivision, a comparison of the salient hydrologic characteristics in Figure 1(b) shows that against a small difference in the density of the distribution system, the design water allocations for Dhaular are higher by more than 20%. In fact, given the near equal proportion of the commanded area within the gross, the design allocations for the Wer should have been higher by *at least* 40% over the current sanction. The word *at least* has been used because the relatively large size of the commanded area per watercourse (with its own share of conveyance losses) also has to be taken into account.

The hydrological network closely follows the direction of the natural relief that varies between 142-163 meters above sea level. For this difference in relief, the average topographic slope to the south is approximately 0.00025 that is evenly distributed across the entire length of the Subdivision. The lower reach of the Subdivision below the tail of the Bhangu Branch is intersected by the parallel run of the two major canals of Haveli and the Trimmu-Sidhnai Link that offtake from the Trimmu headworks located to the immediate west of the Subdivision. Resultantly, nearly 20% of the Subdivision's gross area to the south of this intersection receives siphoned irrigation supplies from the minors offtaking from the tail trifurcation of the Bhangu Branch.

*Soils*: Because of its immediate proximity to the young flood plain of the Chenab River, the depositional patterns of the soils across the Dhaular Subdivision are much more varied and complex in comparison to the other units of the LCC system. In general, based on the soil series differentiation appearing under Figure 6(b), areas closer to the river are relatively finer in texture; the differentiation is more obvious given the near exclusive confinement of the Jhang series (sand, loamy sand, sandy loam) in between the Bhangu Branch and the Dhaular Distributary. The moderately fine profiles of the Farida series predominate the entire Dhaular Subdivision and are overlain by the fine sandy loams in the surface. The homogeneity in stratification is also common for the medium textured soils wherein the Buchiana series profiles are overlain by the loams/silt loams in the surface. The significantly large patches of these medium textures in the command of the Dhaular Distributary make it particularly suitable for the growth of major crops in the area.

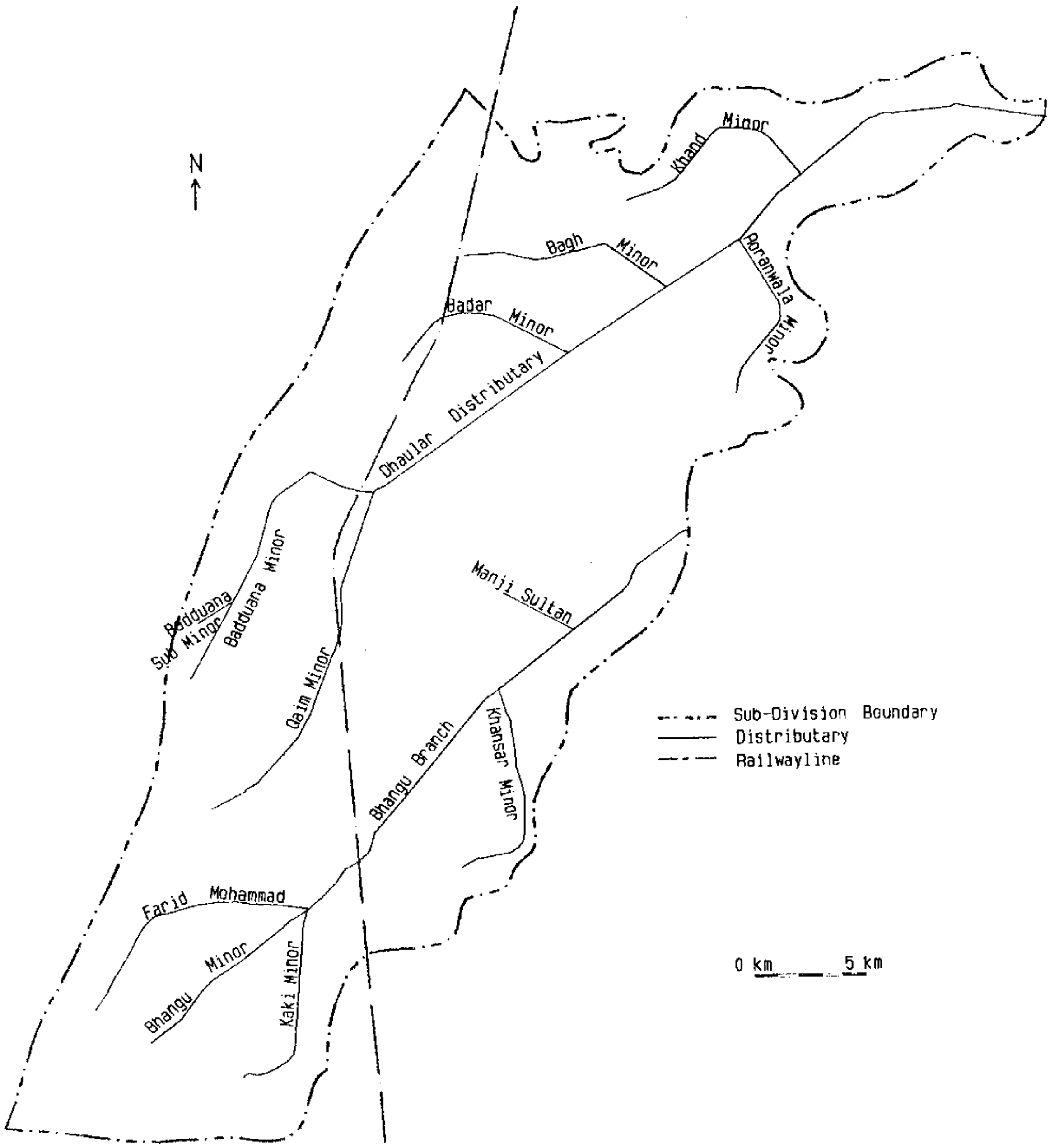



Figure 6(a) Dhaular Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

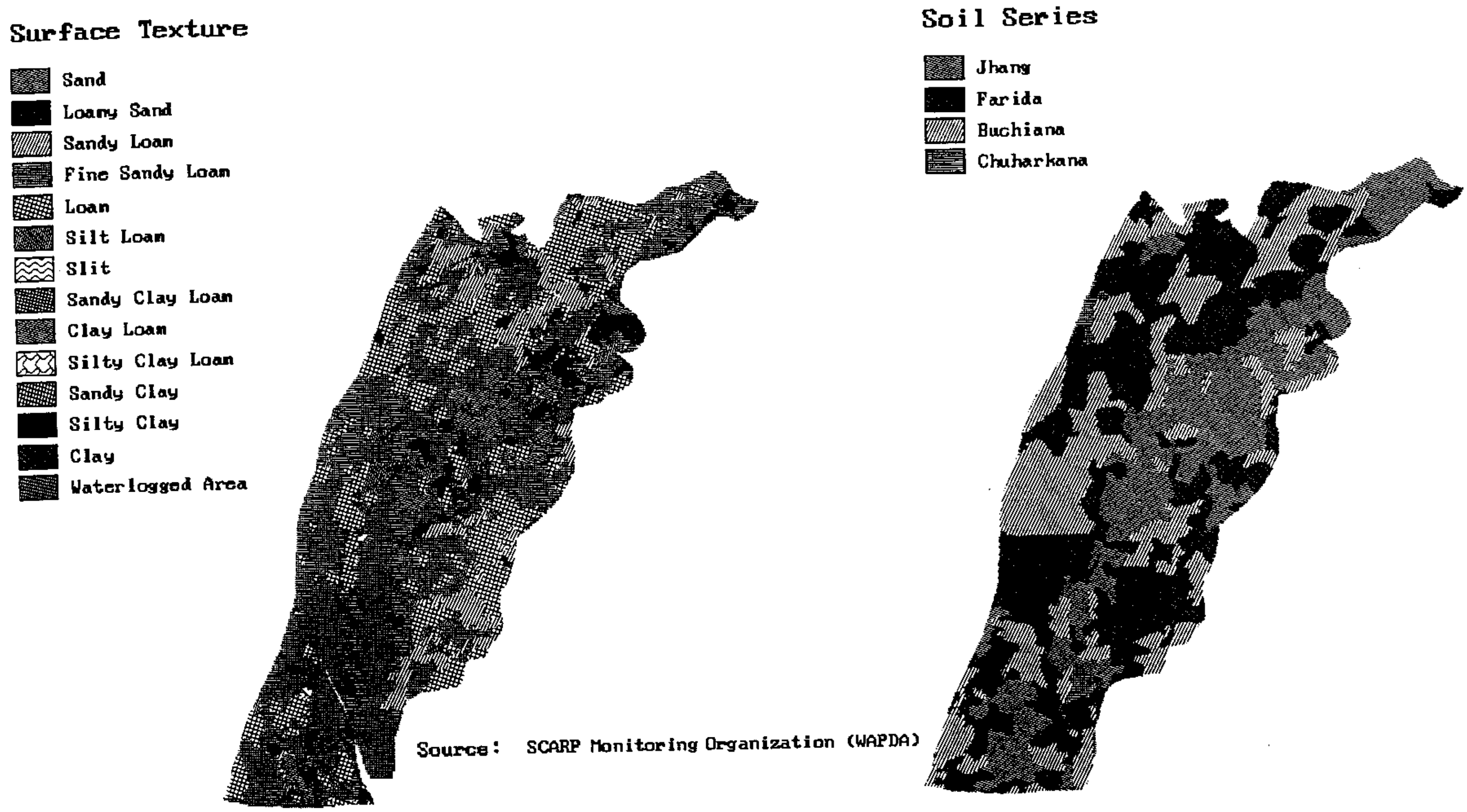
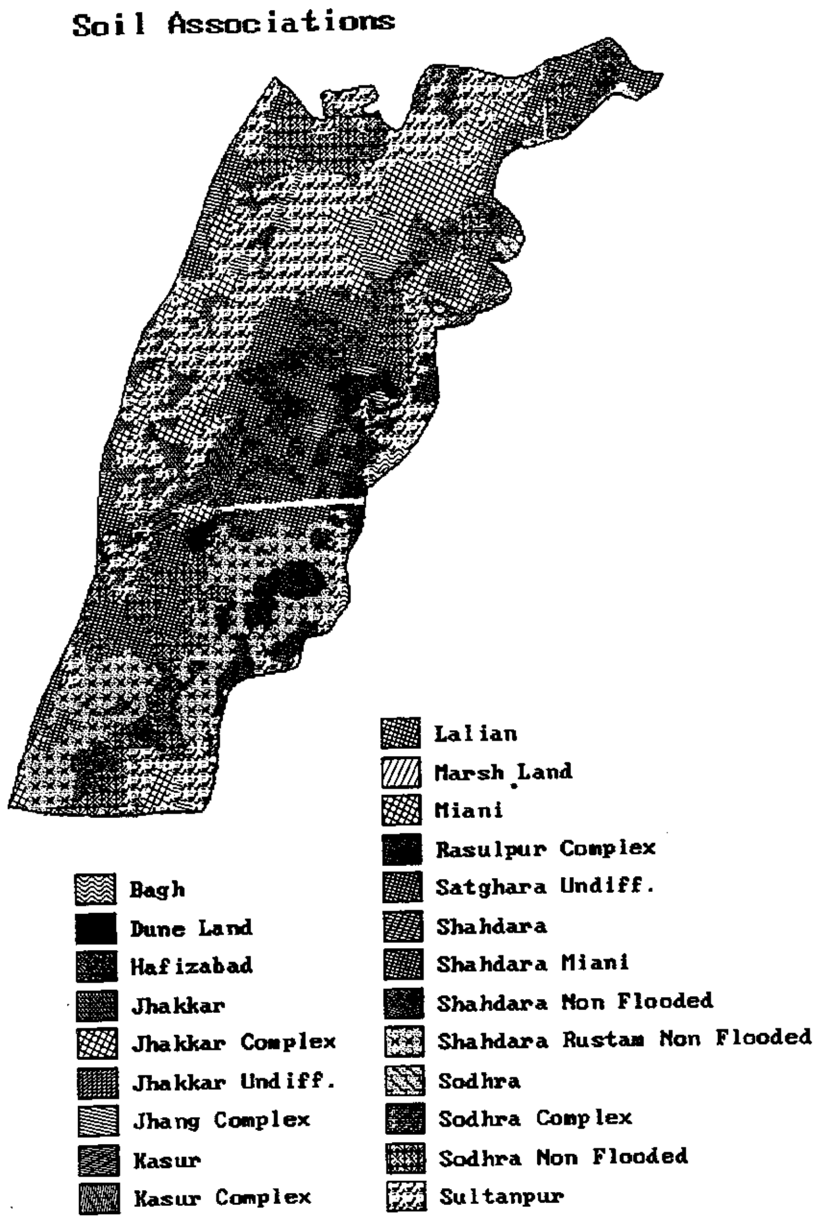



Figure 6(b) Surface and Profile Texture of the Soils in the Dhaular Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

The SSoP interpretations on the associative differentiation of the soils confirm the above textural separations; the coarse textures of the Sodhra Complex, Rasulpur Complex and the Sodhra non-flooded associations overlap the Jhang/Farida series differentiations above (Figure 6(c)). Similarly, the Sultanpur silt loams coincide with the Buchiana loams/silt loams in the profile. This overlapping trend is less evident in the tail portions where there is a very large spatial distribution of fine soil textures. However, for much of the Subdivision, a significantly homogeneous stratification of the coarse/moderately coarse to medium soils is quite well established. The presence of the Satghara and Jhakkar/Jhakkar Complex soils in the head reaches of the Dhaular Distributary and along the western edge of the system indicates strongly alkaline silt loams. Rather surprisingly, this degradation is of quite limited extent in the tail reaches of the Subdivision, where the silt loams and very fine sandy loams of the Kasur and the silty clays/clays of the Satghara association have a scattered presence. This phenomenon could have been more widespread given the very fine textures of the Shahdara Rustam Non-flooded soils that predominate this part of the system.

*Soil Drainability and Crop Suitability*: Based on the stratified homogeneity in texture-specific aggregtions observed above, the major differences in the drianage profile are easily differentiated in space. From Figure 6(c), the soils become progressively finer when moving laterally across the Subdivision from east to west. Resultantly, there are large discontinuous extents of excessively well drained stratum paralleling the Bhangu Branch. The central divide, covering the entire length of the Subdivision, is a hybrid mix of excessive to moderately well drained soils. The tail of the system below the twin canal intersection is primarily a well drained to moderately well drained environment. Finally, the largely well drained environment beyond the right bank of the Dhaular Distributary has significant imperfections in vertical flow caused by the strongly alkaline Jhakkar/Jhakkar Complex soils of medium texture.

In between the twin extremes of excessive and imperfect drainage limitations, crops with the most suitable growth conditions include rice and sugarcane. This is largely facilitated by the contiguous spatial extents of the medium to fine soil textures that are well distributed throughout the Subdivision (Figure 6(d)). The comparatively larger extent of the soils favoring rice growth is because of its resistance to saline-alkali conditions, such as the ones expected against the Jhakkar, Kasur and Satghara soils. Soils suitable for cotton are restricted to the left and right bank commands of the Bhangu and Dhaular irrigation channels, respectively. However, the mixed calcareous environment of the Shahdara-Miani silty clay loams/clay loams in the center of the Subdivision would be only moderately suited to the growth of rice. Conditions favorable to wheat are well scattered amongst soils offering poor growth, this being especially true for the eastern half of the Subdivision. To the west, the saline-alkali soils further limit its extent. Probably, the most suitable mix of soils amenable to its growth would include the silt loams and the silty clay loams of the Sultanpur and Shahdara-Rustam/Shahdara-Miani non-flooded associations that are well distributed in the Dhaular Distribnutary command.



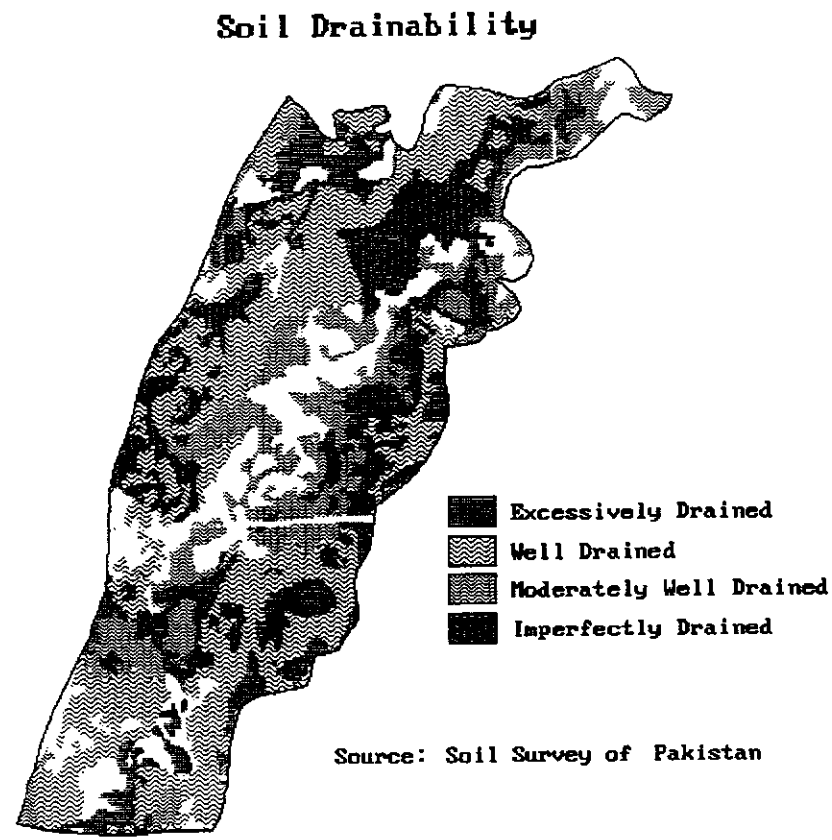




Figure 6(c) Associative Classification of the Soils and their drainability Characteristics the Dhaular Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

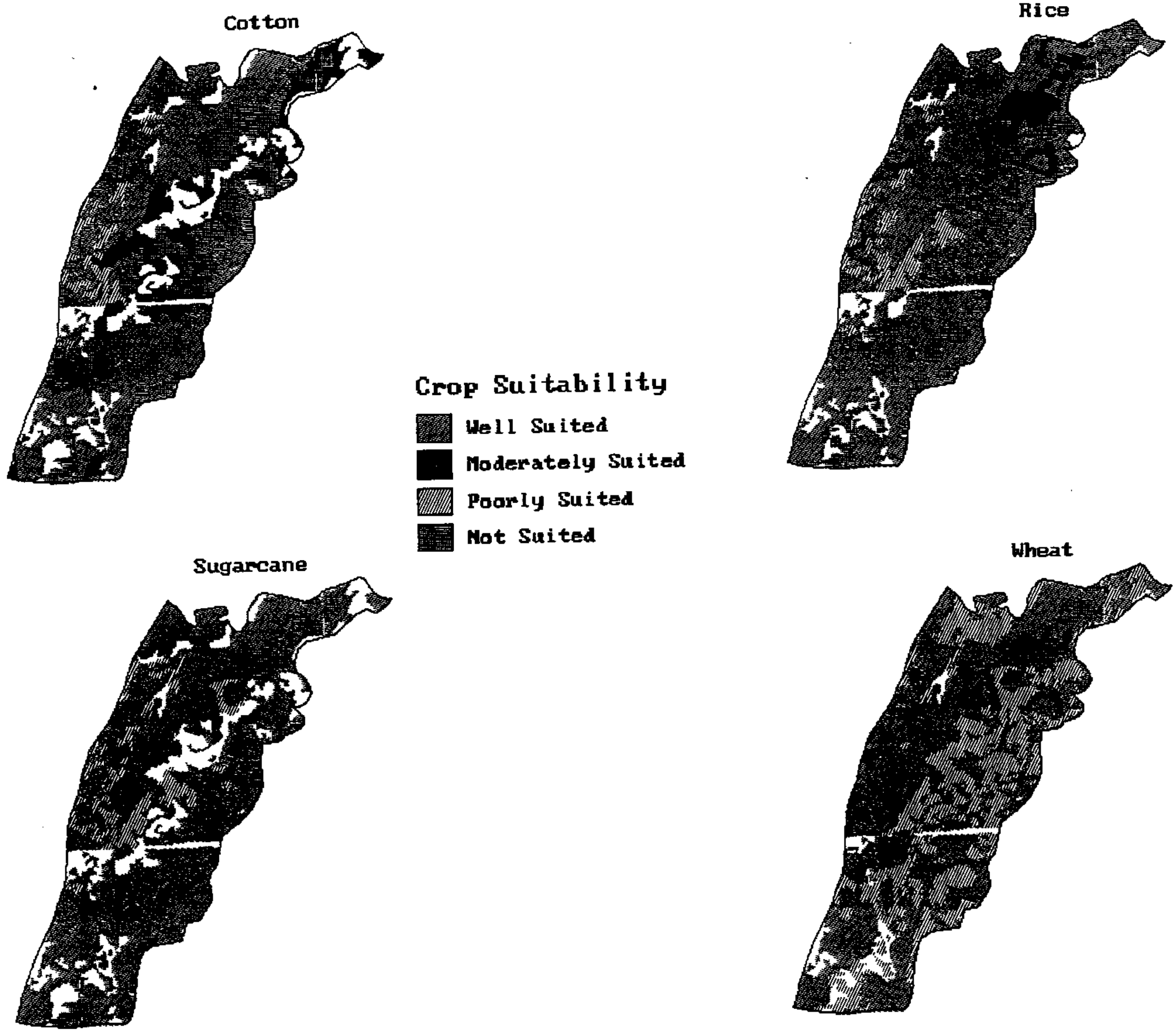



Figure 6(d) Soil Suitability for Major Crops in the Dhaular Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

*Soil Salinity and Waterlogging*: WAPDA's MPR survey data of the 1975-77 period indicates the incidence of S4 category of surface salinity is limited to the finer textures of the Satghara and Jhakkar Complex saline-alkali soils previously identified by the SSoP in the 1965-67 period (Figure 6(e)). Most of the Subdivision is non-saline in the surface, however profile data indicates extensive clustering of non-saline sodic and saline-sodic soils in the lower two-thirds of the Subdivision. Rather surprisingly, areas previously shown to be severely affected by the strongly alkaline Jhakkar Complex soils in the head reach have either disappeared altogether or have dissipated to the S2 levels of surface salinity.

The data on interseasonal changes in the water levels from 1980 onwards shows insignificant fluctuations below the root zone (Figure 6(f)). In fact, the tail portions of the system actually show a decrease in the water levels following the monsoonal recharge. An increase in the water levels was initially noticeable near the head of the system; however, it also seems to have blended with the less than noticeable changes elsewhere. This overall situation coincides with the additional details on the subsurface slopes (Figure 6(g)) wherein noticeable changes in lateral movement are mostly restricted to the head reaches of the system, and that also well below the root zone.

*IIMI Sampling for Soil Salinity and Texture*: IIMI's eleven sample sites in the Dhaular Subdivision, covering approximately 9850 ha, were clustered in the head and tail reaches of the system. Nearly 82% of the 891 paired observations of salinity recorded through the EM 38, and after conversion to the $EC_e$ values, showed non-saline soils within the root zone. This is similar to the constituent composition of the non-saline cultivated tracts in the neighboring Subdivisions of Wer, Aminpur and Veryam. From Figure B5, Volume Four, there was no recorded occurrence of the S4 category of surface salinization; the slight to moderate levels of salinity were mostly manifested in the moderately coarse to medium textures ranging from sandy loam to loam. The proportion of the finer soil textures increases towards higher levels of salinity; however, the incidence of salinization in these soils is not as rampant as would have been expected in lieu of the higher susceptability of these clay bearing associations in retaining the saline-sodic admixtures of irrigation induced salinity.

From Figure C5, Volume Four, the pattern of land use follows the dominant soil textures observed above. Out of the major categories of land use shown, the finer textures are limited only to the fodders. Since sandy loam is the most dominating texture across the sampled areas, the recorded occurrence of even the higher consumtive use crop like sugarcane follows the general trend. The proportion of the textural separations are identical for the ploughed and fallow land categories, however, the latter has incrementally higher levels of soil salinity.

*IIMI Farm Level Sampling*: Based on the sample interview of 33 farmers in the Dhaular Subdivision, the percentage figures for the land use and the cropping intensities are equal to, or even better than, the subdivisions located in the central reaches of the LCC system. This is primarily due to the conducive groundwater use conditions that curtail the tendency

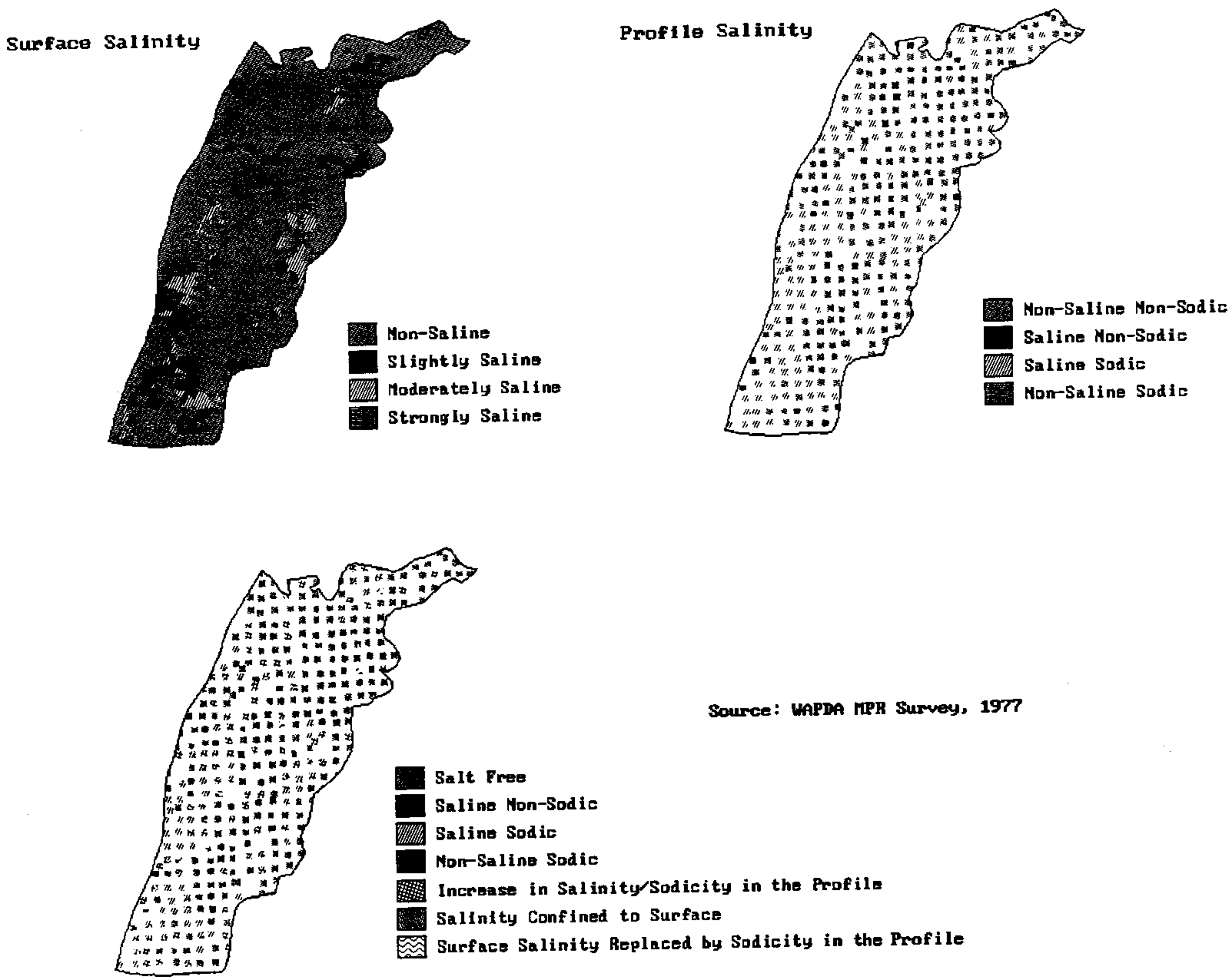
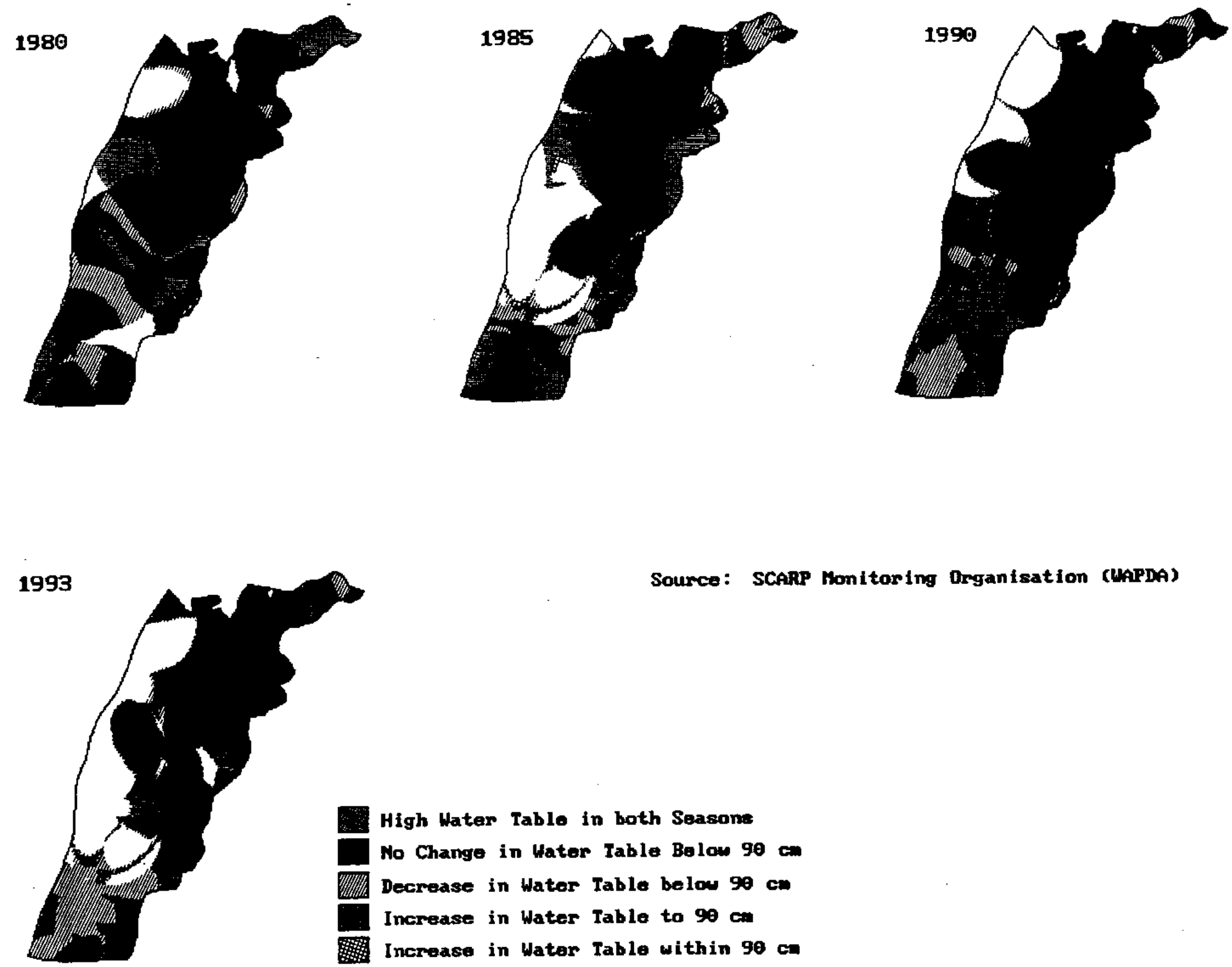
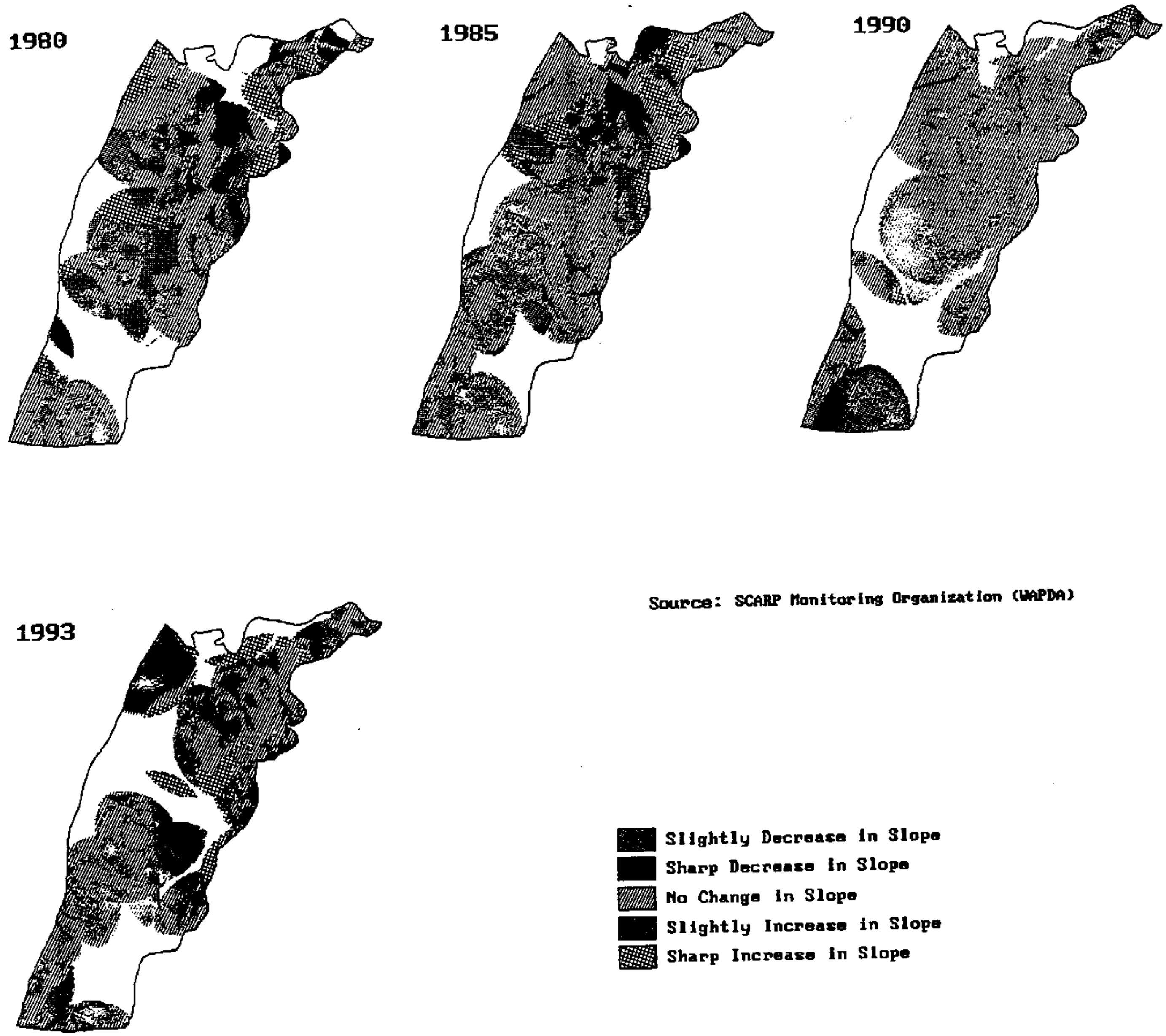



Figure 6(e) Surface and Profile Salinity in the Dhaular Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organisation (WAPDA)

Figure 6(f) Temporal Variations in the Depth to Water Table, Dhaular Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 6(g) Interseasonal Slope Variations in the Subsurface Flows, Dhaular Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

towards fallowing (Figures H1 & H2, Volume Four). Still, the majority of the farmers cited a scarcity of irrigation supplies, over and above the impairment due to salinization, as the major impediment towards boosting the existing cropping intensities (Figure H3, Volume Four); this is in an environment wherein the major crops already constitute the highest proportion (81%) from the gross cropped area reported by the farmers. When considered in the context of the entire farm holding, the cropping intensity for the wheat crop is significantly high, but remains much lower for both rice and cotton (Figure H4, Volume Four).

In reference to Figures H6-H13, the median level of gross income from the major crop of wheat is directly related to the high cost of fertilizer inputs and reliance on supplemental irrigation supplies that significantly disfavor higher overall profits. In comparison, despite higher production costs, the gross income and profits from the cotton crop are quite favorable. The rice crop had the highest yields reported from amongst all of the subdivisions; this puts the figures on gross income and profit at par with the more traditional rice growing subdivisions to the north. Its total costs remain low due to the most favorable conditions for soil puddling available throughout the Subdivision (Figure 6(d)). The choice of the sandy loam soils, in addition to the loams/silt loams, for the sugarcane crop (Figure C5, Volume Four) is not the most preferred one; this is manifested in one of the highest irrigation costs across the LCC subdivisions.

### F. Haveli Subdivision

*Hydrologic Regime*: In gross area, the Haveli Subdivision is slightly larger than the neighboring Dhaular (Table 1). At the time of writing of this report, the data specific to the irrigation network could not be made available. However, the general layout of the system appears in Figure 7(a). The Subdivision is a fairly well bounded regime due to its occurrence at the very tail of the Rechna Doab. The parallel run of the Haveli and the T.S. Link separate its irrigation system from the rest of the doab. Haveli Subdivision is also unique in terms of the multiple sources of irrigation supplies; commands parallel to the Chenab River and in the center of the Subdivision are dependent on the main Haveli Canal, whereas areas along the eastern boundary are irrigated by the tail channels of the Lower Gugera system. The commands along the Ravi River are siphon irrigated by the Koranga channel belonging to the Lower Bari Doab Canal. There is less accurate data available for the topographic elevations within the Haveli Subdivision, however, the difference is at least two orders of magnitude higher along the Chenab River in comparison to the Ravi River. In general, the topographic relief within the larger expanse of the system differs by no more than 5 meters towards the confluence.

*Soils*: Figure 7(b) shows the distribution of the soil series and surface texture interpretations by WAPDA within the Haveli Subdivision. Stratum-wise, the soils within the command of the Shorkot Distributary paralleling the Chenab River are predominantly the coarser textures of the Jhang and Farida series. Areas bordering the Ravi River comprise the fig.

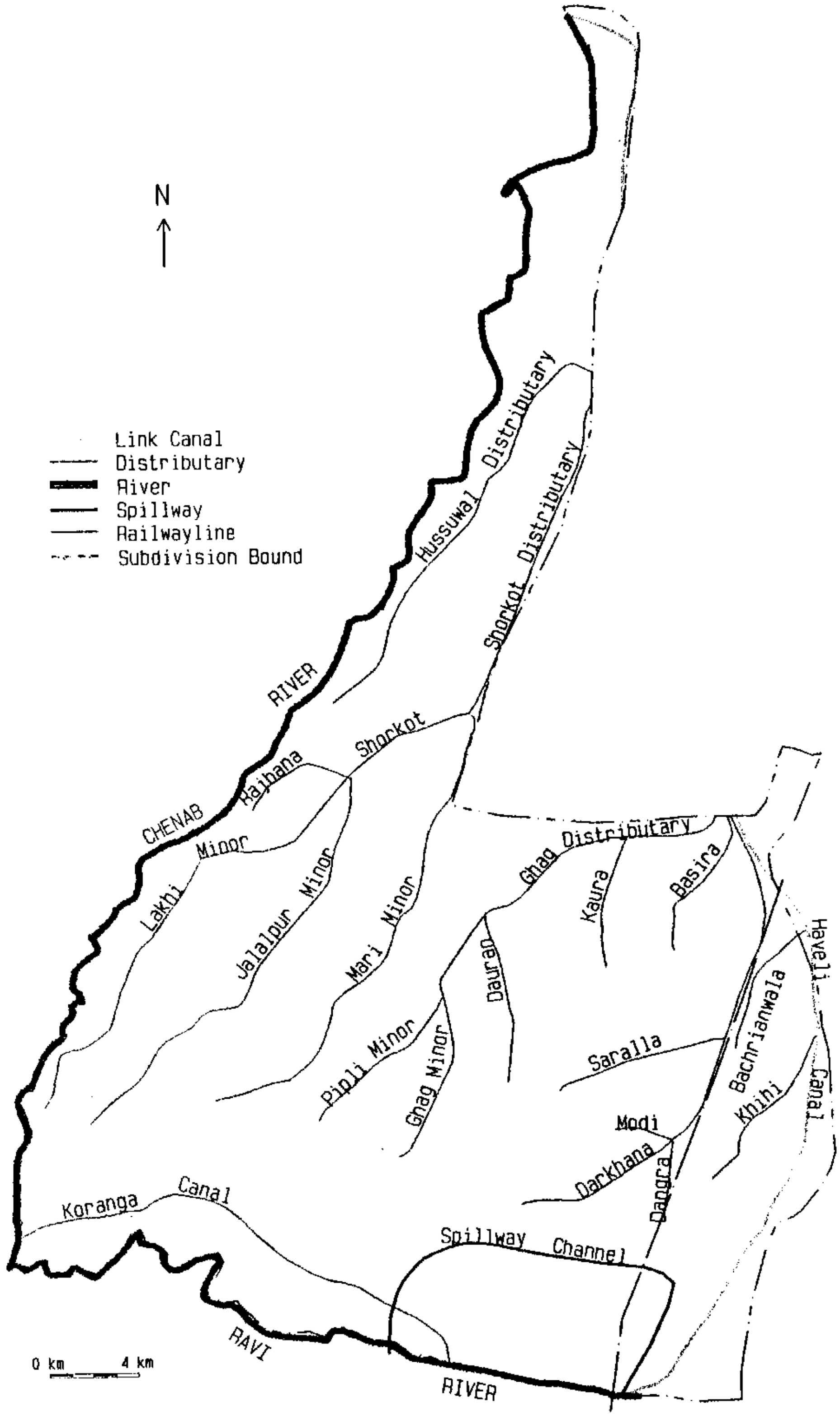



Figure 7(a) Haveli Irrigation Subdivision in the Rechna Doab, Punjab, Pakistan.

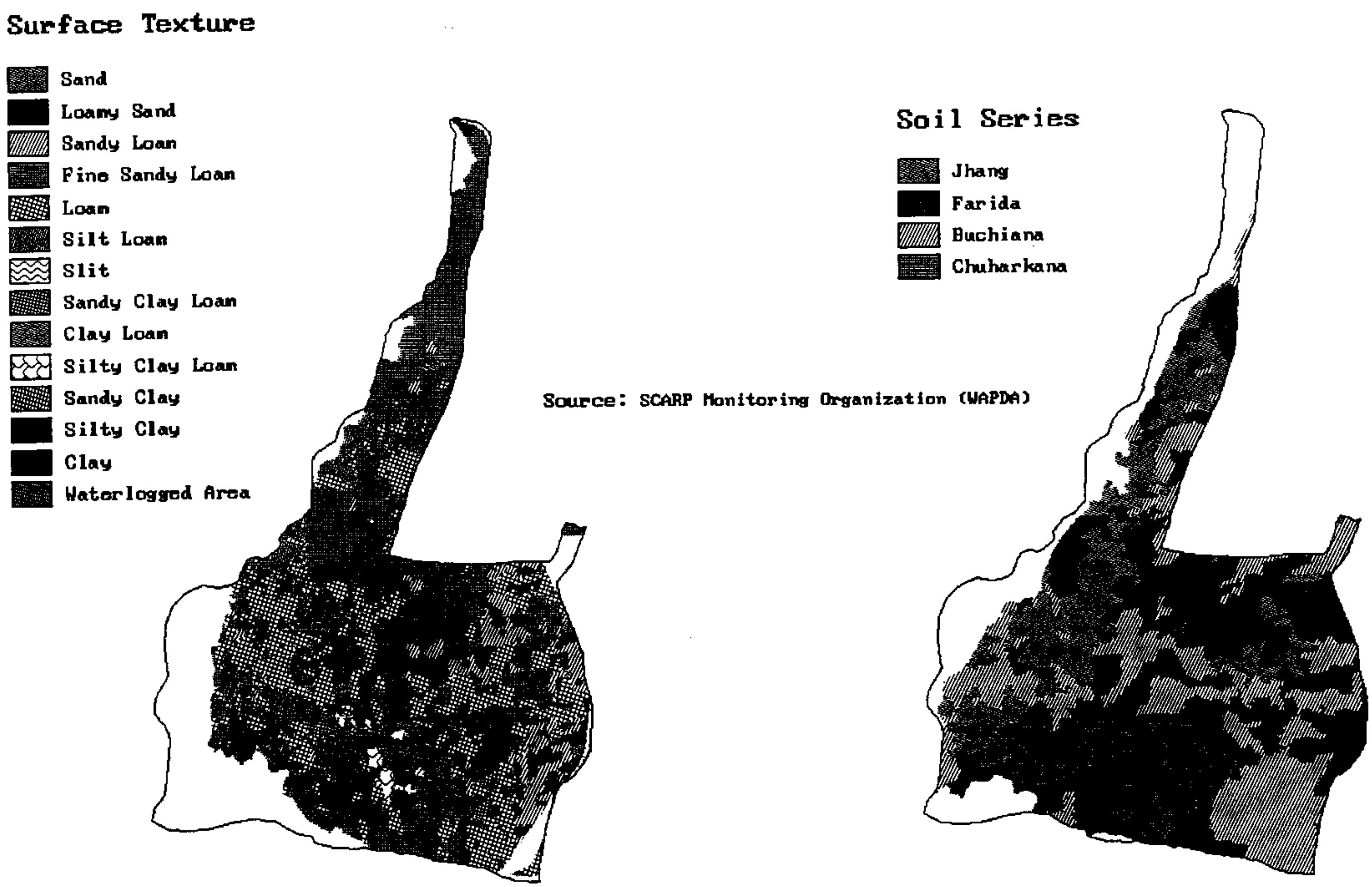
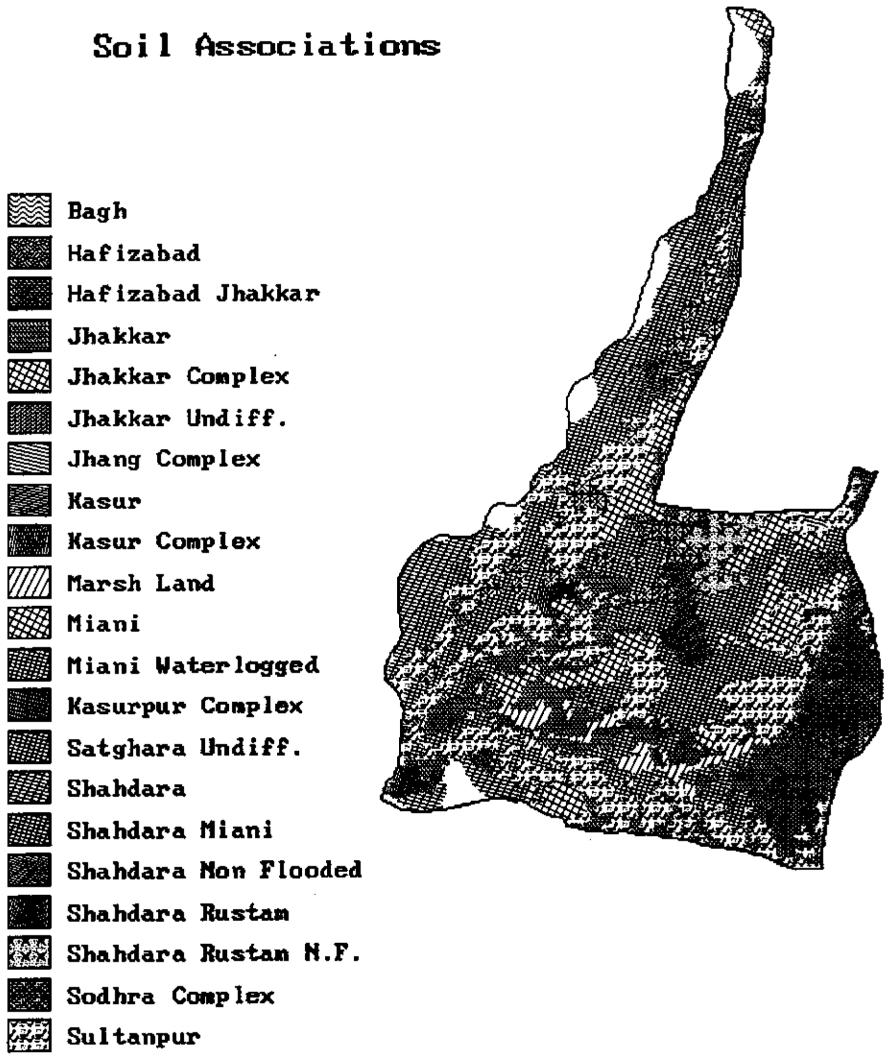



Figure 7(b) Surface and Profile Texture of the Soils in the Haveli Irrigation Subdivision, Rechna Doab, Punjab, Pakistan.

medium to moderately fine textures of the Buchiana and Chuharkana soils, especially within the looping confine of the spillway (Nikasu Nala) that is almost entirely made up of the medium textured alluvials. These areas have been subjected to repeated flooding from the Ravi River that is in part explained by the meanders of the depositional patterns aligned with the River itself. Such spatial diversity in profile textures are specific to the confluence regime at the tail of the Rechna Doab. There is, comparatively, less variation within the stratum as the surface soil textures match the sub-stratum and stratum conditions below. The silty/sandy clays and the silty clay loams correspond to the lateral expanse of the Chuharkana series near the Ravi River, whereas the silt loams and the loams overlap with the medium Buchiana textures.

The above textural correspondence is retained in the interpreted soil associations within the Haveli Subdivision (Figure 7(c)). The very fine sandy loams/silt loams/silty clay loams of the Shahdara and Shahdara-Miani associations (that are known to have sand within 2 meters of the stratum) follow the parallel run of the coarser Jhang and Farida soil series along the Chenab River, whereas the silty/sandy clays of the highly saline Satghara association intermingle with the Shadara-Rustam and Miani waterlogged soils in what is essentially a close overlap with the Chuharkana series bordering the Ravi River. The medium textured alluvium confined by the spillway channel are identified as strongly alkaline soils of the Jhakkar Undifferentiated Group. The other variants of the Jhakkar soils ring inward from this confluence regime towards the center of the Subdivision where predominantly moderately fine textures of the Shahdara Non-flooded, Shahdara-Rustam Non-flooded, Shahdara-Miani and Miani associations coexist with the saline-alkali Jhakkar Complex and Satghara soils. The most productive and deep calcareous silt loams of the Sultanpur association occupy the high and level areas along the flood plains of the Chenab and Ravi rivers; additionally, they match the lateral extensions of the Buchiana series that extend westwards of the railway line linking Shorkot Cantonment to areas across the Ravi River.

***Soil Drainability and Crop Suitability***: The contrasting intermixtures of the soil regime in Figure 7(c) above are reduced to a meandering pattern that is rather easy to interpret with respect to the drainability of the regime. These meanders represent pathways of flood waters along the topographic slopes wherein the depositional pattern of the moderately fine/fine soils is fully exposed. Resultantly, these clay-rich soils have moderate to imperfect drainage characteristics across an otherwise severely fragmented well drained regime. These conditions produce a widely scattered spatial pattern of crop suitability, such as the one given for the major crops in Figure 7(d). The commands of the distributaries offtaking from the head reaches of the Haveli Canal are well suited for the sugarcane crop; this range of spatial suitability is extended further by the rice crop that is well suited even in those areas that would be poorly suited for sugarcane, i.e. the Miani waterlogged soils in the center of the Subdivision. These areas would remain less suitable for growing wheat; lesser still would be the suitability of cotton over the moderately fine textures abundant in the commands adjacent to the Chenab River. It well suited only for the Sultanpur soils that are limited to the high and level areas of the old flood plain.



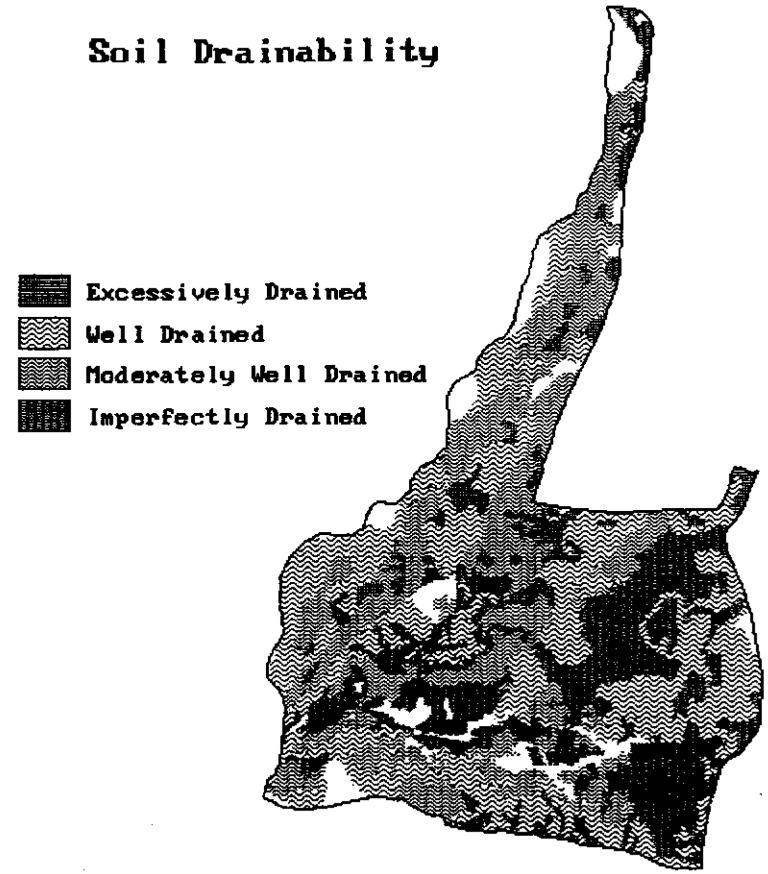




Figure 7(c) Associative Classification of the Soils and their Drainability Characteristics the Haveli Irrigation Subdivision, Rechna Doab, Punjab, Pakistan.

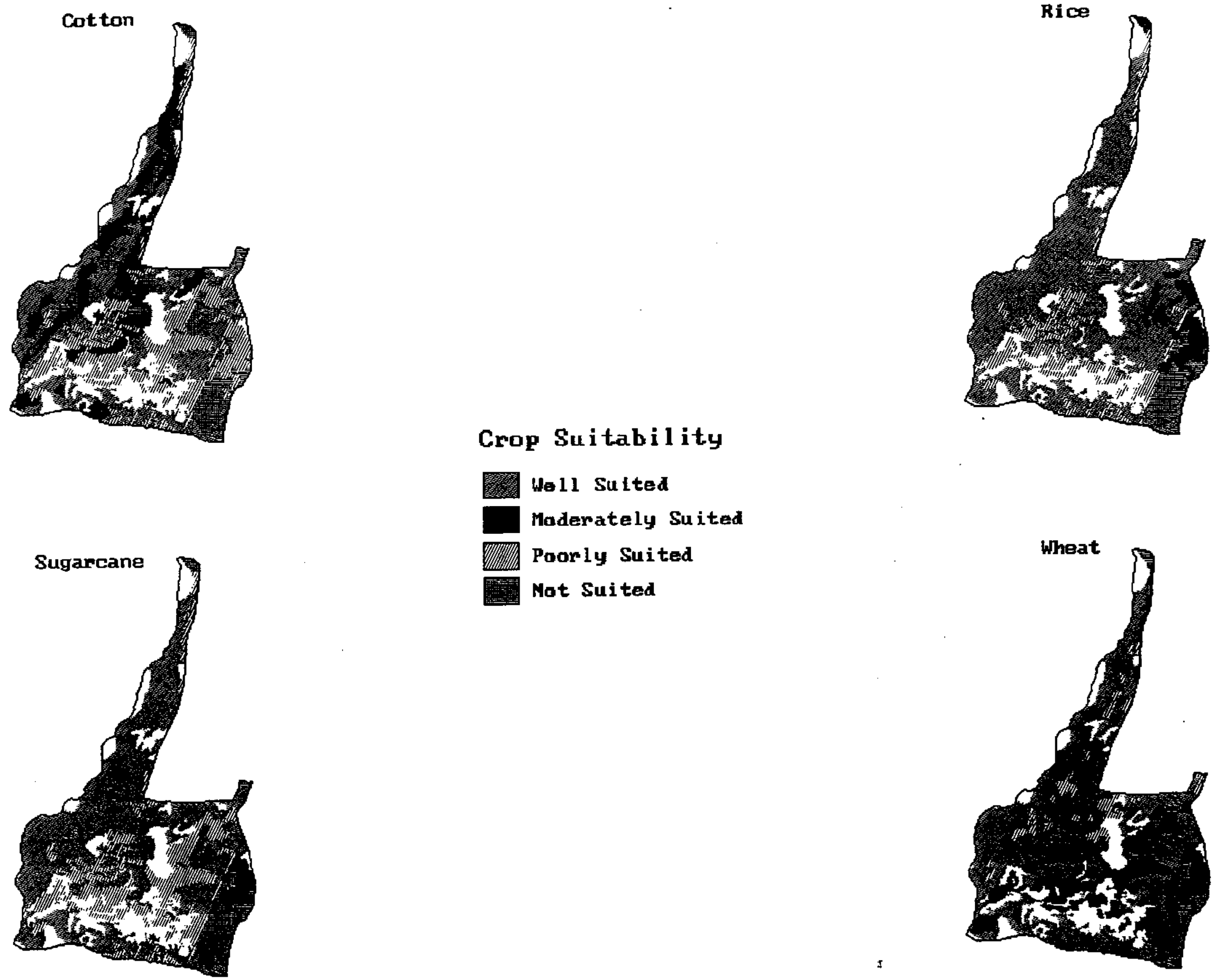



Figure 7(d) Soil Suitability for Major Crops in the Haveli Irrigation Subdivision, Rechna Doab, Punjab, Pakistan.

*Soil Salinity and Waterlogging*: WAPDA's MPR survey data for the 1976-79 period indicates very high incidence of salinization in the fine textured soils adjacent to the Ravi River (Figure 7(e)). This affectation not only has a wholesome presence in the area enclosed by the spillway channel, but also occurs on either side of the railway track mentioned above. The commands worst affected include the tails of the Khikhi and Bachrianwala channels belonging to the Lower Gugera command, Darkhana Distributary offtaking from the Haveli Branch and the right bank of the Koranga Feeder irrigating the southern most portions of the doab. These soils have a very significant sodic profile in addition to highly saline-sodic conditions in the surface.

For the subsurface water levels, the historical record from 1980 onward indicates significant spatial extents of season-specific rises that are mostly confined to the regime severaly affected by salinity (Figure 7(f)). The tails of the channels belonging to the Lower Gugera command and the Darkhana Distributary have a near permanent presence of high water tables, whereas areas along the path of the Koranga Feeder are repeatedly exposed to water levels approaching the root zone. The commands of the secondary system offtaking from near the head of the Haveli Canal are generally free of such drastic variations in close proximity to the root zone. This is also supported by the slope variations in the lateral flow regime that remain largely unaffected across much of the Subdivision. Restrictions to these flows are much more evident in areas adjacent to the Ravi River (Figure 7(g)) where the highly suitable Sultanpur silt loams are much favored for growing rice. The bunded regime in these areas is a major impediment to the surface runoff. Additional restriction occurs because of the extensive presence of the moderately fine textures of the Chuharkana soil series in an exclusively saline-alkali mix of the Satghara/Miani waterlogged conditions that are highly impervious to vertical drainage.

*IIMI Sampling for Soil Salinity and Texture*: The twelve sample areas spread over 13574 ha of the Haveli Subdivision were confined to the eastern and southern halves of the system in the commands of the Ghag, Darkhana, Khikhi and Koranga channels. The moderately fine to fine soil textures in these areas are highly affected by salinity/sodicity, the corroborating evidence for which is provided by IIMI's field survey wherein nearly 38% of the 958 paired EM 38 observations are classed to be variantly saline. From Figure B6, Volume Four, the wide diversity in textures of the non-saline category is replaced by succeedingly fewer constitutions within the moderately coarse to fine soil groupings. The finer textures prevail in higher levels of salinity; however, the most extreme incidence of soil degradation comprises the coarser sandy loams/fine sandy loams in the head reach command of the Ghag Distributary and the Saralla Minor command of the Darkhana Distributary. The SSoP identifies these sample area soil types to be the Sodhra and Shahdara Non-flooded for the Ghag Distributary and overwhelmingly Miani waterlogged for the Saralla command.

In terms of land use, almost all of the fields that were cultivated with rice and sugarcane were non-saline (Figure C6, Volume Four); somewhat surprisingly, the number of rice fields in the moderately coarse sandy loam were about the same as for the preferred fine soils of

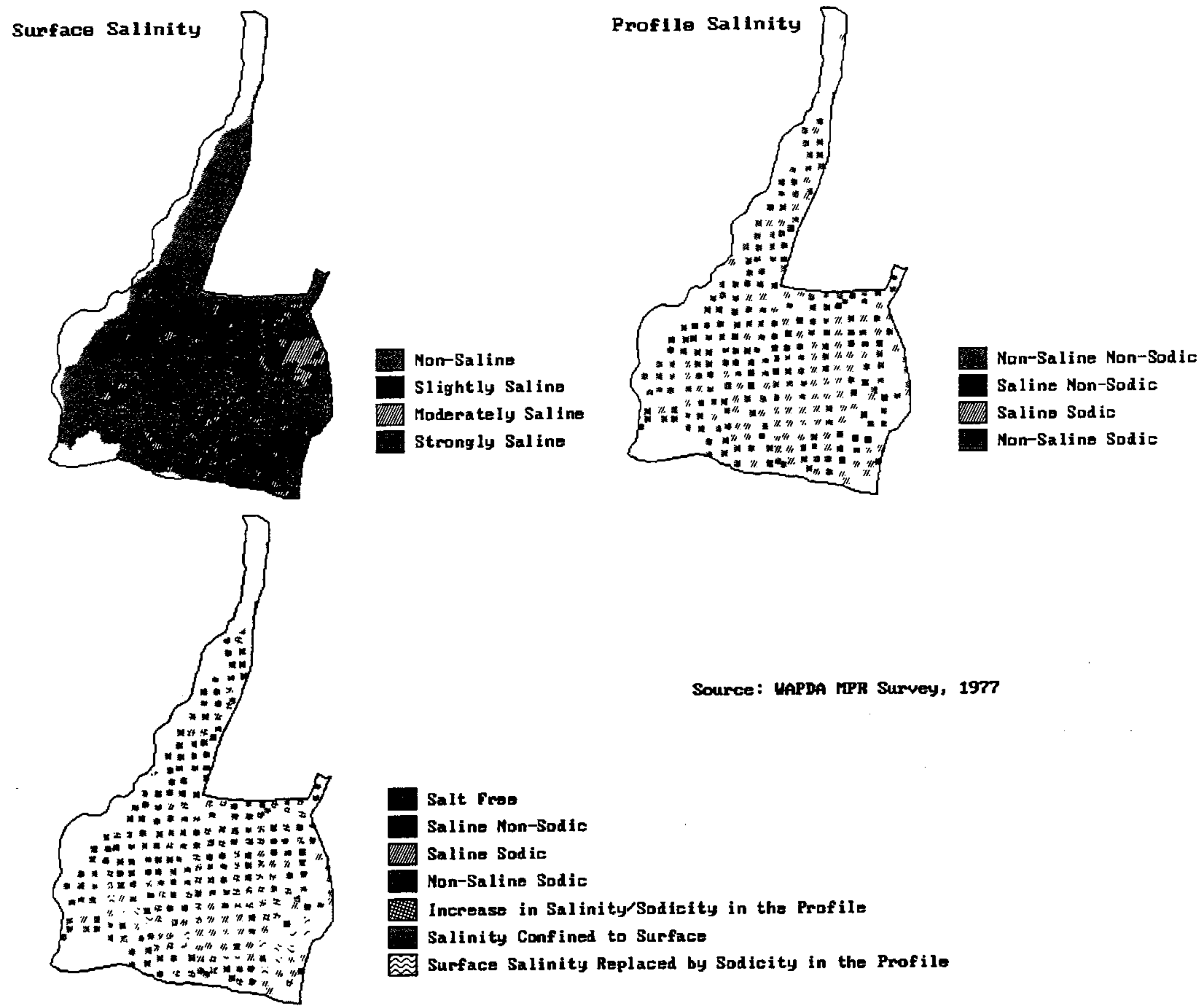



Figure 7(e) Surface and Profile Salinity in the Haveli Irrigation Subdivision Rechna Doab, Punjab, Pakistan.

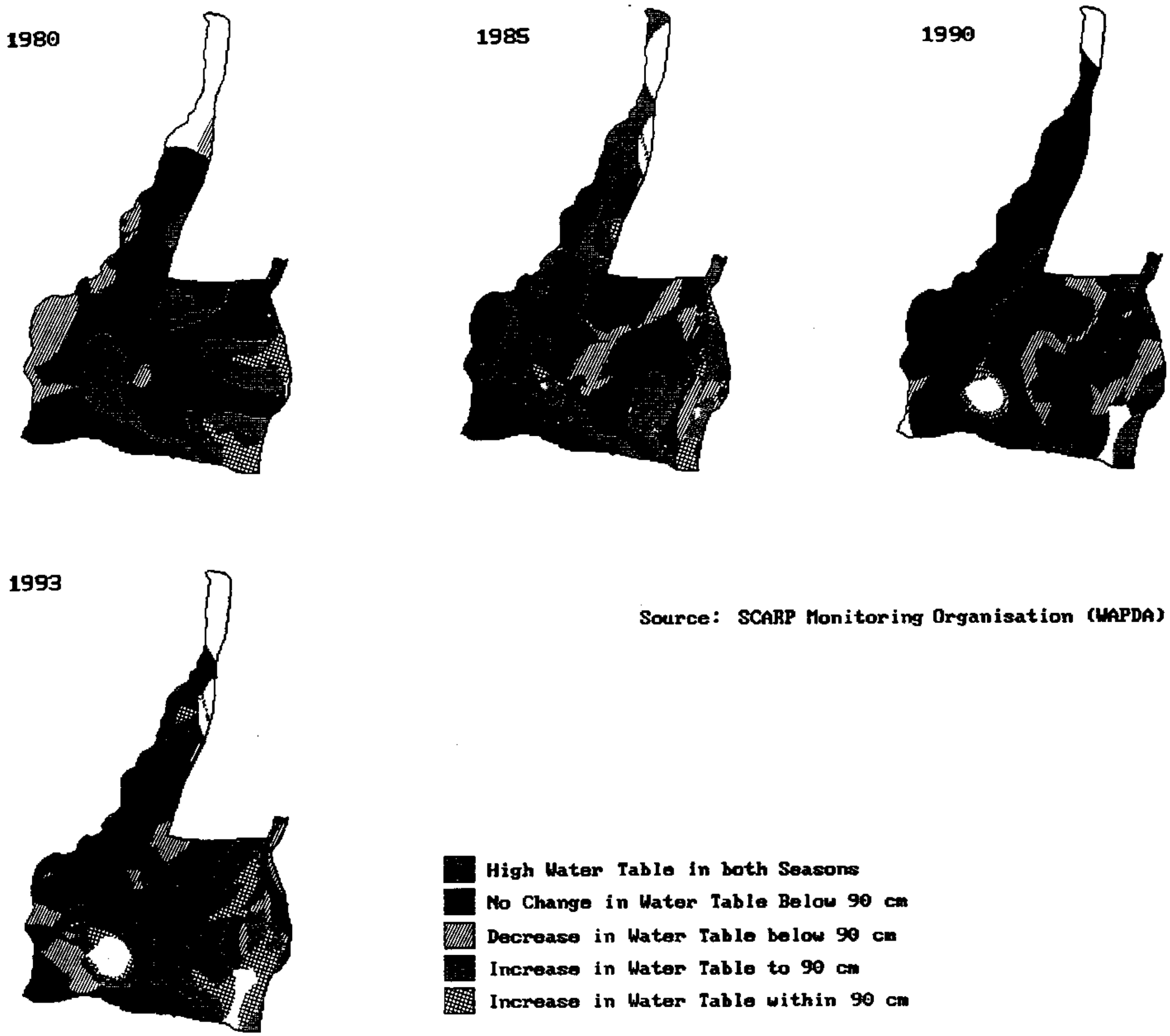



Figure 7(f) Temporal Variations in the Depth to Water Table, Haveli Irrigation Subdivision, Rechna Doab, Punjab, Pakistan.

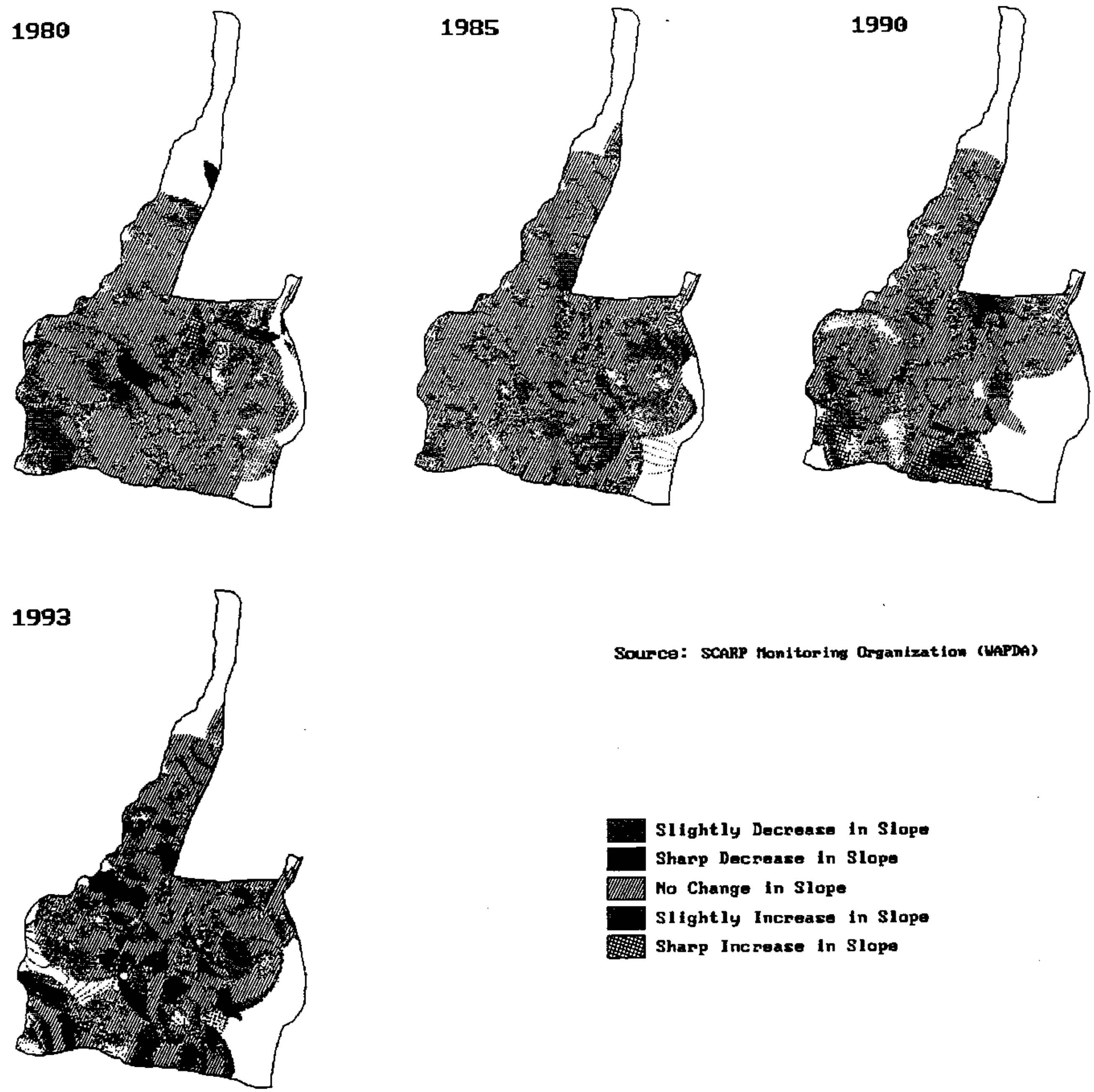



Figure 7(g) Interseasonal Slope Variations in the Subsurface Flows, Haveli Irrigation Subdivision, Rechna Doab, Punjab, Pakistan.

clay/sandy clay. For sugarcane, the preference was clearly in favor of the fine soils. In comparison to these higher consumptive use crops, fields that were ploughed or grown with fodder were noticeably coarser in texture. Cotton cultivation was observed across all levels of salinity, however, the maximum variation in texture was accounted for by the overwhelmingly non-saline category. Here again, like rice, its cultivation was contrasted in between the near extremes of predominantly moderately coarse loams/sandy loams versus the fine clays/sandy clays, despite the fact that the latter category of textures are not recommended for its growth. Finally, unlike the rather broad dispensation of salinity classes in the barren lands category across the other subdivisions, the constitution of such lands within Haveli is totally saline (categories S3 & S4). The general inference would be that areas remaining out of active cultivation, even if at the boundaries of the productive tracts, are susceptible to progressive salt accumulation in their root zone without the differentiation of the soil type and texture.

*IIMI Farm Level Sampling*: Given the rather widespread levels of soil salinization in this Subdivision, the overall land use intensity remains one of the lowest (Table H1, Volume Four). Resultantly, about 29% of the farm land is reported to be a culturable waste. When not accounting for this culturable waste, the overall cropping intensities, including those of the major crops, compare with the qualitatively much more productive subdivisions like the Chuharkana. Another reason for these high intensities is the relatively fewer number of farmers citing scarcity of surface irrigation supplies in an environment where nearly two-thirds of the farmers reported useable groundwater quality for supplemental irrigation purposes.

The major crop intensities, based on the gross cropped area, for the neighboring Haveli and Dhaular Subdivision are very close; both of them are primarily wheat growing areas with nearly equal intensities of wheat and rice. However, the increased preference for cotton in the Haveli is matched in equal measure for the higher intensities of the sugarcane in the Dhaular. The reason for this discrepancy is not readily evident given the same mix of the most suitable soils of Sultanpur and Shahdara associations across both the subdivisions. This discrepancy is not supported even by the gross macro economic indicators (Figure H8, Volume Four) where higher returns are indicated to favor Dhaular rather than the Haveli Subdivision. The same farm level macro economic indicators for the wheat crop show Haveli to have one of the lowest returns in comparison to the other subdivisions; this is despite the fact that the expenditure on fertilizer inputs remain high.

The above comparisons for the lower agricultural returns from the Haveli Subdivision are especially reinforced for the rice crop wherein, despite equivalent intensity levels, there is a yawning gap in favor of the Dhaular Subdivision with respect to the gross incomes, yields and profits that are exceptionally high.

## G. Kanya Subdivision

*Hydrologic Regime*: Kanya is the second smallest subdivision after Sangla in terms of gross area (77,473 ha). Its fifteen secondary level distribution channels (Figure 8(a)), sourced by the Burala Branch, cover a total of 302 watercourses for an average commanded area of 186 ha. The total relief difference from head to the tail is of 19 meters, but the slopes are much steeper in the lower reaches of the system (0.0006) in comparison to the upstream average of 0.0002. The eastern half is largely irrigated by the Kajwani Branch offtaking from the Burala in the head reach of the system. Areas to the west of the Burala are covered by several distributaries and minors that run parallel to the main Branch. For the 56114 ha of the commanded regime, the calculated water duty based on the cumulative flows remains less than the maximums observed elsewhere (Figure 1(b)). Assuming that these channels have been operating at 10-15% above the stipulated allocations, the actuals may serve to narrow such discrepancies amongst the subdivisions. The calculated deficit in surface allocations for the Kanya Subdivision, based on the maximums observed for the Tandlianwala and Wer subdivisions, is about 2.1 cumecs. Given the expected improvements of 25% or more in the allocations along the distribution system following desiltation of the irrigation channels, such as in the Lagar Distributary in 1989 (see Figures 56(a) & 57, Volume Two), it would be possible to accomodate the 2.1 cumecs increase to the existing 13.046 cumecs design capacity of the distribution system within Kanya without resorting to remodelling or extension of the secondary level network. In fact, given the assumption that the actuals are already 10-15% over the design, this targeted increase of 2.1 cumecs may well have been achieved under normal operation of the system. This is partially confirmed by the current levels of cropping intensities that are at par with those in the highly productive Chuharkana Subdivision (Figure 1(d)).

*Soils*: The earliest surveys by WASID in the early 1960s show soils in the Kanya Subdivision to largely comprise the moderately coarse fractions of the Farida series (Figure 8(b)). Interspersed within this series is the distribution of the medium textured Buchiana soils in the head reaches and the coarse Jhang soils in the middle and tail portions of the system. Considering also the overwhelming distribution of the coarse to mederately coarse fractions in the top soil, the general conclusion about the stratum-wise differentiations are likely to remain in favor of deeply homogeneous profiles. The presence of the Buchiana soils in the head reaches may partly be related to the rather low values of the sloping relief favoring deposition of finer materials. The slopes increase by nearly three orders of magnitude towards the middle and lower reaches of the system where the sandy strata is most prolific.

The SSoP interpretations exhibit an even greater uniformity in the soil textures wherein the medium textures of the Faisalabad silt loams are shown to dominate the entire Subdivision (Figure 8(c)). While this would contrast with the moderately coarse textures mapped by the WASID in their earlier surveys, the mismatch shown here (between the fine sandy loams of the Farida series and the silt loams of the Faisalabad association) is probably the best example of the difference in interpretations between two public sector organizations. In any case, there is little doubt that the stratum is comprised of highly porous soils.

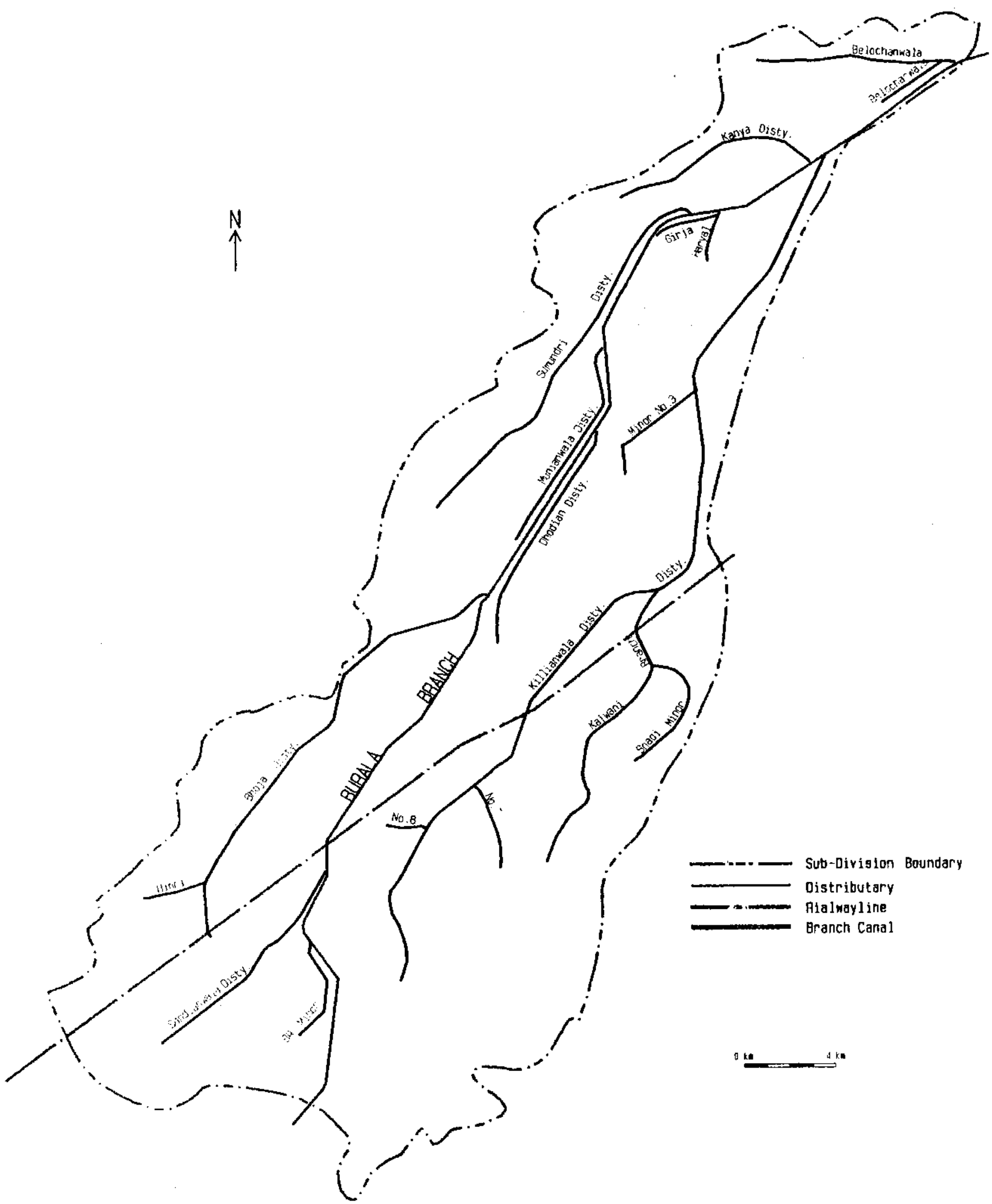
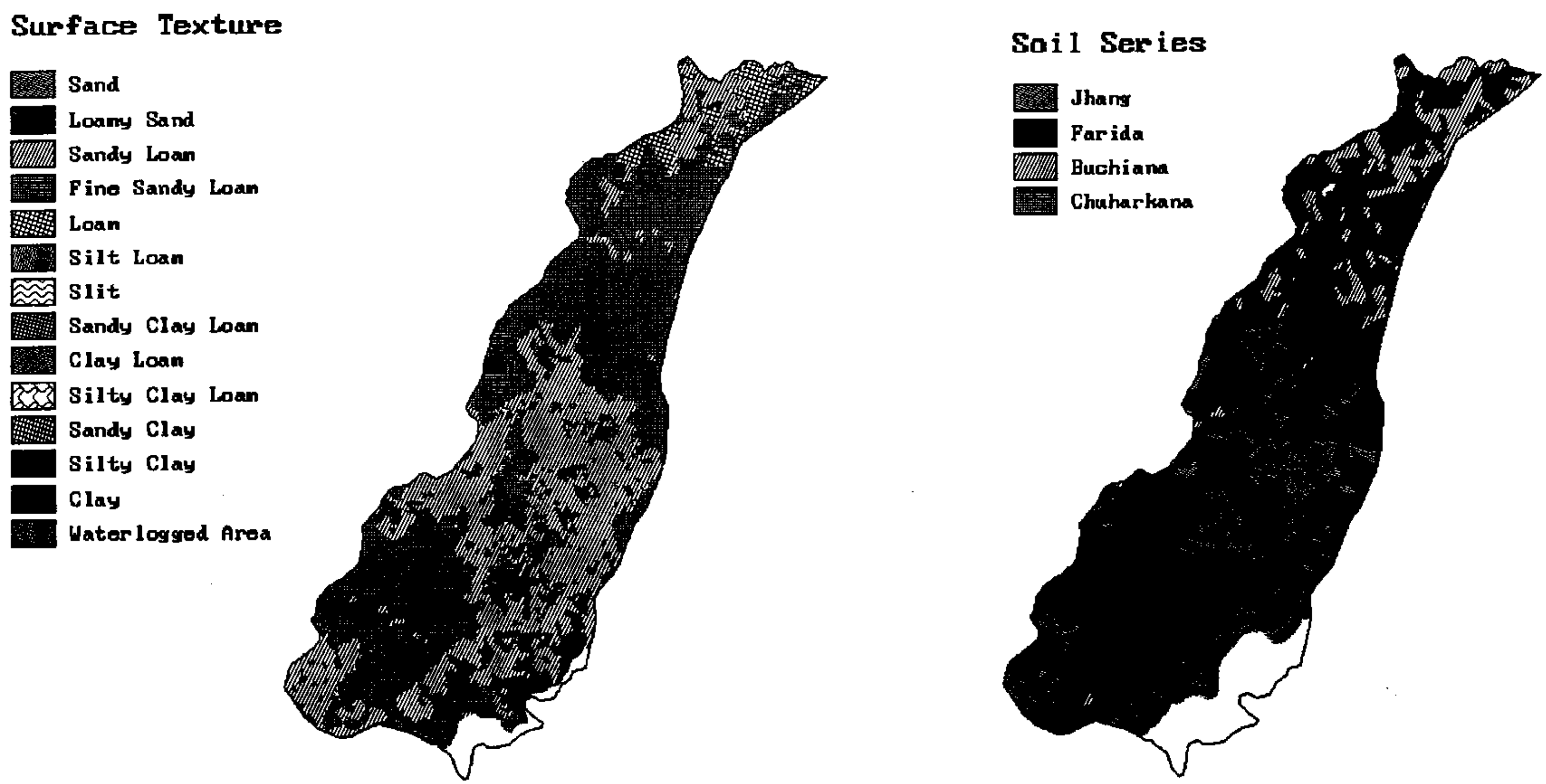



Figure 8(a) Kanya Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan




Source: SCARP Monitoring Organization (WAPDA)

Figure 8(b) Surface and Profile Texture of the Soils in the Kanya Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

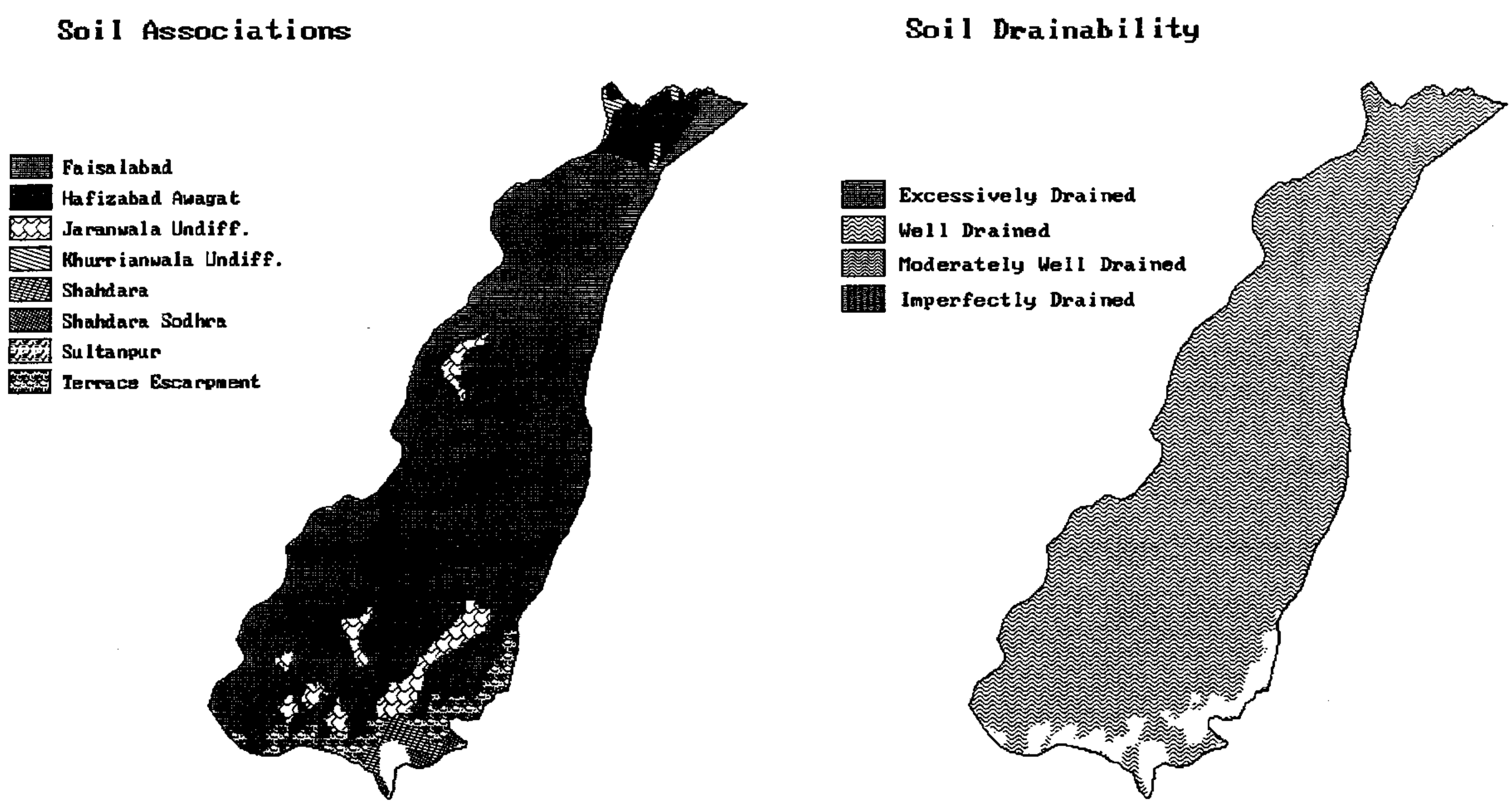



Figure 8(c) Associative Classification of the Soils and their Drainability Characteristics the Kanya Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

*Soil Drainability and Crop Suitability*: Figure 8(c) above also shows the status of vertical drainage in the Kanya Subdivision. This interpretation is based on the medium textured Faisalabad silt loams that are considered to be well drained soils. It is more likely that these soils are coarser in the profile in comparison to the surface and, hence, the actual drainability may be somewhat higher. These conditions, though quite unsuitable towards the cultivation of the high delta crops like rice, would be adequately permissive towards the other major crops like cotton, wheat and sugarcane (Figure 8(d)).

*Soil Salinity and Waterlogging*: From Figure 8(e), there is very little evidence of soils being strongly salinized in the surface; the moderate to slight levels of salinization are clustered mostly in the head reaches of the system where there is an exclusive concentration of the medium textured Buchiana soils. This spatial pattern of distribution of salinity is highly supportive of the situation presented in Figure 8(b) and the conventional wisdom wherein salts are less likely to accumulate across the deep porous profiles prevailing in most of the Subdivision. Thus, evidence pertaining to higher concentration of salts in the root zone, such as in the WAPDA profile sampling shown in Figure 8(e), should conform to the distribution pattern of the Buchiana loams/silt loams within Kanya. This logic is adequately satisfied by the spatial overlap of the saline-sodic profiles with the medium textured horizons common to the Buchiana soils. This salinization of the root zone is partly traceable to the restrictions in drainage caused by high water tables observed in these areas (Figure 8(f)).

*IIMI Sampling for Soil Salinity and Texture*: The nine IIMI sample sites, totalling nearly 8,000 ha, were all limited to the head reaches of the Subdivision. This bias was largely to accomodate the observed diversity in the soils and the levels of salinity already cited in the discussions above. Out of the 792 recorded observations of soil salinity, about 79% were processed to be non-saline. These non-saline observations overwhelmingly belong to the medium textures of the loam and silt loam, and this trend continues across higher levels of salinity in a manner wherein these textures become exclusive to the highest recorded levels of soil salinization (Figure B7, Volume Four). This dominance also prevails across all levels of major landuse (Figure C7, Volume Four), and more particularly for the cultivations of the cotton and sugarcane crops that are beneficiaries of a near singular reliance on this textural combination. This reckoning may be extended to the cultivation of the wheat crop when accounting for the land preparation under the ploughed category.

Note: Due to the inadequate sampling of the farmholdings in the Kanya Subdivision, there is insufficient data to support a substantial discussion.

## H. Kot Khuda Yar Subdivision

*Hydrologic Regime*: Located in the head reach command of the Jhang Branch that passes through its center (Figure 9(a)), Kot Khuda Yar Subdivision has a gross area of 81,250 ha of which only 63% is canal commanded, a fraction that is the lowest in the entire LCC system. With over four hundred tertiary level irrigation units in this rather small CCA, the

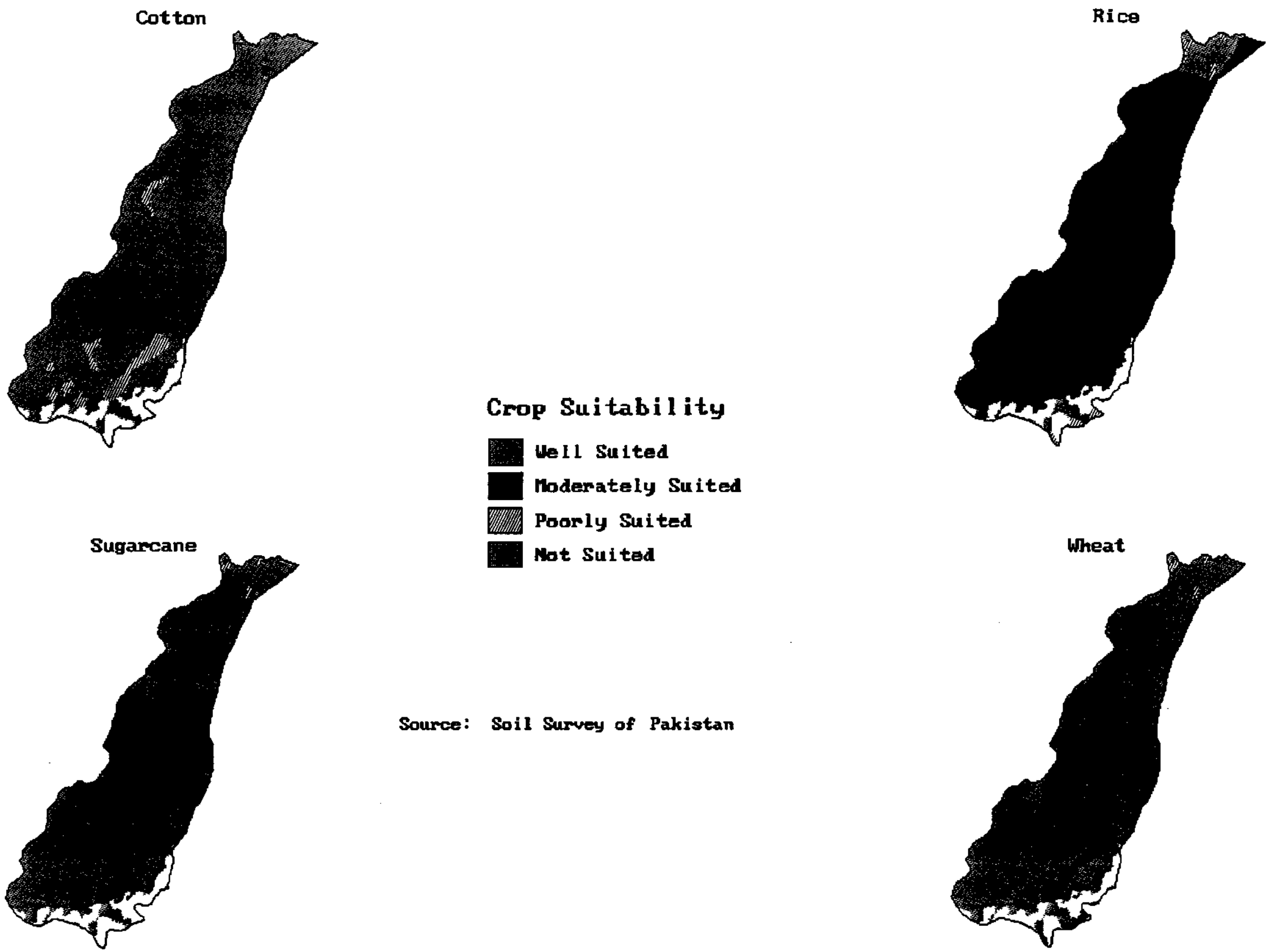



Figure 8(d) Soil Suitability for Major Crops in the Kanya Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

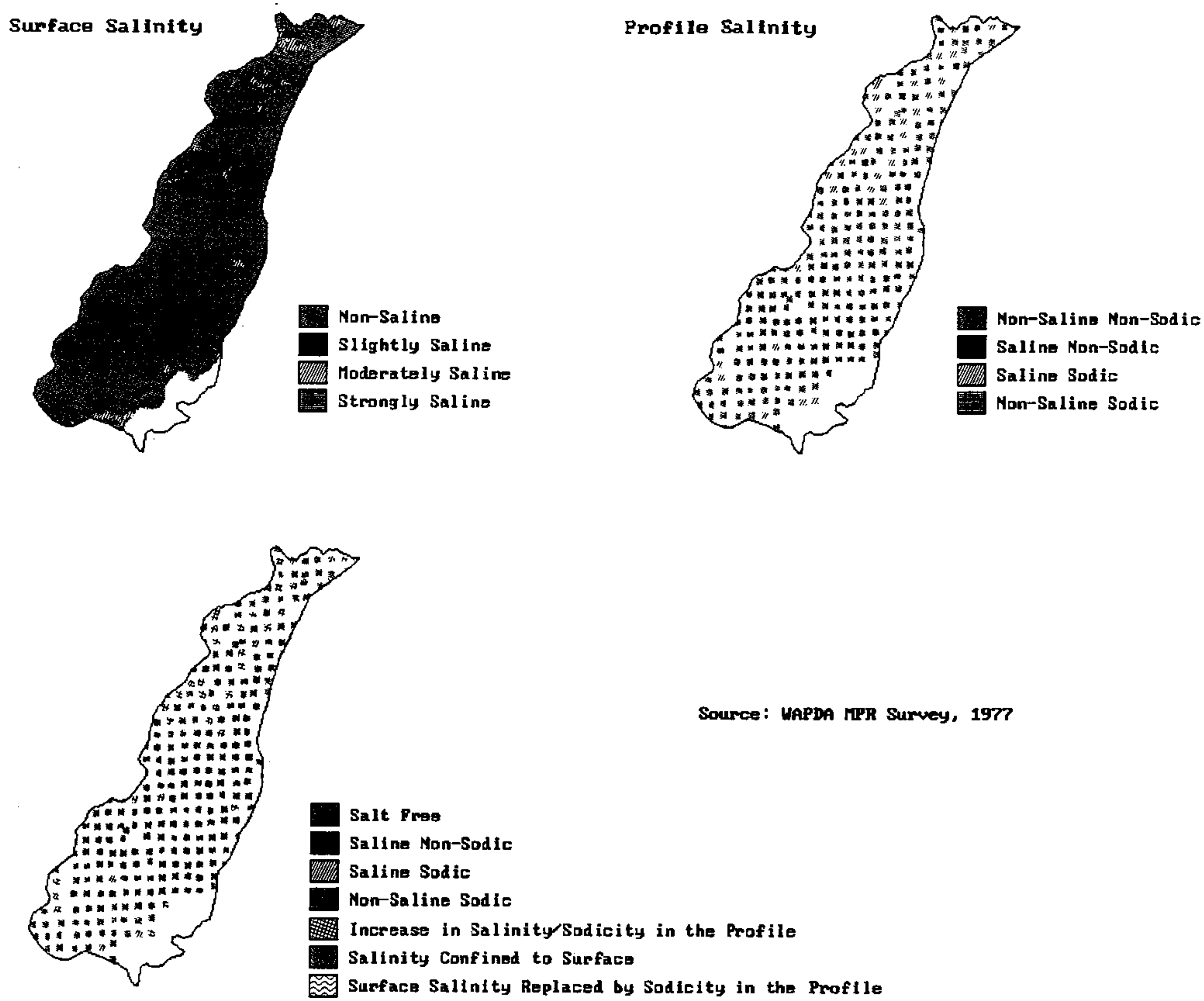
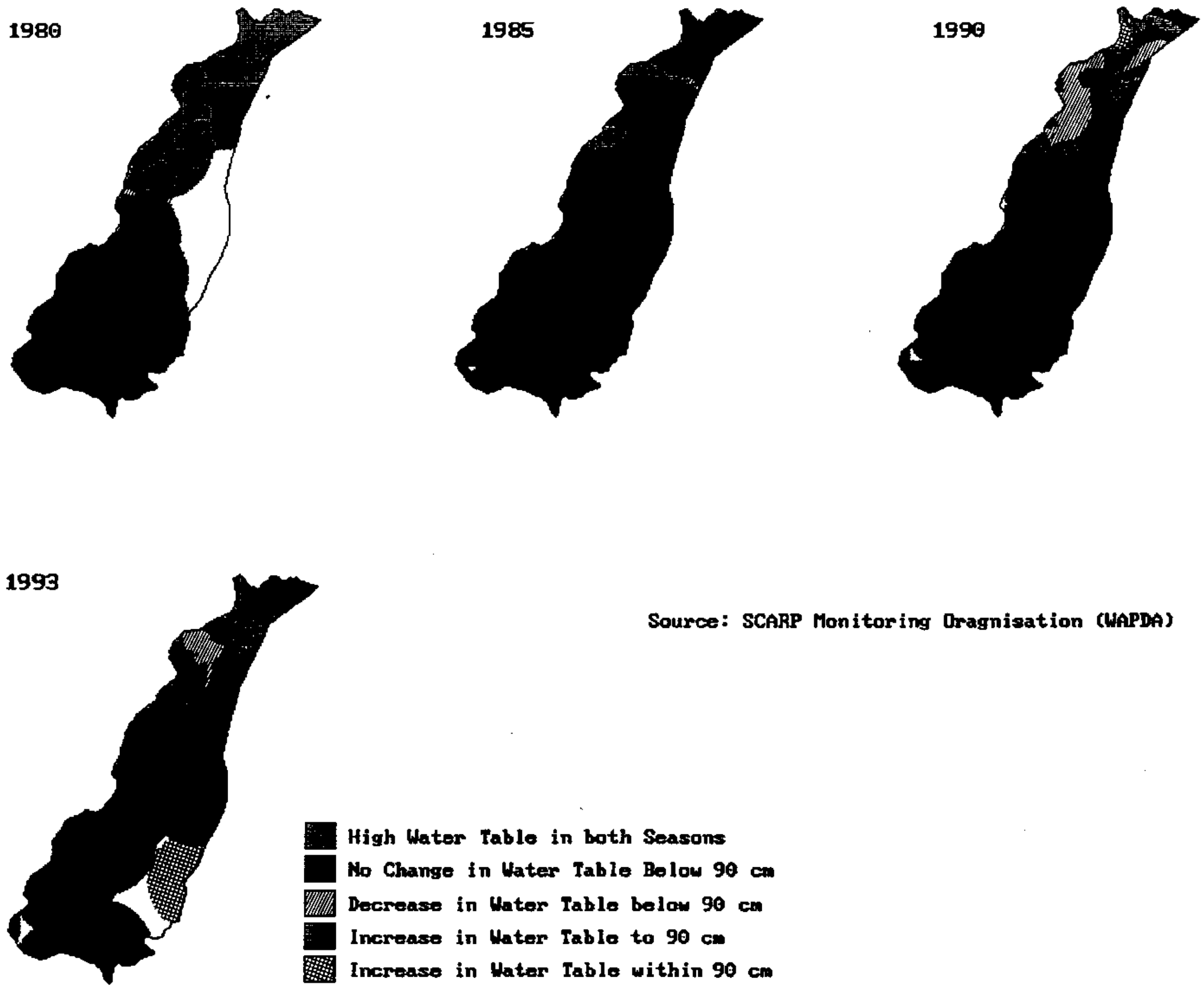



Figure 8(e) Surface and Profile Salinity in the Kanya Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Oragnisation (WAPDA)

Figure 8([illegible]) Temporal Variations in the Depth to Water Table, Kanya Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

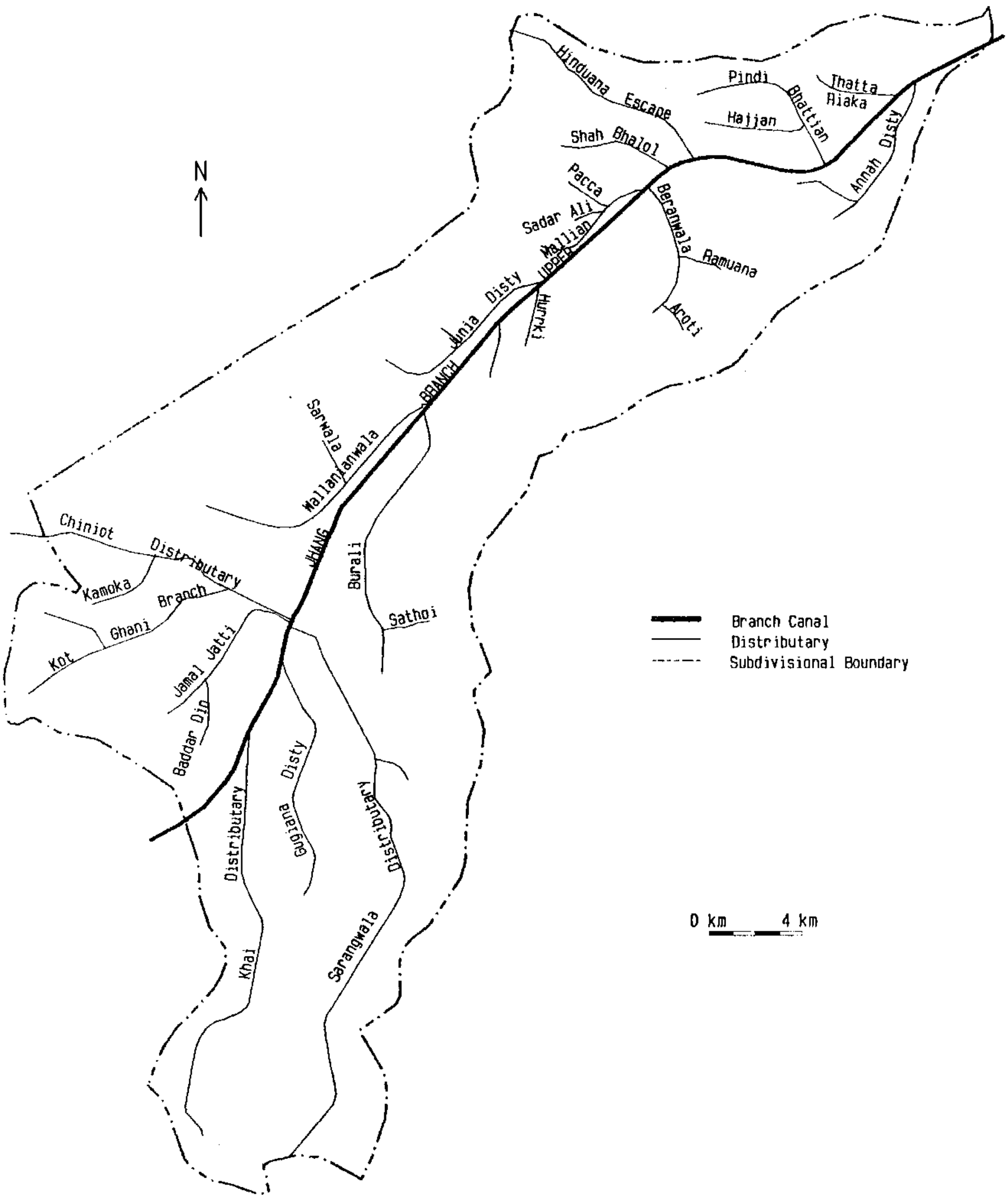
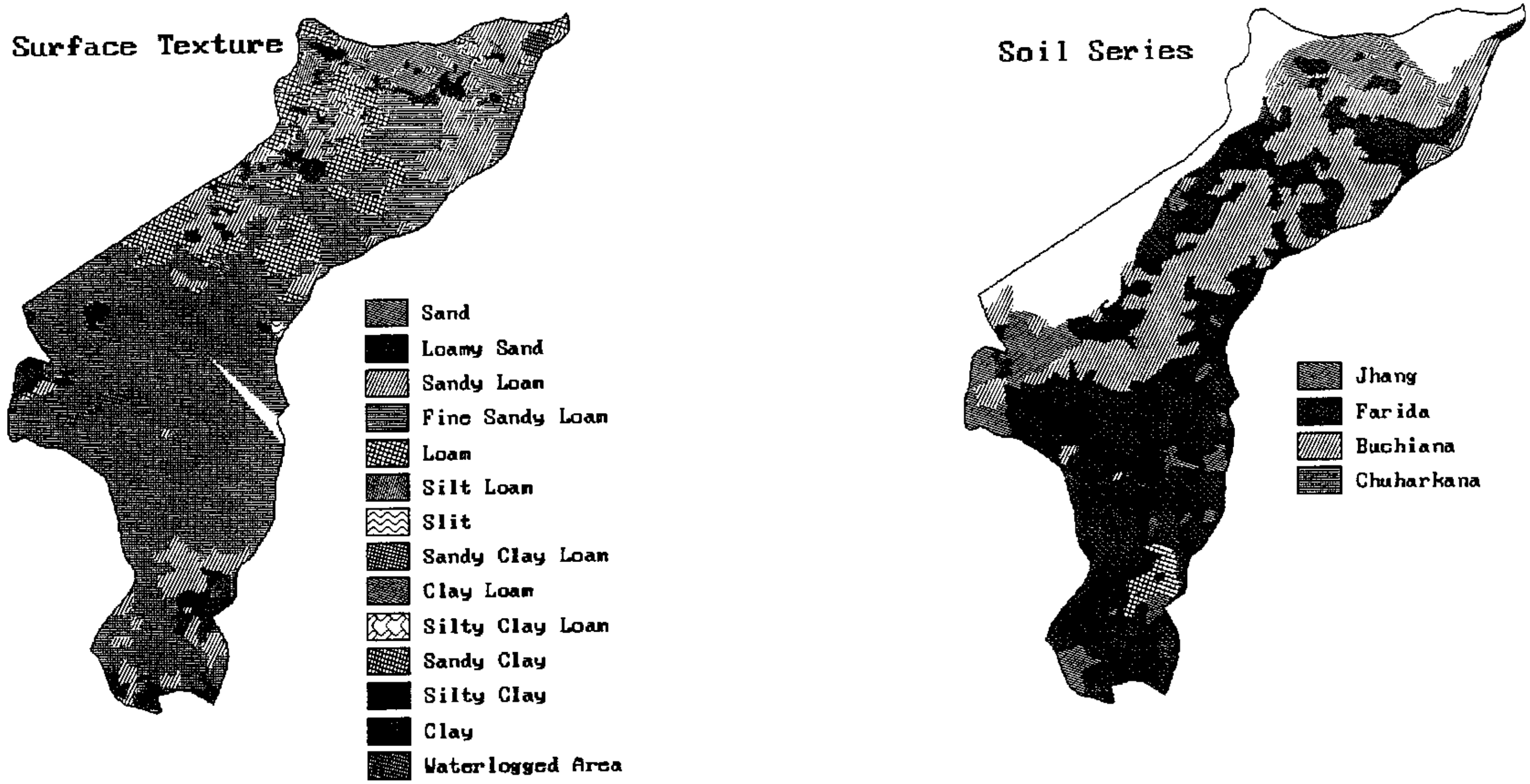



Figure 9(a) Kot Khuda Yar Irrigation Subdivision in the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

average of 126 ha per watercourse is also the lowest within the system. In many ways, its limited irrigated extents allow it the advantage of having higher water allowances across a well distributed network. This can be ascertained from a comparison with the neighboring Pacca Dala Subdivision with analogous figures on the gross area and the length of the distribution network. The benefits of the nearly 20,000 ha of extra commanded area within the Pacca Dala Subdivision are not readily translated to equivalent gains in the system allowances and proportionate increases in the density of the distribution system. From Figure 1(b), Kot Khuda Yar is one of the three subdivisions within the LCC and Haveli command where the surface water allocations are the highest (0.27 cumecs/1000 ha CCA). If the 15% higher than design operating flows are assumed for this network, then this system may already be drawing water at an allowance rating of 0.31 cumecs/1000 ha CCA or an equivalent of 4.42 cusecs/1000 acres CCA. It is no surpirse then that this Subdivision retains cultivated area cropping intensities of around 130%, which is an above average figure for the Rechna Doab.

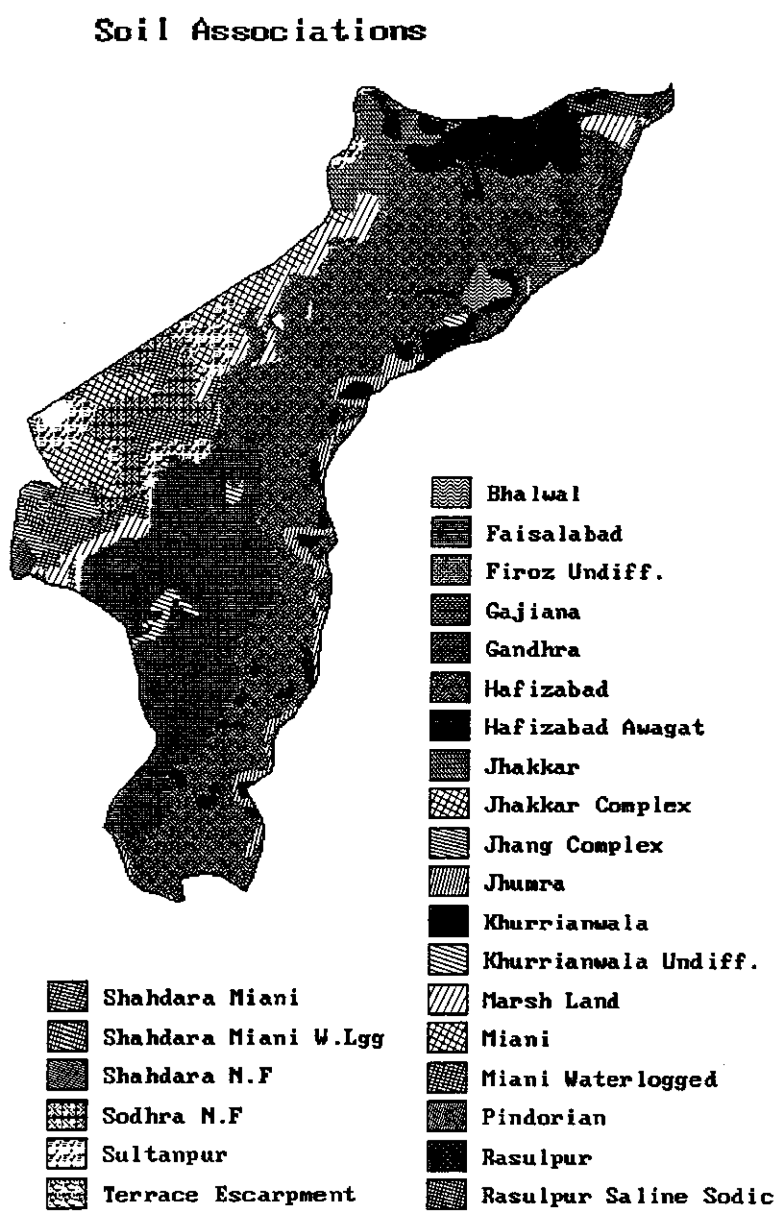
*Soils*: The topography within the Kot Khuda Yar Subdivision is bidirectional; against a relief difference of about 19 meters in the upper half of the Subdivision, the slopes are much sharper (0.0004) and directed towards the river Chenab to the west. The relief in the lower reaches of the system has an average value of about 0.00025 and is sloping towards the city of Faisalabad to the southeast. Wherever there are abrupt changes in the relief, like along the Hinduana Escape in the head reach and the Chiniot Distributary command comprising the extreme western edge close to the Chenab River, there are large pockets of the coarser Jhang series soils (Figure 9(b)). Elsewhere, the finer deposits of the Buchiana soils conform to the meanders of the topographic slopes but remain limited only to the upper half of the system. The soils in the lower reaches comprise the uniform expanse of the moderately coarse Farida series that are occassionally interrupted by the still coarser fractions of the Jhang. The homogeneity in the strata is highly dependent on the topographic variations; the Jhang and Farida series profiles are much more correlated in space with the surface textures than the medium Buchiana loams/silt loams. For the medium soils, this homogeneity is more apparent where the surface slopes are noticeably low, e.g. along the western boundary and the course of the main Jhang Branch.

The mapped delimitation of the Faisalabad and Hafizabad loams/silt loams by the SSoP as the dominant texture within the Kot Khuda Yar Subdivision overlaps the fine sandy loam/Farida soil interpretations by the WASID (Figure 9(c)). While the nature of this offset in the soil textures defined by the SSoP and WASID is quite universal across the Rechna Doab, other more conforming interpretations are also evident, such as the distribution of the coarse sandy profiles of the Jhang series that are coincident with the Jhang Complex and Sodhra Non-flooded associations. The spatial pattern of soil distribution is much more complex along the boundary with the Chenab River where the Sultanpur silt loams intersperse with the Shahdara Miani, Miani and Shahdara Non-flooded associations to form a continuous belt. The incidence of saline-alkali soils is exclusive to the eastern and western fringes of the Subdivision as distinct pockets of Khurrianwala, Jhakkar, Jhakkar Complex and Jhumra associations.




Source: SCARP Monitoring Organization (WAPDA)

Figure 9(b) Surface and Profile Texture of the Soils in the Kot Khuda Yar Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.



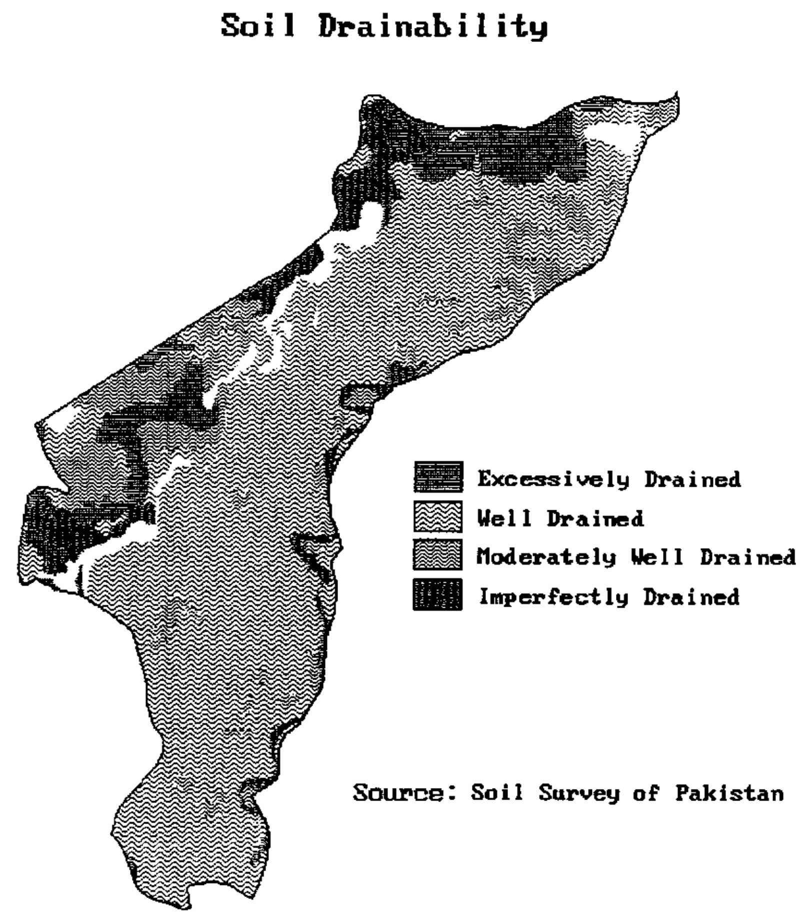




Figure 9(c) Associative Classification of the Soils and their Drainability Characteristics the Kot Khuda Yar Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

*Soil Drainability and Crop Suitability*: From Figure 9(c) above, the overwhelming proportion of the medium textured soils within the Subdivision allow for well-drained conditions in the profile. The moderately fine textures of the Gandhra (porous saline-alkali), Pindorian and Miani soils are scattered along the fringes of the Subdivision; their proximity to the otherwise strongly saline-alkali soils results in conditions that are restricted in vertical drainage. Hence, cultivation of rice in contiguous stretches is only favorable in areas close to the boundary with the Chenab River (Figure 9(d)). For the other major crops of cotton, wheat and sugarcane, this Subdivision has one of the best soil conditions across the LCC system.

*Soil salinity and Waterlogging*: The distribution of the imperfect drainage conditions shown under Figure 9(c) above is entirely due to the occurrence of the saline alkali/waterlogged soils. These locations, originally surveyed between 1965-67, have high spatial correlation with the subsequent investigations by WAPDA in the 1976-79 period (Figure 9(e)). The surface salinization mostly conforms to the S3 & S4 categories of classification, whereas in the profile, they are more non-saline sodic in the head reaches. Elsewhere, the soils have a large scatter of saline to saline-sodic profiles. The distributaries that are less affected include Burali, Sarangwala, Hurrki, Mallian and Shah Bhalol, whereas the worst affectation is in the commands of the Annah, Pindi Bhattian, Jamal Jatti, Chiniot and Khai distributaries.

Thematic data on interseasonal variations in water tables indicates a higher incidence of root zone affectation in the head reaches of the system (Figure 9(f)). This pattern persists across the entire period of comparison between 1980-93, the worst year being 1985 when the water levels stayed just below the root zone throughout much of the Subdivision. This behavior is explained more readily by the sequence of variations in subsurafce slopes shown in Figure 9(g). Much of the repeated bottleneck in subsurface flows occurs in the regime that straddles across the Jhang Branch at a point that is about one-third its initial traverse through the Subdivision. From 1990 onwards, this phenomenon is also noticeable in distinct pockets within the middle and tail reaches of the system but its significanace, in the context of the root zone, is limited to the middle reaches of the Sarangwala Distributary command.

*IIMI Sampling for Soil Salinity and Texture*: The eleven sample sites, comprising 7658 ha gross, were limited to the lower half of the Subdivision. The 1325 paired observations of apparent soil salinity, upon conversion to the saturation extract equivalents, showed more than 93% of the cultivated lands to be non-saline. In fact, the incidence of salinization was limited only to the S2 category. From Figure B8, Volume Four, these saline observations were nearly synonymous with the moderately fine textures of sandy/silty clay loams. Together with the fine textured silty clays, their composition within the non-saline S1 category was also observed to be the highest in comparison to the moderately coarse and medium textures. This rather large sample of the finer soils, not observed in the other Subdivisions, has some interesting results when considered in the context of the land use shown in Figure C8, Volume Four. The ploughed land, presumably being prepared for the rabi cultivation of wheat, had nearly equal distribution of the loams/silt loams/sandy loam

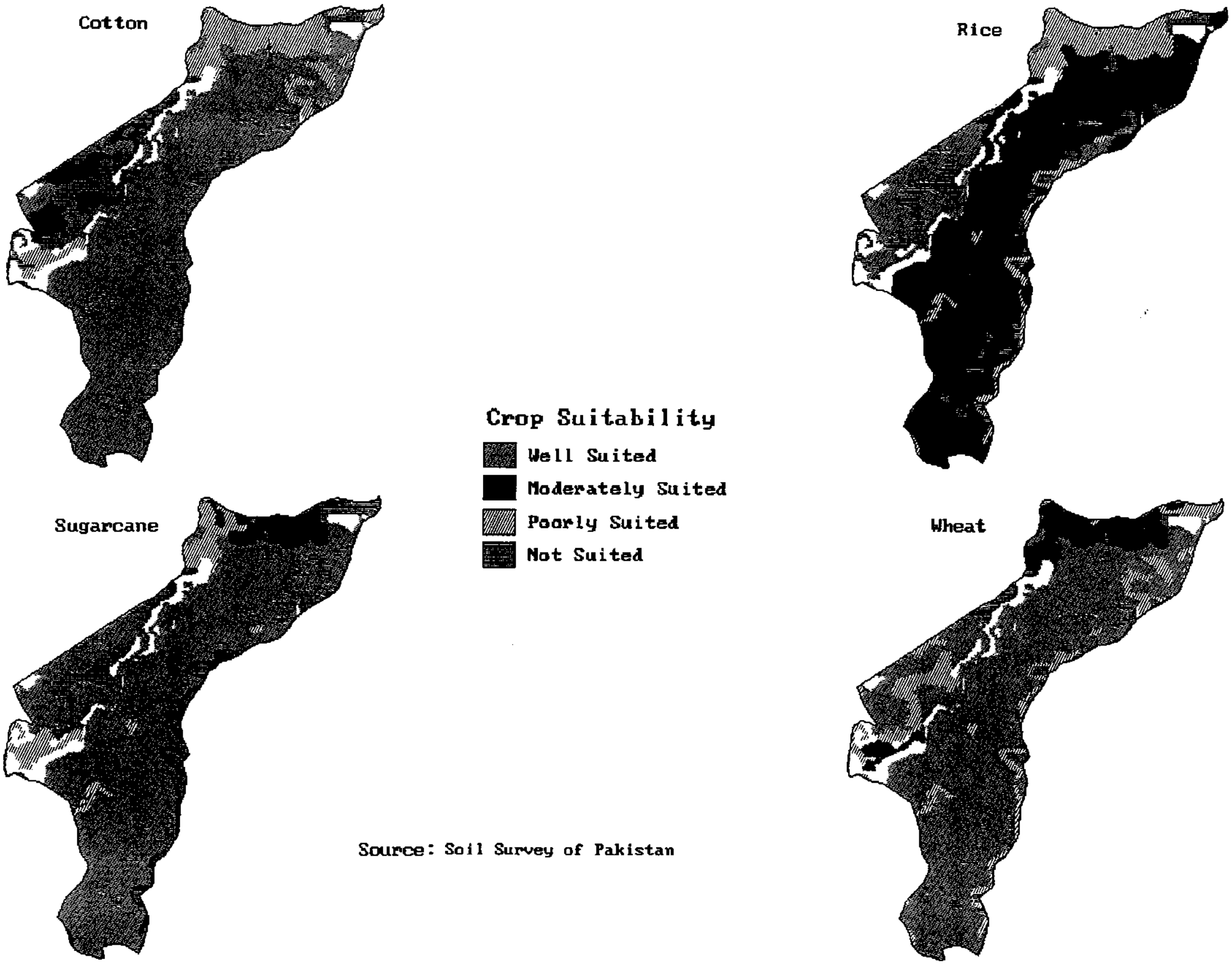



Figure 9(d) Soil Suitability for Major Crops in the Kot Khuda Yar Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

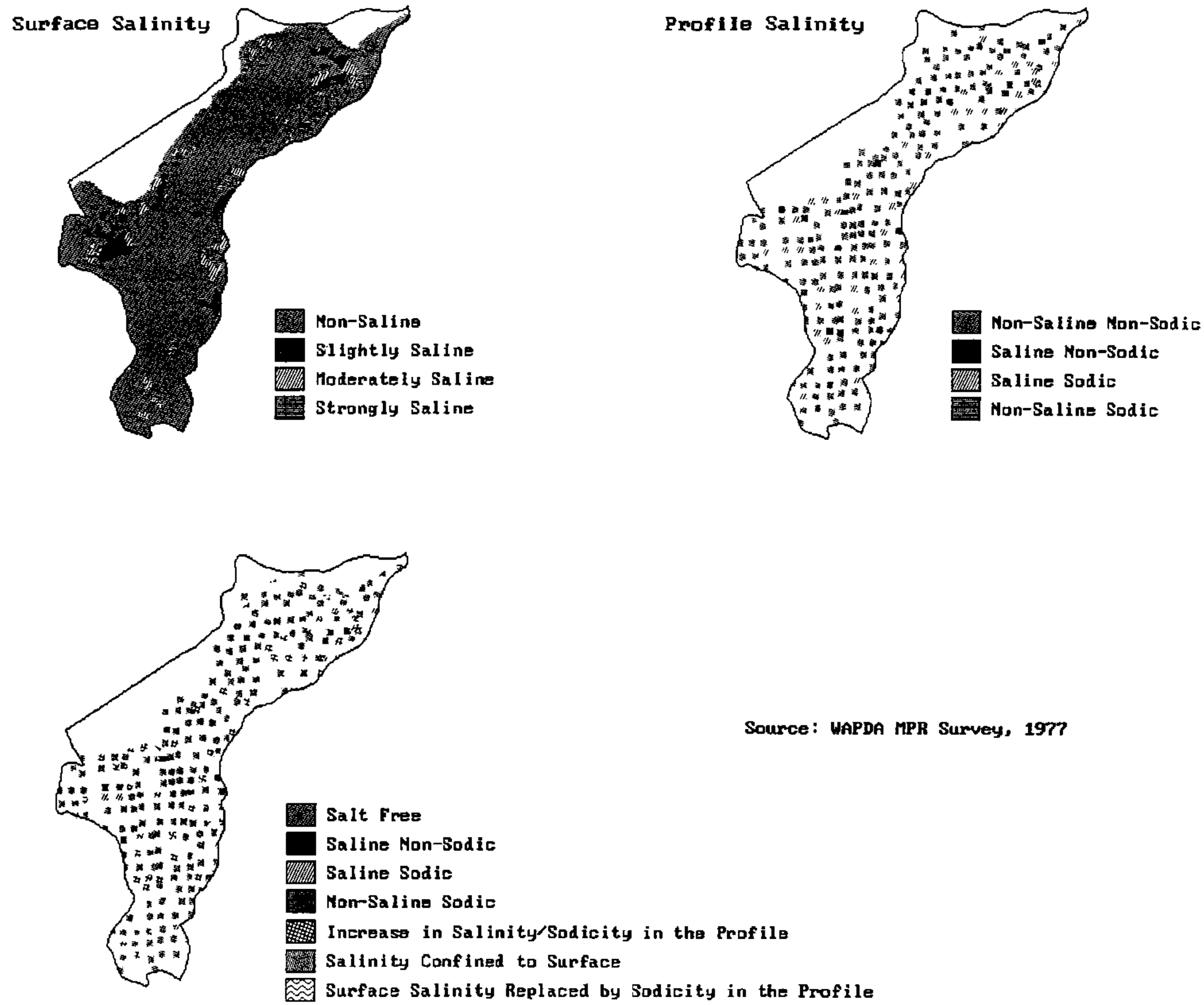
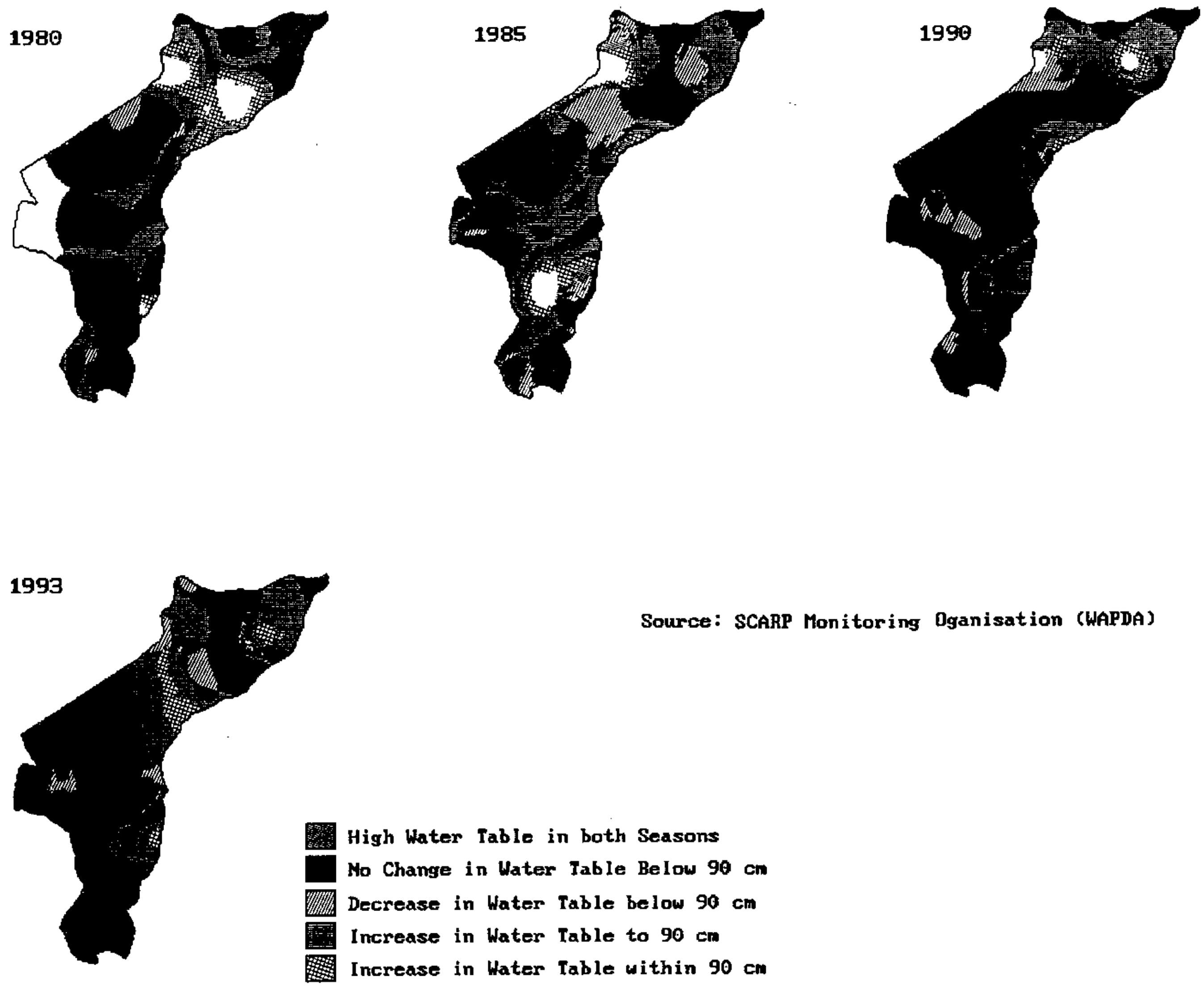
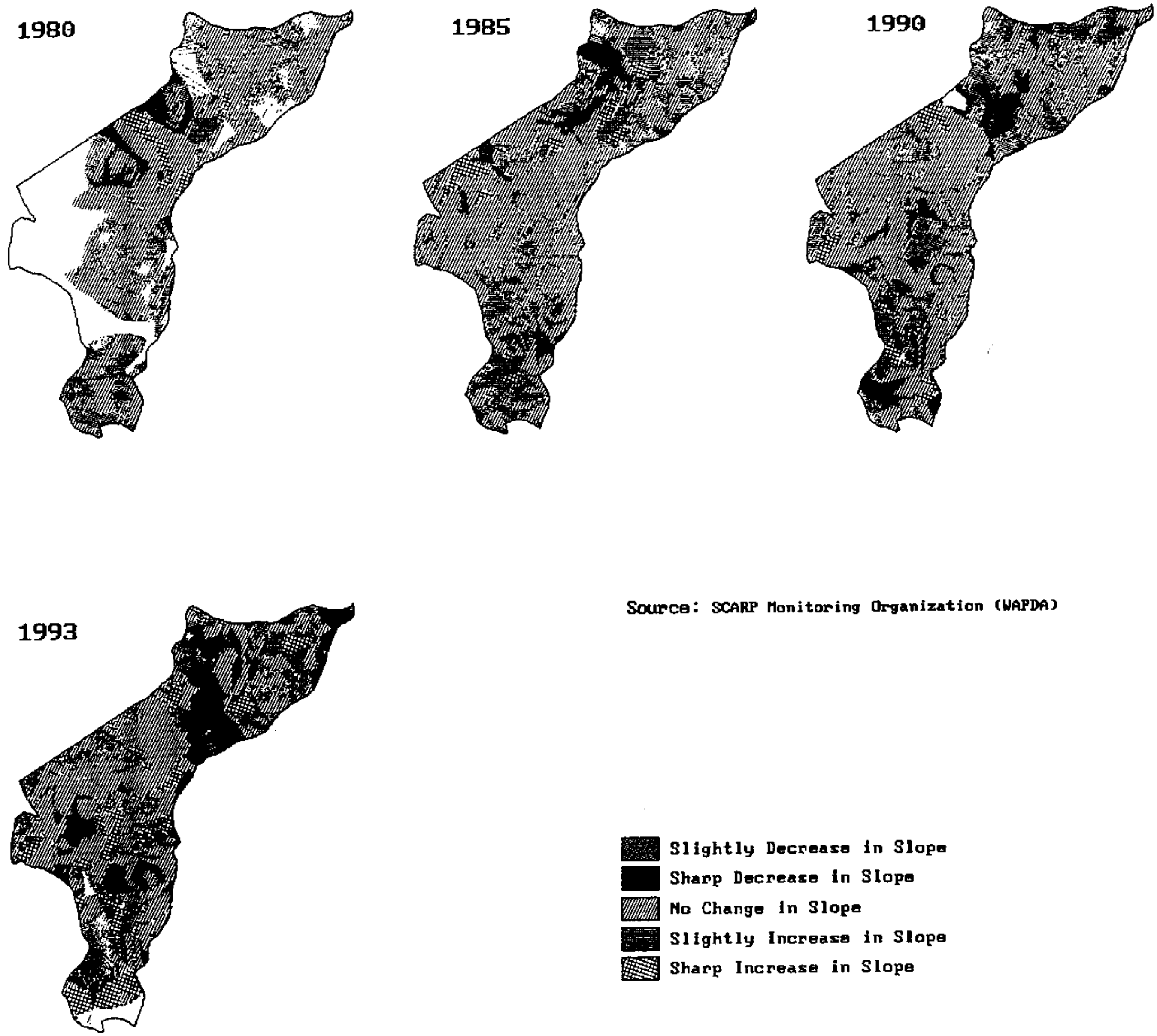



Figure 9(e) Surface and Profile Salinity in the Kot Khuda Yar Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Oganisation (WAPDA)

Figure 9(f) Temporal Variations in the Depth to Water Table, Kot Khuda Yar Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 9(g) Interseasonal Slope Variations in the Subsurface Flows, Kot Khuda Yar Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

soils with the moderatley fine to fine textures. Cotton cultivation, on the other hand, was observed to be overwhelmingly on the moderately coarse to medium textures. The emphasis towards the finer textures was much more obvious for the rice crop than sugarcane; the reason being that despite being a high delta crop, sugarcane is much more adapted to the coarser loams given the overall less consumptive use. The few saline observations of the S2 category mentioned above were confined to the fodder cultivation where its significance in terms of any perceived crop damage remains mute.

*IIMI Farm Level Sampling*: The twenty-five sample farms in the Kot Khuda Yar Subdivision reported above average land use and cropping intensities (for the cultivated areas). These values are less than in the neighboring Pacca Dala, and probably also less than Sangla which lies even nearer. In many ways, Kot Khuda Yar is similar to the farming trends in the Kanya Subdivision, although the fewer number of samples in the latter may not fully substantiate this claim. At the farm level, both the subdivisions have nearly equal major crop intensities and the highest cultivation intensities devoted to the sugarcane crop. It is rather surprising that the fallowing within the cultivated lands is very high, being 49.4 % for kharif and 31.5% during rabi, despite the fact that supplemental reliance on the groundwater is not constrained and that the design surface water allowances are at the maximum. The farmers, however, are less than convinced about the adequacy of irrigation supplies that would suppress these rather unusual levels of fallowing (Figure H3, Volume Four). Thus, it is not difficult to conclude that the above average figures on the overall cropping intensity are sustained on the basis of more land being devoted to the minor crops and the significantly higher intensity of the sugarcane crop. There is adequate scope for increasing the overall crop intensities if the large extents of fallowing, particularly during the kharif season, could be reduced.

For the major rabi crop of wheat, adequate profits are not visible, despite higher overall investments into fertilizer and irrigation inputs. When compared against the situation in the neighboring Pacca Dala and Aminpur subdivisions, its yields beget a yawning difference of about 450 kg/ha that are primarily responsible for the lower gross incomes accruing to the farms (Table H2, Volume Four). The higher investments for the sugarcane crop are much more responsive, wherein the yields are the highest reported across the entire LCC and Haveli system (Table H5, Volume four).

## I. Mohlan Subdivision

*Hydrologic Regime*: In terms of gross area, Mohlan is the second largest irrigation subdivision within the LCC system (Figure 10(a)). For the 80% of its land falling within the culturable command, the extensive network of the irrigation channels (sourced by the Upper Gugera Branch) distributes irrigation supplies across 435 tertiary units for an average commanded regime of about 205 ha. The topographic slopes are evenly distributed towards the southwest at an average of about 0.00021, which is low compared with the relief further southwards. Records of the Irrigation Department indicate that its aggregate allocations per

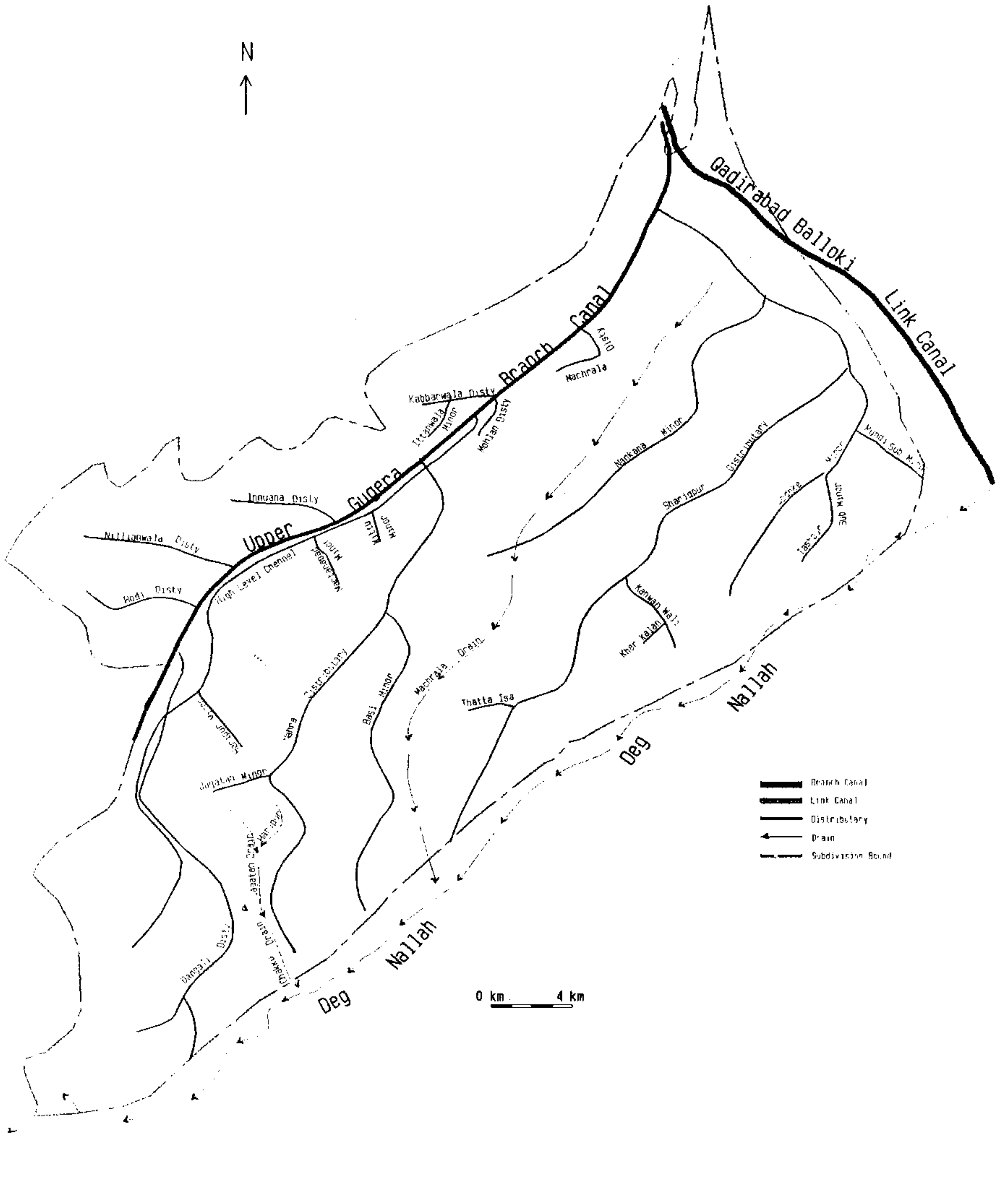



Figure 10(a) Mohlan Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

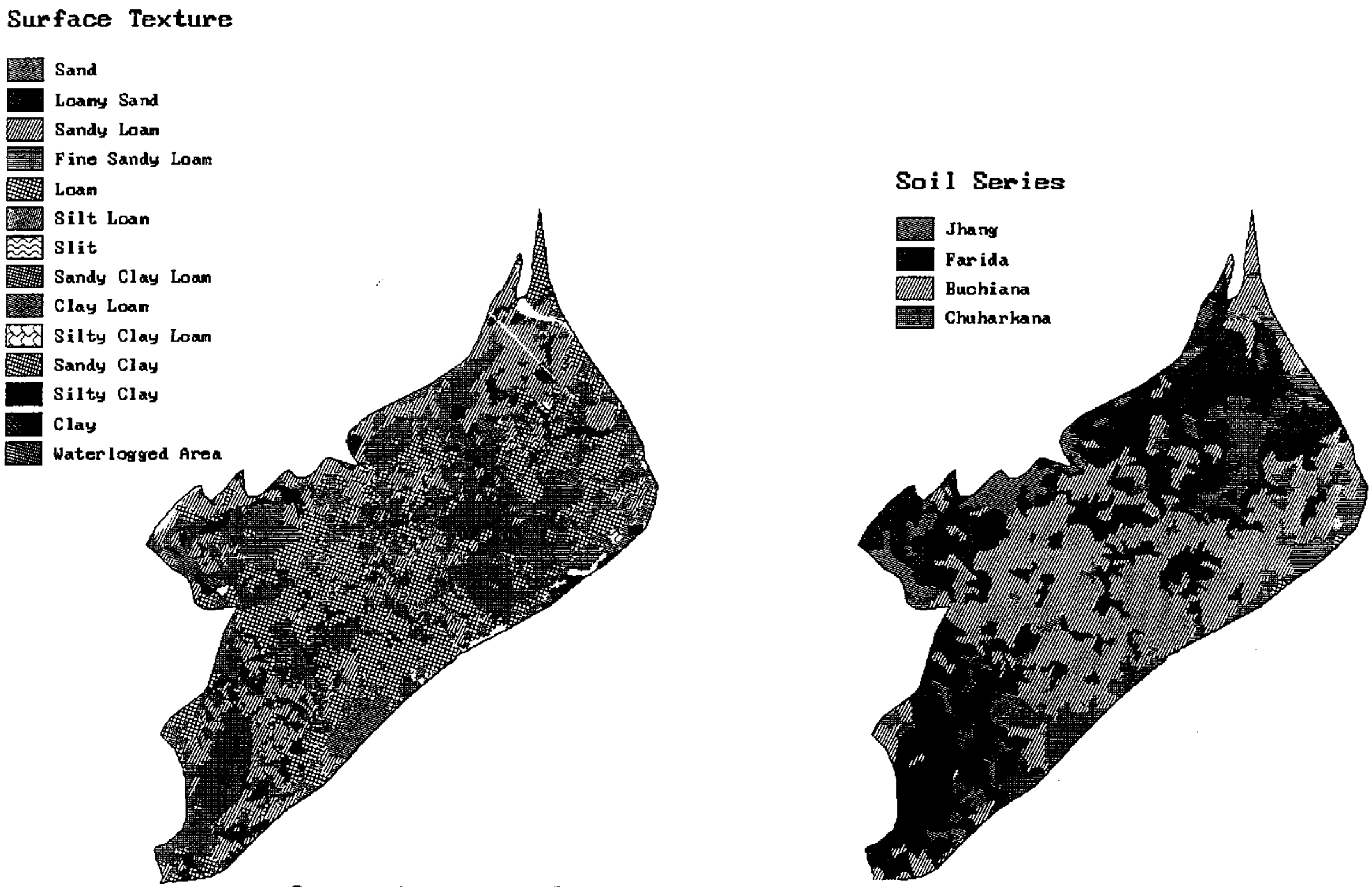
1000 ha of CCA are quite low but at par with the situation observed in the neighboring Chuharkana and Buchiana subdivisions. From Table 3, the calculated deficit towards a water duty of 0.27 cumecs/1000 ha CCA (3.86 cusecs/1000 acres CCA) is about 6.6 cumecs, which is achievable without resort to extensive modeling or extension of the system. Given the above average cropping intensities in this Subdivision (Figure 1(d)), the impact of these adjustments is more likely to be in of favor the higher consumptive use crops like rice and sugarcane that are already benefitting extensively from useable groundwater supplies.

*Soils*: The low topographic slopes within the Mohlan Subdivision have created a pattern of soil depositions that has extensive proportions of the finer particulates ranging from medium to moderately fine textures. Except for the fine soils of Nokhar, all the other four major soil series definitions (to a depth of 2 meters) are found in Mohlan, the pattern becoming distinctly finer towards the Deg natural drain (Figure 10(b)). This channel has a history of flood water overflows following the monsoonal rains in its upper catchment areas in the northern Rechna Doab. The surface textures in the Subdivision are consistent in space across the series differentiations, thereby revealing the homogeneity within the respective soil horizons.

The SSoP interpretations, shown in Figure 10(c), also are indicative of a trend in textural differentiations, whereby the finer soil associations of Shahpur, Miranpur and Satghara in the east (near the Deg channel) are succesively replaced by the moderately fine textures of Nabipur, Sindhelianwali, Gajiana and Miani soils closer to the main distribution channel of Upper Gugera Branch. Areas along the western boundary of the Subdivision are mainly the loams /silt loams of the Bhalwal, Faisalabad and Hafizabad associations. Many of these soils are either outright saline-alkali, like the Satghara, Gajiana, Jhakkar and Sindhelianwali, or have phases with high salt accumulations such as the deep calcareous loams/silt loams of the Nabipur and Shahpur series occurring in the meander floodplains.

*Soil Drainability and Crop Suitability*: The combination of saline-sodic soils and the dominance of the silty clay loam/silty clay associations cited above make for a restricted set of drainage conditions that are extensive beyond the left flank of the Gugera Branch. The soils on the other side of this channel comprise the silt loams and loams of the Faisalabad, Hafizabad and Bhalwal associations that are characteristically well drained. Across the distribution network, the soils with moderate to imperfectly drained conditions are more numerous in the commands of the Sharqpur and Nahra distributaries that offtake from the left side of the Gugera Branch; it is in these commands that the most favorable soil drainage conditions are available for the cultivation of rice (Figure 10(d)). Commands elsewhere in the system have well drained soils that would favor the cotton crop. Overall, the Subdivision should be considered well suited for the extensive cultivation of rice, sugarcane and wheat.

*Soil Salinity and Waterlogging*: The meandering pattern of soil deposition shown in Figure 10(c) above has a very complex interweave of saline versus non-saline soils. One such traverse through the southwesterly sloping terrain cuts across the associations of Gajiana, Miranpur, Sindhelianwali, Shahpur, Nabipur, Jhakkar and Miani soils. Five of these seven




Source: SCARP Monitoring Organization (WAPDA)

Figure 10(b) Surface and Profile Texture of the Soils in the Mohlan Irrigation Subdivision, Lower Chenab Canal (East) Circle. Rechna Doab. Punjab. Pakistan.

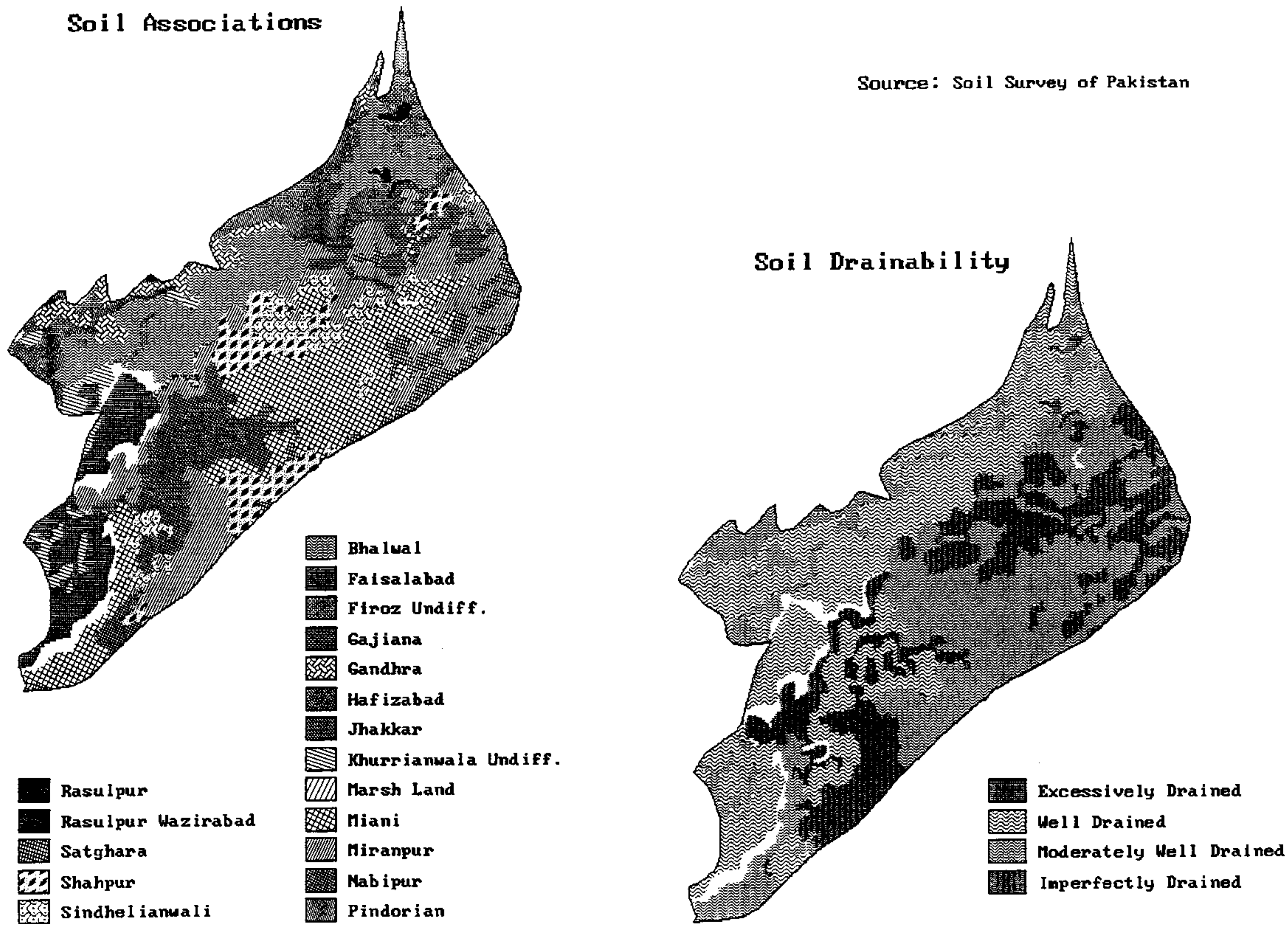



Figure 10(c) Associative Classification of the Soils and their Drainability Characteristics the Mohlan Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

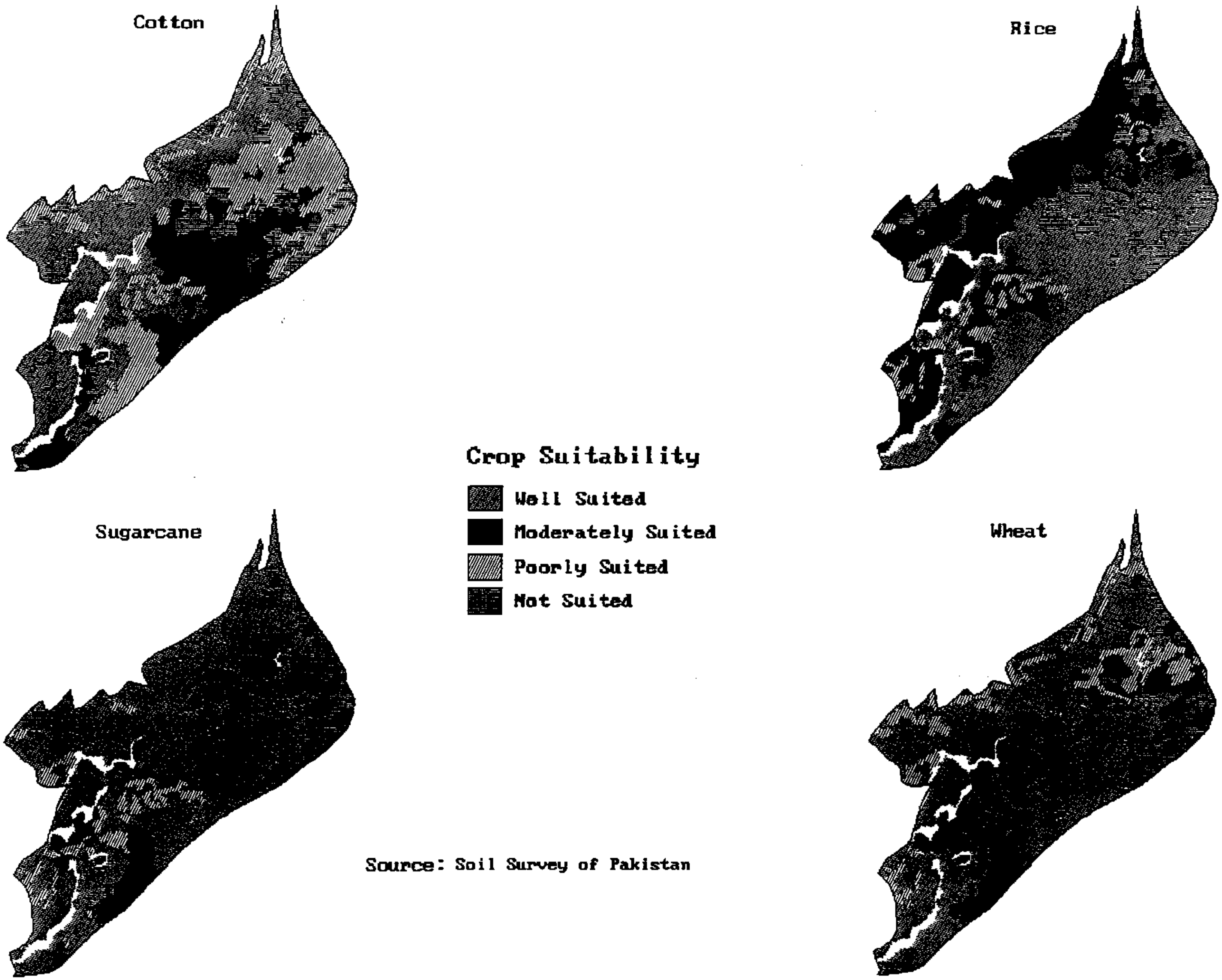



Figure 10(d) Soil Suitability for Major Crops in the Mohlan Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

soil associations have strong saline-alkali characteristics. Such a strong mix of saline-alkali soils is reinforced further by the isolated occurences of the highly saline/alkaline Satghara, Gandhra and Khurrianwala/Firoz Undifferentiated groups within the larger expanse of the Mohlan Subdivision.

The general impression from the foregoing SSoP interpretations towards the potential impact of salinization would be less encouraging for productive crop growth. Indeed, Mohlan seems to have more than its share of the diversity of soils afflicted with salinity. The negative impacts that would normally be assumed in this context are, however, less than obvious when compared with the WAPDA MPR survey delimitations on the extents of surface salinization. Figure 10(e) shows that not only these visual interpretations are not as numerous as cited by the SSoP ten years ago, but that the extreme ranking within this assessment, the S4 class, is quite restricted to a few pockets in the east near the Deg drainage channel. The impact in the profile, however, is much more widespread wherein the medium to moderately fine textures of Buchiana and Chuharkana soils overlap extensively with the reported incidence of salinity/sodicity.

WAPDA SMO records of water table fluctuations indicate isolated pockets of limited extents within the Mohlan Subdivision where the rise in the subsurface levels stays just below the root zone (Figure 10(f)). These fluctuations are not location specific in the period monitored between 1980-93, except in areas forming the commands of the Nillianwala and Rodi distributaries that offtake from near the exit-reach of the main Gugera Branch. The rise of the water levels in these areas, sometimes to near critical levels, is generally supported by the evidence of a restriction in subsurface drainage; however, the decreasing slopes of the lateral flows, as in Figure 10(g), are not necessarily exclusive to such fluctuations elsewhere. This would be evident from the situations where the lateral outflows may be restricted in regimes where the concurrent rise in the water tables would still remain well below the root zone.

*IIMI Sampling for Soil Salinity and Texture*: The fifteen sample sites in the Mohlan Subdivision, comprising 11,115 ha, were distributed in clusters across the head, middle and tail reaches of the system comprising the commands of the Sharqpur and Nahra distrbutaries. Over 94% of the 1470 EM 38 observations on soil salinity were processed to be non-saline. A majority of these non-saline observations were in the loam/silt loam categories of texture followed by the finer clayey compositions (Figure B9, Volume Four). In fact, this proportion is recurrent across all major categories of land use within the Subdivision, except sugarcane, where the finer clay loams are preferred over the loams (Figure C9, Volume Four). Surprisingly, given the known susceptibility of these soils to salinization, the incidence of strongly saline strata was completely remiss from the observations; the lower values of salinity belonging exclusively to the loam textures. Whatever the distribution of these saline observations, an overwhelming percentage of the major land use within the sample domain remained unaffected by this incidence.

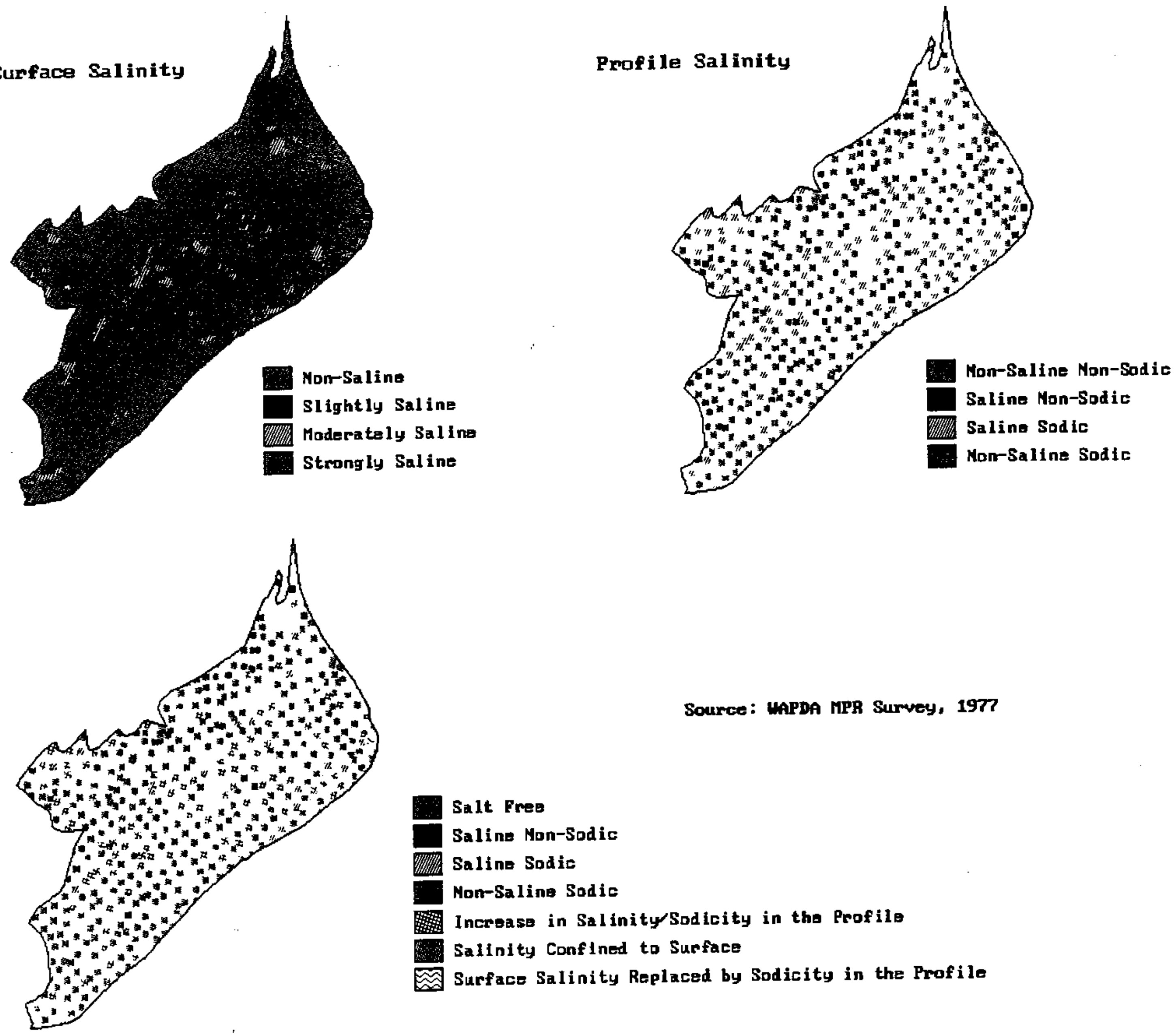



Figure 10(e) Surface and Profile Salinity in the Mohlan Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

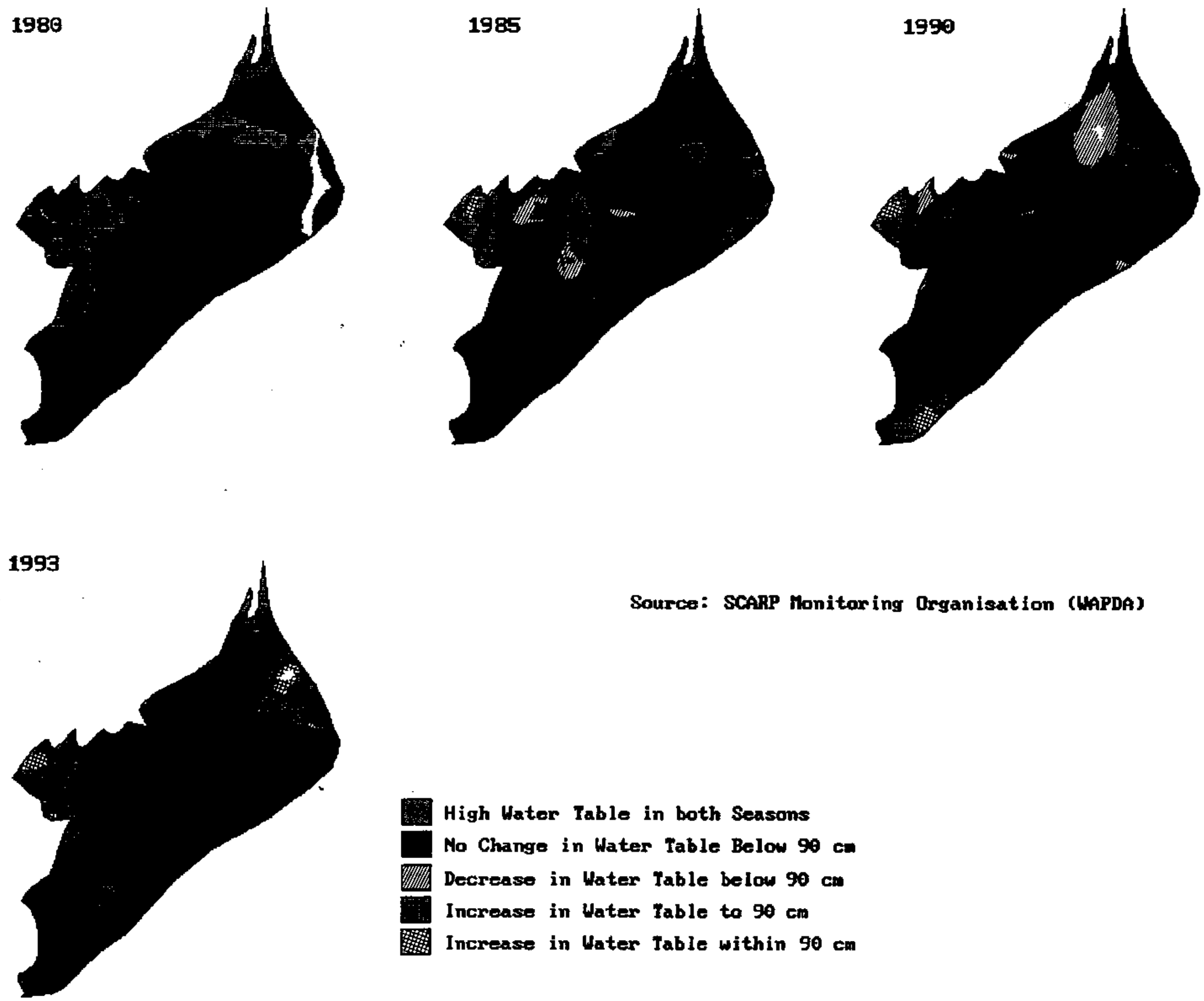



Figure 10(f) Temporal Variations in the Depth to Water Table, Mohlan Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

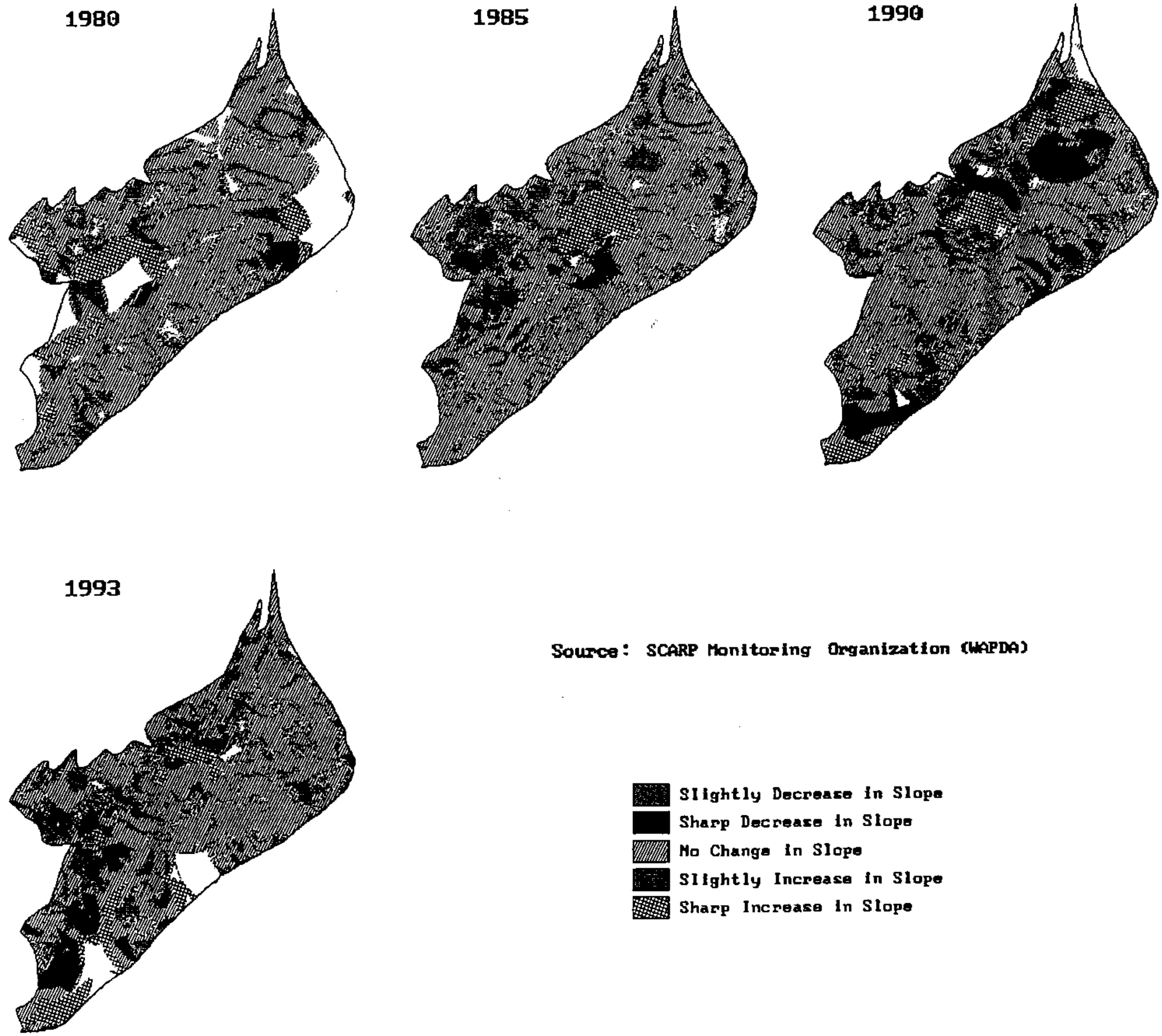



Figure 10(g) Interseasonal Slope Variations in the Subsurface Flows, Mohlan Irrigation Subdivision, Lower Chenab Canal (East) Circle. Rechna Doab. Punjab. Pakistan.

*IIMI Farm Level Sampling*: The 36 farmholdings sampled within the Mohlan Subdivision showed high land use and cropping intensities that are typical of the productive regimes within the Rechna Doab. In fact, if the influence of the inadequate sampling within the Sagar, Sultanpur and Wer Subdivisions is discounted, then the combination of the high landuse and cropping intensities ranks Mohlan as the third most productive subdivision within the LCC system. It is not surprising, then, that these subdivisions of Chuharkana, Mohlan and Tandlianwala have a contiguous geography that is exclusive to the command of the Gugera Branch. The Chuharkana and Mohlan subdivisions share similar physiographic characteristics, but their major crop intensities are internally differentiated; Chuharkana grows more rice than Mohlan, however, the difference is replaced in near equal measure by the higher intensity of sugarcane cultivation in the latter (Table H1, Volume Four). This emphasis on sugarcane, also applicable to Tandlianwala, translates into a 10-12% advantage in lesser extent of land devoted to fallowing in these subdivisions in comparison to the Chuharkana. This advantage in fallowing could then be converted into cropping intensities matching those found in the Chuharkana if the major constraint of scarcity of irrigation supplies is suitably addressed (Figure H3, Volume Four). Since the high land use efficiency in Tandlianwala is unable to compete with the other two subdivisions in the cumulative cultivation of the high delta crops (due to porous soils), its emphasis on the minor crop intensities (primarily fodder and maize) has been observed to be the highest across the entire LCC. In this respect, the proportional benefits from increased water supplies in this Subdivision will accrue more in favor of wheat/maize cropping intensities than rice, which would be more likely for the Mohlan. This is not to say that Mohlan Subdivision is unlikely to realize increases in the existing cropping intensities of wheat that at present are nearly equal to that of the Chuharkana. In fact, based on Figures H6 and H7 along with Table H2, despite higher investments in fertilizer, irrigation and land preparations , the Chuharkana Subdivision is unable to gain appreciably higher yields than those in Mohlan; hence, the benefits of higher gross income are not reflected in the profits. In this situation, Mohlan's total overall costs for wheat cultivation may be further averted in lieu of the enhanced surface irrigation supplies.

The current intensity of the rice crop in the Mohlan Subdivision is about 19% of the total cropped land. This is nearly 13% less than the intensity in the Chuharkana, a difference that can likely be bridged through narrowing the existing shortages in the surface irrigation supplies. But there are other factors that contribute profoundly to overall production, as is evident from the sum total of investments made by the farmers in the Chuharkana Subdivision. The more than 470 kg/ha yield advantage within Chuharkana is largely because of the higher investments in land preparation and fertilizer inputs by the farmers. Also, these higher yields are being achieved with less irrigation-related costs, a factor that works significantly to the advantage of the Chuharkana Subdivision given the nearly equal design irrigation allowances for both of the subdivisions (Figure 1(b)).

The costs for sugarcane cultivation are generally much lower in the Mohlan Subdivision than in the Chuharkana (Table H5, Volume Four). It is rather surprising that despite lower investments in land preparation and fertilizer/FYM application, the average yields are higher by more than 4,600 kg/ha against the Chuharkana Subdivision. This is one reason for the observed higher intensities of this crop within Mohlan. However, this does not translate into profits to the extent that would be expected due to the unusually high costs associated with the harvesting of this crop.

## J. Pacca Dala Subdivision

*Hydrologic Regime*: The commands of the Pacca Dala Subdivision draw all of their surface irrigation supplies from the Mian Ali Branch that offtakes below the confluence of the LCC Feeder and the LCC main line (Figure 11(a)). The Subdivision itself is located in the center of the Rechna Doab and has a gross area of 78,108 ha of which 91% is CCA. The size of the cultivated regime would equate it with the neighboring Chuharkana to the east; however, the higher number of watercourse units within the Pacca Dala would mean lower average for the commanded areas at the tertiary level. Figure 1(b) shows that against a small difference in the density of the secondary distribution system, the surface water allowance is much higher in the Tarkhani Subdivision, although both still remain below the maximums observed elsewhere in the LCC system. Assuming these maximums are achieved, calculations in Table 2 (in reference to Figure 1(c)) indicate that both Pacca Dala and Tarkhani will be needing an expansion of their respective distribution networks over and above attempts to increase the current carrying capacity via remodeling (see the impact of desiltation under Table 3). This expansion is not difficult to construe given the deficiencies in the existing network coverage wherein only two distribution channels of Khurrianwala and Shahkot command the entire two-thirds of the system downreach from the tail of the Mian Ali. The net impact of these adjustments to the distribution system is most likely to be realized in favor of the higher consumptive use crops given the low proportion of the culturable waste in this Subdivision. In fact, this would be expected given the existing share of more than 20% of these crops in the gross cropped area.

*Soils*: The 21 meters of head to tail difference in relief has a uniform slope average of 0.0003. These slopes are intermediate by the Rechna Doab standards and, hence; progenitor of the most common soil textures encountered in such topography. WASID soil investigations show two major series that are characteristic of the area, i.e. the medium textured Buchiana soils that are limited to the head reaches of the system and the moderately coarse Farida soils that are nearly exclusively below the tail of the Mian Ali Branch (Figure 11(b)). The surface texture overlays indicate these soils to be highly homogeneous and uniformly developed across the moderately coarse to coarse textures in the strata. This is not evident for the Buchiana loams/silt loams that have sandy loams in the surface.

The SSoP interpretations show a strong presence of the Jhumra, Pacca and Dungi soils with related silty clays in the head and middle reaches of the system, which is in major contrast against the dominant textural differentiations given above (Figure 11(c)). These clayey extents are not exclusive to the Buchiana soils identified above, but also overlie the

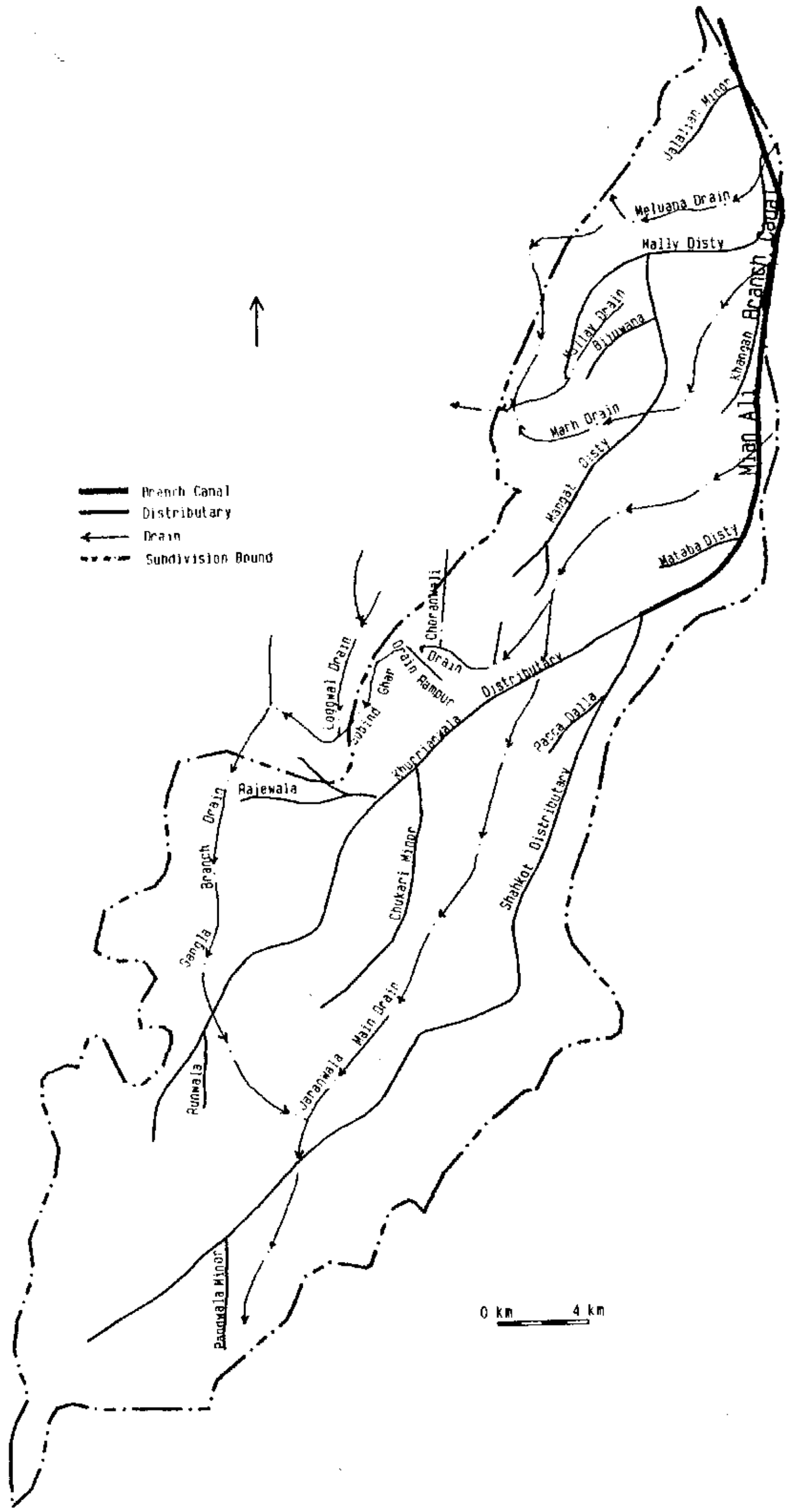
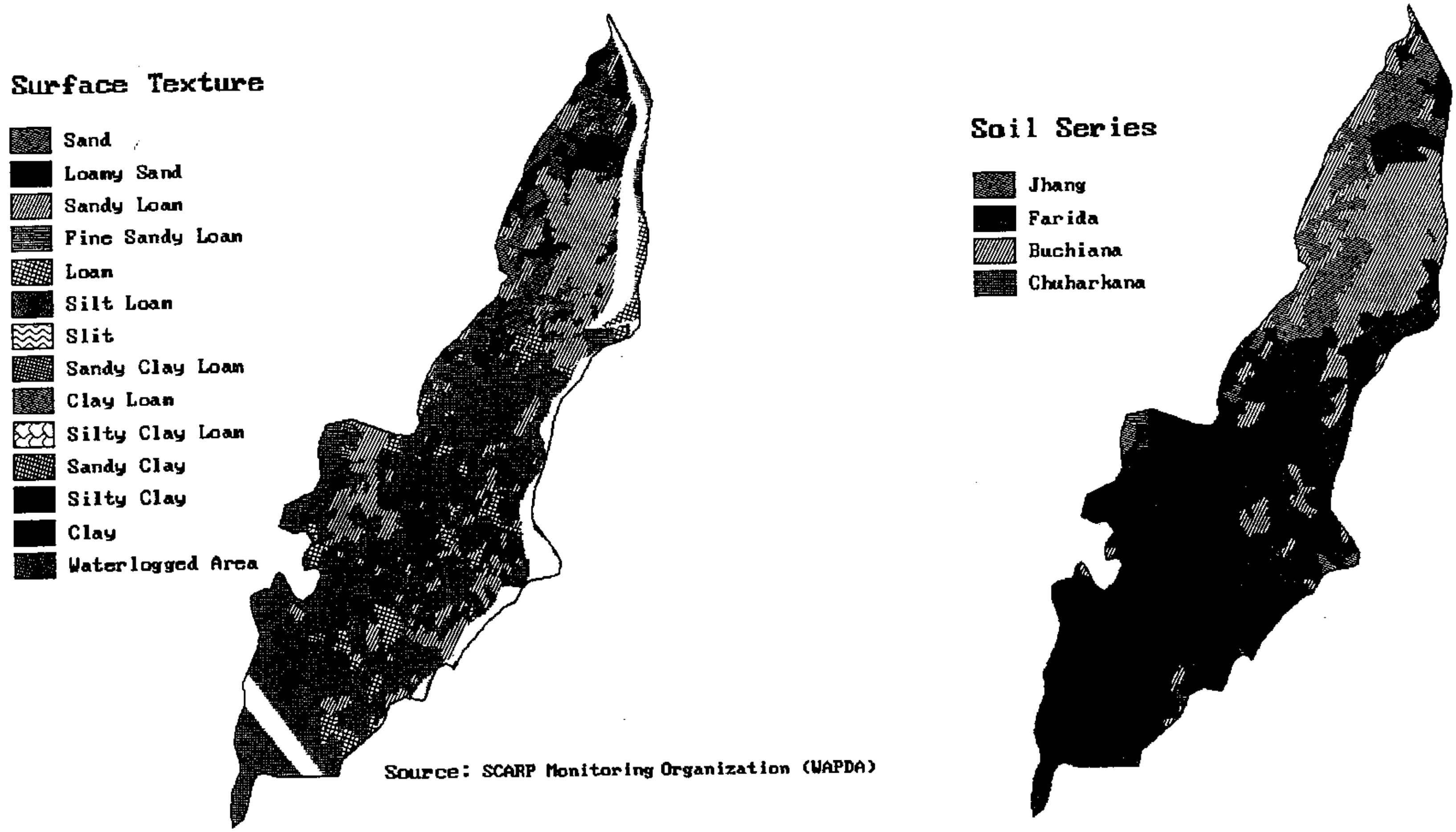


Figure 11(a) Pacca Dala Irrigation Subdivision in the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 11(b) Surface and Profile Texture of the Soils in the Pacca Dala Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

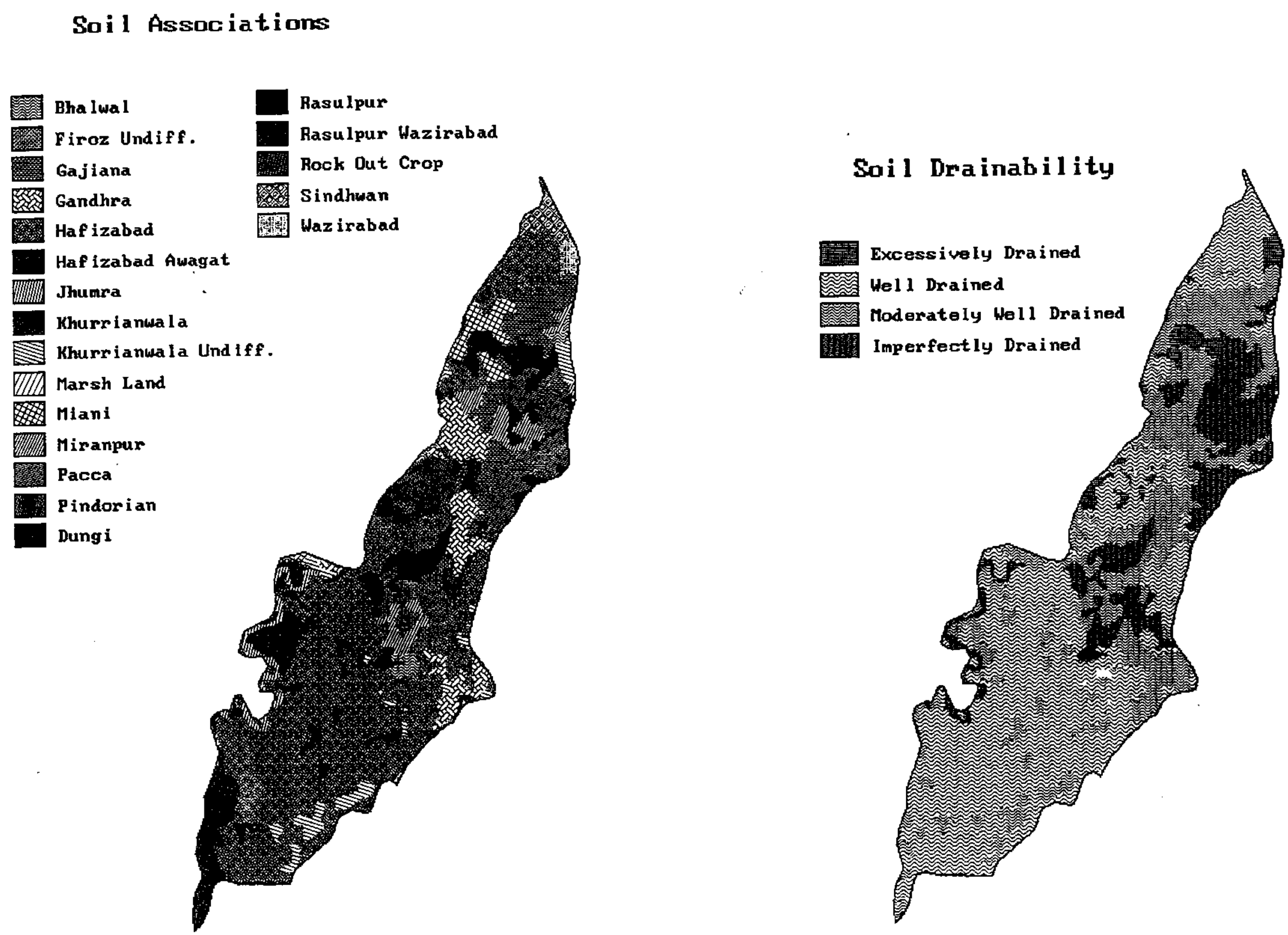



Figure 11(c) Associative Classification of the Soils and their Drainability Characteristics the Pacca Dala Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

moderately coarse textures of the Farida series further southwards. The mismatch is even more outstanding for the WASID delimitations of the sandy Jhang soils against the medium to moderately fine textures of the Sindhwan, Hafizabad, Miani, Gandhra and Miranpur soil associations. Overall, the most dominant textures are related to the loams of the Hafizabad association that has a contiguous presence in the lower half of the system. The western fringes of these loamy extents comprise the Hafizabad-Awagat association that is known to have 15-20% occurrence of the saline-alkali soils in its phases. A rather limited, but strong, saline-alkali presence of Jhumra soils is also visible along the western boundary of the system; however, the larger salinized extents are more synonymous with the Khurrianwala and its undifferentiated groups that are largely scattered across the lower half of the system.

*Soil Drainability and Crop Suitability*: The soil drainability map for the Pacca Dala Subdivision also appears in Figure 11(c) wherein the majority regime in the head and middle reaches is shown to have limited or imperfectly drained conditions in the stratum. These poor drainabilities implicate less of the dispersive tendencies of the saline-alkali soils in comparison to inherently high clayey fractions. The remaining areas are predominantly well drained, in large measure due to the Hafizabad loams and to a lesser extent because of the Pindorian and Sindhwan series in the middle and head reaches, respectively. The complex multitude of these soils creates a pattern of crop suitability conditions that is quite heterogeneous (Figure 11(d)). Exclusive to the patchy distribution of the soils with saline-alkali phases, the Pacca Dala Subdivision has what would appear to be the most uniform mix of well to moderately well suitability conditions for rice cultivation. The other major crops are probably best suited for the lower half of the Subdivision where the loams are likely to sustain higher productivities in comparison to the head reaches. The heterogeneity in suitability rankings is most acute in the head reach where both wheat and sugarcane could benefit from sustainable yields across nearly equal spatial extents. Considering the most predictable results, cotton would thus be confined largely to the commands below the tail of the Mian Ali Branch .

*Soil Salinity and Waterlogging*: The WAPDA MPR survey of the surface and profile soil salinity within the commands of the Pacca Dala Subdivision confirm much of the earlier patchy distributions of the salinized tracts by the SSoP. The strongly saline (S4) soils, though not confined to any one part of the Subdivision, are much less than the moderately saline (S3) occurrence of the affliction (Figure 11(e)). The slightly saline soils are largely confined to the upper reaches of the system and coincident with a wide range of textural associations ranging from the moderately coarse Rasulpur, to medium Miranpur, to fine Gandhra and Pacca horizons. When the incidence of surface salinization is compared with the pattern of salt accumulation in the root zone, the evidence points largely to a deterioration that even circumvents locales with no visible incidence of salinity. This phenomenon is less widespread in the head reaches, but gains spatial significance when moving downreach of the system. It is in these lower reaches of the system where non-saline sodic profiles are nearly exclusive.

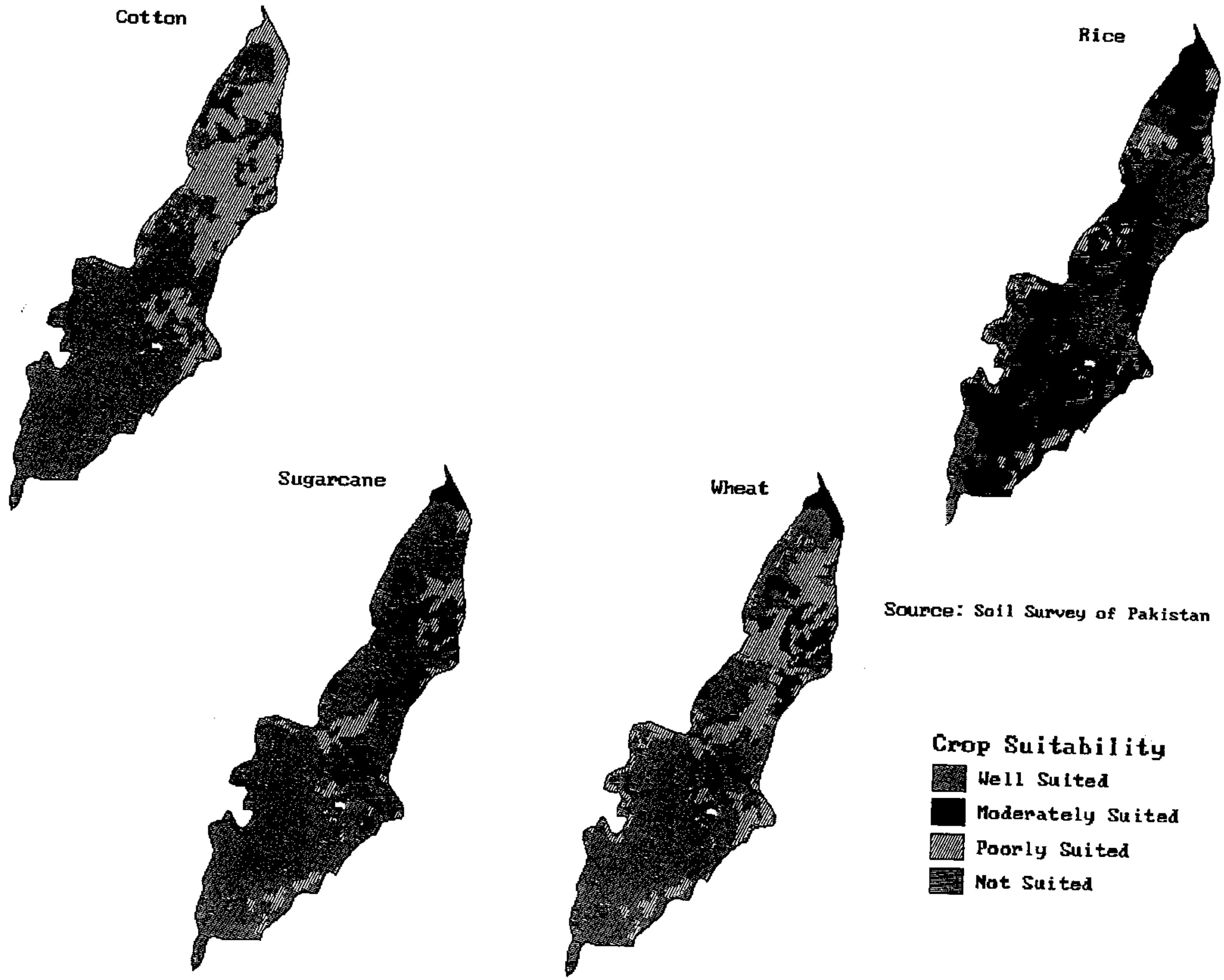



Figure 11(d) Soil Suitability for Major Crops in the Pacca Dala Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

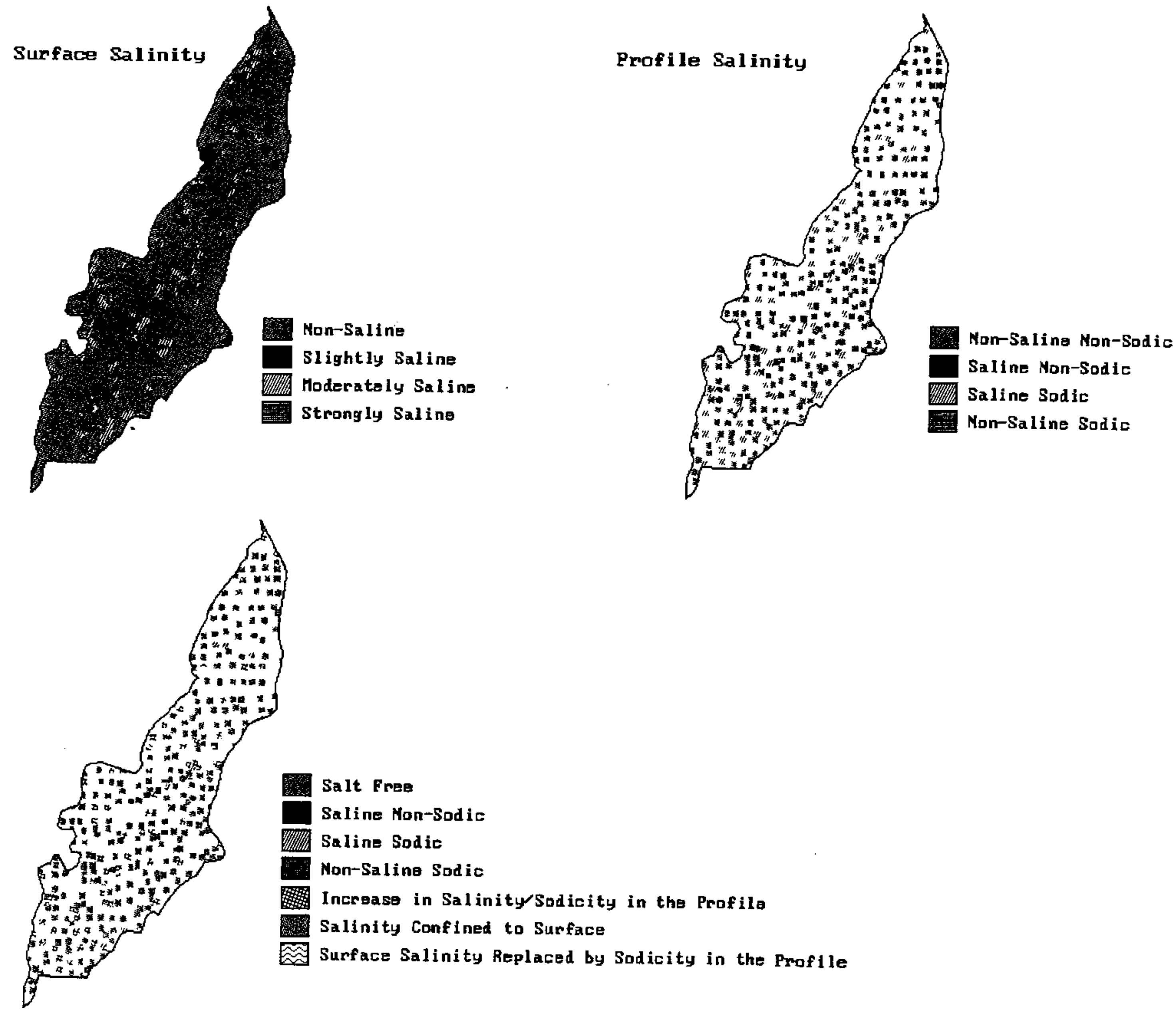



Figure 11(e) Surface and Profile Salinity in the Pacca Dala Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

The seasonal rise of the water table seems to have much improved since the earliest available data compared for this study. The thirteen years of comparison shown in Figure 11(f) increasingly suggests the diminishing significance of the subsurface fluctuations that could be threatening to the root zone. In fact, the downstream reaches are less supportive of a recharge related rise in the water levels to the extent that large areas have actually experienced a decrease over the pre-monsoon levels.

*IIMI Sampling for Soil Salinity and Texture*: The Pacca Dala Subdivision represents the highest concentration of the IIMI sample sites for field level appraisal of both surface and profile salinity concentrations in the cultivated tracts. The sample domain comprised 12,198 ha, mostly in the commands of the Khurrianwala and Shahkot distributaries, for which over 2000 observations of $EC_a$ were collected via the EM 38. Upon conversion to the equivalent $EC_e$ values, more than 90% of the observations were found to be non-saline. Figure B10, Volume Four, shows the texture-wise distribution of these observations across all saline and non-saline classes. The non-saline soils are overwhelmingly constituted by the moderately coarse to medium textures that largely comprise the sandy loams and loams. The S2 and S3 levels of salinization have a nearly equal divide in the textural distribution between the moderately coarse to medium soils versus the moderately fine to fine soils.

All of the major categories of land use are non-saline; there is only evidence of S2 levels of salinization in only a few fields under the ploughed catergory, and that too mostly under medium to finer soil fractions. In terms of the land use, the ploughed, fallow and fodder categories make use of the greatest diversity in soil textures that has not been witnessed elsewhere. Internal to this diversity is the comparatively greater reliance of the fodder cultivation on moderately coarse textures (Figure C10, Volume Four). Fields left fallow basically fall into the two groups of textures with the sandy loams and loams dominating the finer fractions. Samples from both the sugarcane and the cotton crops are non-saline; the soil preference for the sugarcane crop being more towards the medium to moderately fine soils in comparison to the moderately coarse (and some clayey soils) dominating the cotton crop. The general evidence for salinization is mostly confined to the barren tracts in the immediate vicinity of the cultivated lands where both S2 and S3 levels have been observed, but remain exclusive to medium to moderately fine soils. Data indicates that were soils to remain non-saline across these barren tracts, then loams would probably be the most predictable of textures in such situations.

## K. Sagar Subdivision

*Hydrologic Regime:* Sagar is the head reach Subdivison of the entire LCC system, and also the second largest in terms of the gross area. Its western edge parallels the Chenab River, whereas the main LCC defines the upper half of its eastern boundary that is also home to the intersection of the main line LCC with the Qadirabad Balloki Link at Sagar Head. Much of the data pertaining to the hydrology of this area could not be accessed at the time


Figure 11(f) Temporal Variations in the Depth to Water Table, Pacca Dala Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

of writing this report; however; Figure 12(a) shows the map of the irrigation network that, in comparison to the other Subdivisions, appears to be quite adequate in spatial coverage. The layout of this network slopes entirely towards the Chenab River and includes the principal channels of Manchar and Vanike in the head reach, Kot Nikka Branch and Gajar Gola in the middle reach, and the Jalalpur and Jandoli distributaries in the tail reach. The topographic slope is southwesterly and has a total relief difference of about 24 meters at an average slope of 0.0003. The slopes are somewhat flatter in the lower two-thirds of the system.

*Soils*: The low values of the topographic slope correspond with a dominance of the medium textured Buchiana series soils across the entire length of the system (Figure 12(b)). Their overwhelming presence in the upper half of the system is interspersed with significant patches of the still finer Chuharkana soils. Elsewhere, such as in the lower reaches and along the boundaries, the Buchiana loams/silt loams mix with the moderately coarse fractions of the Farida series. These soils are fairly homogeneous given the good spatial overlap between the surface and profile textures. The SSoP interpretations appearing under Figure 12(c) show the head reaches to be primarily made up of the loams/silt loams of the Hafizabad, Gandhra and Sindhwan associations. The coarser textures of the Rasulpur soils are discontinuous across the mid system lateral divide where the silt loams of the Bhalwal and Khurrianwala associations overlap the WASID interpretations of the Buchiana and Chuharkana soils, forming a contiguous stretch along the longitudinal axis of the Subdivision. Elsewhere, the Rasulpur soils match well with the distribution of the Farida series along the western boundary of the Subdivision. It is in the tail reaches of the system where their presence circumvents the near exclusive expanse of the Hafizabad loams that covers much of the lower one-third of the system command.

*Soil Drainability and Crop Suitability*: Figure 12(c) also shows the overall picture for the vertical drainage within the Sagar Subdivision. The coarser Rasulpur association, in its overlap with the Farida series soils, forms a central divide across the Subdivision that is made up of the fairly porous sandy loams in the stratum. These soils have a continuation further south along the western fringes of the Subdivision whereby they are nearly exclusive in the tail. The areas on either side of this divide, because of the dominant loams and silt loams in their composites, have a well drained capability. Much of the homogeneity in these well to excessively drained conditions is disrupted by the significance of the Khurrianwala silt loams, largely restricted to the upper half of the system, that are characteristically saline-alkali and relatively impervious to vertical drainage. This pattern of vertical drainage results in a situation whereby the cultivation of rice remains restricted to the loams/silt loams which are only moderately suitable for its growth (Figure 12(d)). For the same conditions, cotton would most likely fluorish. However, a relaxation in these rankings between well to moderately well suitability scales should see a somewhat uniform distribution of conditions favoring the cultivation of wheat and sugarcane.

*Soil Salinity and Waterlogging*: WAPDA investigation in the mid 1970s indicate S3 and S4 levels of surface salinization to be mostly confined to the commands between the Vanike

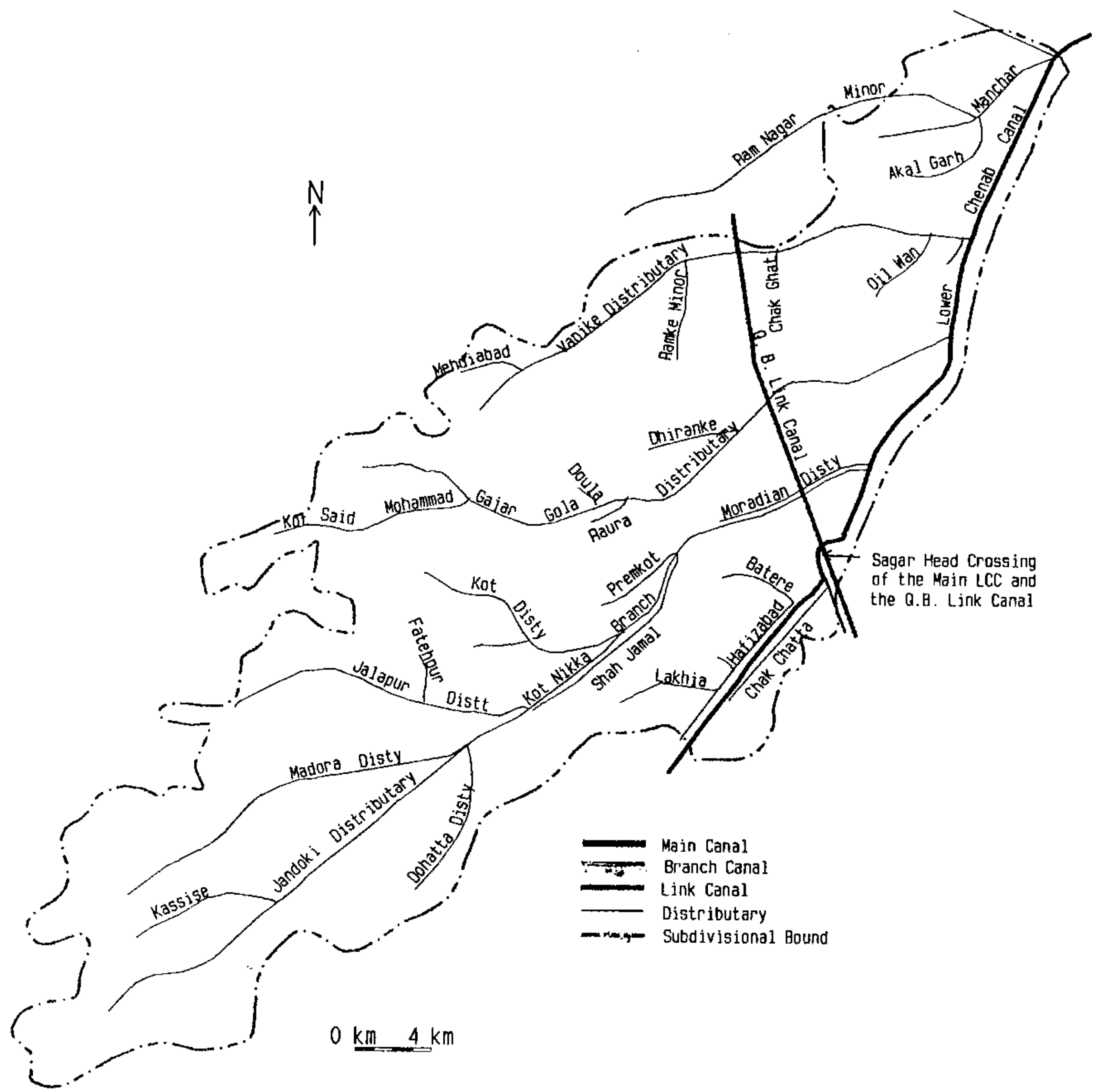
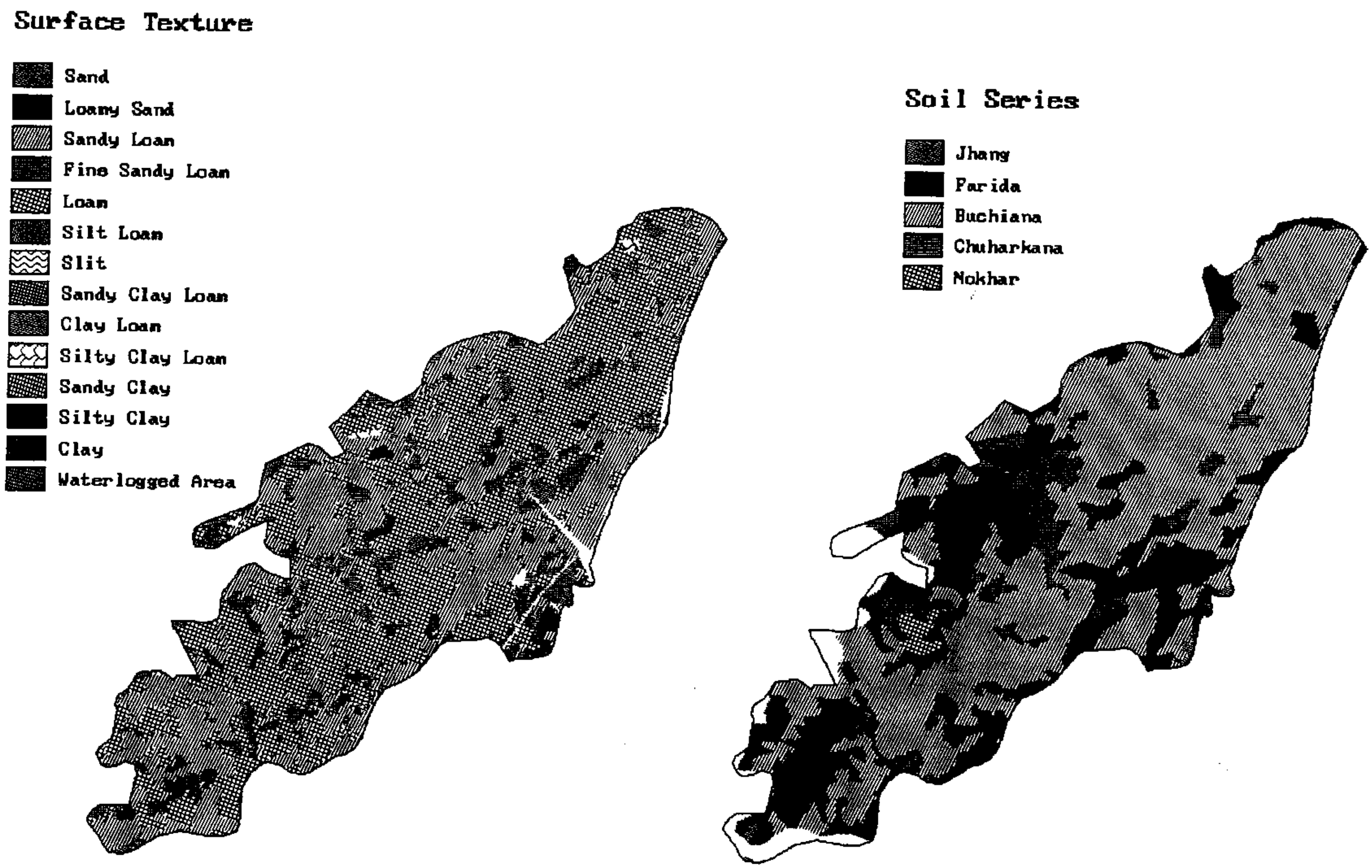



Figure 12(a) Sagar Irrigation Subdivision in the Lower Chenab Canal (Main) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 12(b) Surface and Profile Texture of the Soils in the Sagar Irrigation Subdivision, Lower Chenab Canal (Main) Circle, Rechna Doab, Punjab, Pakistan.

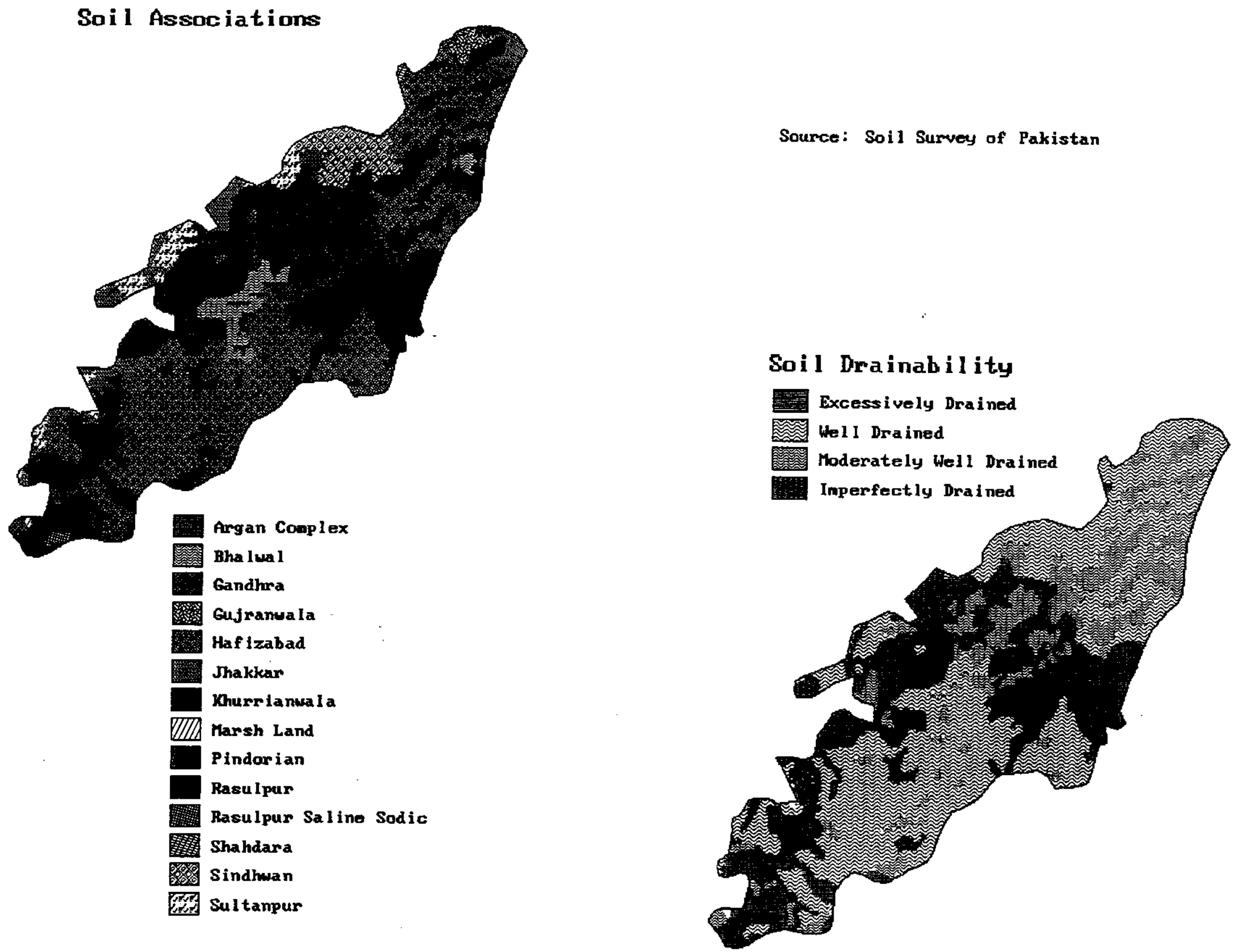



Figure 12(c) Associative Classification of the Soils and their Drainability Characteristics the Sagar Irrigation Subdivision, Lower Chenab Canal (Main) Circle, Rechna Doab, Punjab, Pakistan.

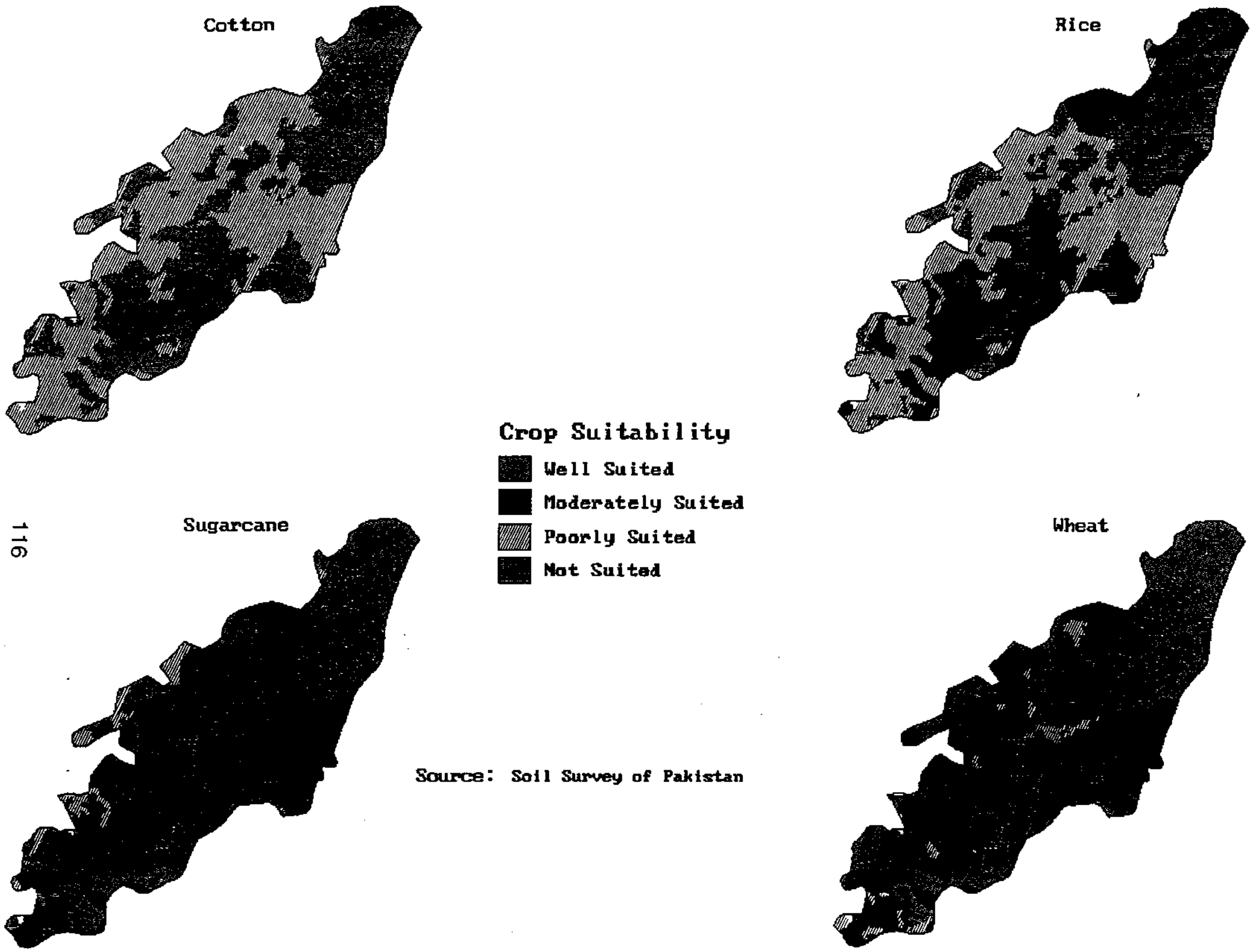



Figure 12(d) Soil Suitability for Major Crops in the Sagar Irrigation Subdivision, Lower Chenab Canal (Main) Circle, Rechna Doab, Punjab, Pakistan.

and Gajargola distributaries that offtake from the main LCC upstream of the Sagar Head (Figure 12(e)). The extensive nature of this salinization is highly correlated in space to the Khurrianwala soils earlier mapped by the SSoP during the mid 1960s. Further south, this phenomenon has a very scattered presence; the S4 levels are fairly restricted to the commanded regime between the Jalalpur and Madora distributaries that extend below the tail of the Kot Nikka Branch. Concurrent data on profile salinity indicates that much of the surface salting has a strong sodic counterpart in the soil horizons. In areas where the effects of surface salinization are less than evident, like in the tail reaches of the system, the insidious presence of these sodic salts in the soil horizons is quite widely distributed. In fact, to varying degrees of salinization, this phenomenon of root zone affectation is quite rampant, the exception being the command of the Kot Nikka Branch.

The temporal records of water table fluctuations indicate a strong spatial coincidence between the worst extents of salinization, such as in the areas between Vanike and Gajar Gola channels, and the rise of the water tables to the root zone (Figure 12(f)). This recharge related fluctuation was most severe in the early 1980s but has been receding to the extent that by 1993 its significance had substantially diminished. The thirteen years of comparison across seasonal fluctuations has yielded contrasts wherein previously permanently waterlogged regimes have undergone reductions in water levels below the root zone.

Note: There was no sampling done by IIMI in the Sagar Subdivision pertaining to salinity and farm level economics.

## L. Sangla Subdivision

*Hydrologic Regime*: Sangla Subdivision is unique amongst the administrative units of the LCC system in that its head reach marks the termination point of the two parallel channels of the LCC Main and the LCC Feeder coming down from the Sagar Head. These two channels merge just prior to the downstream bifurcation into the main Rakh and Jhang branches (Figure 13(a)). Hence, Sangla's irrigated command, the smallest within the entire LCC system, receives supplies from multiple main canal systems that successively traverse the entire longitudinal stretch of the system across a total relief difference of about 8 meters. The slopes are very gentle at an average of 0.00017 and are distributed evenly across the 241 sanctioned watercourses. From Figure 1(b), the design surface water allowances across the secondary network are much below the maximums observed elsewhere within the system. This becomes more apparent when comparing with subdivisions like Kanya and Tandlianwala where, for nearly equivalent distribution densities, the design allowances within Sangla are observed to be much less. Towards a system-wide equity based on the observed design maximums, the surface water allowances within the Sangla Subdivision are unlikely to be realized even with secondary level desiltation (Table 3). Figure 1(d) indicates that despite these calculated scarcities in the irrigation supplies, the observed cropping intensities within the Sangla Subdivision may already be benefitting in

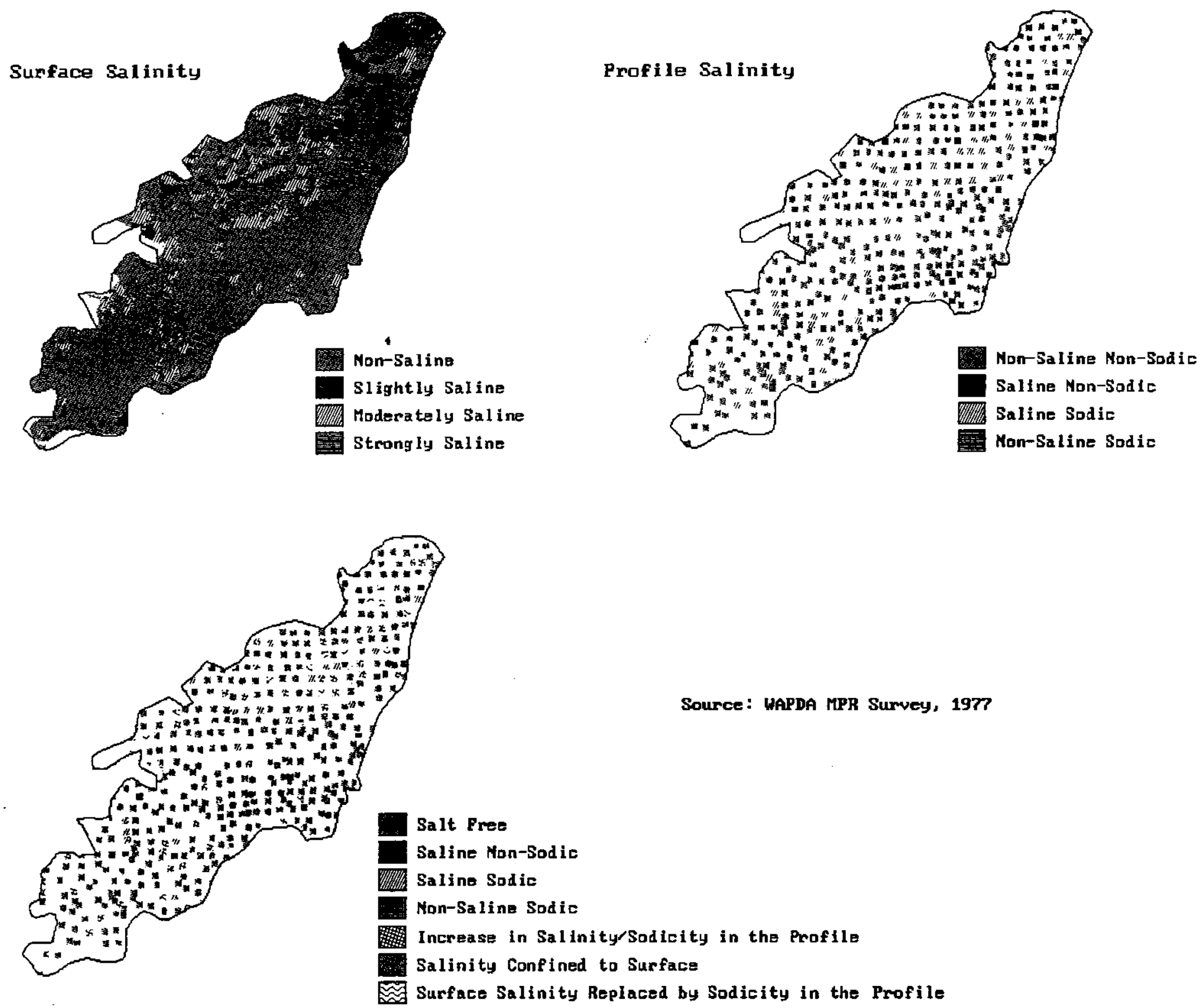



Figure 12(e) Surface and Profile Salinity in the Sagar Irrigation Subdivision of the Lower Chenab Canal (Main) Circle, Rechna Doab, Punjab, Pakistan.

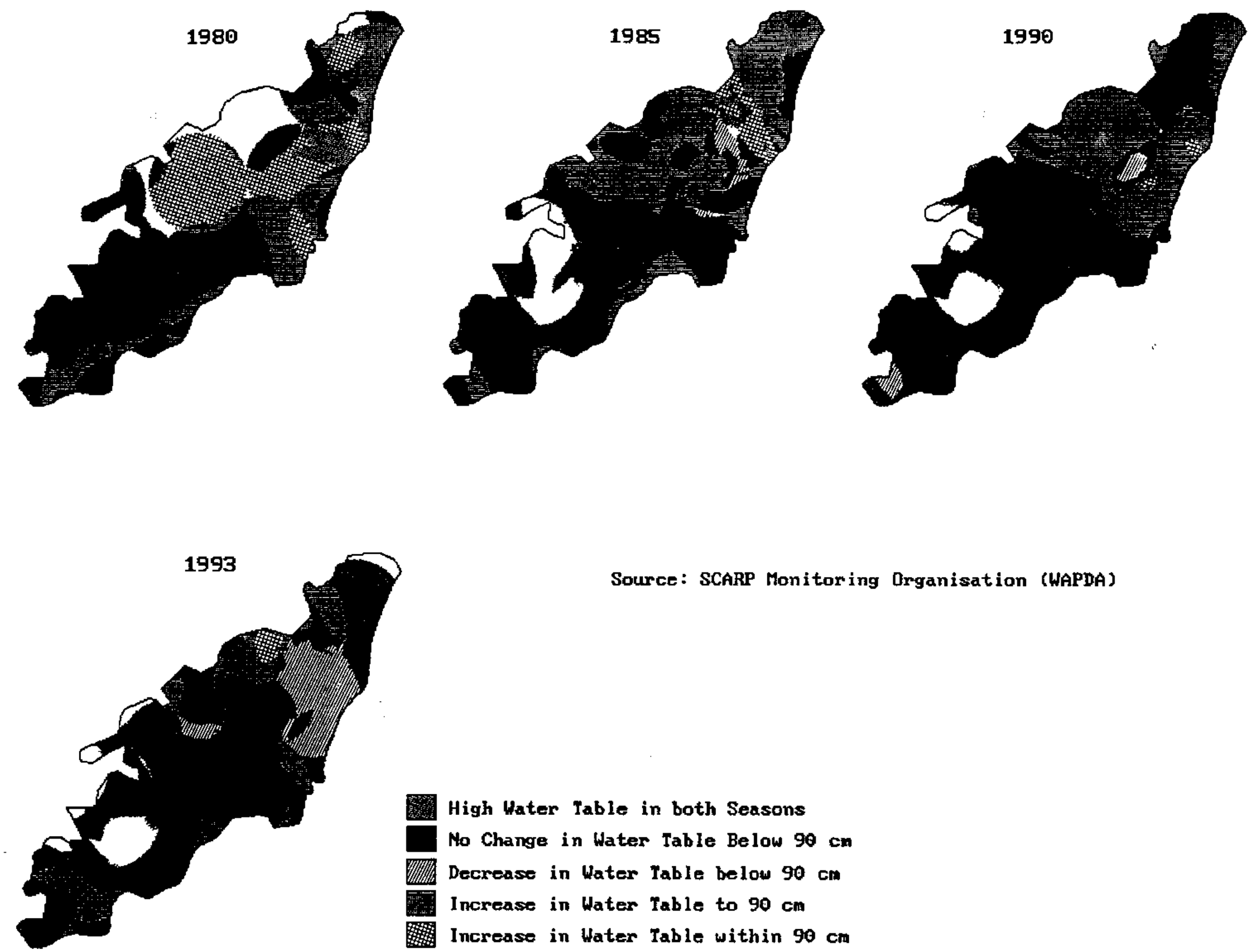



Figure 12(f) Temporal Variations in the Depth to Water Table, Sagar Irrigation Subdivision, Lower Chenab Canal (Main) Circle, Rechna Doab, Punjab, Pakistan.

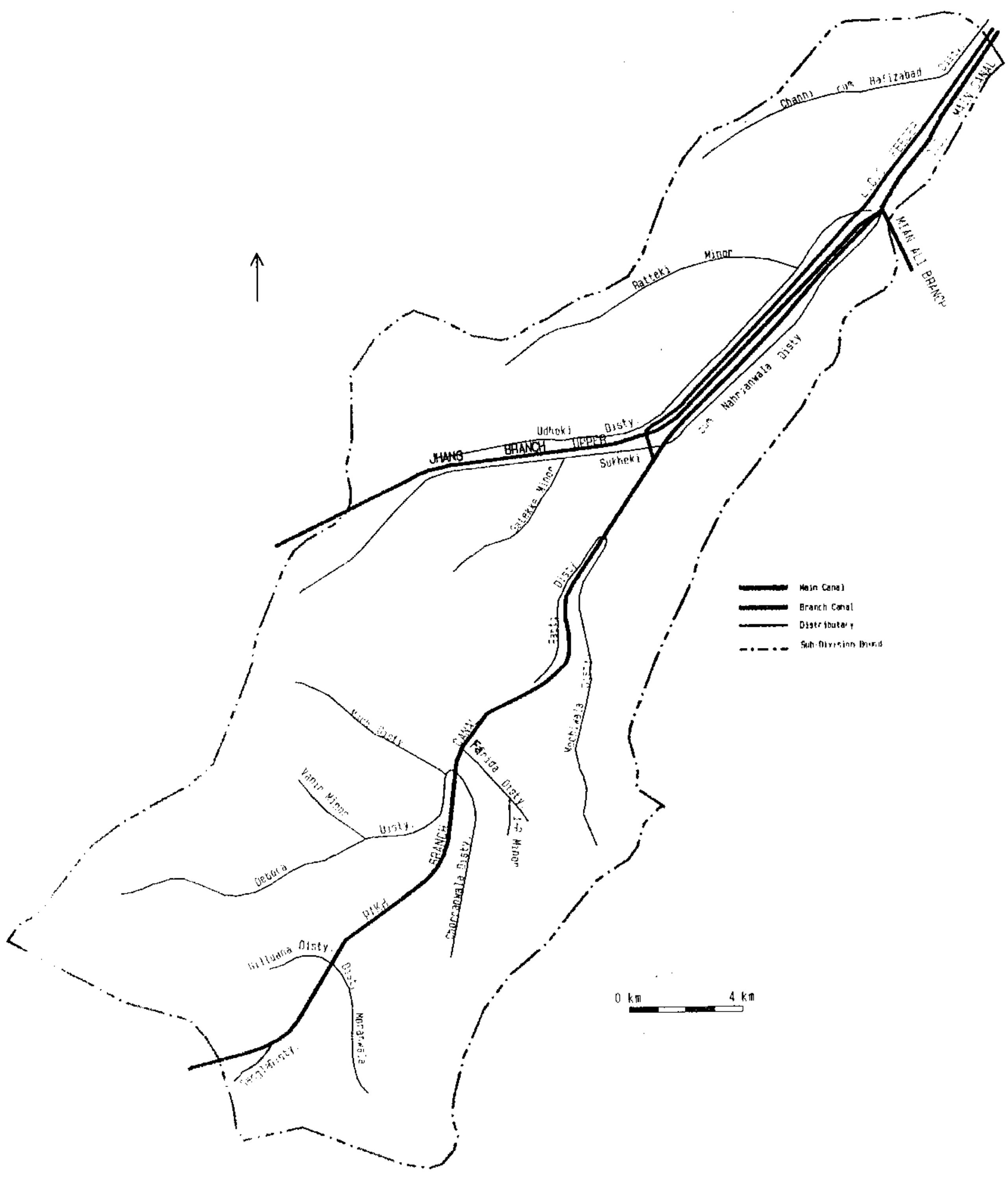


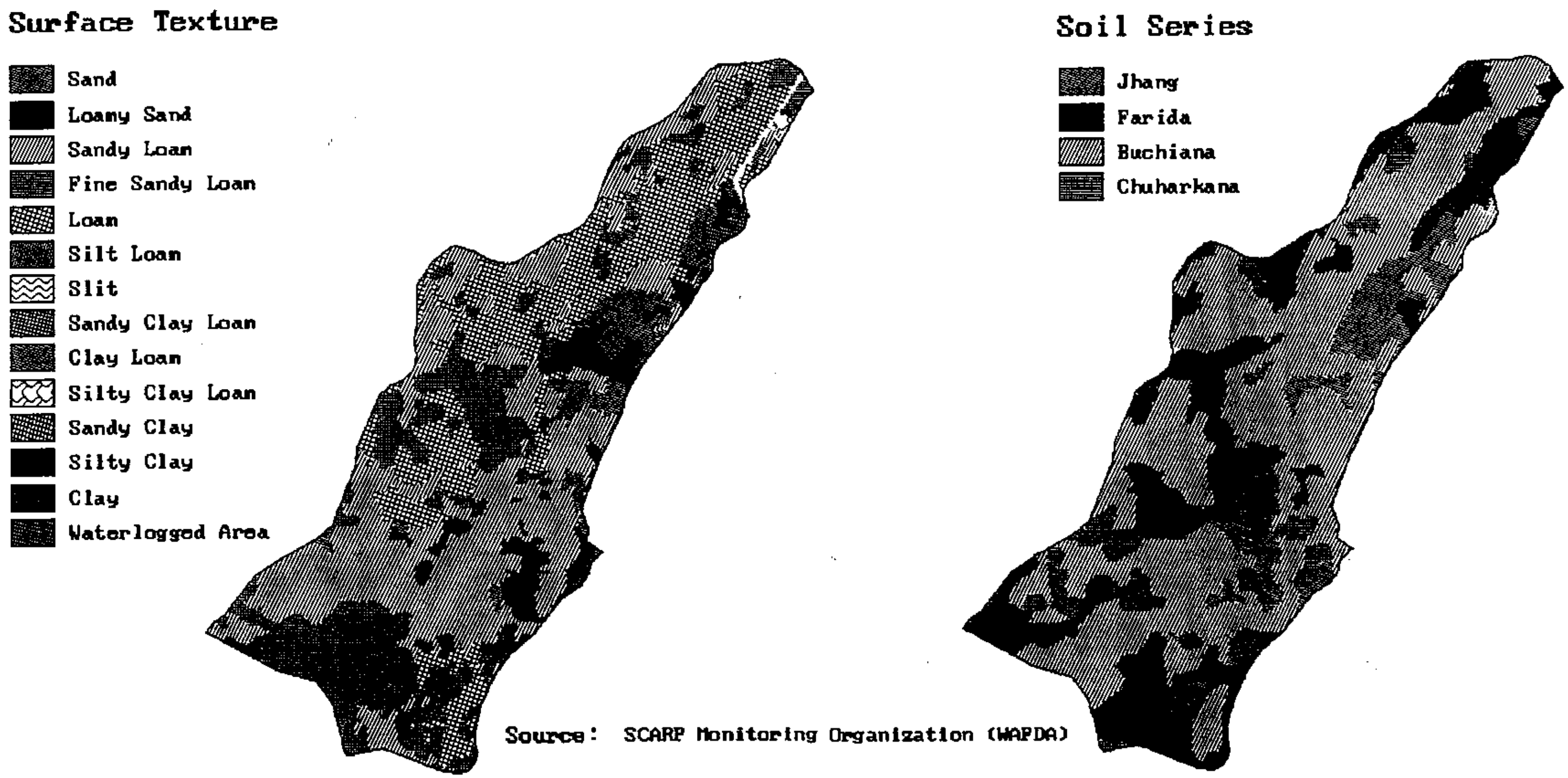

Figure 13(a) Sangla Irrigation Subdivision in the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

some measure from an enhanced level of surface supplies in addition to the extensive reliance on fresh groundwater pumpage.

*Soils*: The low topographic slopes within the Sangla Subdivision have been the major influence on the surface deposition patterns of the soils. From Figure 13(b), the medium textures of the Buchiana soils dominate the landform across the entire length of the Subdivision. The flattening of the topography towards the lower half of the system has significant manifestations for the still finer fractions of the Chuharkana series soils occuring in large patches. The SSoP intepretations also confirm the significance of these silty clay loams through the delimitation of the Gandhra and Gajiana associations known for their saline-alkali profiles (Figure 13(c)). In contrast, the more than 9 meters of difference in relief concentrated along a limited stretch beginning just below the Mian Ali Branch offtake has a significant presence of the coarse Jhang soils. However, notwithstanding these relief-specific textural differentiations, much of the observed homogeneity in surface and profile conditions is limited to the loams overlying the Buchiana series, that too mostly in the head and middle reaches of the system. This is additionally confirmed by the overlap of the Hafizabad, Bhalwal and Sindhwan series loams/silt loams with the dominating presence of the Buchiana soils.

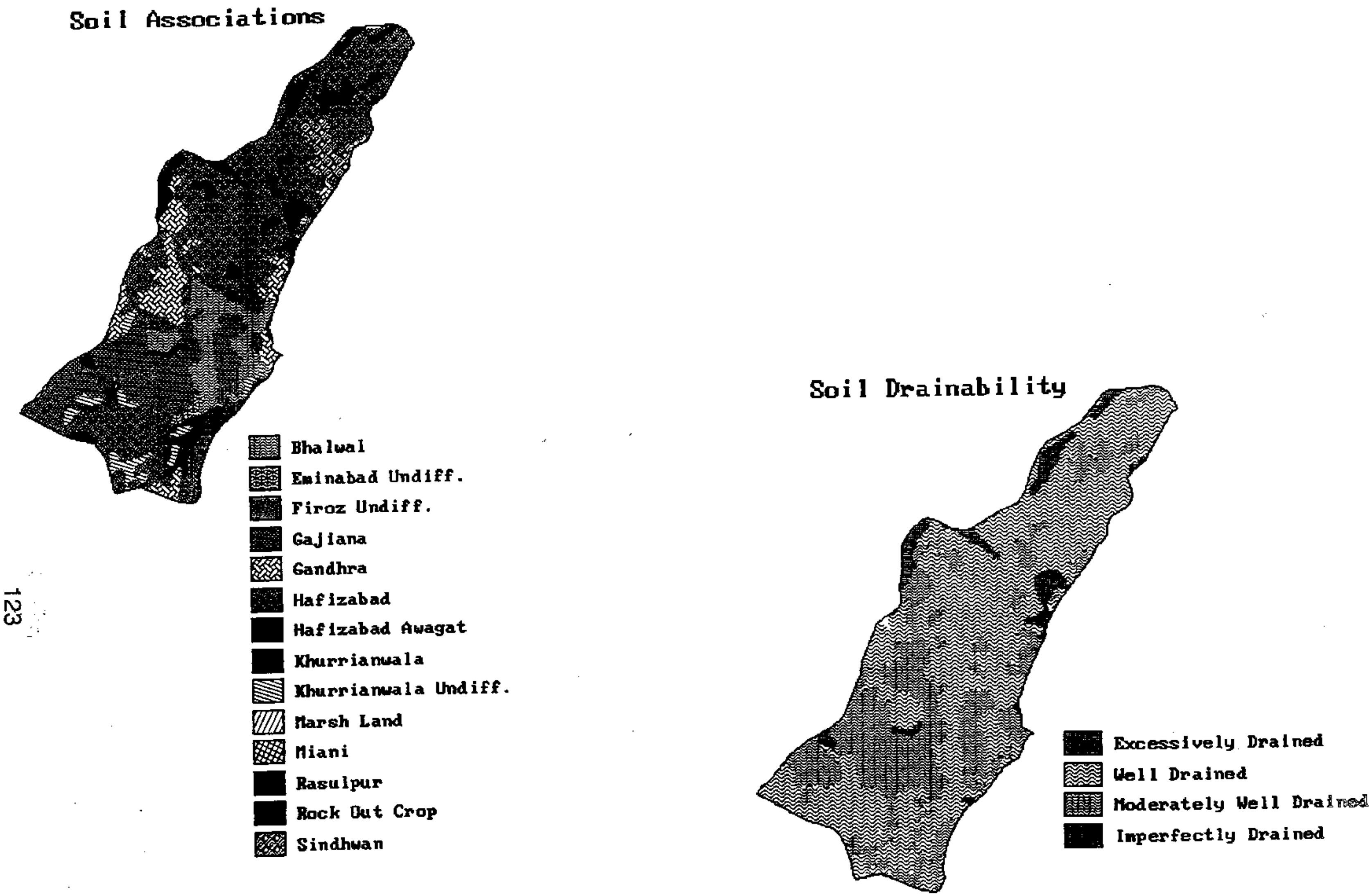
***Soil Drainability and Crop Suitability***: The above differentiations of the dominant soil textures in terms of the medium and moderately fine fractions readily translate into a well defined pattern of the vertical drainability within the Sangla Subdivision. Much of the upper half of the Subdivision remains a well drained environment; transitions to limited drainage occur in the downstream reaches of the system wherein the largely clayey soils with porous saline-alkali characteristics retard vertical movement of the water (Figure 13(c)). Assuming the Gandhra and Gajiana soils to be less damaging to the root zone, there is substantial potential within the Sangla Subdivision to uniformly exploit the cultivation of rice. The same assumption applied to the sugarcane crop would probably lead to the most dominating pattern of potential suitability amongst all the major crops (Figure 13(d)).

***Soil salinity and Waterlogging***: WAPDA MPR data on soil salinity indicates a significant presence of S4 level of salinization in the tail reaches of the Sukheki Distrbutary that parallels the Jhang Branch (Figure 13(e)). In large measure, much of the S3 and S4 levels of salinization are confined to the commands between the Jhang and the Rakh branches that have significant overlap with the Gandhra and Gajiana soils. Overlap also exists with the Khurrianwala saline soils identified by the SSoP along the parallel length of the Rakh and Jhang branches and with the silt loams of the Sindhwan and Bhalwal associations in the commands of the Ratti and Mochiwala distributaries on either side of the Rakh Branch. This rather extensive pattern of surface salinization has a strong bearing on the extent of salt accumulation in the profile. Data indicates increasing evidence of sodicity affecting the root zone. In places of extensive surface salinization, the profiles are exclusively sodic. Probably the worst affectation is near the tail reaches of the system in the area buttressed between the commands of the Debora and Marh distributries, an area exclusively having silty clay loams of the Gajiana soils.




Source: SCARP Monitoring Organization (WAPDA)

Figure 13(b) Surface and Profile Texture of the Soils in the Sangla Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: Soil Survey of Pakistan

Figure 13(c) Associative Classification of the Soils and their Drainability Characteristics the Sangla Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

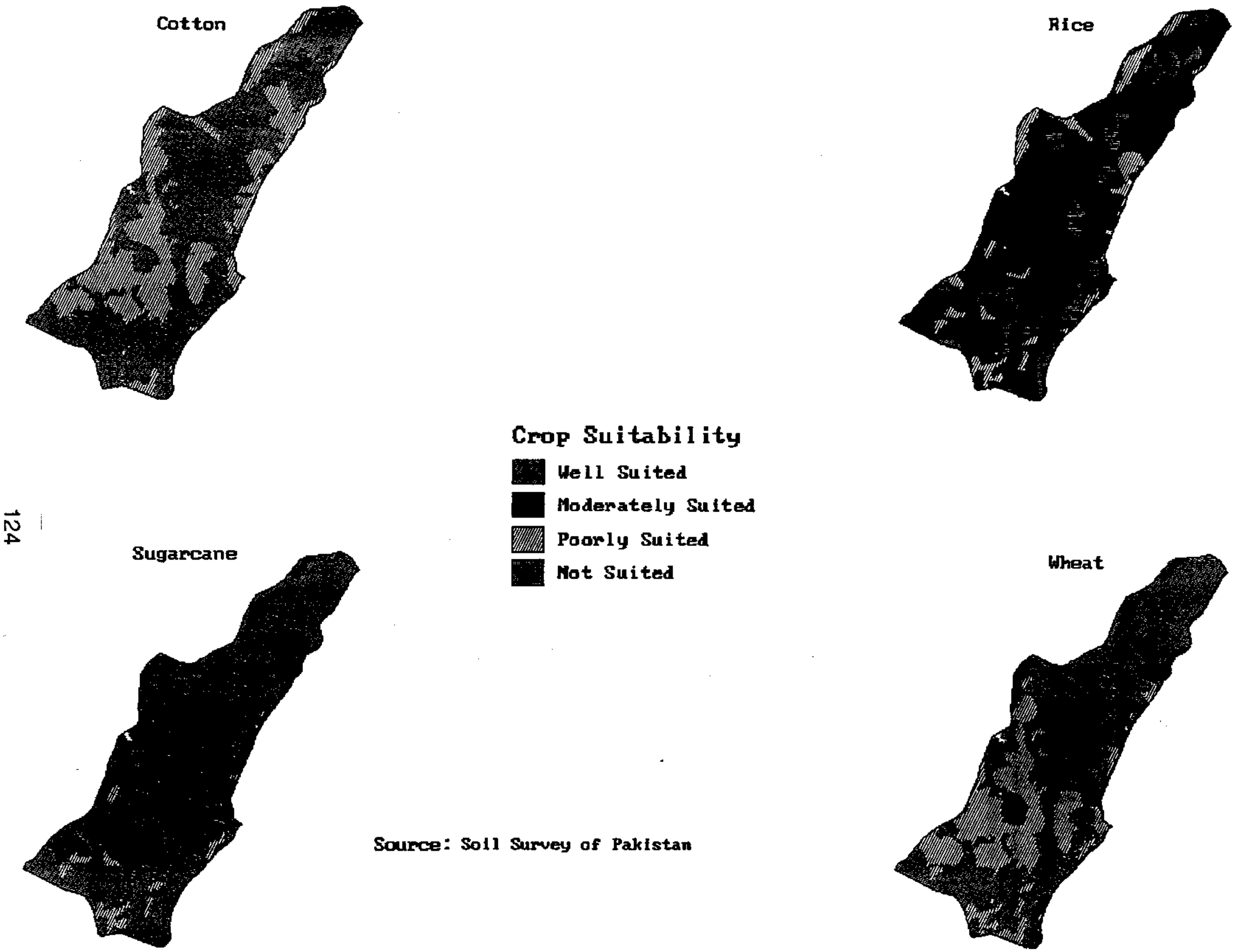



Figure 13(d) Soil Suitability for Major Crops in the Sangla Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

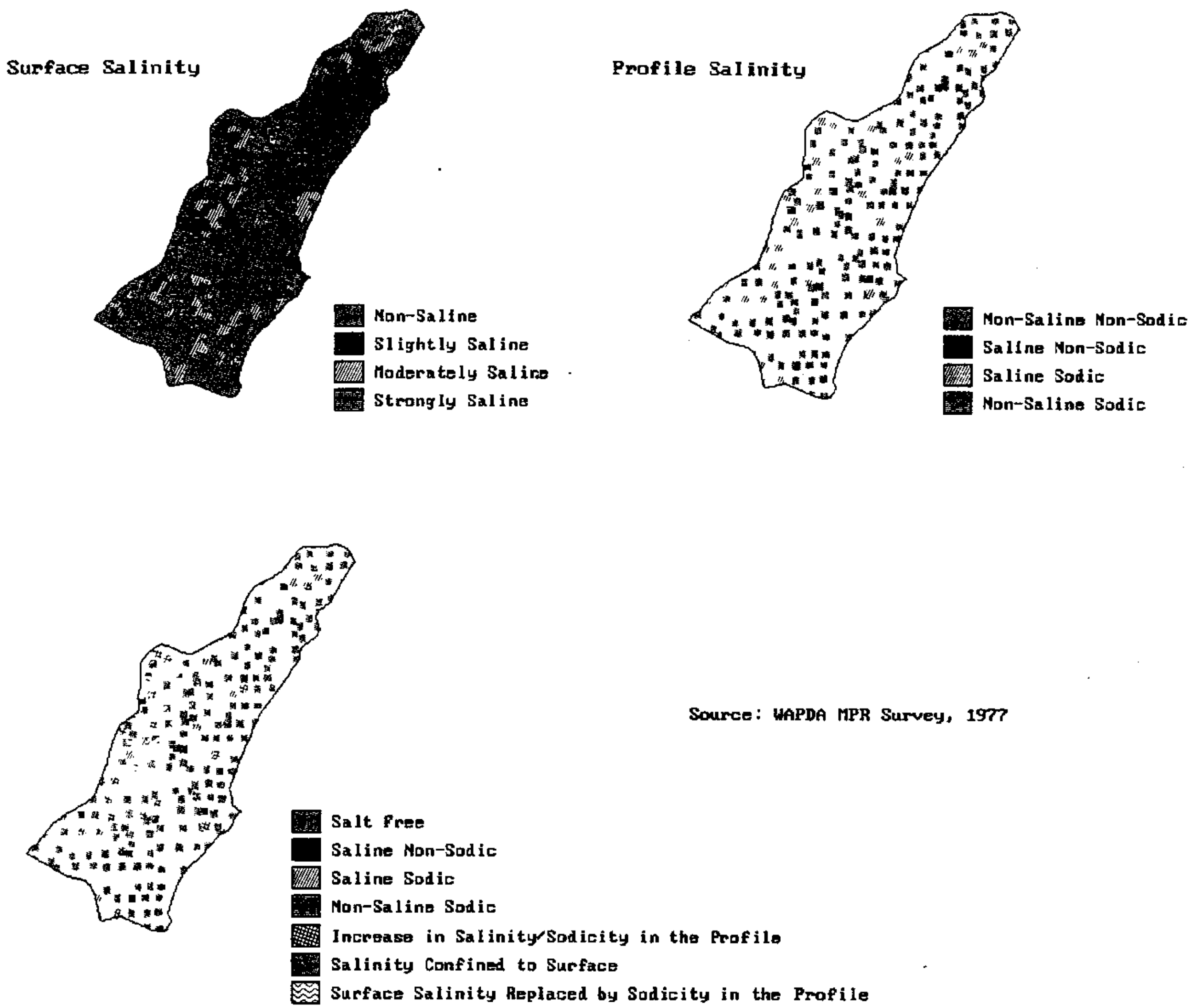



**Figure 13(e)** Surface and Profile Salinity in the Sangla Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

The temporal records on seasonal fluctuations in the subsurface water levels indicate that the conditions have improved significantly since the near waterlogged situation in the 1980s (Figure 13(f)). Over a period of thirteen years, the recurrent rise has had a waning presence in the head reaches of the system and the emphasis now seems to have been largely confined to the lower half. Additionally, there is no reccurrence of the situation wherein the water levels would actually enter the root zone and create surface ponding. In fact, limited instances of decreasing water levels may actually be suggesting groundwater pumpage coincident with the October period of kharif water shortages. There is supporting evidence to this effect within the subsurface slope variations observed for the Sangla Subdivision. From Figure 13(g), there are numerous pockets in the middle and tail reaches that show flow disturbances across a regime largely characterized by near constant water levels or unchanging slopes.

***IIMI Sampling for Soil Salinity and Texture***: There were only four sample sites within the Sangla Subdivision that were evenly distributed in the middle and tail reaches of the system. These areas, comprising 3,322 ha, were chosen specifically in those areas that were known to have a strong occurrence of the saline-sodic soils based on the past investigations by both the SSoP and WAPDA. The initial conclusion from these public sector investigations is that soil salinity is a widespread phenomenon within the Sangla Subdivision and much of it is synonymous with the distribution of the fine soil textures in the downstream reaches of the system. Interestingly, IIMI's own surveys in these areas do not confirm the intensity of the salinization reported by these investigations; the over 500 sample observations of texture related salinity showed more than 90% of the land to be non-saline. Somewhat more surprising is the fact that no S3 or S4 levels of salinization were recorded in areas previously mapped for rather extensive tracts of surface visible salinity, e.g. the tail command of the Sukhekhi Distrbutary. Elsewhere, such as the tail of the system and very near the exit point of the Rakh Branch, slight to moderate incidence of root zone salinization has been observed (in barren lands adjacent to the cultivated tracts) where previously there was none (Figure 13(e)). The textural composition of these saline observations is given in Figure B11, Volume Four, wherein the loams are owed to the Hafizabad/Hafizabad-Awagat associations with significant spatial overlap with the Buchiana soils in the two meter profile. The sandy clay loams may have resulted from the scatters of the Gandhra association that are not explicitly captured by the mapping provided by the SSoP under Figure 13(c). The secondary land use within the ploughed, fodder and oilseed categories is mostly limited to moderately coarse to medium textured soils where even moderate levels of salinization are not damaging to the extent as they would be for a grain or cash crop. Figure C11 captures these land use-specific textural preferences much more clearly in the context of the higher consumptive use crops like rice and sugarcane that are dominantly cultivated over the less porous silty and sandy clay loams.

Note: Due to the inadequate sampling of farm holdings within the Sangla Subdivision, the discussion on the salient features of the farming has been omitted.

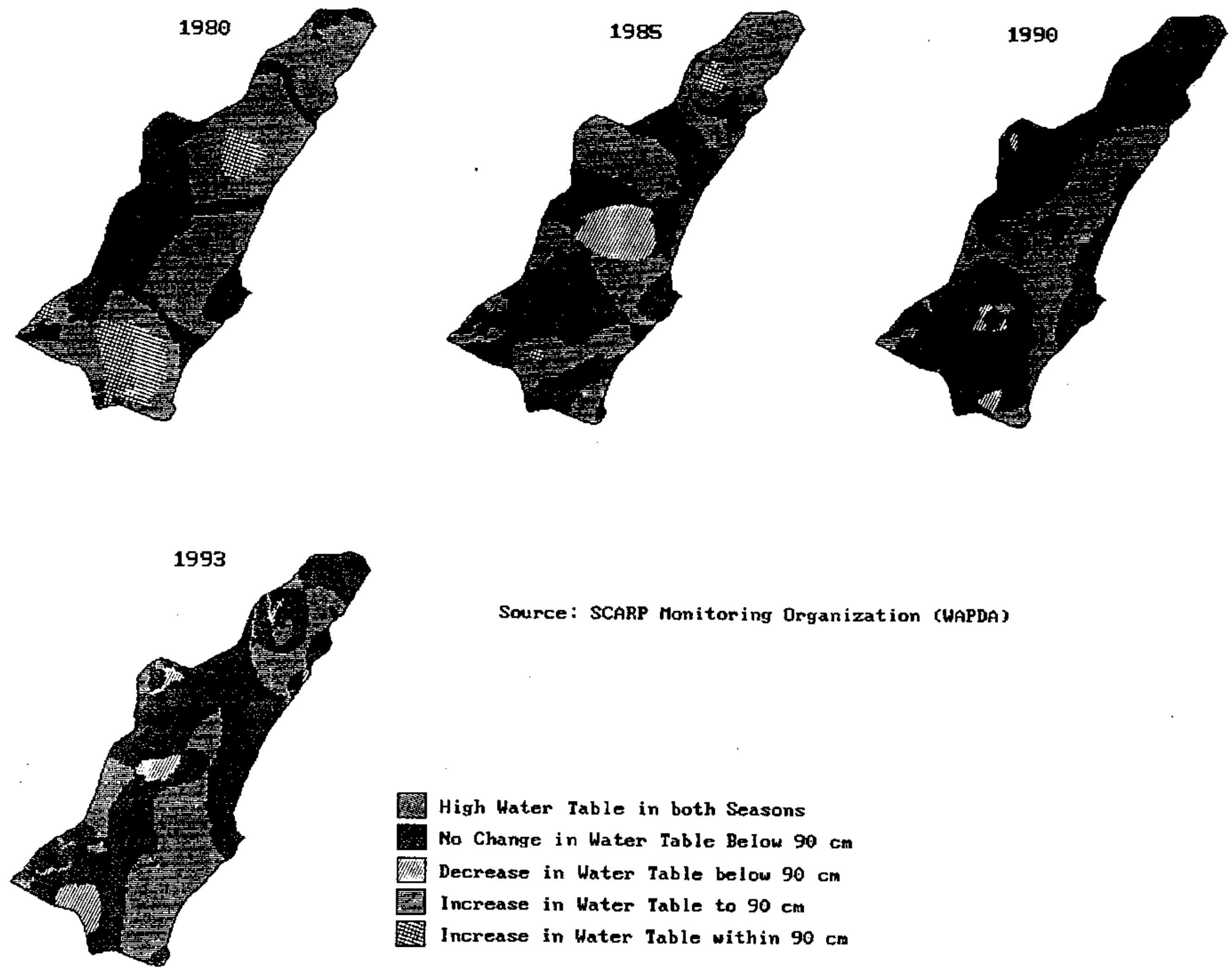



Figure 13(f) Temporal Variations in the Depth to Water Table, Sangla Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

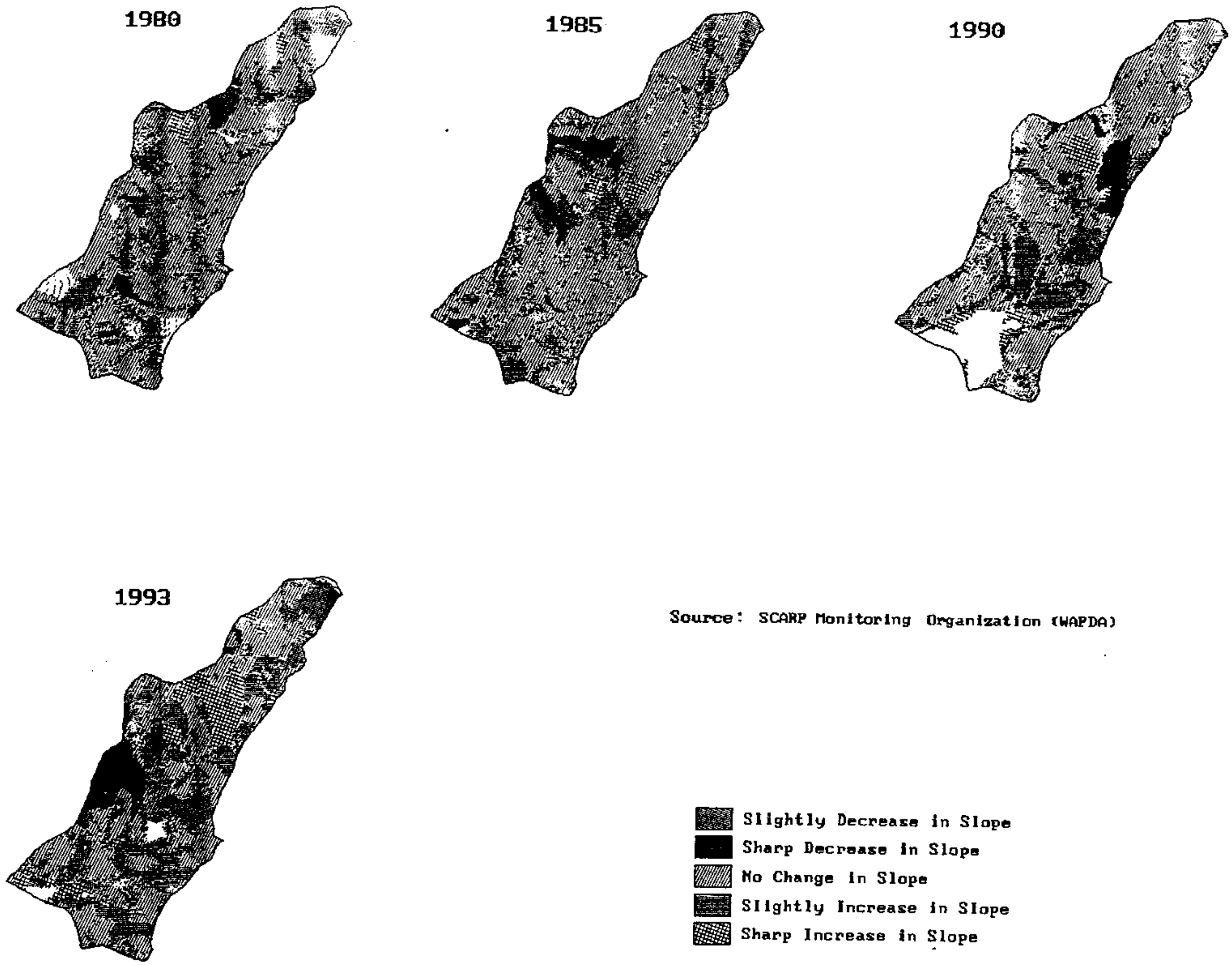



Figure 13(g) Interseasonal Slope Variations in the Subsurface Flows, Sangla Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

## M. Sultanpur Subdivision

*Hydrologic Regime*: The Sultanpur Subdivision has the second smallest gross and cropped area after Sangla and is commanded by the Burala Branch that has its tail in the head reach of this Subdivision (Figure 14(a)). The Subdivision has the lowest number of tertiary level commanded units within the entire LCC and Haveli system, however the relatively flat slopes, at an average of 0.00028 across the more than 60 km length of the Subdivision, permit a comparatively higher average for the cultivated area watercourse commands. The long and narrow shape of the Subdivision allows for high densities of the distribution system and, from Figure 1(b), the aggregate water allowance is also near the observed maximums within the LCC. This is also reflected in Figure 1(d) wherein the observed cropping intensities are the highest anywhere in the LCC system.

*Soils*: The alignment of the Sultanpur Subdivision parallel to the Ravi River reflects the characteristic depositional pattern of the flood plain soils (Figure 14(b)). The medium textures of the Buchiana series predominate the system reaches close to the river; areas further to the west comprise the coarser Farida series soils where soil homogeneity in both surface and profile textures is much more apparent. Other than this east-west differentiation, the head reaches of the system have large aggregations of medium textures in the profile. The SSoP interpretations of the saline-alkali soils belonging to the Jhakkar Undifferentiated and the Hafizabad-Jhakkar associations are mostly limited to the tail portions of the system and match the loams/silt loams in the surface texture mapping by WAPDA (Figure 14(c)). Across the geographical extreme, the command of the Kalera Distributary in the head reach of the system comprises the medium textured Shahdara Undifferentiated Group. In between these extremes, there is an unbroken expanse of the deep calcareous Sultanpur silt loams occupying the high and level areas along the flood plain.

*Soil Drainability and Crop Suitability*: Other than the abovementioned scatters of the saline-alkali soils characterized by imperfect drainage, the continuum of the medium to moderately coarse-soil textures in Subdivision represent a well drained environment. The Sultanpur silt loams make this Subdivision particularly suitable for all of the major crops (Figure 14(d)).

*Soil Salinity and Waterlogging*: The tail of the Subdivision represents a locational concurrence in the extents of surface salinization mapped by WAPDA and the earlier investigations by the SSoP. WAPDA's aerial photo interpretations show these contiguous extents to be of S2 and S4 classes that are underlain by saline-sodic and non-saline sodic profiles (Figure 14(e)). This occurrence, to a much lesser extent, is repeated in the center of the Subdivision where soils of the Jhakkar Undiffernetiated Group mix with the S2 and S4 categories of salinity. The evidence from the profile sampling indicates higher levels of saline-sodic salts in the profile across the entire Subdivision except for the areas in the head reaches of the system bordering the river. From Figure 14(f), these salt accumulations are unlikely to have been caused by high water levels; the situation in the tail reaches indicates these fluctuations to have been significant enough to impact the root zone.

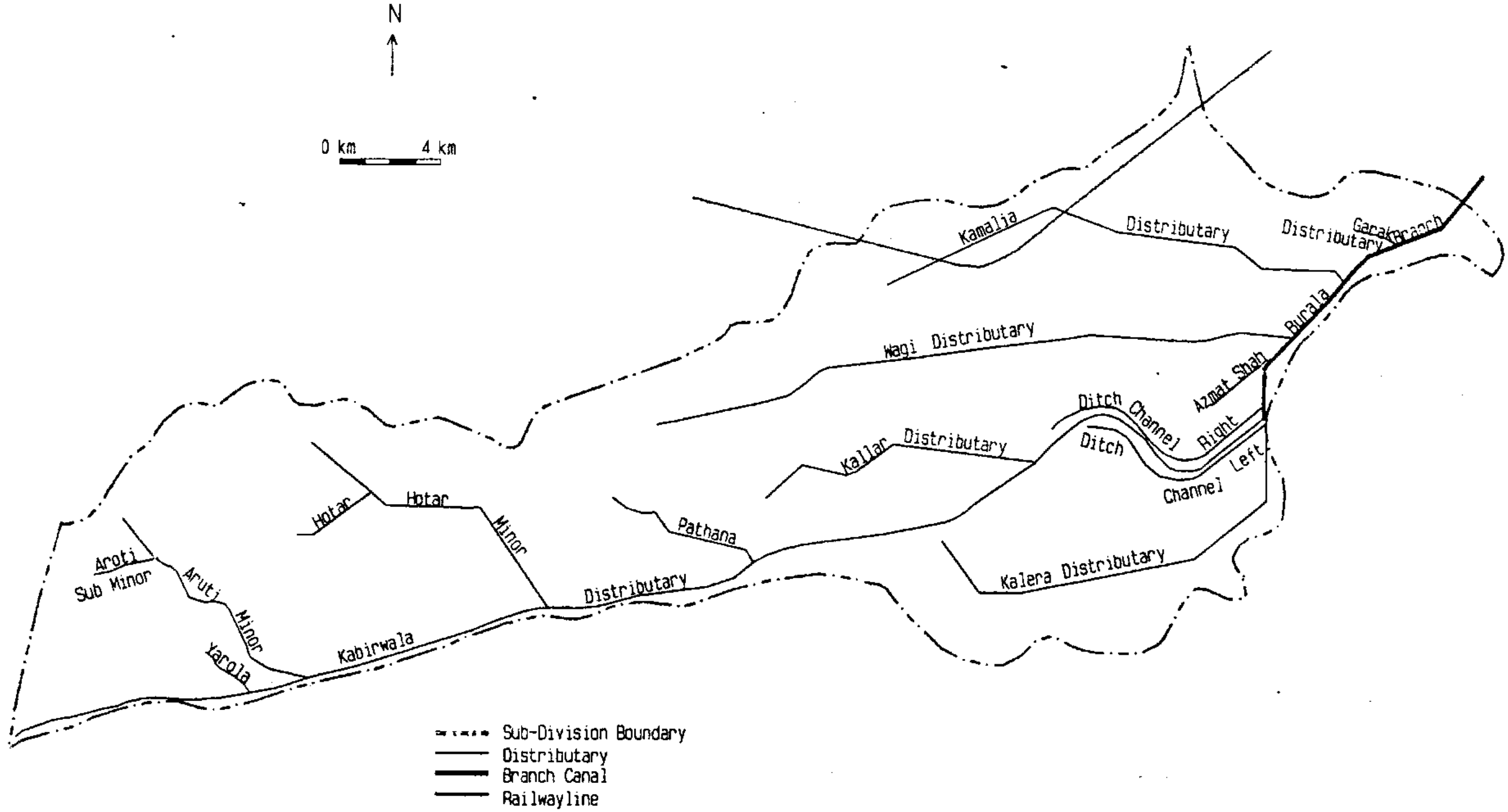
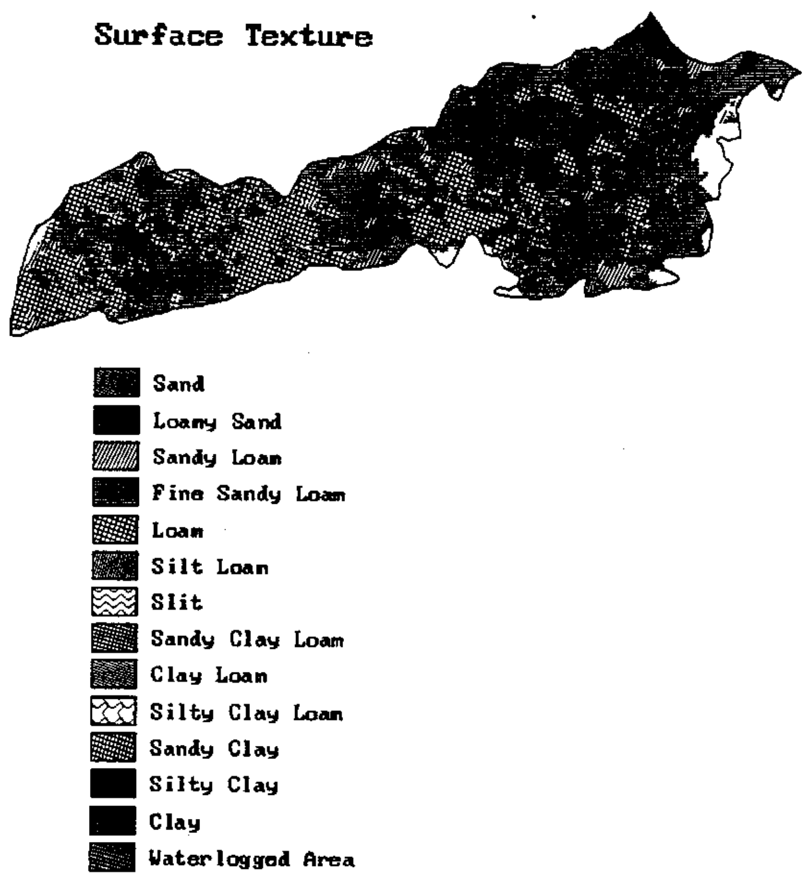
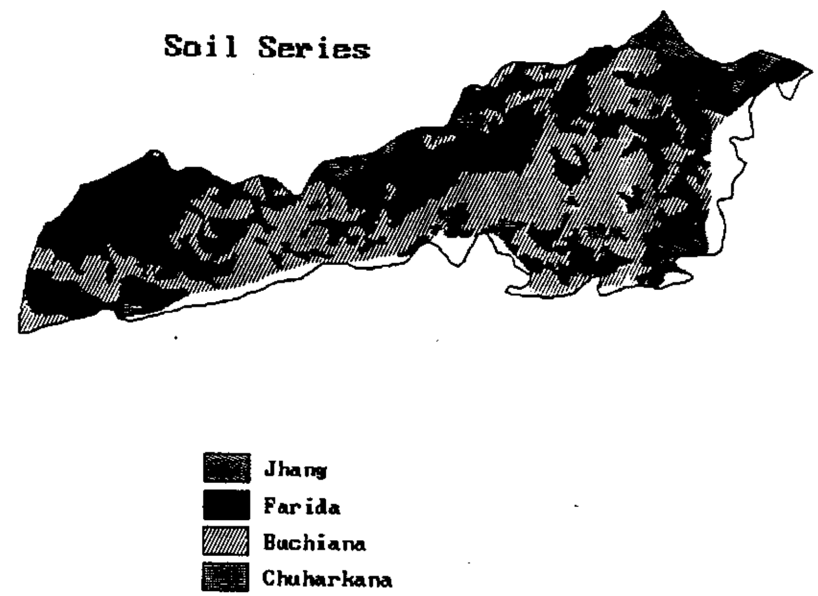


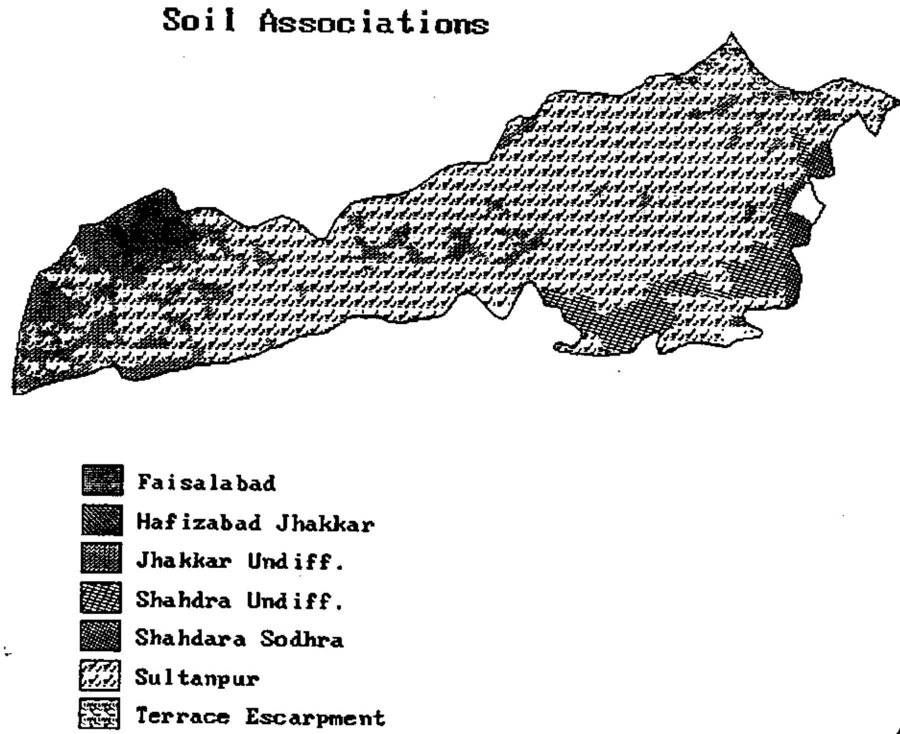

Figure 14(a) Sultanpur Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 14(b) Surface and Profile Texture of the Soils in the Sultanpur Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: Soil Survey of Pakistan

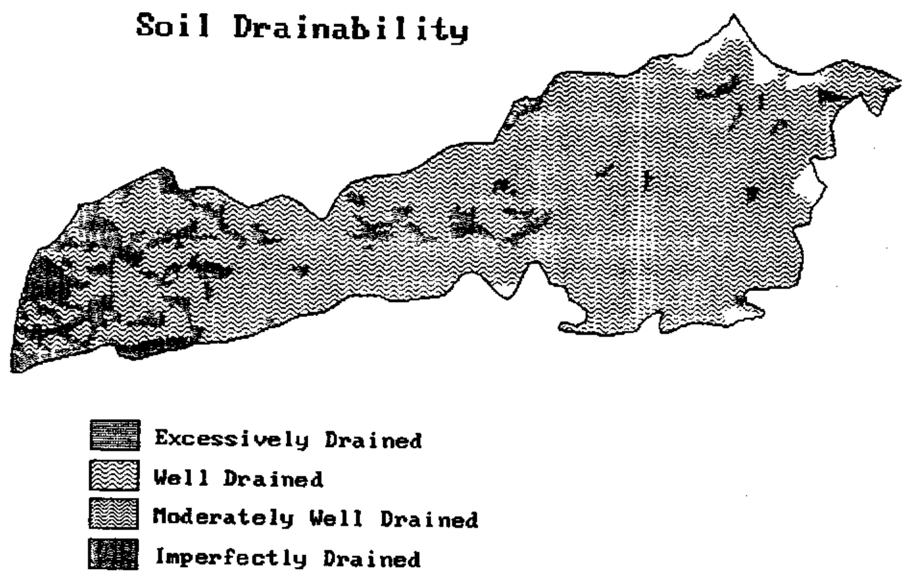
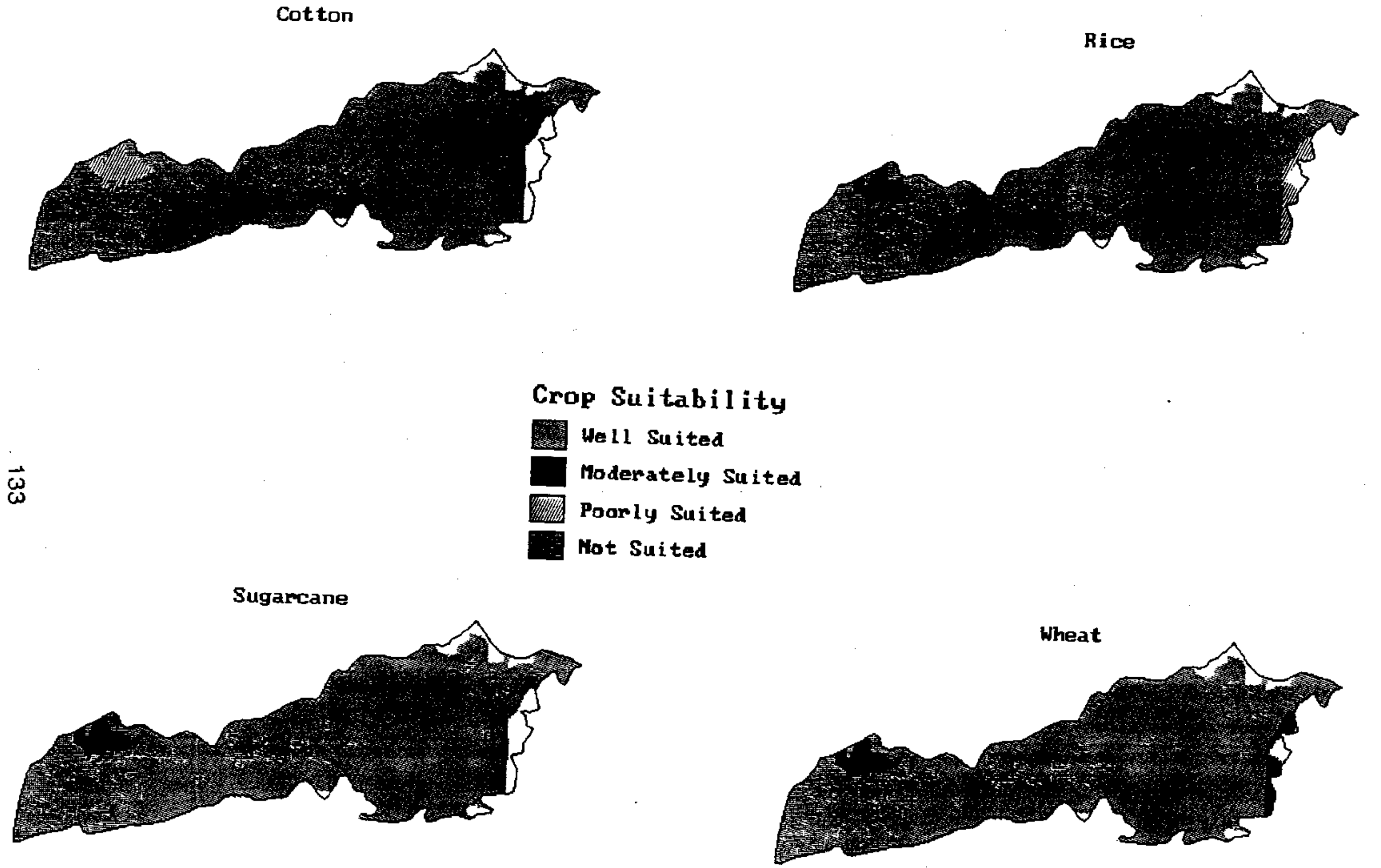



Figure 14(c) Associative Classification of the Soils and their Drainability Characteristics the Sultanpur Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: Soil Survey of Pakistan

Figure 14(d) Soil Suitability for Major Crops in the Sultanpur Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

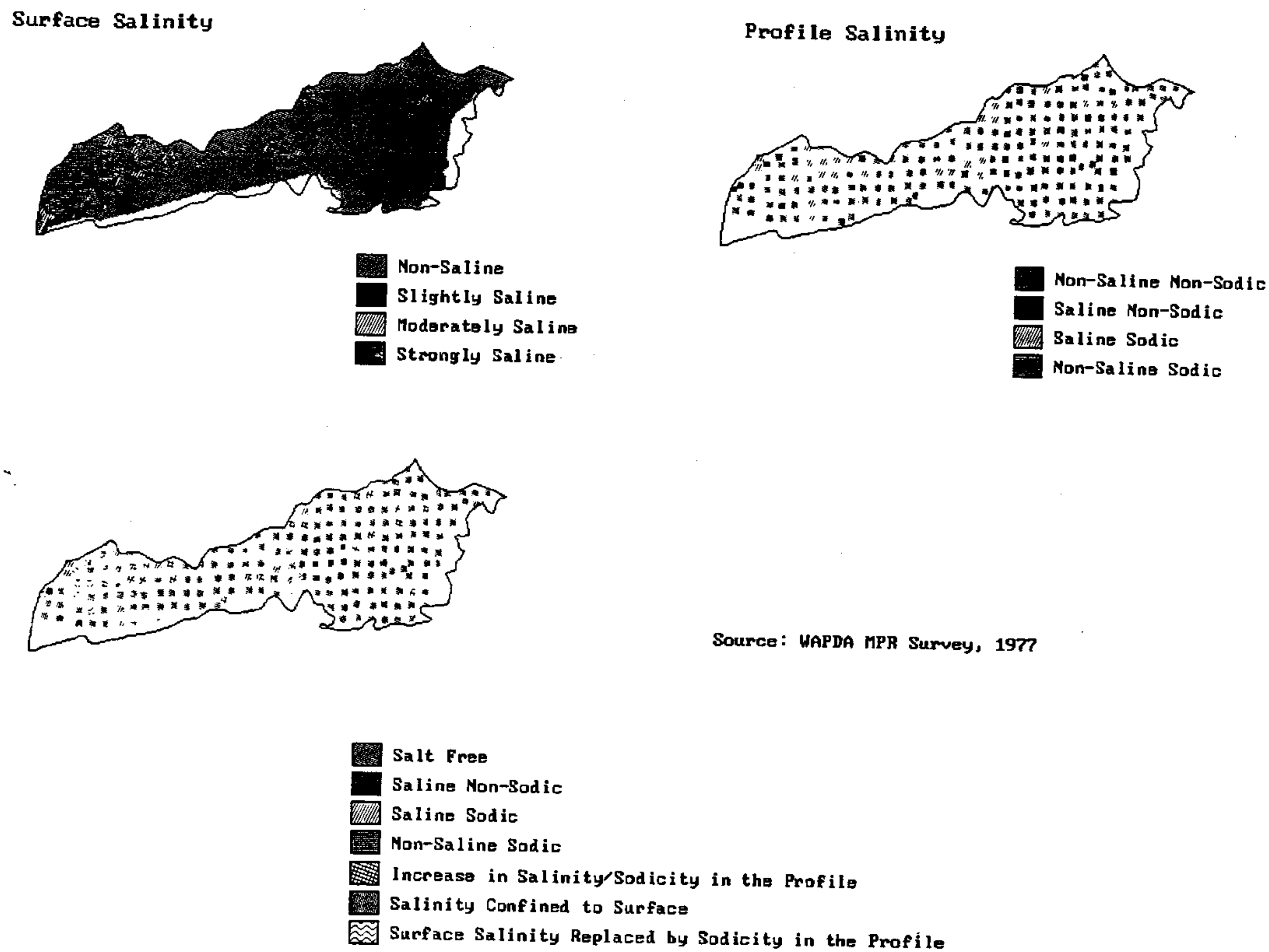
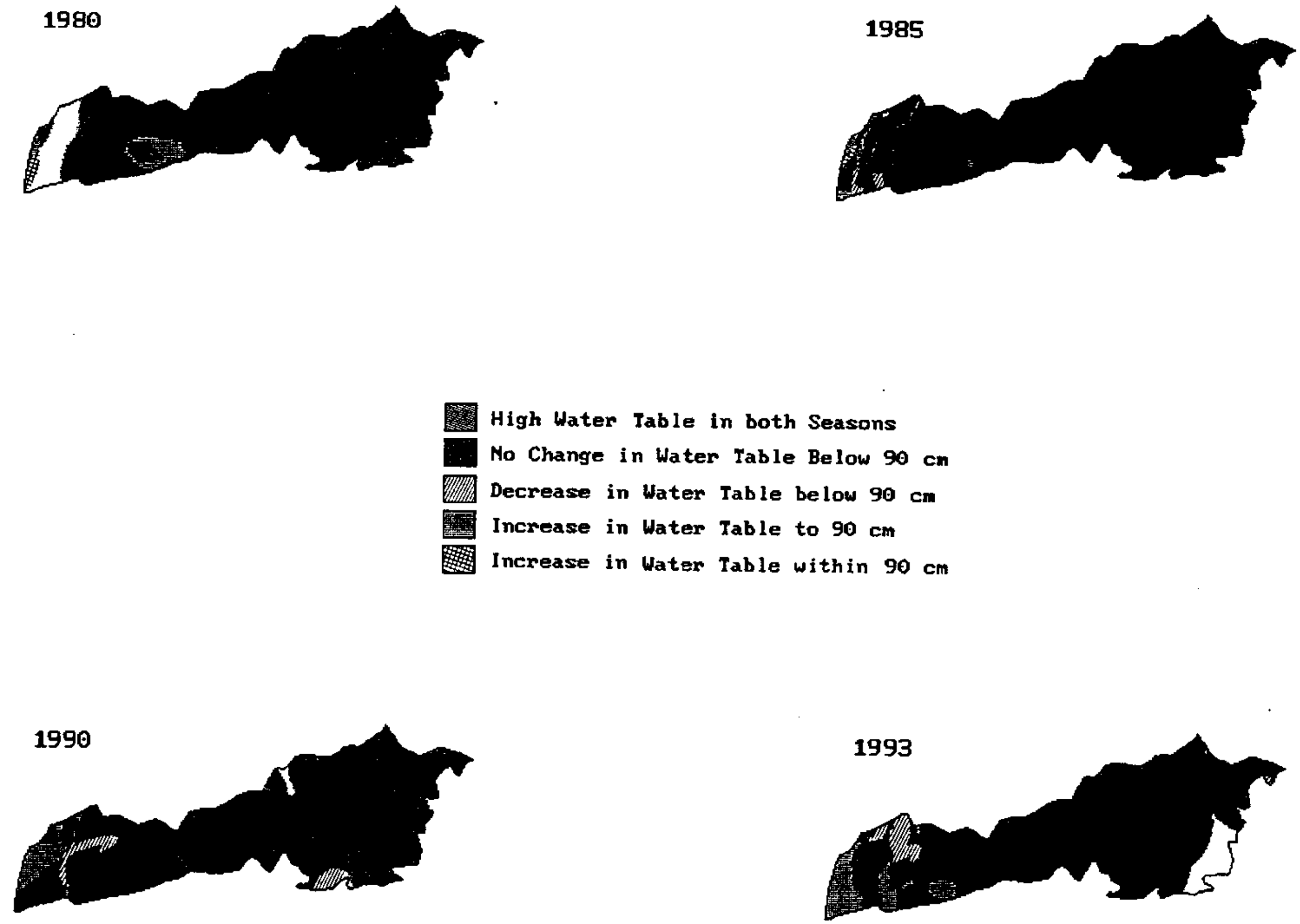



Figure 14(e) Surface and Profile Salinity in the Sultanpur Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organisation (WADPA)

Figure 14(f) Temporal Variations in the Depth to Water Table, Sultanpur Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

***IIMI Sampling for Soil Salinity and Texture***: The three sample sites covering nearly 3,200 ha were exclusive to the tail portions of the Subdivision where the reported incidence of soil salinization was higher. Although this level of sampling would be considered inadequate, given the lack of spatial coverage and biased distribution across the Subdivision, the 222 paired observations of salinity give a broad indication of the most likely trends in the context of the salinity-texture relationships. Based on Figure B12, Volume Four, the dominating textures of the top soil in the sampled areas are of medium to moderately fine categories that are nearly 80% non-saline. There were no recorded values belonging to the strongly saline S4 class. There is a distinct preference for sugarcane on the silty clay loams, whereas cotton cultivation is favored more for the medium textures. The cultivation of rice takes advantage of the slightly saline loams/silty clay loams, a situation not found in similar textural combinations across the ploughed/fallow land use.

Note: Due to the limited (six) number of farms sampled in the Sultanpur Subdivision, the discussion on the salient features of its farming regime has been omitted.

## N. Tandlianwala Subdivision

***Hydrologic Regime***: The Tandlianwala Subdivision is the first of the three subdivisions in the command of the Burala Branch that offtakes from the main Lower Gugera Branch at Buchiana Head (Figure 1(a) & 15(a)). The irrigation network is well distributed within the Subdivision comprising 439 watercourses. In terms of both gross and commanded area, it is the fourth largest subdivision within the LCC and Haveli system. The surface water allowances for this commanded regime are comparable to the highest observed elsewhere for the Kot Khuda Yar and Wer subdivisions, but with two important differences; first, in comparison to these subdivisions, the proportion of commanded regime within Tandlianwala is the highest. Secondly, this is being accomplished with the lowest density of the secondary level distribution amongs the three subdivisions (Table 1). The resultant effect of these higher surface irrigation supplies is clear from Figure 1(d) whereby the Tandlianwala Subdivision shows one of the highest cropping intensities within the LCC system..

***Soils***: The textural separations under the moderately coarse soils of the Farida series are the most significant phenomenon across the Tandlianwala Subdivision (Figure 15(b)). These soils are overwhelming in the lower half, and elsewhere retain large extents in combination with the Jhang (head reaches), Buchiana (middle reaches) and Chuharkana series. The surface textures are complementary to these conditions in the profile wherein loamy sands/sandy loams/fine sandy loams correspond to the spatial distribution of the Farida soils and the loams/silt loams overlie the medium textured Buchiana soils.

The significance of a dominant textural class/group in the Tandlianwala Subdivision is also reflected in the SSoP mapped interpretations showing the Faisalabad silt loam as a contiguous mass that extends across the entire system (Figure 15(c)). It is only in areas along the eastern boundary of the Subdivision, and partially paralleling the Ravi River, that

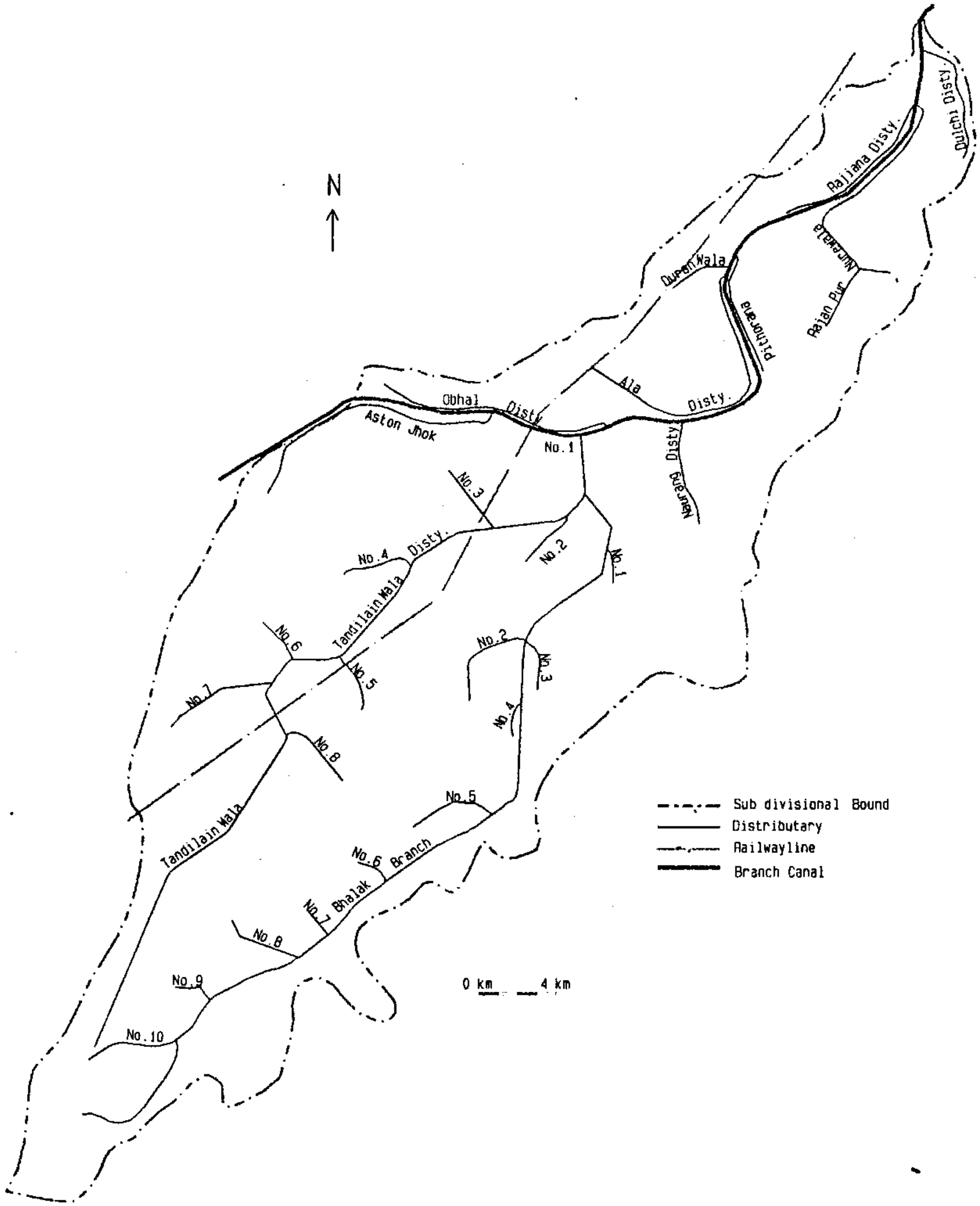



Figure 15(a) Tandlianwala Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

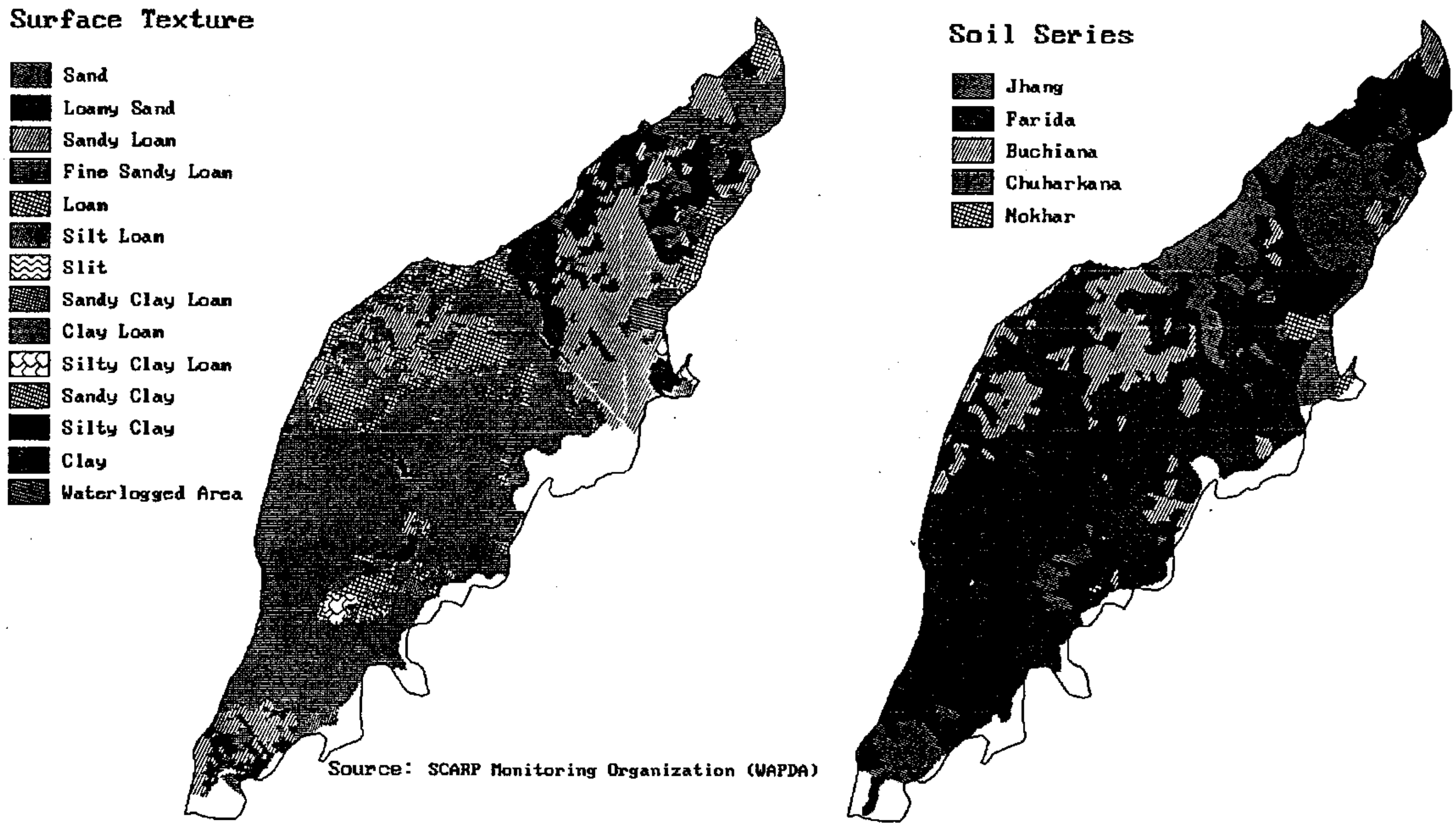



Figure 15(b) Surface and Profile Texture of the Soils in the Tandlianwala Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

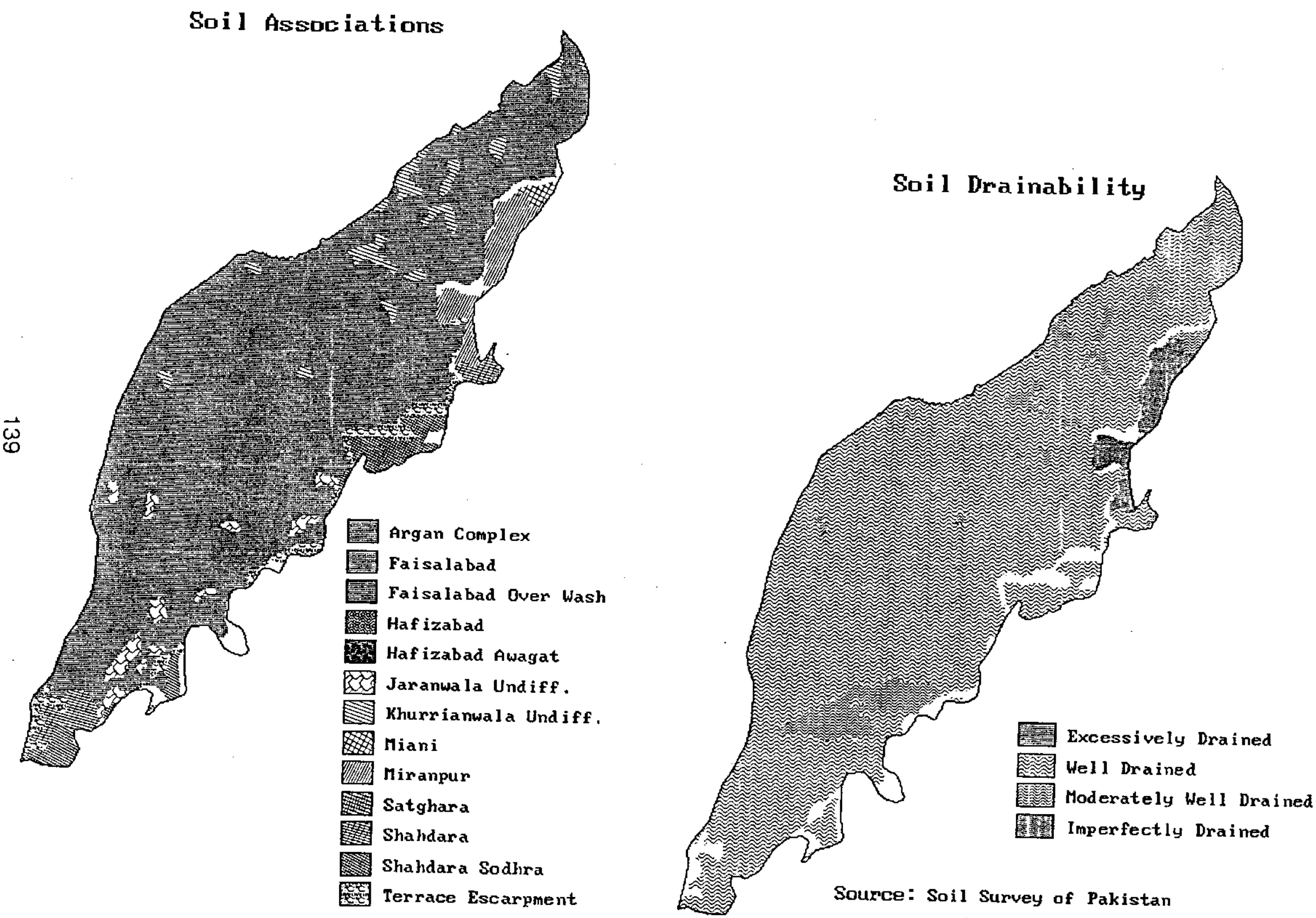



Figure 15(c) Associative Classification of the Soils and their Drainability Characteristics the Tandlianwala Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

other textural combinations occur under Shahdara/Shahdara-Sodhra and Miranpur associations. In places, like the tail of the system, the coarser textures of the Shahdara-Sodhra and the Shahdara association (that are underlain by sand within two meters) overlap with the moderately coarse Farida soils in the profile. In the head reaches, the alkaline soils of the Khurrianwala Undifferentiated Group are shown to exist in soils previously interpreted by WAPDA to be coarser fractions of the Jhang series that are also loamy sand to sandy loam in the surface. For these soils to have been affected by a severe degree of alkalinity reflects significantly in the discrepancies borne out by the comparison of these data sets from two different Government agencies. Elsewhere, in the lower reaches of the system, the lateral extension of the loams/silt loams/silty clay loams in the surface is supported by the SSoP delimitation of the Faisalabad silty clay loam overwash that is specific to areas bordering the Ravi River.

*Soil Drainability and Crop Suitability*: Because much of the Subdivision is underlain by the moderately coarse aggregates belonging to the sandy loam and fine to very fine sandy loam, these soils retain a well drained profile (Figure 15(c)). The few areas corresponding to the Faisalabad silty clay loam overwash and the clayey Miranpur association (that is spatially coincident with the Chuharkana and the Nokhar soil series in the profile) have restricted drainage conditions that are particularly suited to growing rice. Other than these limited domains favorable to the growth of high delta crops, the overwhelming expanse of the porous soils within the Tandlianwala Subdivision offer conditions that are well suited for large scale cultivation of cotton, sugarcane and wheat (Figure 15(d)).

*Soil Salinity and Waterlogging*: WAPDA's MPR survey data indicates Tandlianwala Subdivision to be largely free of the effects of visible surface salinization (Figure 15(e)). The few areas reported to be saline-sodic in the surface and profile are limited to the fine textured soils of the Chuharkana and Nokhar series. Elsewhere, the scatter of saline-sodic profiles in the center and near the western boundary of the Subdivision corresponds closely with the medium textures of the Buchiana soils with loams/silt loams in the top soil. A majority of these saline-sodic samples confirm the earlier mapping of the same by the SSoP in the context of the strongly saline-alkali Khurrianwala Undifferentiated Groups, meaning that these areas have remained uncultivated/barren in the time period between the two independent public sector surveys.

From Figure 15(f), historical data on interseasonal fluctuations in the water table indicates a near absence of conditions adversely impacting the root zone. Since the water tables remain well below the ground surface, the variations in the subsurface slope, though indicative of obstructions/interventions to the natural lateral flow regime, become largely insignificant. This phenomenon is shown separately under Figure 15(g) where the low subsurface levels in the head reach of the Bhalak Branch experience recurrent decreases in the lateral flows. In situations where the water levels are within the root zone, such as in the tail reach of the system, the corresponding decrease in the subsurface outflows is quite evident. There is some degree of spatial consistency in the recorded rise of water levels near the root zone along the western boundary of the Subdivision; this is likely caused fig.

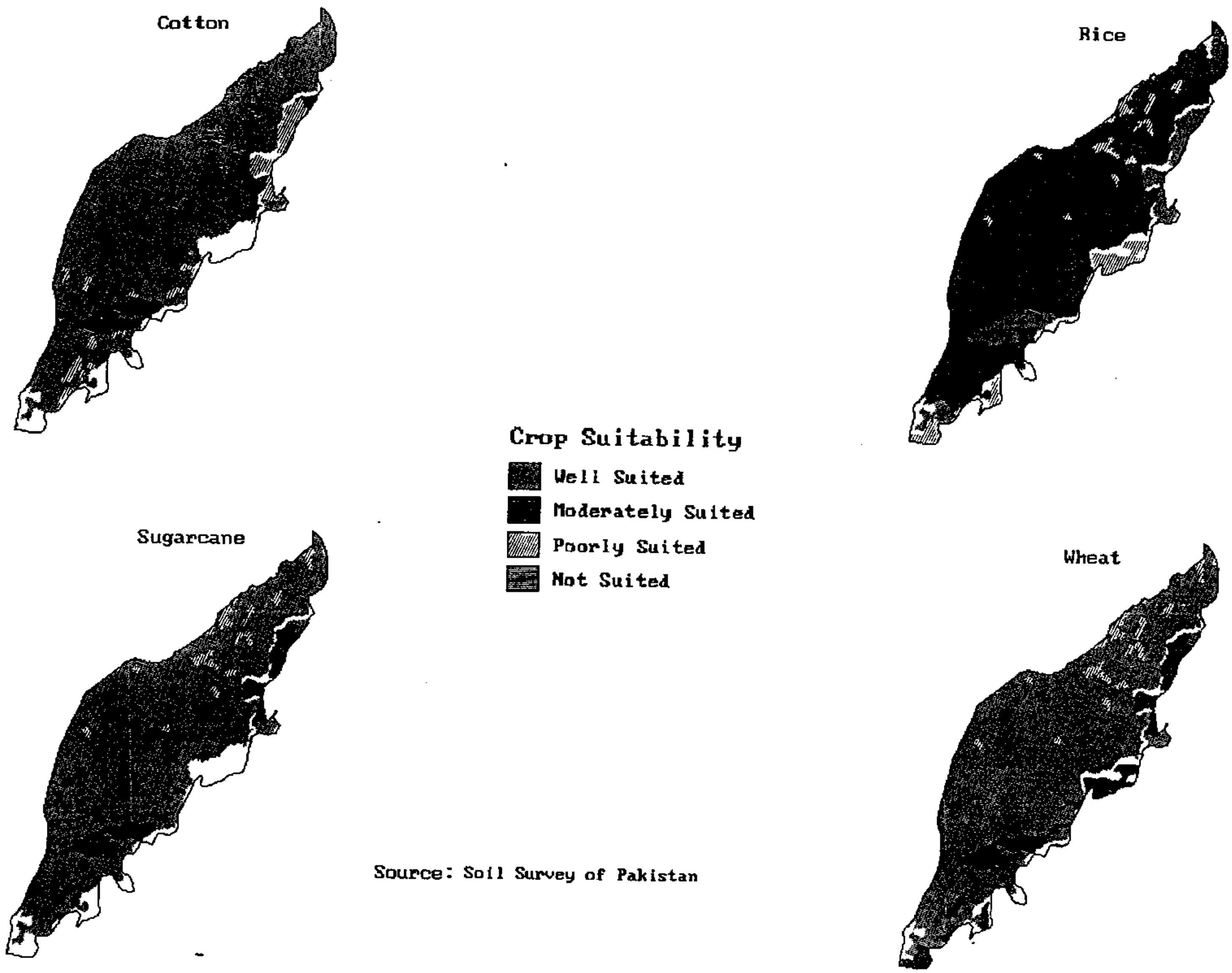
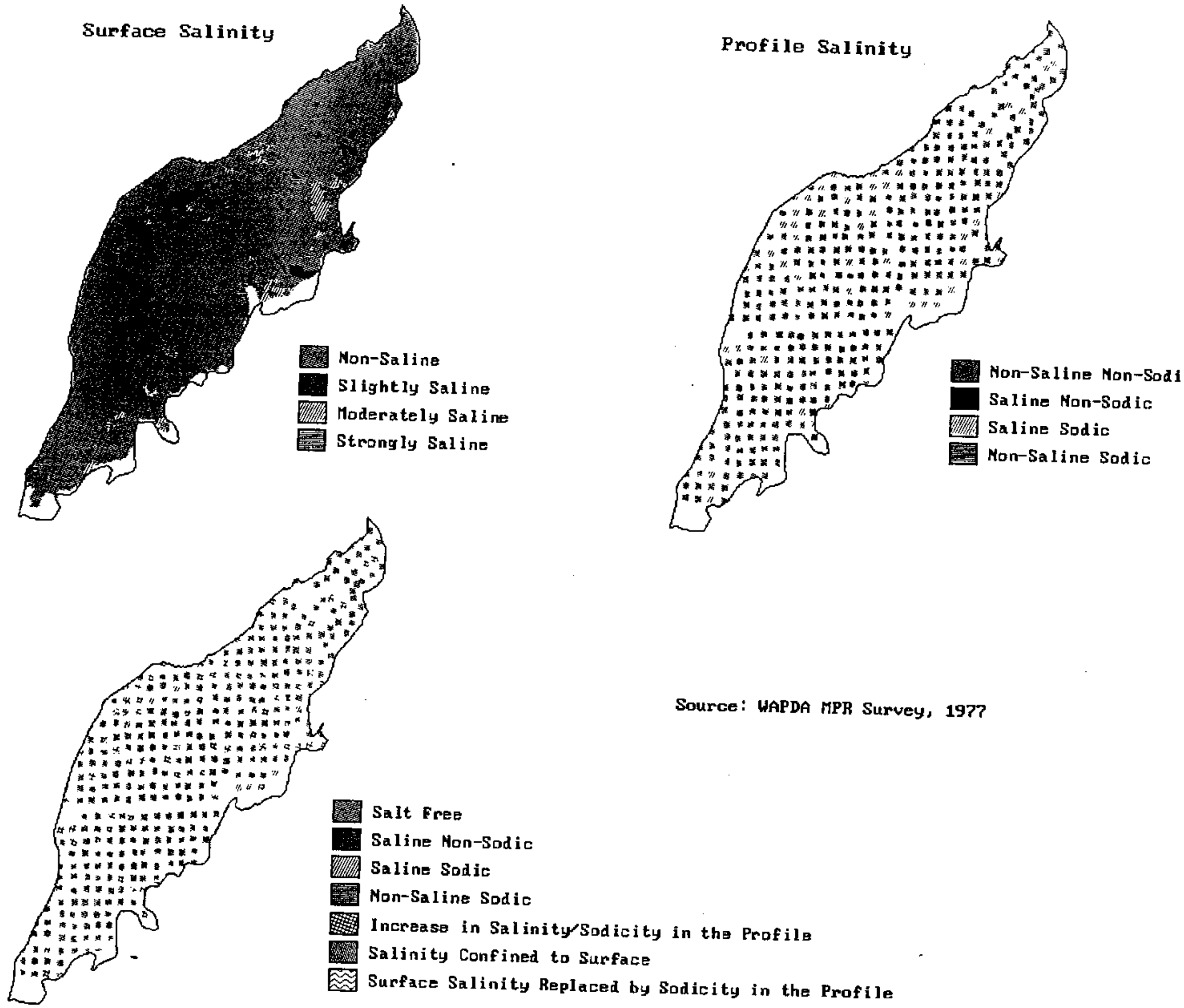



Figure 15(d) Soil Suitability for Major Crops in the Tandlianwala Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: WAPDA MPR Survey, 1977

Figure 15(e) Surface and Profile Salinity in the Tandlianwala Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

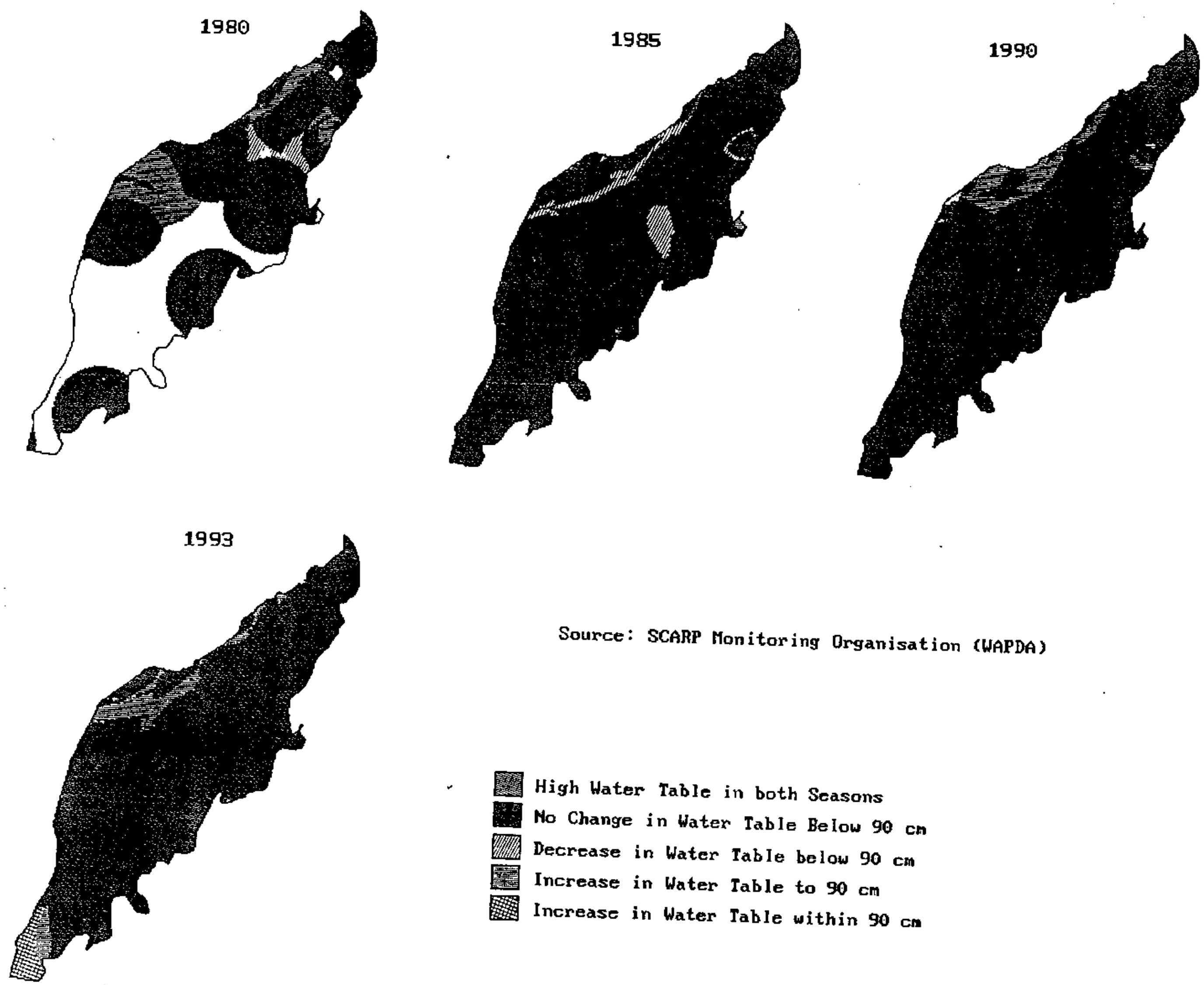
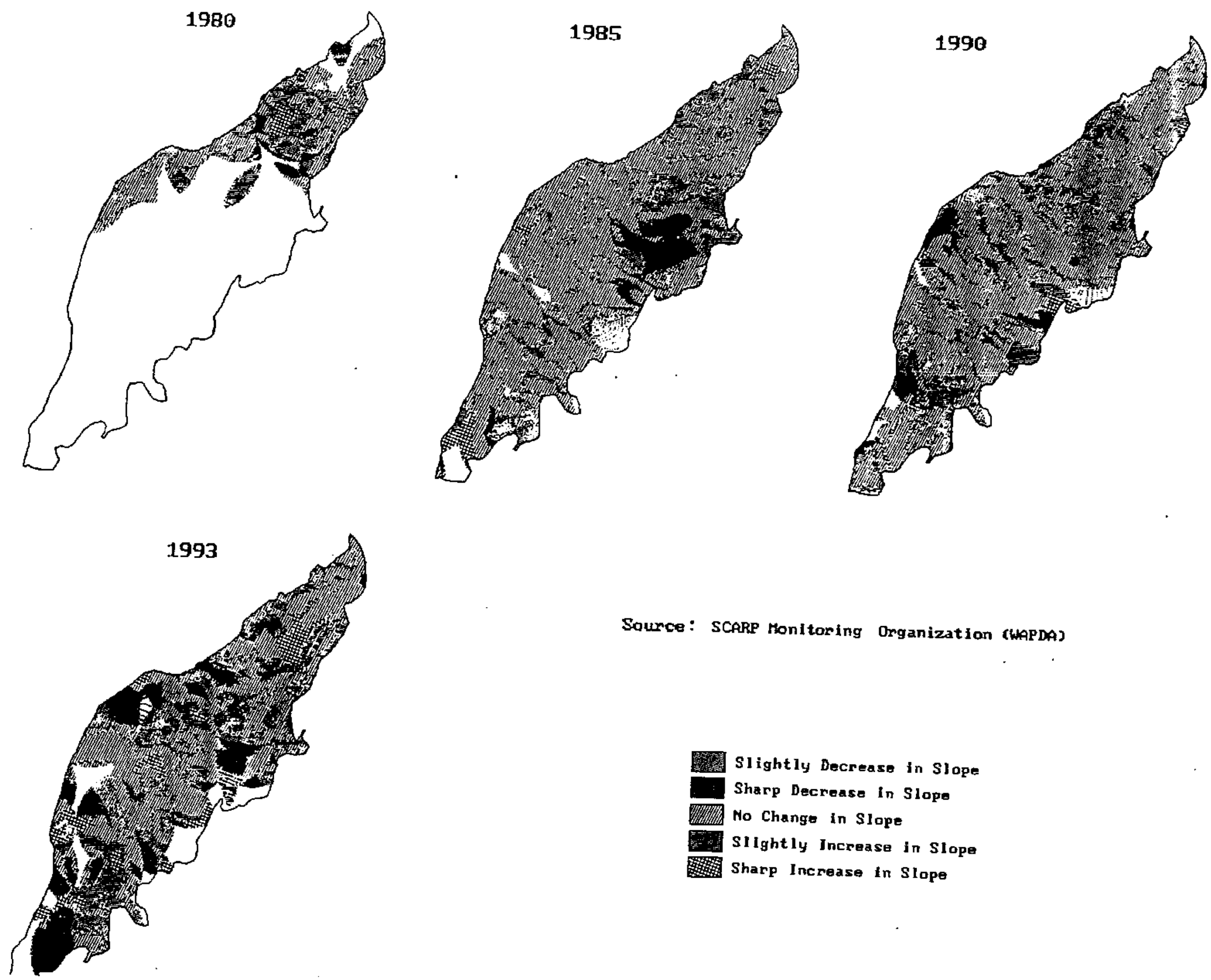



Figure 15(f) Temporal Variations in the Depth to Water Table, Tandlianwala Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure, 15(g) Interseasonal Slope Variations in the Subsurface Flows, Tandlianwala Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

by the limited drainage crossovers for the runoff across the railway line that runs parallel to these areas.

*IIMI Sampling for Soil Salinity and Texture*: The six sample sites in the Tandlianwala Subdivision were evenly distributed across 5500 ha of the regime in the head and middle reaches of the system. Over 84% of the 556 paired EM 38 observations on salinity were processed to be non-saline, whereas the remaining observations were limited to the S2 and S3 categories (Figure B13, Volume Four). The major crops are substantially tolerant of the S2 levels of salinity, especially in situations where the underlying strata contains higher proportions of moderately coarse fractions, such as found in the Tandlianwala Subdivision. The increasing concentrations of salts are more likely retained in the finer fractions, which is reflected in the sampled data shift from the sandy loam/fine sandy loam to loam soils for the S3 category. Its significance is better emphasized in the context of the loam soils dominating all major categories of land use in this Subdivision (Figure C13, Volume Four).

*IIMI Farm Level Sampling*: The Tandlianwala Subdivision has one of the best combinations of the reported higher land use and cropping intensities, coupled with very low values of the culturable waste lands, that are second only to the Chuharkana Subdivision. These statistics are helped by the low levels of fallowing that is facilitated largely by supplemental reliance on useable groundwaters. This figure would most likely reduce in favor of higher cropping intensities if the reported water scarcities are averted. Wheat, sugarcane, and to some extent cotton, are the major crops in this area, but their cumulative intensities are likely to remain low given the predominnace of the porous soil textures. Potential improvements to the area cultivated under wheat are likley to improve the overall low of 56% to levels comparable with the neighboring subdivisions of Buchiana and Tarkhani. This would also require significant improvements to the yield that are currently benefitting much less through low investments in fertilizers (Figures H6 & H7, Volume Four). In comparison, the higher costs associated with the plant protection, fertilizer and irrigation inputs are not translated into above average levels of yield for the cotton crop. Resultantly, the gross incomes and the related profits remain lower than the average in the subdivisions further south (Figures H8 & H9, Volume Four).

Potential improvements to the current realizations from the sugarcane yield are unlikely to materialize given the rather large offsets in low fertilizer investments and the rather high cost of irrigation. The latter is borne by IIMI's own field observations pertaining to the cultivation of this high delta crop on porous sandy loams/fine sandy loams that is likely to translate into lower yields and high irrigation costs. These offsets are not readily overcome through cultivations on the more suitable mix of loams/silt loams that are normally expected to sustain the current average levels of gross income from this crop.

## O. Tarkhani Subdivision

*Hydrologic Regime*: Tarkhani Subdivision, the second in sequence along the length of the Lower Gugera channel (RD 200000 to 340000, 42.45 kms) (Figure 16(a)) comprises 18 irrigation units of which 11 are at the distributary level. Based on the current design discharge allocation of 16.5 cumecs (495 cusecs), approximately 76% of the Subdivision's gross area is canal irrigated at an average of 189 ha per outlet. Given the rather low density of the secondary level distribution system, much of these above average discharges are being retained by the principal distributaries of Tarkhani and Mungi that collectively cover 72% of the gross CCA. However, calculations from Tables 2 and 3 indicate that if the allocations were to be increased to the maximums observed elsewhere within the system, the additional 1.61 cumecs would certaily require an extension of the distribution network within the Subdivision. Perhaps, prior to such system-wide improvements, there is a need to explore why this Subdivision is unable to achieve proportionately higher cropping intensities than the upstream Buchiana Subdivision where, despite the lower surface water allowances and higher intensity of fallowing in both growing seasons, the overall intensities are comparable to Tarkhani. This concern is further highlighted by the additional similarities in these two subdivisions in terms of the rather high incidence of culturable waste and the nearly equal major cropping intensities.

*Soils*: WAPDA data on surface soils indicates fine sandy loam to be the most dominant texture across the entire Subdivision (Figure 16(b)). Scattered in between are the fractions of sandy loam, dominating the tail of Tarkhani Distributary, and the still coarser loamy sand in the command of the Janiwala Distributary. These moderately coarse textures are underlain by the equally coarse Farida soil series in the profile. In short, the distribution of coarser soils is quite uniform across both the surface and profile of the Subdivision's morphology.

In places, like the command of Bhail Distributary, the coarse loamy sand overlies a loamy profile; however, this occurrence is quite restricted. There are also very few consolidated profiles of loam soils, but are too scattered to be of localized significance.

The Soil Survey classifies Tarkhani's soil to be the predominantly Faisalabad silt loam across the length of the system (Figure 16(c)). Towards the west, starting from the off-take of the Bhail Distributary and extending on both sides of the Lower Gugera channel, there is a very large extent of Hafizabad soils. This includes the area buttressed between the head reaches of the Tarkhani and Mungi distributaries, and wholly includes the Janiwala Distributary command. Frequently interspersed within the Hafizabad association distribution are the pockets of highly saline Khurrianwala silt loam association characterized by up to a 35% mix with the coarser Rasulpur series.

Somewhat similar is the case in the head reaches of the Subdivision comprising Russiana Distributary where there is a mix of Khurrianwala Undifferentiated Group within the loamy Hafizabad-Awagat soils. The SSoP reports that for this combination, approximately 20%

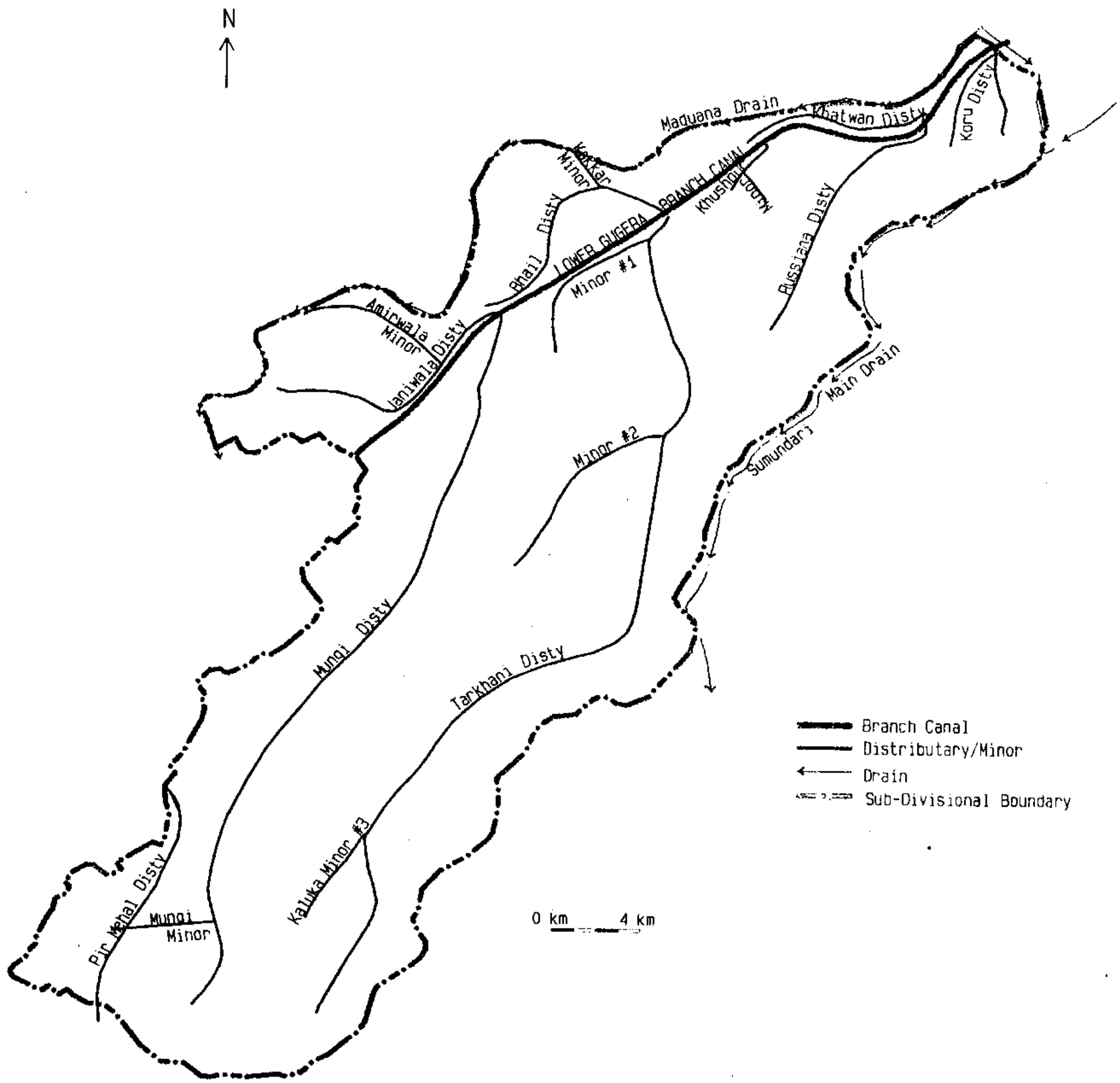
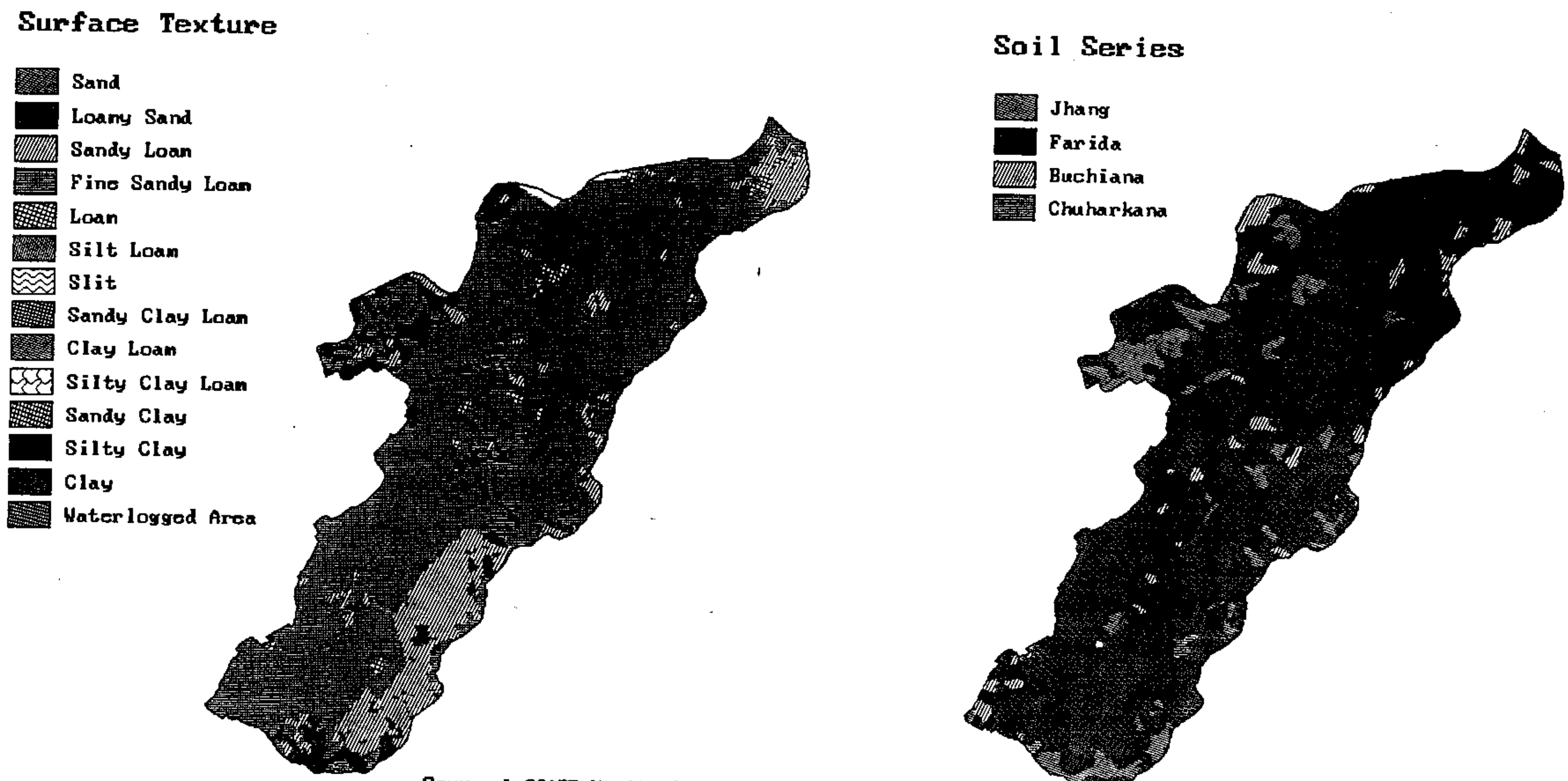



Figure 16(a) Tarkhani Irrigation Subdivision in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 16(b) Surface and Profile Texture of the Soils in the Tarkhani Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

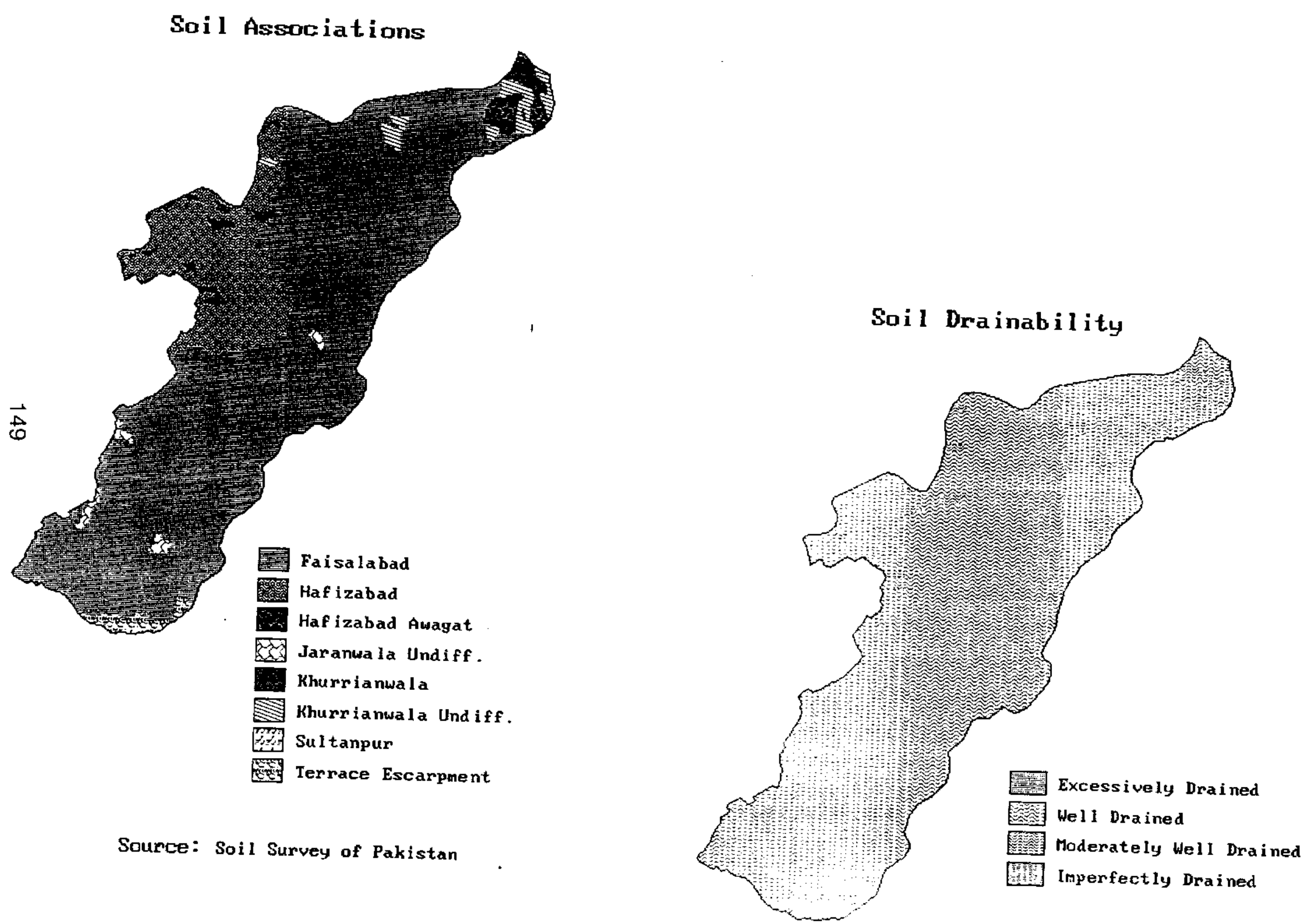



Figure 16(c) Associative Classification of the Soils and their Drainability Characteristics the Tarkhani Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

of the Hafizabad and 25% of Awagat is saline. The demarcation of the Faisalabad series, that varies from silt loam to fine sandy loam, is in general agreement with the WAPDA classification of fine sandy loam to be the dominant textural group in the area. In fact, the Khurrianwala Undifferentiated Group also includes the saline alkali phases of Faisalabad, and as a series its texture varies from very fine sandy loam to silt loam and occasionally loam. However, the location of the calcareous Hafizabad soils by the SSoP does not entirely confirm the presence of rather coarser loamy sand fractions by WAPDA. The association does have a significant presence of coarser Rasulpur soils (gently sloping sandy areas) that also have a kankar zone starting below 120 cms and extending up to a 150 cms; this contrasts with the shallower kankar zone of Faisalabad soils within 120 cms.

*Soil Drainability and Crop Suitability*: From Figure 16(c), the soils are uniformly distributed to be well drained. The Subdivision lies in the same agroecological zone as Buchiana, and is well suited for the growth of cotton, wheat, and sugarcane; rice is only moderately suited for these well drained soils (Figure 16(d)).

*Soil Salinity and Waterlogging*: WAPDA's salinity survey for the MPR study of 1977-79 indicates an overwhelming presence of surface salinity in the head reaches of the Subdivision (Figure 16(e)). The extent is most severe in the commands of the Russiana and Khushpur distributaries, and is largely exclusive to the previously identified salinity in the area by the SSoP in 1966-67. Across the decade, the emergence of surface salinity, with strong saline-sodic profiles, does not appear to be an isolated phenomenon and is probably due to the increase in water table within the general vicinity of the area. Indeed, WAPDA records for the water table fluctuations from 1980 onwards indicate a general increase in water levels within the head reaches of the system; however, this change remained largely below the root zone (Figure 16(f)). By 1990, these fluctuations had shifted southwards to the head reaches of the Tarkhani Distributary, only to return back to the head reach as indicated by the data available for 1993. Aside from these shifting water levels in the head of the system, the interseasonal fluctuations between 1980-93 were somewhat stable, especially in the lower two-thirds of the Subdivision.

The data on the slopes of the interseasonal fluctuations in water table, regardless of the depth below the Natural Surface Level, indicate a somewhat restricted situation in 1980 that has, however since, showed continuous improvement till the available data for 1993 (Figure 16(g)). Across the Subdivision, the lateral flows have been particularly supportive of drainage in the head reaches of the Mungi and the Tarkhani distributaries (probably due to the hydraulic gradient established by the relatively higher seepage conditions in these two principal distributaries within the system). Again, where the tails of these two distributaries converge, near the tail of the system, the lateral flows have been showing higher gradients following rather restricted conditions in 1980. Towards the center of the Subdivision, where the distribution channel density is much less, little variation in the subsurface hydraulic head in the pre- and post-monsoon comparison for the period 1980-93; a substantial increase in the surface influx may increase the water levels until such time a favorable hydraulic gradient is established. Since the commands along the the main Lower Gugera channel to

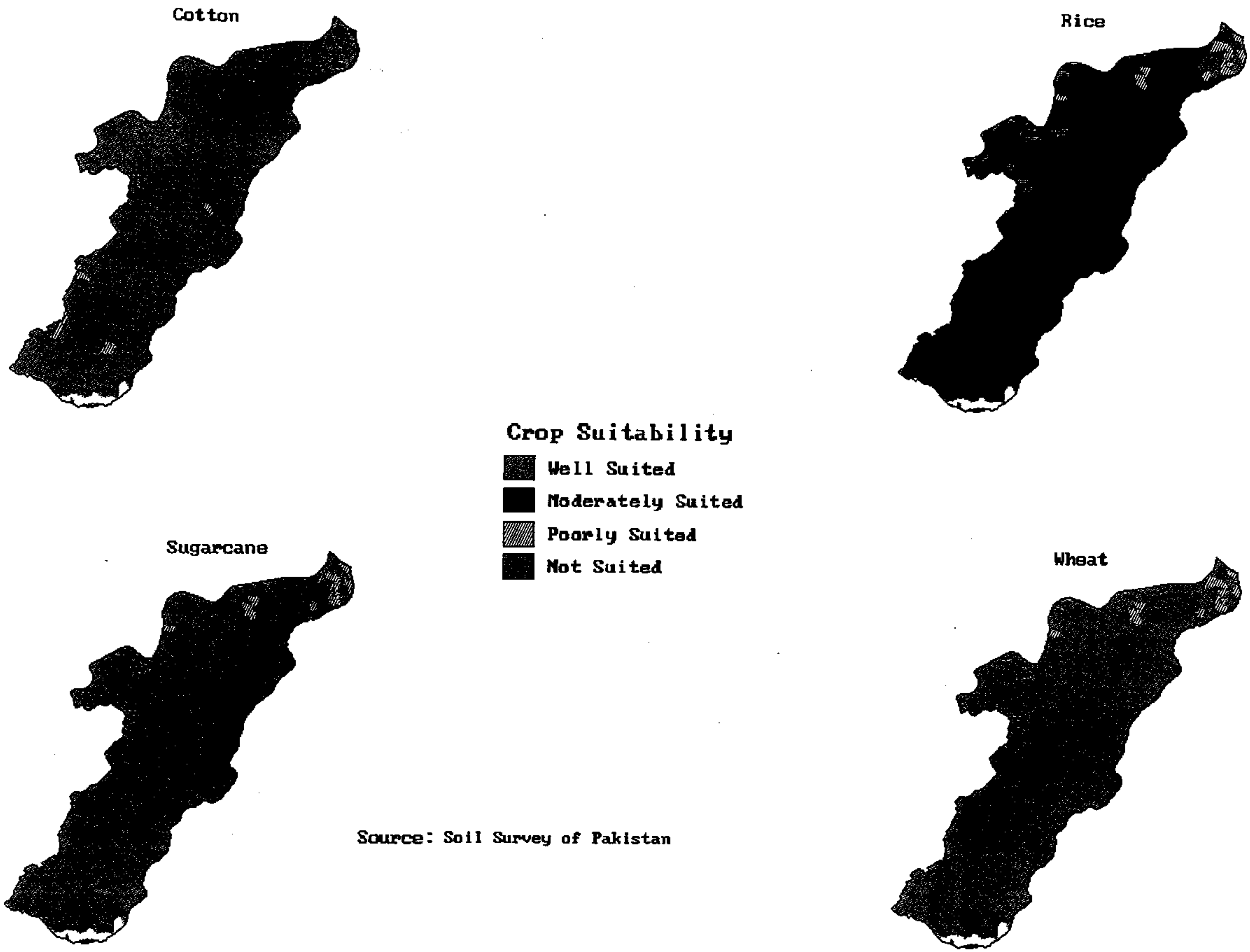



Figure 16(d) Soil Suitability for Major Crops in the Tarkhani Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

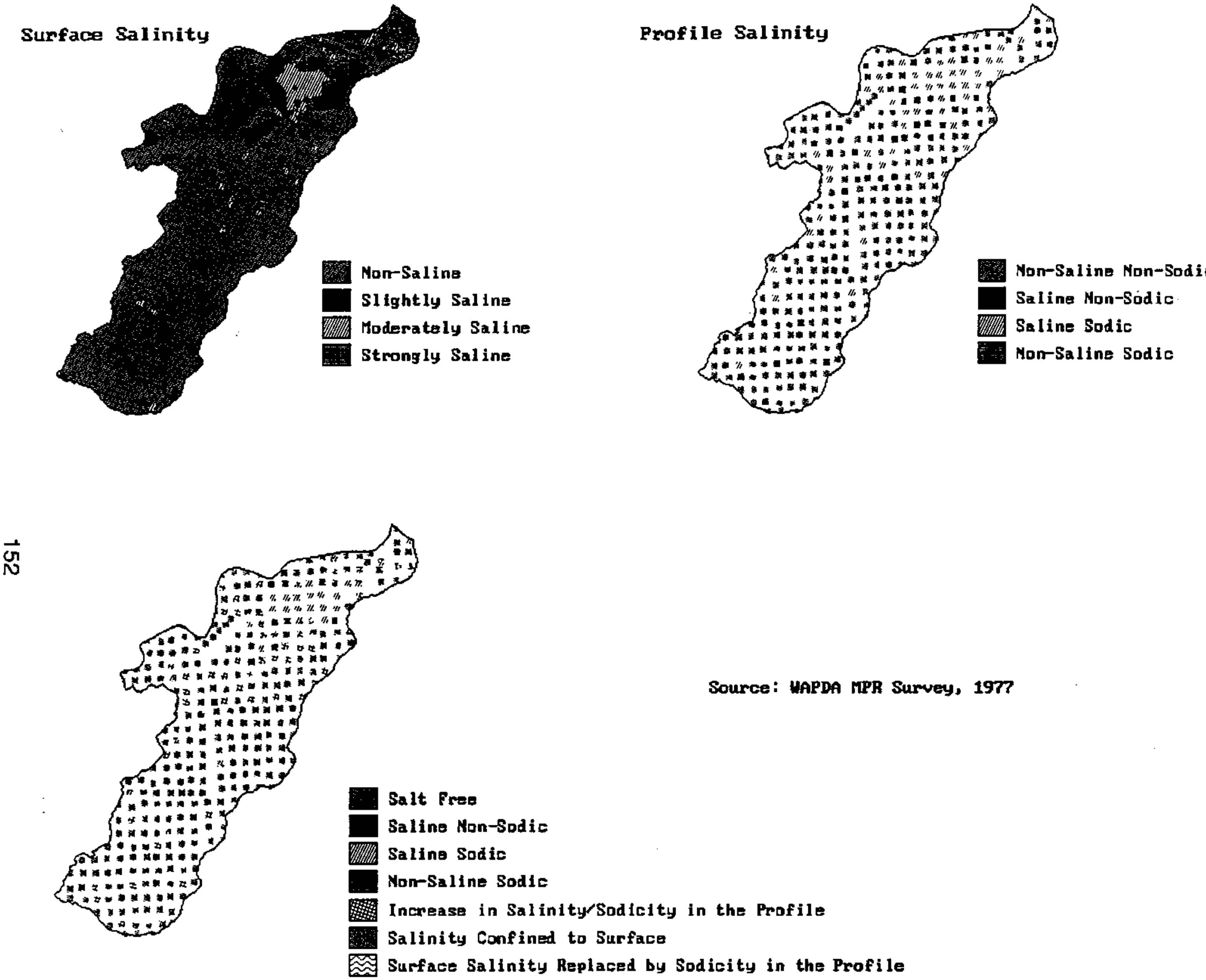
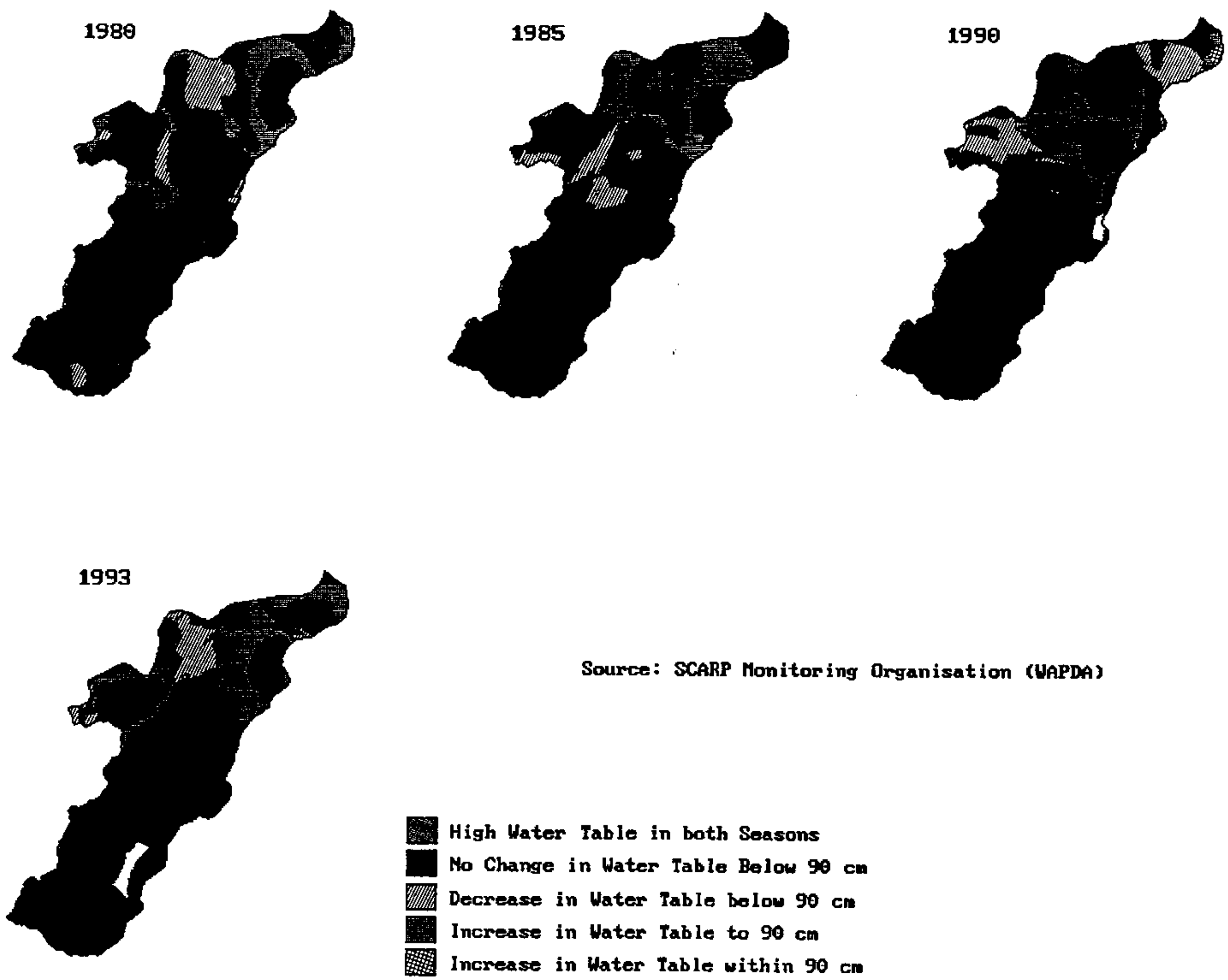
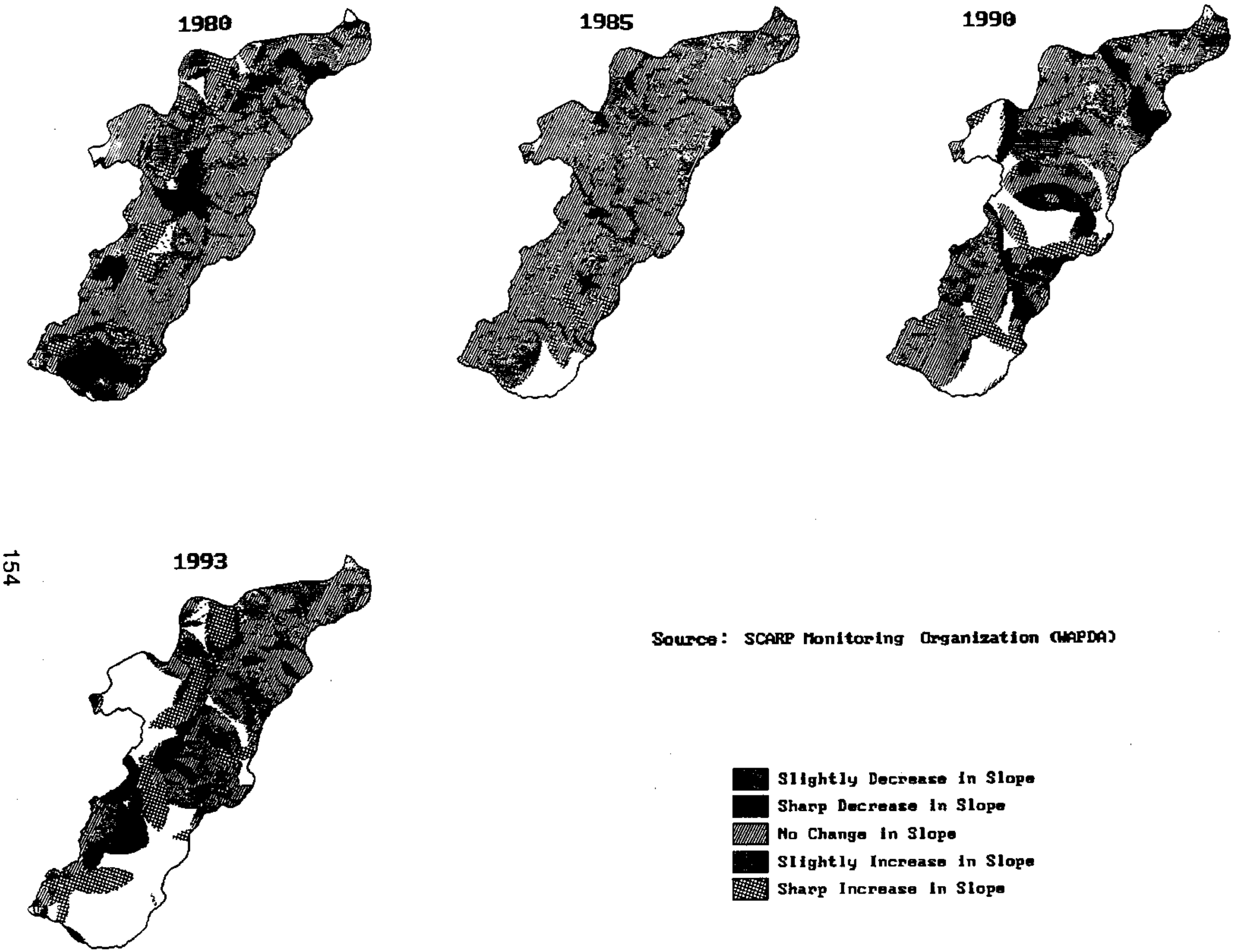



Figure 16(e) Surface and Profile Salinity in the Tarkhani Irrigation Subdivision of the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organisation (WAPDA)

Figure 16(f) Temporal Variations in the Depth to Water Table, Tarkhani Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 16(g) Interseasonal Slope Variations in the Subsurface Flows, Tarkhani Irrigation Subdivision, Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

the west are in the swath of a permanent seepage zone, the hydraulic gradient within the Subdivision is towards the low seepage zones to the east, e.g. the middle reaches of the Mungi and the Tarkhani distributaries where the water tables have not shown major fluctuations.

*IIMI Sampling for Soil Salinity and Texture*: IIMI's salinity survey in the Tarkhani Subdivision was restricted mostly to the head reaches of the system. Across a total sample regime of 10470 ha, over 1000 EM38 observations on surface and profile salinity were collected on selected tracts that cumulatively indicated more than 81% of the cultivated area to be non-saline. Comparison with Buchiana (upstream) and Bhagat (downstream) subdivisions leads to the tentative conclusion that salinity across the cultivated landscape is declining towards the tail reaches of the system, although this would require substatiation due to the absence of sampling in the tail reaches of the Subdivision itself.

A majority of the observations are in the silt loam to loam categories, the former dominating due to the large extent of the Faisalababd soils from the head to tail reaches of the Subdivision. For the sample regime, restricted to the commands of the Russiana and Khushpur distributaries, the ratio of silt loam to loam remains fairly constant in the salinized tracts, thereby indicating that much of the salinity is restricted to a uniform set of soil conditions. For the same morphological conditions further south along the left bank command of Tarkhani, where additional IIMI survey sites were concentrated, the salinity is not as severe. The high salinity observations are restricted to barren/ uncultivated tracts; the extents of lesser levels of salinty are equal in proportion, not only across barren lands, but also in ploughed and fodder categories of land use.

Ploughed land, sugarcane, and cotton predominate the non-saline soils in about equal proportions. While silt loam soils are the preferred choice for the sugarcane, cotton is being grown more extensively on the loams, which is also the case for the lands left fallow for the rabi crop. For fodder, the choice of soil type is not readily distinguishable; however, its growth was also observed on slight to moderately saline silt loam soils.

*IIMI Farm Level Sampling*: IIMI's economic survey for this Subdivision comprised interview data for 40 farmers within head reaches of the system (Russiana, Khatwan, Bhail and Tarkhani distributaries) and middle reach of Mungi Distributary. The cultivation and cropping intensities are not much different from Buchiana upstream, and hence likewise is the case for the proportion of fallow land. Also, problems of salinity/sodicity impacting the fallow practices is less than 20% of the reportage; however, almost 60% of the farmers are linking water shortage to the unavoidable need to leave land fallow. This problem is exacerbated by the nearly 60% of farmers perceiving poor quality groundwater, a figure that is higher than the rest of the Lower Gugera Division. The Subdivision is reporting slightly higher percentages of the cotton crop (10-25% of the respondents), whereas the cultivation intensity for wheat and rice is the same as for Buchiana Subdivision upstream.

## P. Uqbana Subdivision

*Hydrologic Regime*: Uqbana Subdivision is sustained entirely by the supplies from the lower half of the Rakh Branch that enters the area from the north (Figure 17(a)). Its tail is the offtake for the Dijkot Distributary which is the most important secondary channel within the Subdivision. Uqbana has the largest gross and commanded area in the entire LCC system, that also exceeds the area under the Haveli command in the lower reaches of the doab. Given the comparatively large proportion of the commanded area across the 520 watercourses, the density of the distribution network remains low despite the fact that its total length for the secondary channels is exceeded only by Wer Subdivision in the entire LCC system (Table 1). The low density of distribution is owed to the peculiarity of the system wherein there are far more distributaries than minors to cover the commanded regime. This situation often impacts negatively on the equitable distribution of flows, whereby the lesser number of head reach watercourses continue to jugulate the flows that are intended for the linear stretch of the system that extends southwards across an average topographic slope of about 0.00028. The situation is compounded further by the design allocations that are borderline with the minimum specified by the Irrigation Department (Figure 1(b)). Clearly, improvements would be needed most on the distribution side; however, one would expect that in the absence of enhanced surface allocations much of the benefit accruing from such an improvement would be lost to seepage losses or else would require rotation within the system.

*Soils*: Based on WASID data, the soils of the Uqbana Subdivision are overwhelmingly moderately coarse in the profile with few patches of medium soils in the head and tail reaches of the system (Figure 17(b)). The surface texture also conforms to the profile conditions, with the sandy loam/fine sandy loam textures dominating the entire Subdivision. Finer fractions, like clay, are available but limited exclusively to the command of the Sir Wala Distributary offtaking from near the tail of the Rakh Branch. It is also near this tail that a one-to-one correspondence between the moderately fine Chuharkana soil series in the profile and the sandy clay loam patches in the surface is present. The above information contrasts with the textural differentiation provided by the SSoP (Figure 17(c)) wherein the entire Subdivision is shown to be comprising the medium textures of the Faisalabad, Hafizabad and Hafizabad/Awagat associations. The demarcation of the Faisalabad series, that varies from silt loam to fine sandy loam, is in general agreement with the WAPDA classification of fine sandy loam to be the dominant textural group in the area.

*Soil Drainability and Crop Suitability*: From Figure 17(c) above, barring the saline-alkali patches of the Khurrianwala/Khurrianwala Undifferentiated Groups, the Subdivision is universally well drained. This characteristic attribute of the soil is also in agreement with the somewhat coarser description of the profiles by WASID above where the Farida series is shown to dominate the textures. Owing to this characteristic of the soils, the Subdivision remains well suited to the growth of all low to medium delta crops. There are, however, large contiguous tracts in the head reaches of the system, due largely to the presence of the Hafizabad-Awagat soils, that would be well suited for the growth of rice (Figure 17(d)).

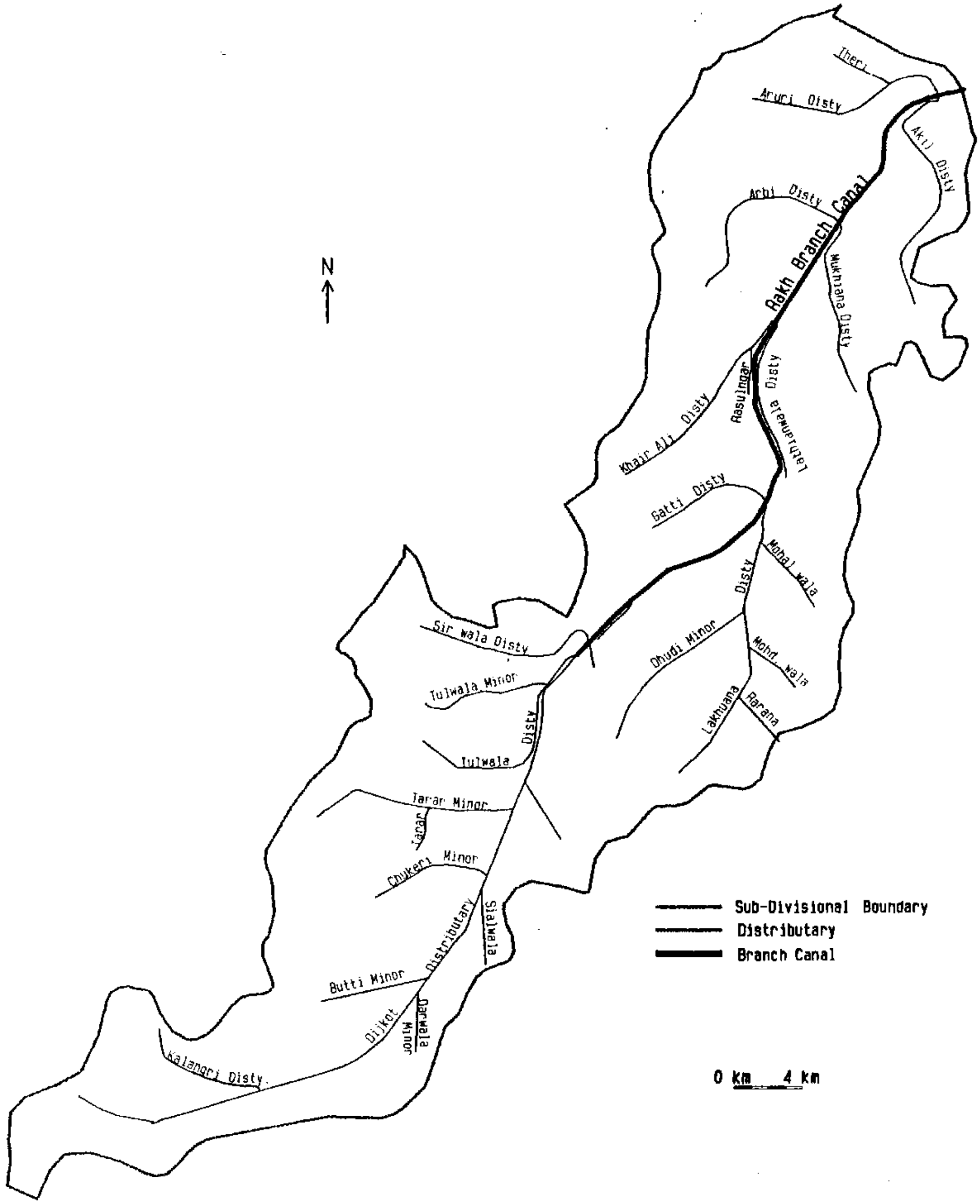



Figure 17 (a) Uqbana Irrigation Subdivision in the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

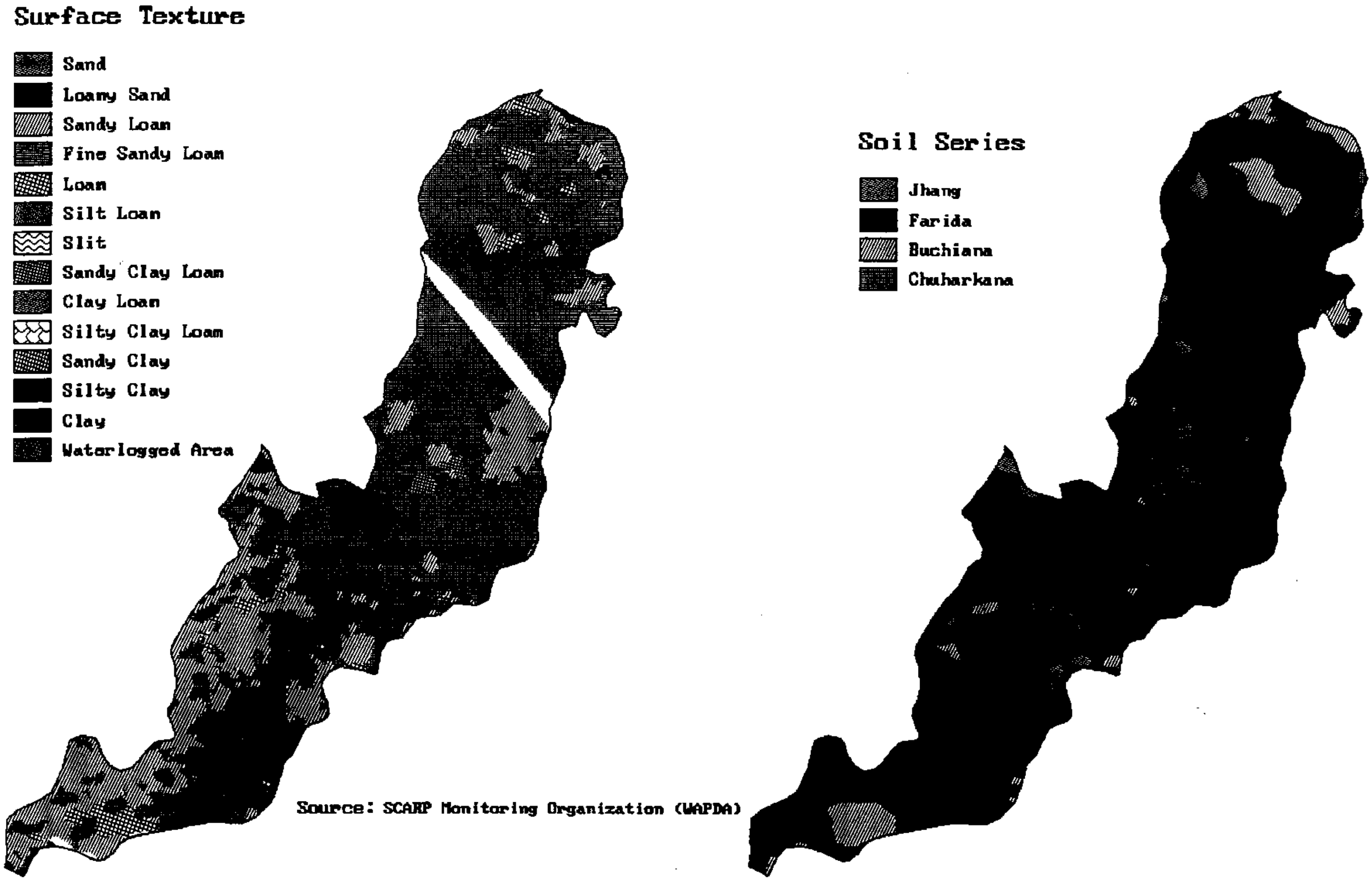
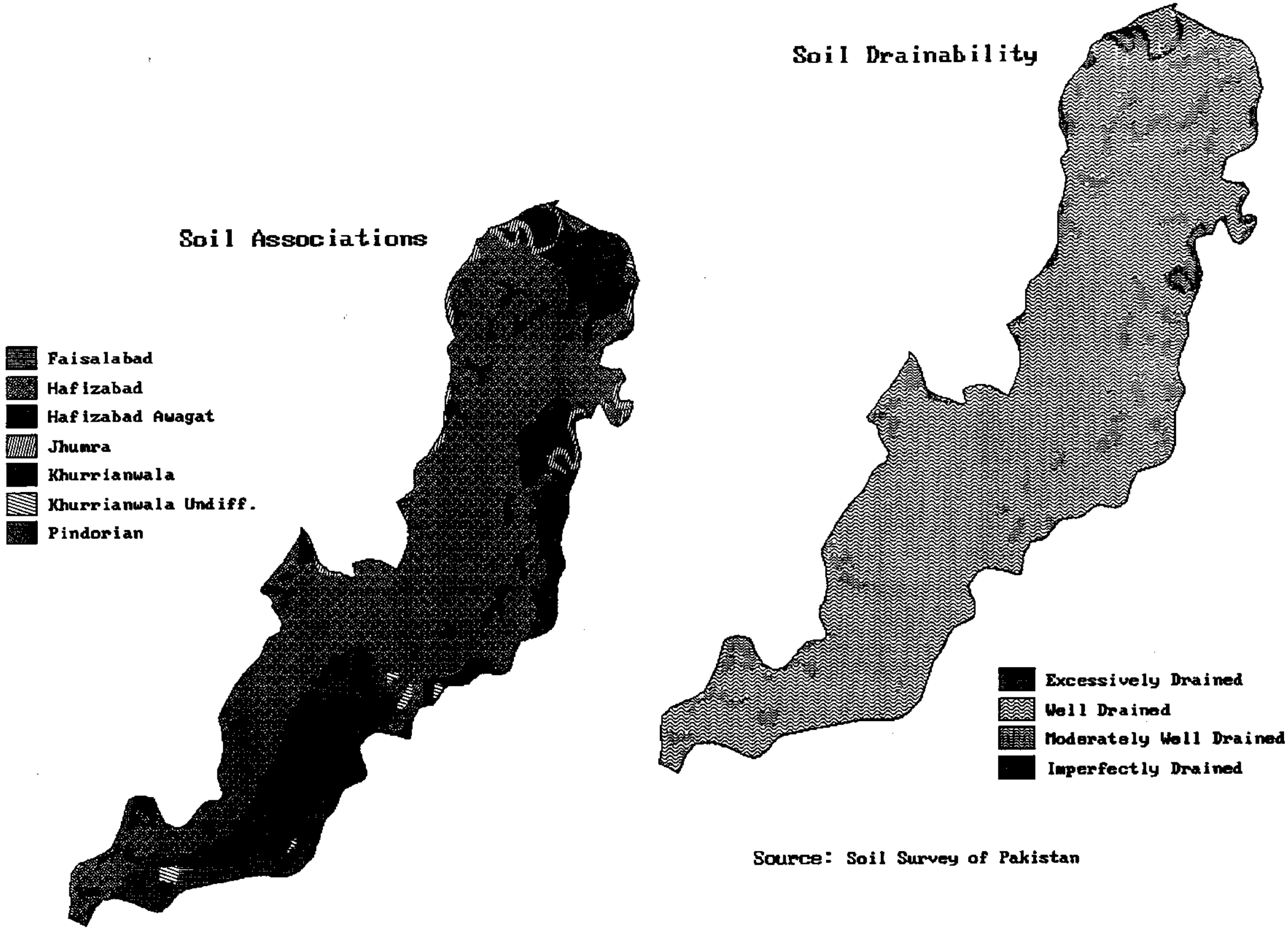



Figure 17(b) Surface and Profile Texture of the Soils in the Uqbana Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: Soil Survey of Pakistan

Figure 17(c) Associative Classification of the Soils and their Drainability Characteristics the Uqbana Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

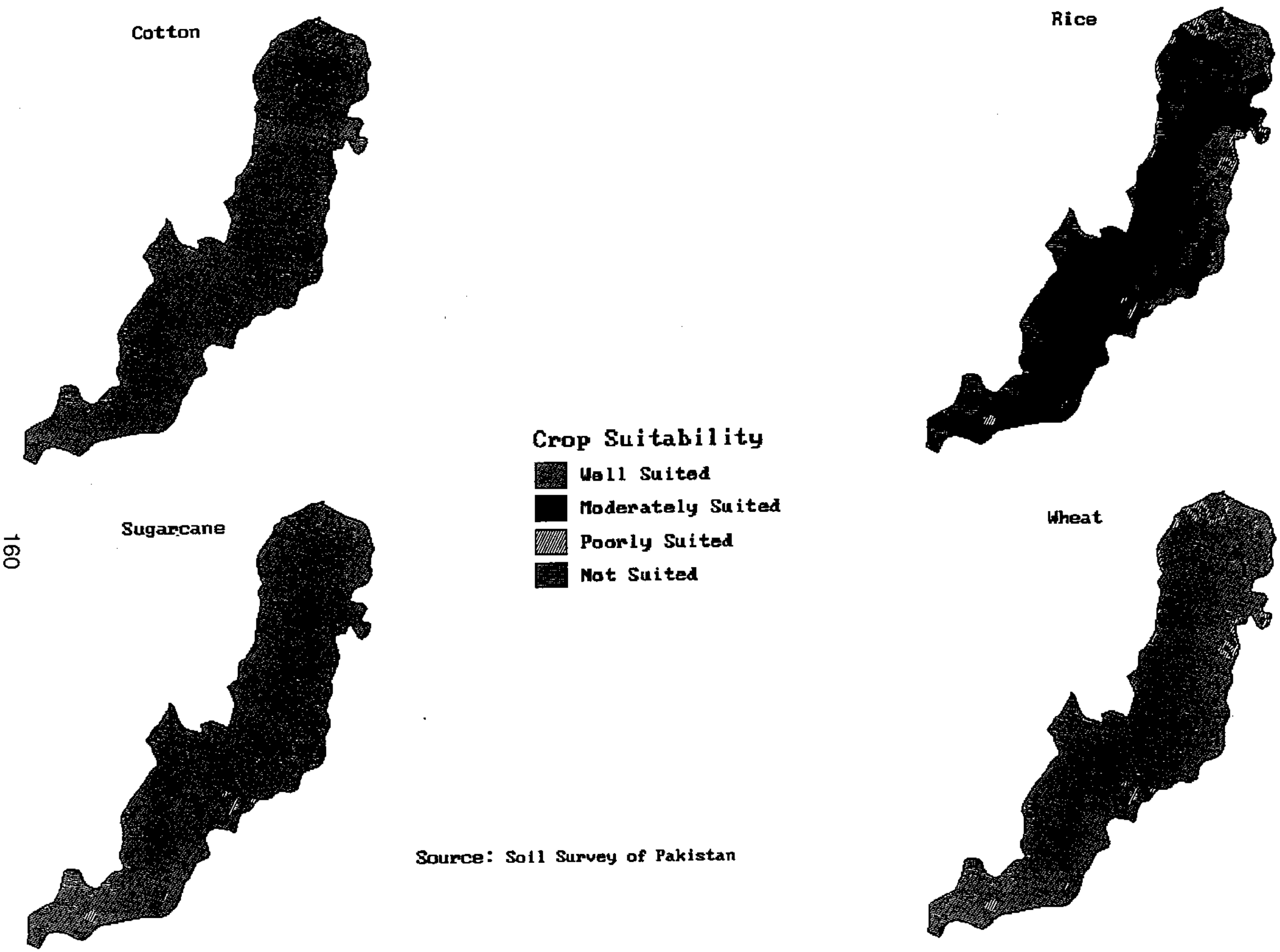



Figure 17(d) Soil Suitability for Major Crops in the the Uqbana Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

*Soil Salinity and Waterlogging*: The mid 1960s data from the SSoP shows a rather large scattering of Khurrianwala soils related to salinity in the upper reaches of the system (Figure 17(c)). They are quite numerous in the head reaches, but further south, they are mostly on the left side of the main branch canal. Subsequent surveys by WAPDA in the 1976-79 period not only confirm this geographic distribution but, given the qualitative aspect of profile sampling, establish this to be significantly associated with the increase in the concentration of the sodic salts. Coincidently, this area of the doab also suffers from poor groundwater quality being used for irrigation applications. From Figure 17(e), the spatial scatterring of the salinity patches seems to have become more numerous since the SSoP surveys of ten years ago. In addition to all the distributaries in the head reaches, the channels offtaking from the left side of the Rakh Branch are the most affected. There is a significant correspondence in the salinized extents reported by the two government agencies in the tail portions of the system, and nowhere is it more strong than in the command of the Kalangri Distributary where a large Khurrianwala series related occurrence seems to have advanced all the way to the head of the channel command.

From WAPDA SMO records of the fluctuations in water levels, there is not much evidence to show root zone affectation due to post-monsoonal recharge. From Figure 17(f), data for 1980 shows parts of the Arbi and Mukhiana distributary commands having experienced high water levels within the root zone; however, the occurrence of this phenomenon is greatly diminished in the subsequent years. In general, high water levels are more frequent in the head reaches of the system, but 1993 data shows exceptions to this occurrence whereby an actual decrease in the water levels seems to have occured in the commands of the Aruri and the Khair Ali distributaries. The lower reaches of the Subdivision are increasingly becoming less responsive to pre-and post-monsoonal comparisons of the water levels to the extent that the very tail portions of the Subdivision, that earlier used to experience a rise in water levels near to the root zone, have actually recorded a decrease. The foregoing geographical differentiation is confirmed by the changes in the subsurface slopes (Figure 17(g)); areas with periodic rise in water levels have a corresponding decrease in subsurface slopes (or slight increase to show subterranean flowout), such as the tail portions of the Subdivision in 1980 and the head and middle reaches in 1993.

*IIMI Sampling for Soil Salinity and Texture*: IIMI's sampling in the Uqbana Subdivision was distinctly divided across the head, middle and tail reaches of the system. Based on 14 sampling sites covering 13153 ha, approximately 1200 observations on apparent soil salinity and surface texture were collected. The conversion to the saturation extract values revealed almost 80% of the samples to be non-saline ($EC_e < 4$ dS/m). A majority of these non-saline observations are in the sandy loam/silty loam/loam categories of surface soil texture; the proportions of finer fractions of sandy clay loam and silty clay loam increase significantly towards higher levels of salinity (Figure B15, Volume Four). The most severe form of salinization, however, remains confined to the dominant surface texture noted above.

All of the major categories of land use in the Uqbana Subdivision are overwhelmingly in the non-saline category (Figure C15, Volume Four). The ploughed category indicates the most

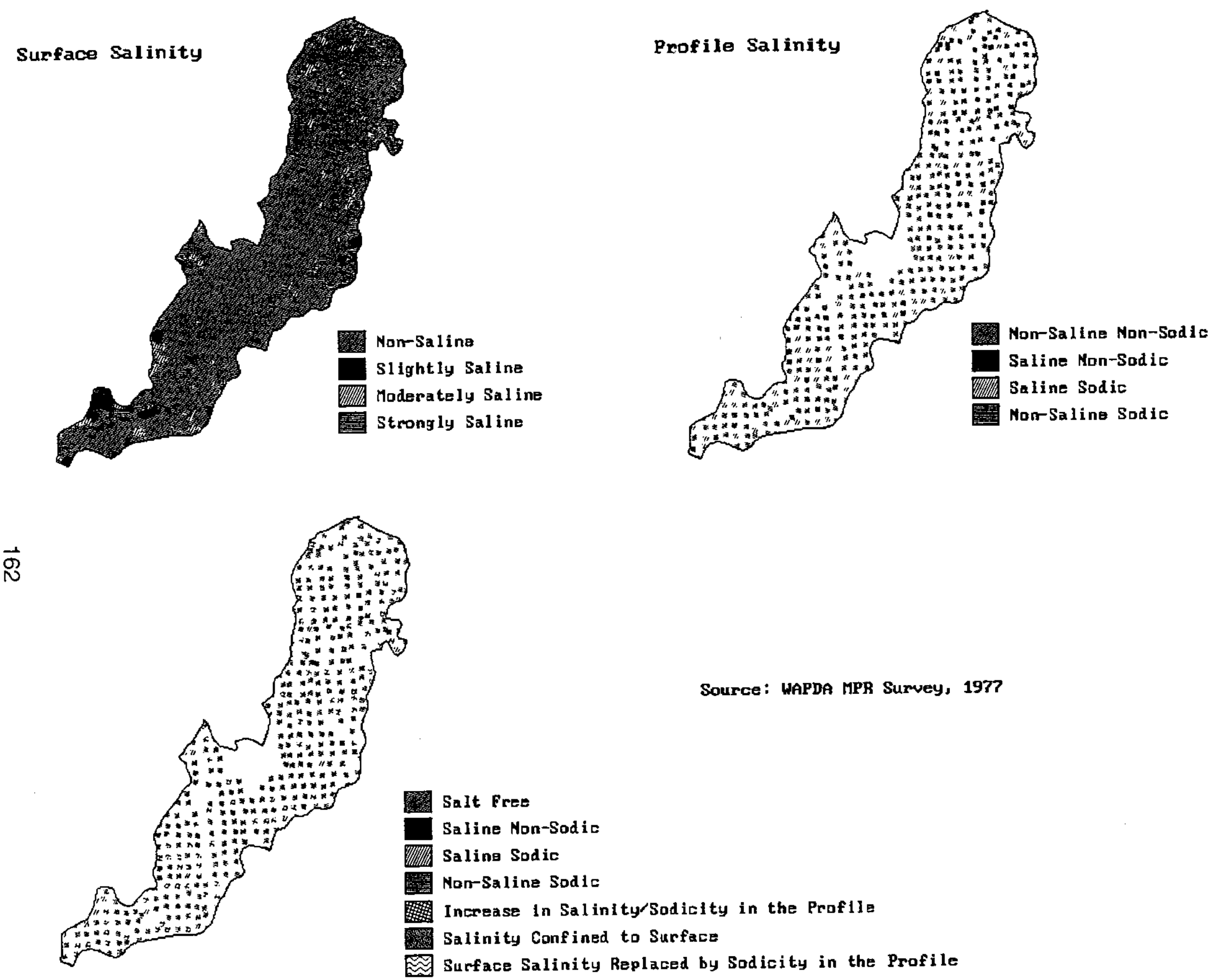



Figure 17(e) Surface and Profile Salinity in the Uqbana Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

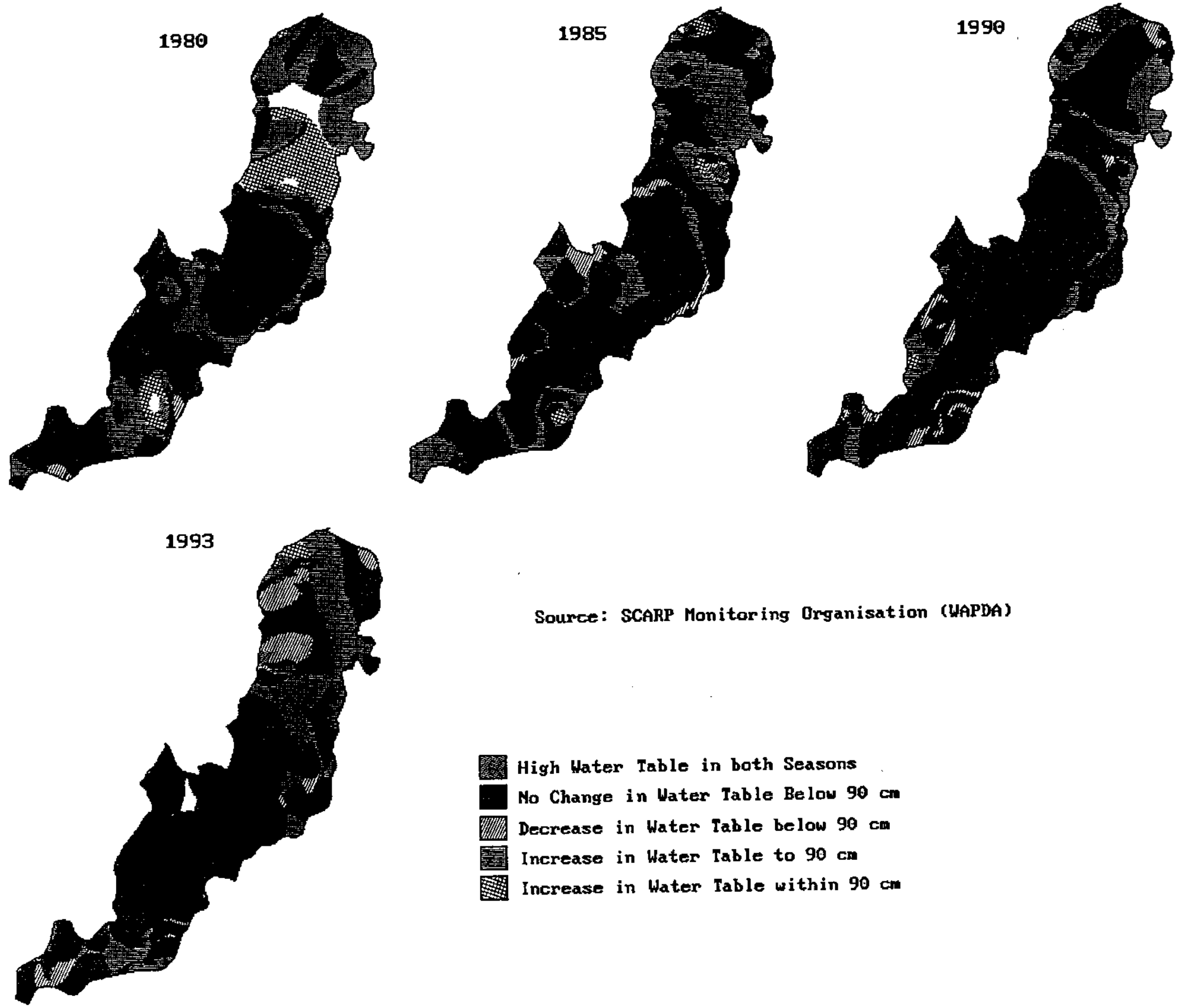



Figure 17(f) Temporal Variations in the Depth to Water Table, Uqbana Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

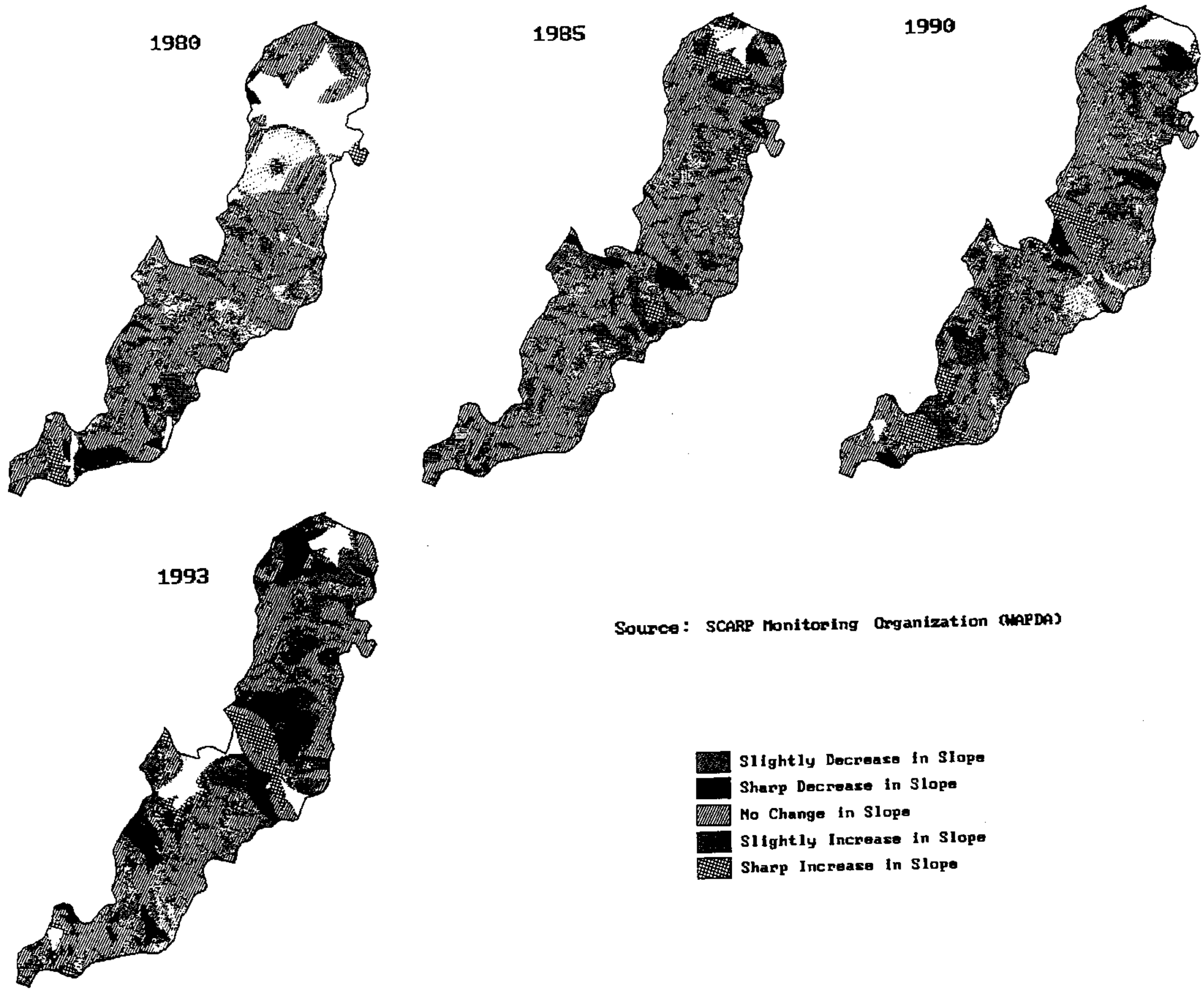



Figure 17(g) Interseasonal Slope Variations in the Subsurface Flows, Uqbana Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

likely pattern of cultivation on soils during the rabi season. This compares well with the lands that were left fallow (or harvested since long) and have not been ploughed yet. Since the cultivation of fodder is not bound by preferences for soil textures, the pattern of its distribution reflects the resource availability after the cultivation of the major crops. This would not be expected for a higher delta crop like sugarcane where medium to moderately fine textures are preferred. In this Subdivision, the cultivation of sugarcane has been observed to be more prevalent across the coarser sandy loams rather than the silt loam or sandy clay loam textures. A converse mismatch exists for cotton where, besides the highest occurrence noted for the loams, the remaining soils are dominated by the moderately fine to fine textures that would normally not be preferred for its growth. Finally, from amongst the four most commonly encountered textures in the sampling, it is the sandy clay loam that remains non-saline even in the barren lands category; the remaining soils of the loam, silt loam and sandy loam category are varyingly affected by higher levels of salinity.

*IIMI Farm Level Sampling*: The Uqbana Subdivision had one of the highest number of sampled farmers reporting in the questionnaire survey. When comparing with other subdivisions in the system, its cropping intensity remains low at 115% (Table H1, Volume Four). This is about the same as for the Bhagat Subdivision, but with one important difference, in that the cropping intensity at the farm level (rather than the total cultivated area) is comparatively higher in the latter even though there is more of the land being left fallow there. This could be explained by the comparatively larger farm sizes in the Uqbana Subdivision. Still further comparison indicates that, despite the larger proportion of the CCA in the Uqbana Subdivision, its share of the culturable waste is four times higher than in the Bhagat Subdivision. This may partly be due to the relatively higher percentage of farmers in the Bhagat Subdivision reporting access to useable groundwater quality in comparison to Uqbana (Figure H1, Volume Four). Resultantly, Uqbana's land use intensity is also much lower (Figure H2). Wheat and sugarcane are the most preferrd crops in the area; however, collectively, the major crop intensity does not exceed 64% of the cultivated area. From Figure H5, this pattern of low cumulative intensities of major crops is specific to the central part of the doab and has the additional accompaniments of relatively higher incidence of culturable wasteland within the gross commanded regime. The regime on either side of this divide has higher cropping intensities. There are exceptions to this coincidence wherein, despite the upto 20% incidence of culturable waste in the Dhaular and Veryam Subdivisions, these subdivisions have major crop intensities exceeding 70%.

Rather surprisingly to note that while the wheat crop in the Uqbana Subdivision follows the medium course in terms of inputs and returns (Figure H6, Volume Four), it is the low cultivation intensity of the rice crop here that draws parallels elsewhere with the most intensive cultivations in the LCC system, e.g. the Chuharkana Subdivision. In terms of gross income, yield and profit, the figures are comparable across both of the subdivisions (Figure H10, Volume Four). This observation is further accentuated in significance by the realtively higher figures of fertilizer cost and irrigation inputs encountered in the typical rice growing area of the Chuharkana Subdivision.

## Q. Veryam Subdivision

*Hydrologic Regime*: Veryam Subdivision, along with the Wer Subdivision, comprises the tail command of the Jhang Branch in the LCC West Circle (Figure 18(a)). Its gross area of 108122 ha makes it the fifth largest subdivisional unit within the LCC system, but with almost 95000 ha of CCA it ranks second only to the Uqbana Subdivision described above; this also distinguishes it with having one of the highest proportions of irrigation commands within the subdivisional administrative units (Table 1). Because of the comparatively fewer number of watercourses in this Subdivision, its average area per watercourse is the highest in the entire LCC system; resultantly, it has the highest cumulative design discharge allocation (and second highest in terms of the allocation per 1000 ha) for the twenty six hydrological units (secondary channels) that are well distributed in space on either side of the Jhang Branch. The Branch itself terminates about two-thirds of the way along the Subdivision's longitudinally shaped command that is topographically sloped (0.0004) towards the southwest across a net difference of about 37 meters. The abovementioned distinctions to its hydrological divide would be incomplete without dwelling on the exceptionally low density of its distribution system that nonetheless has a high number of irrigation channels (Figure 1(b)). The disparity between this low density and the correspondingly high allocation per 1000 ha is exceptional.

*Soils*: WAPDA's soil series interpretation (Figure 18(b)) shows the Subdivision to be predominantly made up of moderately coarse Farida soils in the substratum. The finer medium fractions of Buchiana soils are scattered in large patches near the tails of the Jhang Branch and the Subdivision. In fact, the tail portion of the Subdivision is commanded by the Khewra Distributary (which is the secondary level continuation beyond the tail of the Jhang Branch) that is comprised almost entirely of the medium soils both in the surface and the profile. This uniformity in both surface and profile conditions is also noticeable in other parts of the Subdivision where the loams/silt loams pair with the Buchiana soil series and the loamy sand/sandy loam fractions overlie the Jhang and Farida series. Predominantly sandy strata are uncommon and its occurrence as the Jhang series is limited to the tail portions of the Faqir Sar and Darsana distributaries.

As explained previously, the soil texture interpretations by the SSoP, in comparison to WAPDA, are inclined towards the finer fractions, something that is not uncommon across the other subdivisions of the LCC system. In general, the entire western fringe of the Subdivision comprises the medium soils of the Bagh and Shahdara associations (Figure 18(c)). Towards the east, the area buttressed between the Gojra and Bhamni distributaries is made up entirely of the Hafizabad association. Other than these two geographical extremes, the entire longitudinal stretch of the Subdivision comprises the Faisalabad loams that are mapped as the fine sandy loams by the WAPDA soil series definitions. Where dunelands, or the sandy Sodhra soils had been identified by the earlier SSoP surveys along the western boundary of the Subdivision, WAPDA's classification shows them to be clusters of loamy sand, sandy loam and the larger envelope of predominatly fine sandy loam.

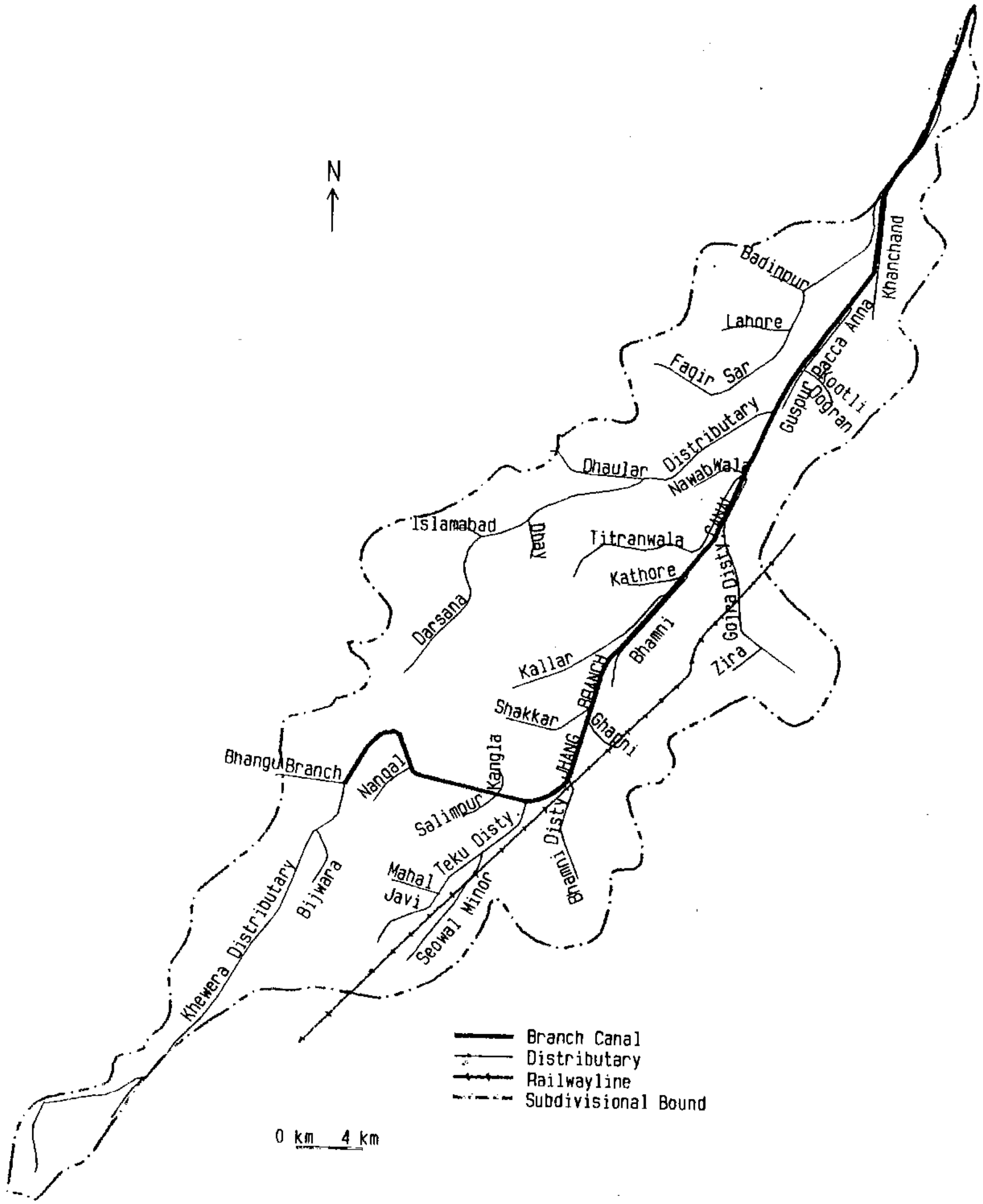
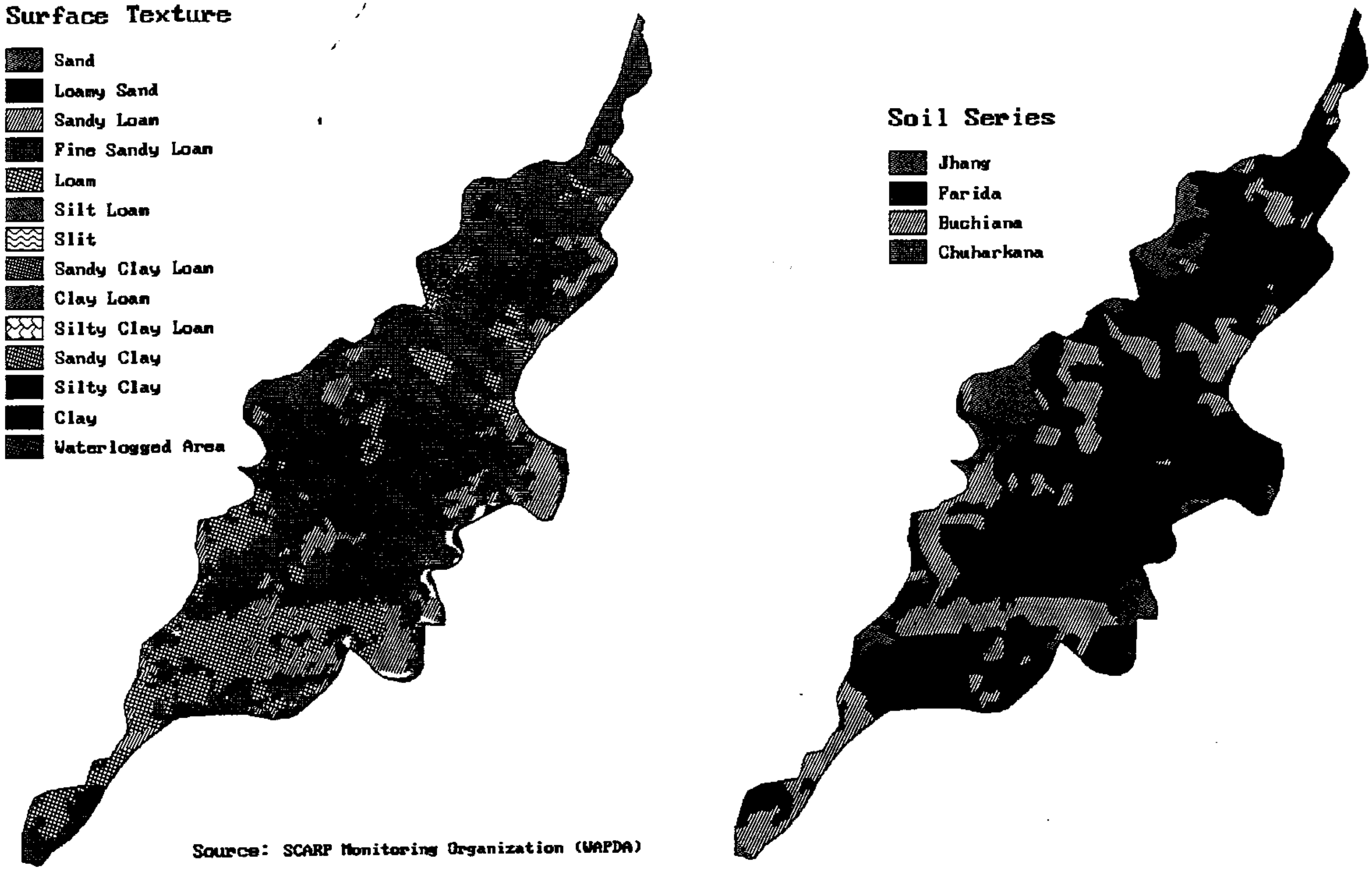



Figure 18(a) Veryam Irrigation Subdivision in the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.




Source: SCARP Monitoring Organization (WAPDA)

Figure 18(b) Surface and Profile Texture of the Soils in the Veryam Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

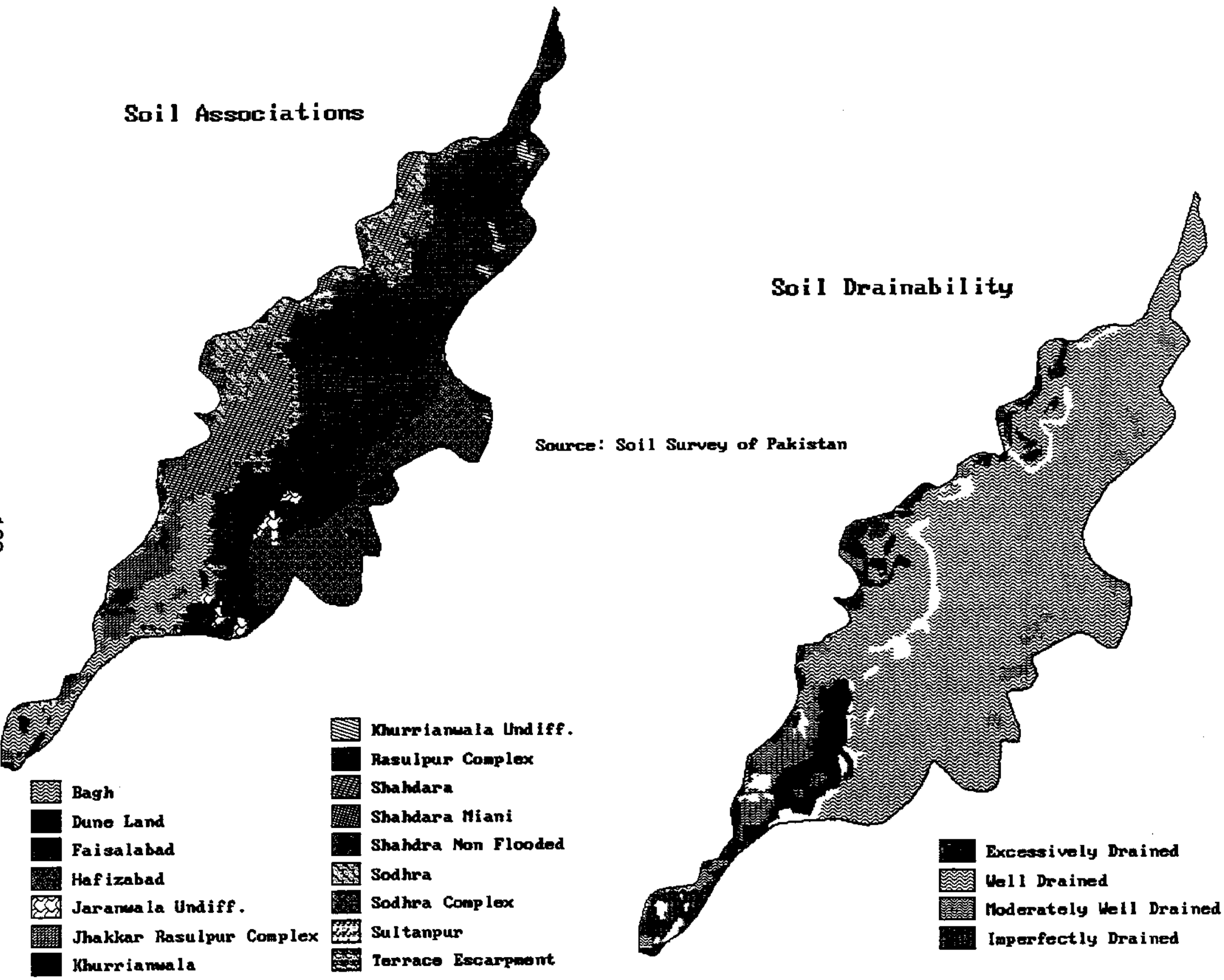


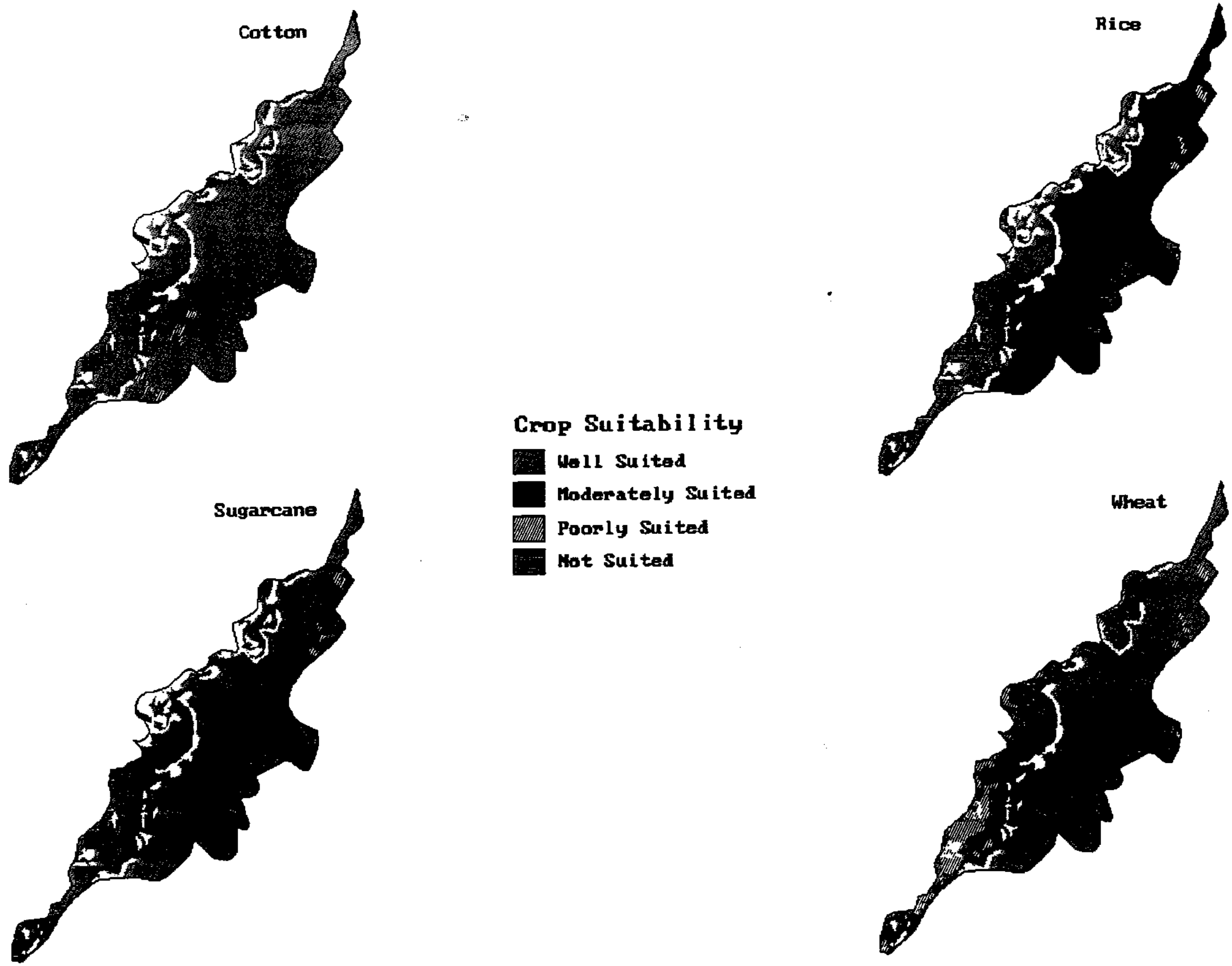

Figure 18(c) Associative Classification of the Soils and their Drainability Characteristics the Veryam Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

The depositional pattern of the soils in the Veryam Subdivision is largely owed to the topographic relief that is influenced by factors both internal and external to the Subdivision. The large mass of the Faisalabad silt loams stretching centrally along its hydrological network form a continuation of the southwesterly sloping relief of the Aminpur Subdivision to the north where matching textural combinations, similar to Veryam, exist both in the surface and the profile. WAPDA's interpretation concurs with that of the SSoP wherein the still finer compositions in medium soils are laterally aligned with this central ridge of fine sandy loams. These moderately coarse to medium fractions are replaced by the successions of the Bagh and Jhakkar-Rasulpur associations that are predominantly silt loam but may retain their coarseness in the deeper profiles.

*Soil Drainability and Crop Suitability*: Based on the depositional patterns identified above, the broad categorizations in soil drainability appearing under Figure 18(c) show stratum-specific imperfections in the tail reaches of the Subdivision. These limitations, restricted to the command of the Khewera Distributary (the secondary level continuation of the Jhang Branch), primarily derive from the 10-15% occurrence of the slight to moderate levels of salinity that is associated with the Bagh and Jhakkar associations. Elsewhere, barring the sandy patches of the Sodhra Complex, the entire Subdivision is a well drained environment that suits the crop growth conditions required for the major crops like cotton, wheat and sugarcane (Figure 18(d)). The conditions favorable to rice would be limited to the occurrence of the silt loam profiles under the Shahdara and Bagh associations along the western fringes of the Subdivision.

*Soil Salinity and Waterlogging*: WAPDA's interpretations on moderate to strong levels of surface salinity in the Veryam Subdivision are partially coincident in space with the saline-alkali Jhakkar-Rasulpur association soils earlier identifed by the SSoP (Figure 18(e)). Since WAPDA's observations are mostly derived out of the aerial photo interpretations, the characteristic brightness of the saline lands has often been misconstrued with the presence of the coarser sandy profiles under the Sodhra series, or even with dunelands. The extent of these saline lands predominates the commands near the tail of the Jhang Branch in addition to the almost one-to-one correspondence observed vis a vis the Jhakkar-Rasulpur Complex soils and the S3 to S4 levels of surface salinization in the command of the Faqir Sar Distributary near the head reach of the Subdivision.

Data on profile salinity indicates that the incidence of higher salt concentrations within and below the root zone is quite well distributed across the entire Subdivision. This contrasts with the peculiarly higher densities of surface salinizations observed in the tail parts of the system. Sampling results from these profile pits revealed that the strata, bearing down to an aggegate depth of almost two meters, has proportionately higher concentrations of sodic salts than the salinity caused by the divalent cation interactions. Many of these profiles also have situations whereby, from a near absence of salinity in the top soil, the strata degrades to a combination of saline-sodic or non-saline sodic conditions.




Foigure 18(d) Soil Suitability for Major Crops in the Veryam Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

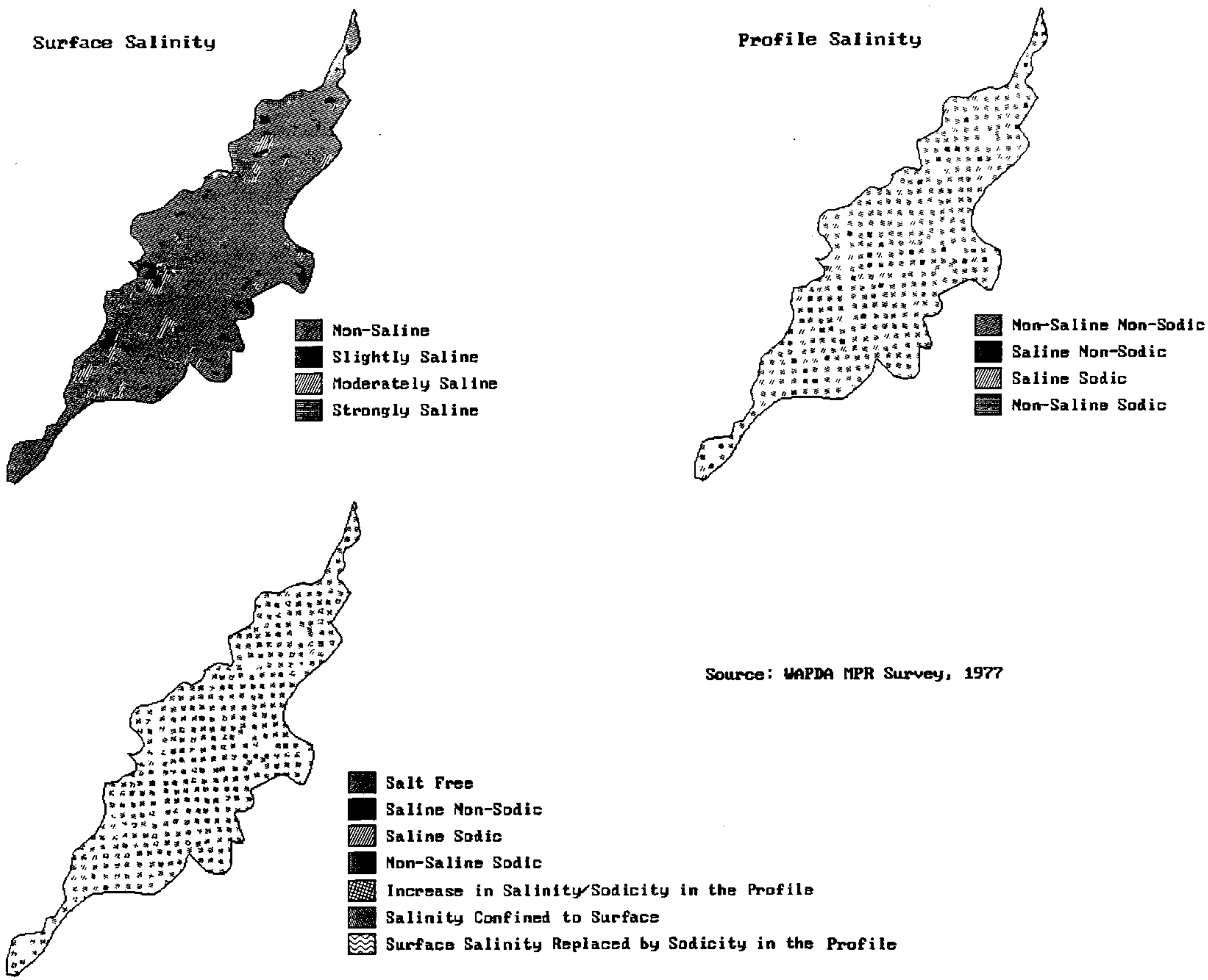



Figure 18(e) Surface and Profile Salinity in the Veryam Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

Until 1980, the WAPDA SMO records on the fluctuations in subsurface water levels between June and October showed aspects of both increases and decreases below the root zone (Figure 18(f)). Somewhat expectedly, the higher water levels were more extensive near the head reaches of the Subdivision; this contrasted with the decreasing levels at the very tail of the Jhang Branch, a situation that was reversed by 1985 wherein the subsurface rise reached the root zone. In between this geographic separation, the water levels near the tail of the Darsana Distributary rose to within the root zone, especially in those areas where the saline-alkali Rasulpur-Jhakkar soils have a very significant presence. It was also in this area that a permanently waterlogged situation emerged by 1985. The period following 1985 shows no significant impact of variations in water levels in the Subdivision that would threaten the top 90 cm of the soil. This is confirmed by the temporal sequence of the thematic data on subsurface slopes in Figure 18(g) wherein much of the lateral flows are not influenced by the seasonal variations in recharge due to the irrigation applications or rainfall. However, towards the end of this temporal comparison in 1993, there is evidence to suggest that water tables, *while remaining below the root zone*, are being increasingly affected through reduced subsurface flowouts. While there is little temporal evidence to support this abrupt development (second legend item in Figure 18(g)), the absence of a determinate argument would necessitate conjecture to the extent that the regime is susceptible to unusual events or externalities that influence normal lateral flows.

*IIMI Sampling for Soil Salinity and Texture*: Across a total of 13 sample locations cumulatively covering 8265 ha within the Veryam Subdivision, IIMI's field measurements for top soil salinity accounted for 1050 paired observations through the EM 38. Over 84% of these observations, after conversion to $EC_e$ ,were found to be compliant with the WAPDA S1 category of non-saline lands. As already stated before, IIMI's sample observations were recorded either in the cultivated areas or barren tracts in the immediate proximity of such tracts. For the Veryam Subdivision, where the samples were taken from the extreme head and tail reaches of the system, the overall distribution of salinity, along with the constituent textural composition, is provided under Figure B16, Volume Four. Medium textured silt loam/loam dominate all categories of soil salinity differentiations; coarser fractions of sandy loam and fine sandy loam are less significant for salinity classes S2 and S3 in comparison with S4. The converse is true for moderately fine silty clay loams that are less evident across higher levels of salinity. This contrasting behavior in these two textural groupings does not affect major categories of land use within the Veryam Subdivision wherein all such observations (Figure C16, Volume Four) are universally confined to the non-saline S1 category. There is a clear tendency to avoid productivity losses due to soil salinization. Nothwithstanding the predominance of silt loams in the observations, the significance of loams and sandy loams as the more desirable preference for growing cotton and orchards is not lost here. Salinity is rather exclusive to the barren lands category and, not surprisingly, it is the medium soils that have been observed to be the most affected.

*IIMI Farm Level Sampling*: From Table H1, Volume Four, a total of 30 farmers were sampled through the questionnaire-based economic survey. Table 1 has already shown this

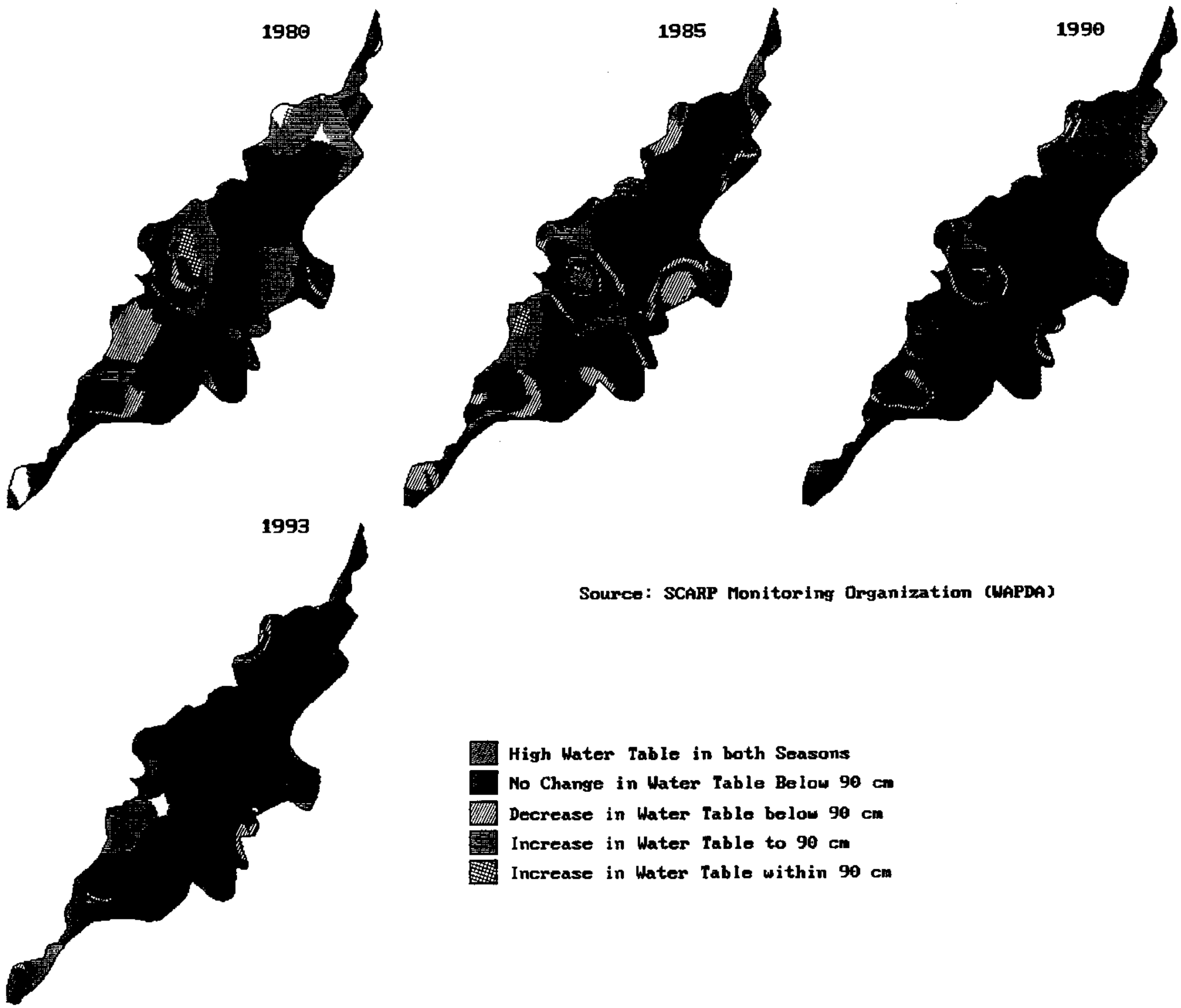



Figure 18(f) Temporal Variations in the Depth to Water Table, Veryam Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

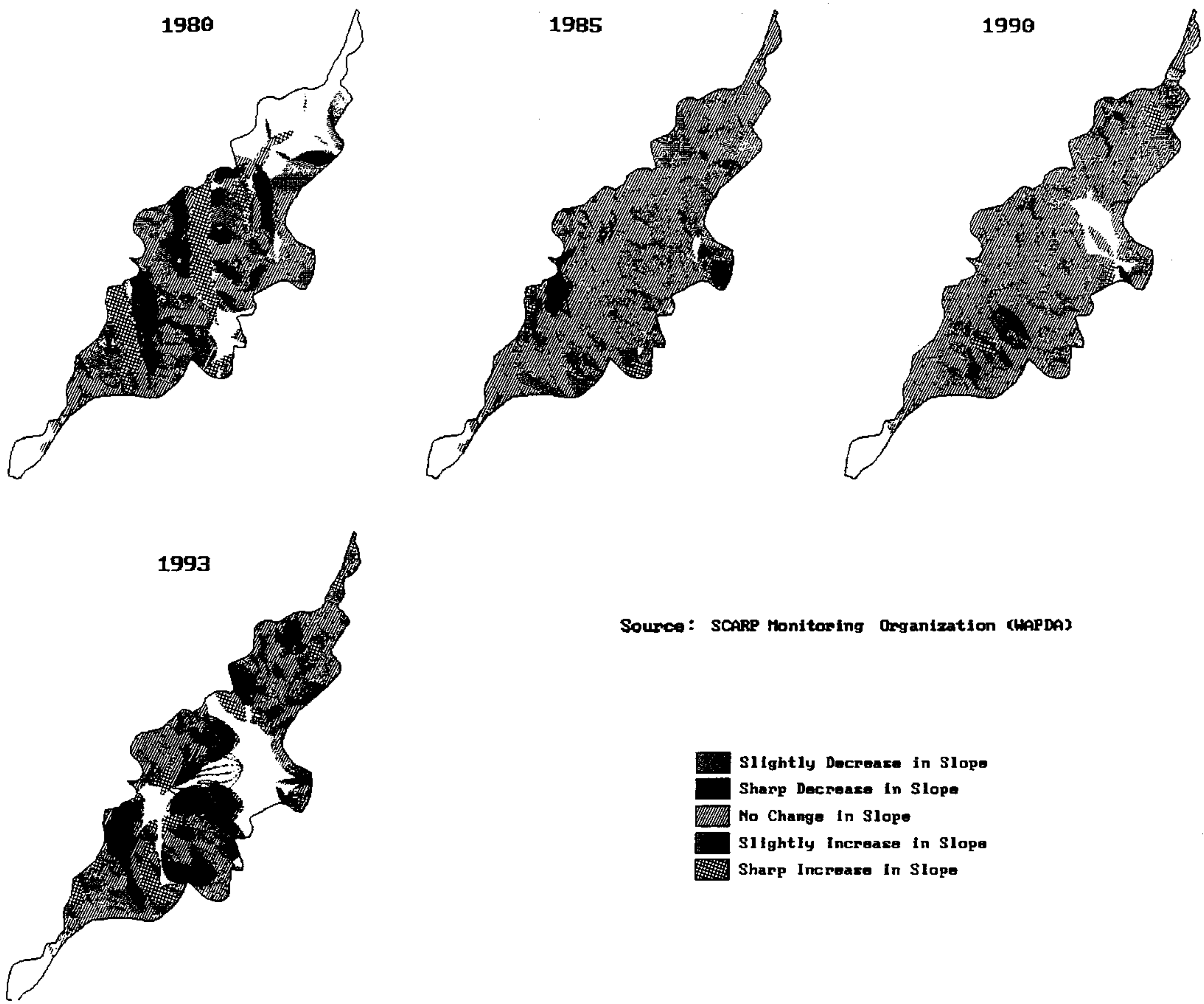



Figure 18(g) Interseasonal Slope Variations in the Subsurface Flows, Veryam Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

Subdivision to have the second highest proportion of the CCA within its gross area which is complemented in equal measure by the land use and farm level cropping intensities. The low incidence of culturable waste is offset by one of the highest intensities of fallowing across the cultivated commands of the LCC and the Haveli system. This has more to do with the scarcity of irrigation supplies than all other factors combined (Figures H2 & H3, Volume Four). The scarcity of irrigation water is contributed in part by the low quality of groundwater that could be used as a supplemental water supply. From Figure H1, Volume Four, the quality-wise differentiation in pumpage reported by the farmers is split roughly in half due to the vast geographic divide separating the head reaches of comparatively useable groundwaters from the tail reaches that coincide with the saline zone (Figure 12, Volume Four).

The major crops of wheat and sugarcane collectively account for a 66% cropping intensity that is one of the highest amongst the LCC subdivisions. This pattern of cultivation is similar to the one observed in the neighboring subdivisions of Aminpur and Wer; however, in terms of gross income and yield of wheat, it ranks behind both of them (Figure H6, Volume Four). The comparative figures for sugarcane relate well with the situation elsewhere, but the profits remain low due to the high cost of irrigation borne against this crop (Figures H12 & H13).

## R. Wer Subdivision

*Hydrologic Regime*: Wer Subdivision, bordering the Chenab River, is part of the larger Jhang Irrigation Division (Figure 19(a)). The Jhang Branch, as its source of surface irrigation supplies, never enters the Subdivision during its course that parallels a small stretch of its northeastern boundary. Other than a few exceptions, the entire secondary level distribution is through a Feeder that offtakes from the head reach of the Branch bordering the Subdivision. Almost one-third of its gross area is not under cultivable command, a figure which is one of the lowest in the LCC system. This is despite the most extensive distribution of its secondary network, comprising 26 channels covering more than 257 kms. However, when considered in the context of the rather small CCA, the resulting density of the distribution network (highest in the LCC) is not matched by the design allocations of surface supplies (Figure 1(b)) that seem to be less by as much as 25%. Taken in the context of the highest average area per watercourse within the LCC and the Haveli Subdivision, the resultant impact on the cultivation and cropping intensities is not difficult to imagine.

*Soils*: Because of its proximity to the Chenab River's floodplain, the soils are a balanced mix between the moderately coarse Farida and the medium Buchiana textures (Figure 19(b)), the latter occurring in larger aggregates along the central longitudinal stretch of the Subdivision. The sandy Jhang series is concentrated in a few significant patches along the eastern boundary of the Subdivision in areas comprising the tail portions of the respective channel commands. These profile differentiations in texture are also replicated in the topsoils where the loams are correlated in space with the Buchiana series and the loamy

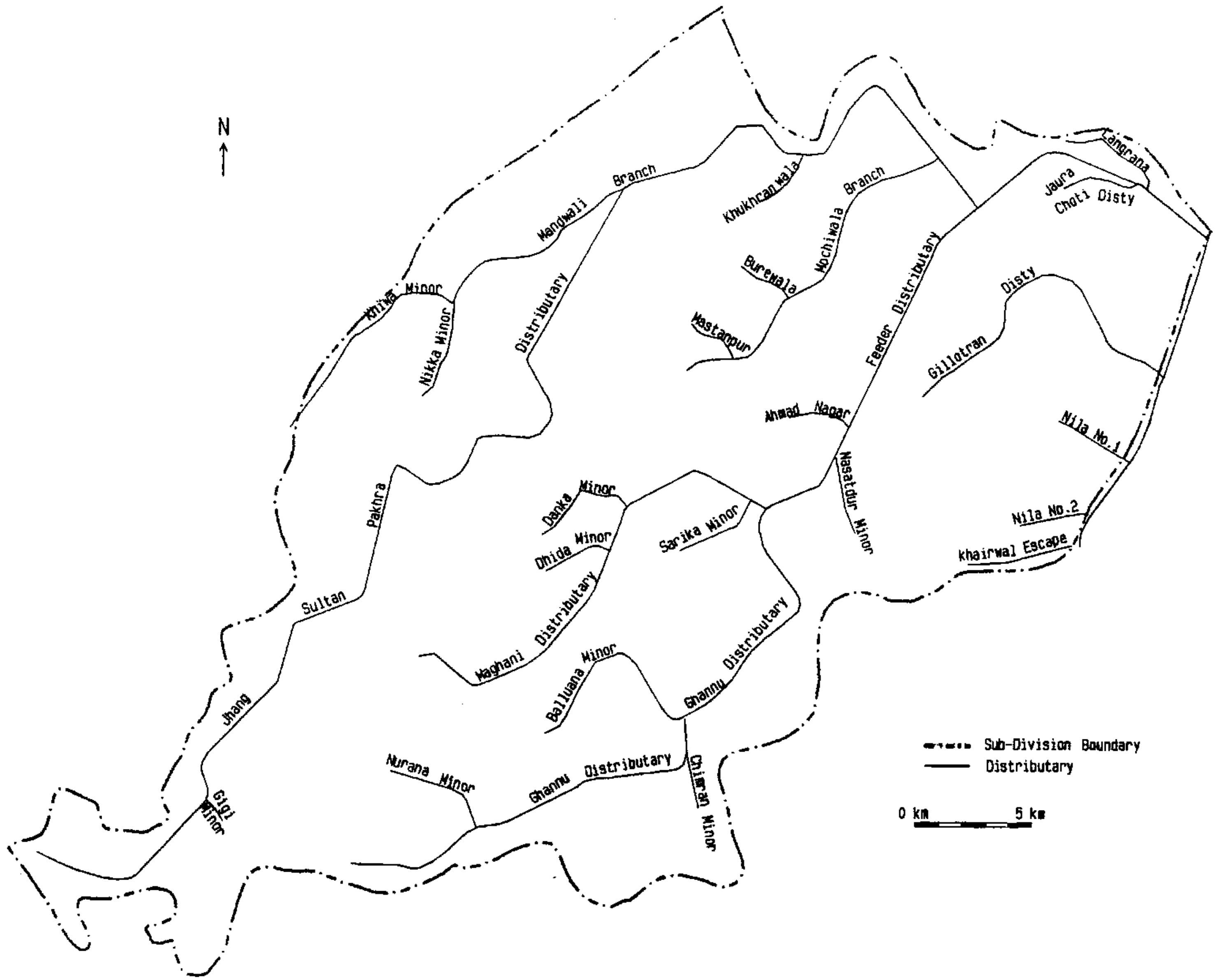



Figure 19(a) Wer Irrigation Subdivision in the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

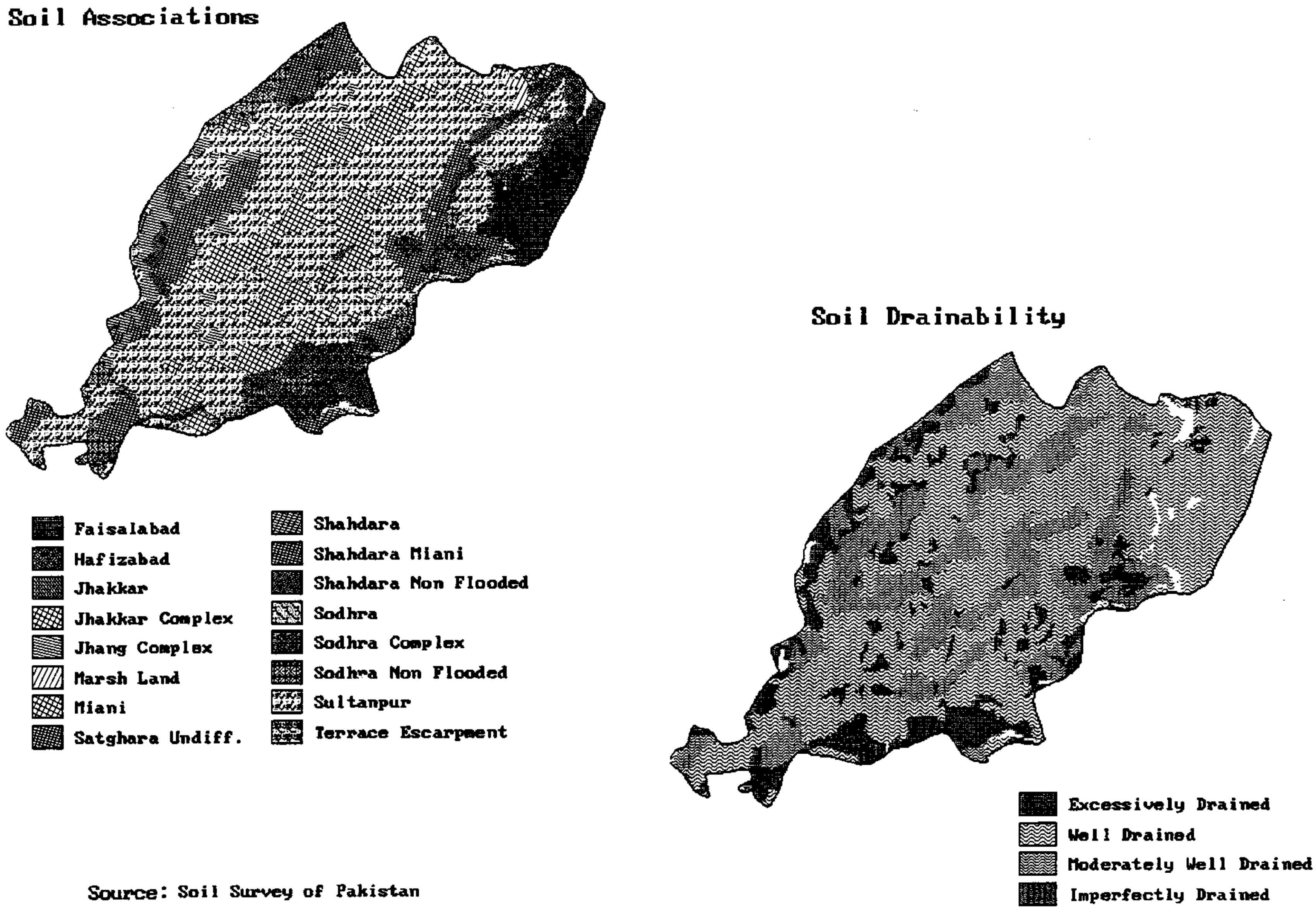

Source: SCARP Monitoring Organization (WAPDA)

Figure 19(b) Surface and Profile Texture of the Soils in the Wer Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

sand/sandy loams are distributed over the Jhang series. In comparison to the situation observed in the other subdivisions, the rather homogeneous nature of soil strata observed here suggests a very significant influence of the topography in shaping the textural divides. This is also confirmed by the earlier interpretations of the texture recorded by the SSoP, wherein much of the high and level areas of the floodplain comprise the calcareous silt loams of the Sultanpur series considered to be the most productive soils within the Rechna Doab (Figure 19(c)). Interspersed across the Sultanpur soils, in a manner similar to the distribution of the Buchiana series within the larger extent of the Farida soils, are the large longitudinal stretches of the Miani association's silty clay loams/clay loams. It is along the sinuous pattern of these soils that the layout of the secondary level distribution network coincides for the major distributaries in the area. A general observation, also noticed for other areas within the Rechna Doab, shows that WAPDA's interpretation of the soil texture are offset from those of the SSoP by one complete class difference; what the former identifies as moderately coarse or medium in texture is a medium or moderately fine soil in the SSoP mapping. Regardless of this difference in the class-wise interpretations, the distribution pattern of the moderately fine textures of SSoP matches the medium textures identified by WAPDA. A more exact concordance exists between the Jhang series interpretation by WAPDA and the Sodhra Complex soils mapped by the SSoP; the more frequent patches of the Jhang Complex in the center of the Subdivision match the sandy loam surface textures mapped by WAPDA.

*Soil Drainability and Crop Suitability*: Based on the spatial distribution of soils under Figure 19(c) above, most of the Subdivision represents a well drained environment within which the channels of the topographic relief comprise the finer textures of the Miani/Shahdara-Miani associations capable of moderate drainage. There are very few, and well scattered, pockets of restricted drainage due exclusively to the strongly alkaline Jhakkar Complex soils. While these pockets would restrict crop growth in general, they are capable of sustaining the cultivation of rice (Figure 19(d)). Overall, excluding the margins, the Subdivision is well suited for the growth of wheat, rice and sugarcane; cotton would be less suited for the finer textures along the center of the Subdivision and its cultivation would be largely unproductive in the alkaline or sandy stratas.

*Soil Salinity and Waterlogging*: The survey of the mid 1970s by WAPDA indicate the Subdivision to be largely free of the debilitating effects of soil salinization (Figure 19(e)). An isolated occurrence of a surface confined strongly saline (S4) patch was observed along the Khairwal Escape that offtakes from about the point where the Jhang Branch veers off from the boundary of the Subdivision. Separate observations of the profile revealed that the saline-sodic and the saline-non-sodic patches to be mostly coincident with the moderately fine soil textures. Somewhat ironically, there is no reported evidence of salinity in the tail reach of the Subdivision. Channels most affected by the concentration of salinity/sodicity in the profile are the Ghannu and the Maghani distributaries that offtake from the tail of the main Feeder supplying irrigation water to the Subdivision. The ten year difference in the reported extents of salinity by the SSoP and WAPDA indicate a significant overlap in the Jhakkar Complex soils and the Slightly saline (S1) levels of salinity. The




Source: Soil Survey of Pakistan

Figure 19(c) Associative Classification of the Soils and their Drainability Characteristics the Wer Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

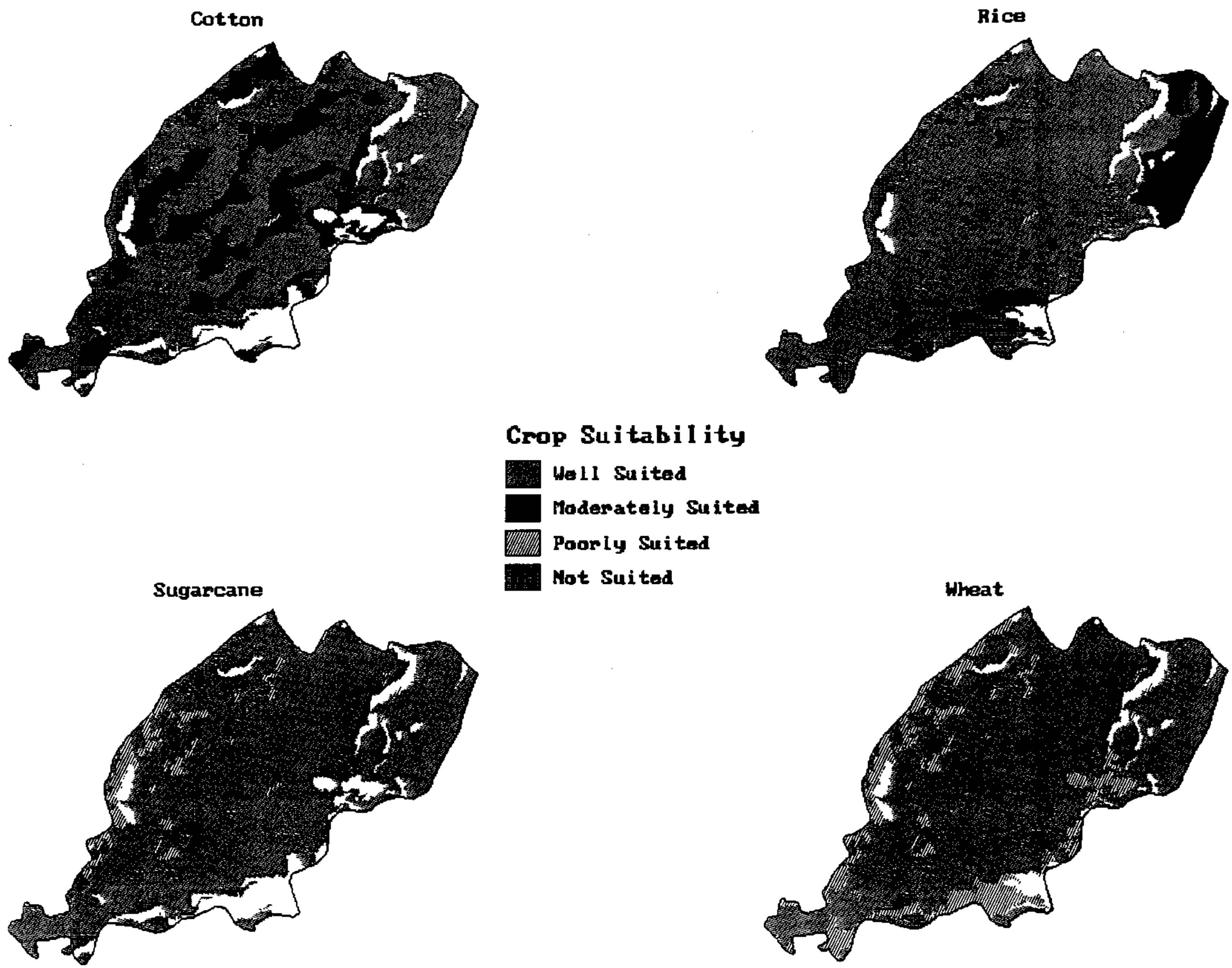



Figure 19(d) Soil Suitability for Major Crops in the Wer Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

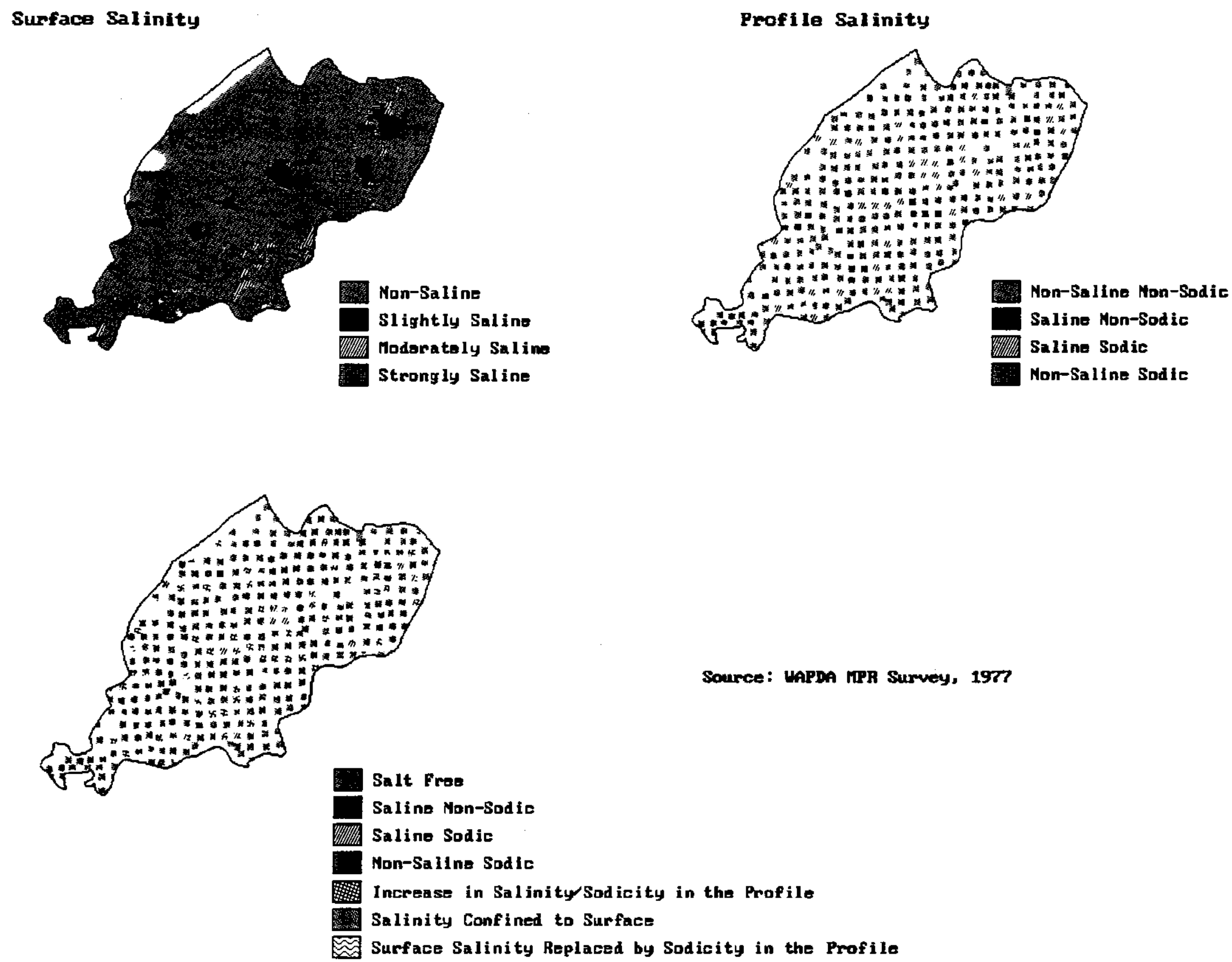



Figure 19(e) Surface and Profile Salinity in the Wer Irrigation Subdivision of the Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

mapped data indicates a significant increase in this incidence not only in the areas previously known for such occurence, like in the command of the Choti Distributary in the head reach of the system, but also in the command of the Ghannu Distributary where the past SSoP observations showed salinity limited mostly to the middle and the very tail reaches.

Temporal comparison of the seasonal fluctuations in the water tables indicates a stable regime below the root zone (Figure 19(f)). The few isolated instances of significantly high water levels are noticeable from the period 1990 and onward; however, they are limited to a localized presence between the eastern boundary of the Subdivision and the Ghannu Distributary. These high water levels correspond to a lateral drainage restriction, rather than a topographic constraint, that is common on either side of the boundary with the Veryam Subdivision (Figure 19(g)). It's impact does not correlate well with the more rigorous evidence of surface salinization elsewhere.

Note: *There was no field sampling conducted by IIMI for soil salinity/texture and farm level interviews for the Wer Subdivision.*

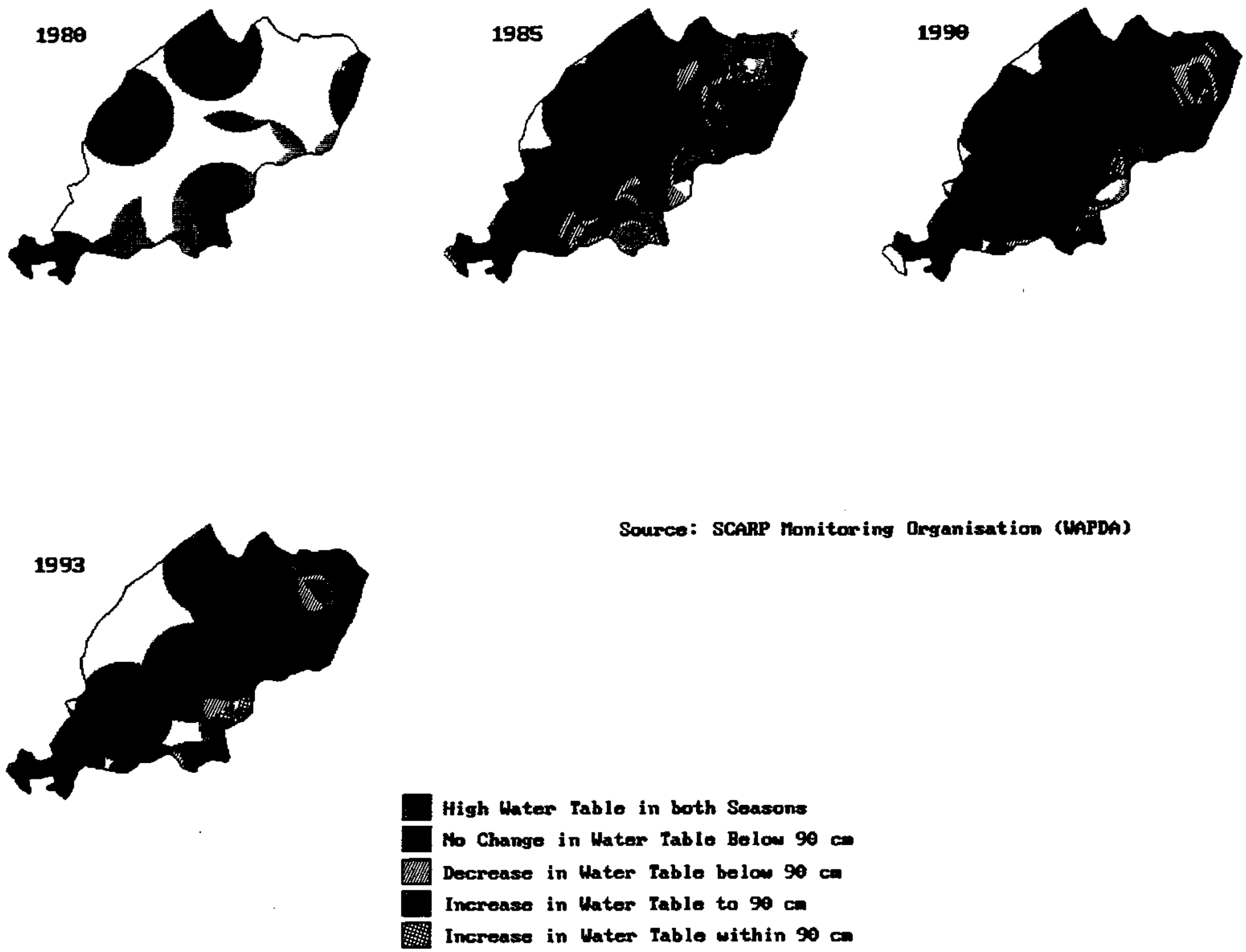



Figure 19(f) Temporal Variations in the Depth to Water Table, Wer Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

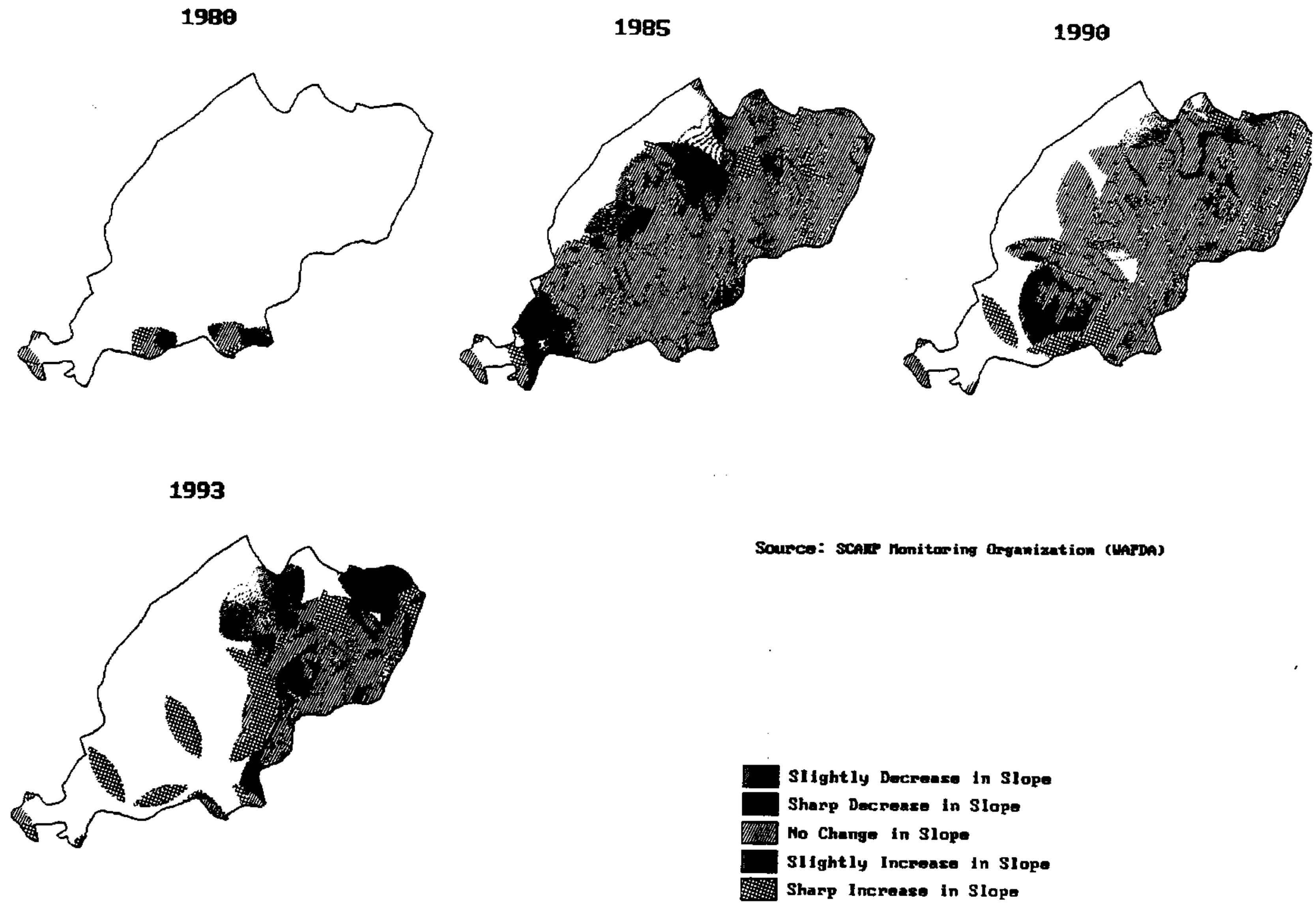



Figure 19(g) Interseasonal Slope Variations in the Subsurface Flows, Wer Irrigation Subdivision, Lower Chenab Canal (West) Circle, Rechna Doab, Punjab, Pakistan.

## III. SUMMARY OF RESOURCE POTENTIAL FOR MAJOR CROPS

The foregoing discussion provided a general inventory of the physical and economic resource potential that exists within each of the subdivision commanded by the LCC and the Haveli system. Towards this descriptive compilation, a comprehensive reliance was made on the data processing accomplished previously under Volume Four. Given the rather vast and complex association of the physical regime towards interactive links with farm level productivity, perhaps much of this discussion could be more usefully exploited as a focused reference to a subdivision. However, the objectives of the study preclude a threadbare understanding of the diversity inherent within each of the subdivisions. The prerequisites to such an approach would necessitate delineations of the commanded regime (not available for this study) whereby firm relationships could be obtained between the cultivated commands, the incidence of secondary soil salinization and the available surface flows. Hence, the abiding emphasis remains within inter-subdivisional variability in terms of the most predominant physical and farming characteristics of the regime. The unbiased nature of this comparison in space is not only apparent from the determination of the sampling regime through multi-layered GIS analysis, but also from the distribution of the farmholdings and the fields for salinity/soil texture assessment that were selected at random from amongst each of the sample areas. Appendices B, C and H in Volume Four capture much of this sampling variability for each of the subdivisional units in the Lower Rechna area. In the discussion that follows, Section A provides a carryover to the unitary calculation of the gross farm inputs and returns towards marginal improvements to major crop intensities at the subdivision level. In this respect, certain assumptions have been made in terms of the resource allocations that favor an *extensive* growth of irrigated agriculture for higher production of major crops. This approach does not interfere with the existing farming preferences for the minor crops, or the reliance on the culturable waste, which in itself is the most significant limitation to higher land use after irrigation supplies.

In Section B, the approach favors *intensive* gains in irrigated agriculture, whereby the production targets set in Section A are met through improvements in yield only. In this respect, the production functions listed under Tables 10(a)-(d) of Volume Four are used to arrive at the comparable figures on gross farm inputs and returns for the major crops. The format of the output is similar across both intensive and extensive levels of redemption in production and hence facilitates a direct comparison of results under Section C.

### A. Marginal Improvements to the Cropping Intensities

The overall situation for the cultivation intensities prevailing across the subdivisions of the LCC and the Haveli system appears under Table 4. Of particular significance are the wide variations in the intensities of the culturable waste and fallowing during the kharif season. The available margin in fallowing is relatively less during the rabi season due to the higher intensities of the wheat crop. The division of the Rechna Doab into the two agroclimatic

Table 4. Distribution Intensities of the Landuse within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

| Subdivision | Major Crops | | | | Minor Crops | | | Fallow | | Waste Intensity |
|---|---|---|---|---|---|---|---|---|---|---|
| | Wheat | Sugarcane | Rice | Cotton | Kharif Fodder | Rabi Fodder | Others | Rabi | Kharif | |
| Aminpur | 54.9 | 14.5 | 0.0 | 1.2 | 9.6 | 8.0 | 11.0 | 24.7 | 50.3 | 22.7 |
| Bhagat | 44.2 | 7.4 | 6.4 | 22.7 | 10.4 | 9.6 | 13.4 | 37.9 | 36.0 | 4.3 |
| Buchiana | 48.3 | 26.0 | 3.2 | 7.7 | 12.6 | 13.6 | 8.0 | 26.2 | 38.0 | 18.1 |
| Chuharkana | 62.2 | 3.3 | 49.9 | 3.1 | 8.9 | 9.4 | 19.1 | 22.9 | 28.8 | 3.1 |
| Dhanlar | 58.2 | 20.0 | 9.9 | 19.4 | 11.1 | 11.7 | 2.5 | 8.1 | 38.8 | 19.5 |
| Haveli | 63.5 | 9.1 | 9.3 | 39.9 | 11.4 | 11.5 | 9.4 | 15.8 | 30.2 | 29.0 |
| Kanya | 54.3 | 35.2 | 4.5 | 2.7 | 23.5 | 19.0 | 17.2 | 13.1 | 34.4 | 24.3 |
| Kot Khuda Yar | 48.5 | 28.0 | 3.1 | 0.7 | 24.7 | 19.4 | 5.6 | 31.5 | 49.4 | 17.9 |
| Mohlan | 57.5 | 18.1 | 26.2 | 4.0 | 11.9 | 10.5 | 8.2 | 10.9 | 31.6 | 5.0 |
| Pacca Dala | 54.4 | 11.7 | 19.4 | 1.8 | 13.5 | 12.9 | 26.0 | 15.6 | 30.3 | 7.4 |
| Sagar | 75.7 | 4.1 | 51.4 | 0.0 | 24.3 | 13.5 | 2.7 | 2.7 | 23.0 | 3.9 |
| Sangla | 57.2 | 6.4 | 17.9 | 0.0 | 25.2 | 24.7 | 6.4 | 13.7 | 51.3 | 9.4 |
| Sultanpur | 67.4 | 11.7 | 28.8 | 21.2 | 19.5 | 16.5 | 15.3 | 8.5 | 10.2 | 31.0 |
| Tandlianwala | 49.1 | 21.2 | 3.9 | 9.0 | 28.6 | 16.3 | 20.5 | 13.7 | 27.1 | 4.2 |
| Tarkhani | 45.6 | 17.8 | 0.8 | 16.6 | 9.0 | 9.1 | 19.2 | 14.1 | 35.3 | 18.8 |
| Uqbana | 42.6 | 20.3 | 6.1 | 4.0 | 13.4 | 9.5 | 5.2 | 21.6 | 41.4 | 16.1 |
| Veryam | 45.7 | 19.2 | 3.0 | 1.9 | 8.4 | 7.6 | 12.6 | 24.9 | 51.7 | 12.2 |
| Wer | 41.7 | 27.8 | 0.0 | 0.0 | 8.1 | 17.4 | 0.0 | 9.3 | 37.0 | 0.0 |

zones of Punjab rice-wheat and Punjab sugarcane-wheat (Figure 20, Volume Three) is clearly observed in the cropping pattern of the major crops wherein areas with higher consumptive use crops have low intensities of the cotton crop, and vice versa. Interestingly, the incidence of the culturable waste is not synonymous with the tail reaches of the system, rather it has been observed to be high in areas that have higher intensities of the wheat crop, or conversely low intensities of the rice crop. The exception to the foregoing is the Haveli Subdivision that has suffered the brunt of the poor subsurface drainage conditions due to excessive seepages from the main Haveli and T.S. Link canals.

When compared in the context of the seasonal fallowing, there is much scope for expansion of the cultivated area devoted to the major crops. Figure H3, Volume Four, has already shown that much of the fallowing is necessitated by the scarcity of surface supplies. Hence, assuming the surface supplies are better managed (options to be discussed separately in Volume Eight), there is room for expansion of the existing cropping intensities of these major crops. The following discussion pertains to the contributions of this area-specific resource augmentation leading to incremental gains in production.

### 1) Incremental Gains in Production

Tables 5(a)-(d) list the marginal improvements to the existing cropping intensities of each of the four major crops of wheat, cotton, rice and sugarcane out of the existing share of the fallow lands in their respective growing seasons. For the wheat crop, as much as <u>50% of the fallow land intensity</u> has been consumed towards bolstering the cropping intensity. Since wheat is universally grown across the Rechna Doab, this implied increase was consistent across all the irrigation subdivisions (Haveli and Sagar subdivisions were omitted because figures on their commanded area were not available). A similar increase in the intensity of the cotton crop has also been implied, however subdivisons like Aminpur, Kot Khuda Yar, Sangla, Chuharkana, Kanya, Mohlan, Pacca Dala, Uqbana and Wer have been omitted due to either already low values of areas under its cultivation or inadequate sample data on farmers reporting its cultivation during the IIMI questionnaire-based field surveys. For the higher consumptive use crops like rice and sugarcane, the increase in their respective cropping intensities (out of the kharif and rabi fallow, respectively) is 10% and 25%. Again, subdivisional level exclusions have been made where necessary (Tables 5(c) and 5(d)).

From Table 5(a), the respective magnitudes of the proposed cropping intensities do not necessarily translate into equivalent gains in production due to variations in the yields. Thus, the lesser area devoted to wheat in the Chuharkana Subdivision would yield nearly the same production as in the neighboring Mohlan, where there remains much less margin for further expansion of its cropping intensity. The Aminpur Subdivision in the Jhang Canal command has the best combination of both the proposed area for its cultivation and the existing yield to give it the highest production levels across the LCC system. Though Bhagat Subdivision is not far behind in second place, it has the unique distinction of having the highest estimated production amongst the tail subdivisions of the system. In fact, for the

Table 5(a). Distribution of Marginal Improvements to the Wheat Crop Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

| Subdivision | Gross Area (ha) | Command Area (ha) | Existing Cropping Intensity (%) | Proposed Cropping Intensity (%) | Existing Fallow Area Intensity (%) | Proposed Fallow Intensity (%) | Existing Cropped Area under Wheat (ha) | Proposed Cropped Area under Wheat (ha) | Average Yield (Kg/ha) | Existing Production (000 m.ton) | Proposed Production (000 m.ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aminpur | 92479 | 78103.84 | 54.9 | 67.25 | 24.7 | 12.35 | 42879.01 | 52524.83 | 2979.30 | 127.75 | 156.49 |
| Bhagat | 96394 | 75167.27 | 44.2 | 63.15 | 37.9 | 18.95 | 33223.93 | 47468.13 | 3157.70 | 104.91 | 149.89 |
| Buchiana | 81151 | 64177.76 | 48.3 | 61.40 | 26.2 | 13.10 | 30997.86 | 39405.14 | 2831.80 | 87.78 | 111.59 |
| Chuharkana | 97417 | 70064.01 | 62.2 | 73.65 | 22.9 | 11.45 | 43579.81 | 51602.14 | 2859.50 | 124.62 | 147.56 |
| Dhaular | 98000 | 66011.76 | 58.2 | 62.25 | 8.1 | 4.05 | 38418.84 | 41092.32 | 2554.40 | 98.14 | 104.97 |
| Haveli | | | | | | | | | | | |
| Kanya | 77473 | 56113.92 | 54.3 | 60.85 | 13.1 | 6.55 | 30469.86 | 34145.32 | 2631.6 | 80.18 | 89.86 |
| Kot Khuda Yar | 81252 | 51289.20 | 48.5 | 64.25 | 31.5 | 15.75 | 24875.26 | 32953.31 | 2550.1 | 63.43 | 84.03 |
| Mohlan | 112694 | 89537.65 | 57.5 | 62.95 | 10.9 | 5.45 | 51484.15 | 56363.95 | 2640.9 | 135.96 | 148.85 |
| Pacca Dala | 78108 | 71029.07 | 54.4 | 62.20 | 15.6 | 7.80 | 38639.81 | 44180.08 | 3013.5 | 116.44 | 133.14 |
| Sagar | | | | | | | | | | | |
| Sangla | 51610 | 40224.70 | 57.2 | 64.05 | 13.7 | 6.85 | 23008.53 | 25763.92 | 2442.8 | 56.21 | 62.94 |
| Sultanpur | 60629 | 44524.49 | 67.4 | 71.65 | 8.5 | 4.25 | 30009.51 | 31901.80 | 2092.1 | 62.78 | 66.74 |
| Tandlianwala | 110879 | 84752.00 | 49.1 | 55.95 | 13.7 | 6.85 | 41613.23 | 47418.74 | 2621.9 | 109.11 | 124.33 |
| Tarkhani | 88240 | 67067.83 | 45.6 | 52.65 | 14.1 | 7.05 | 30582.93 | 35311.21 | 3098.8 | 94.77 | 109.42 |
| Uqbana | 119053 | 98322.00 | 42.6 | 53.40 | 21.6 | 10.80 | 41885.00 | 52504.00 | 2752.20 | 115.27 | 144.50 |
| Veryam | 108122 | 94923.90 | 45.7 | 58.15 | 24.9 | 12.45 | 43380.22 | 55198.25 | 2460.40 | 106.73 | 135.81 |
| Wer | 93768 | 63683.80 | 41.7 | 46.35 | 9.3 | 4.65 | 26556.14 | 29517.44 | 2767.50 | 73.49 | 81.69 |

Table 5(b). Distribution of Marginal Improvements to the Cotton Crop Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

| Subdivision | Gross Area (ha) | Command Area (ha) | Existing Cropping Intensity (%) | Proposed Cropping Intensity (%) | Existing Fallow Area Intensity (%) | Proposed Fallow Intensity (%) | Existing Cropped Area (ha) | Proposed Cropped Area (ha) | Average Yield (Kg/ha) | Existing Production (000 m.ton) | Proposed Production (000 m.ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aminpur | 92479 | 78103.84 | 1.20 | 1.20 | 50.30 | 0.00 | 937.25 | 937.25 | 494 | 0.46 | 0.00 |
| Bhagat | 96394 | 75167.27 | 22.70 | 40.70 | 36.00 | 18.00 | 17062.97 | 30593.08 | 1302 | 22.22 | 39.83 |
| Buchiana | 81151 | 64177.76 | 7.70 | 26.70 | 38.00 | 19.00 | 4941.69 | 17135.46 | 1005 | 4.97 | 17.22 |
| Chuharkana | 97417 | 70064.01 | 3.10 | 3.10 | 28.80 | 0.00 | 2171.98 | 2171.98 | 999 | 2.17 | 0.00 |
| Dhaular | 98000 | 66011.76 | 19.40 | 38.80 | 38.80 | 19.40 | 12806.28 | 25612.56 | 1438 | 18.42 | 36.83 |
| Haveli | | | | | | | | | | | |
| Kanya | 77473 | 56113.92 | 2.70 | 2.70 | 34.40 | 0.00 | 1515.08 | 1515.08 | 1779 | 2.70 | 0.00 |
| Kot Khuda Yar | | | | | | | | | | | |
| Mohlan | 112694 | 89537.65 | 4.00 | 4.00 | 31.60 | 0.00 | 3581.51 | 3581.51 | 972 | 3.48 | 0.00 |
| Pacca Dala | 78108 | 71029.07 | 1.80 | 1.80 | 30.30 | 0.00 | 1278.52 | 1278.52 | 1176 | 1.50 | 0.00 |
| Sagar | | | | | | | | | | | |
| Sangla | | | | | | | | | | | |
| Sultanpur | 60629 | 44524.49 | 21.20 | 26.30 | 10.20 | 5.10 | 9439.19 | 11709.94 | 758 | 7.15 | 8.88 |
| Tandlianwala | 110879 | 84752.00 | 9.00 | 22.55 | 27.10 | 13.55 | 7627.68 | 19111.58 | 1285 | 9.80 | 24.56 |
| Tarkhani | 88240 | 67067.83 | 16.60 | 34.25 | 35.30 | 17.65 | 11133.26 | 22970.73 | 1163 | 12.95 | 26.71 |
| Uqbana | 119053 | 98322.00 | 4.00 | 4.00 | 41.40 | 0.00 | 3933.00 | 3933.00 | 1059 | 4.16 | 0.00 |
| Veryam | 108122 | 94923.90 | 1.90 | 13.27 | 51.70 | 11.37 | 1803.55 | 12600.20 | 1631 | 2.94 | 20.55 |
| Wer | | | | | | | | | | | |

Table 5(c). Distribution of Marginal Improvements to the Rice Crop Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

| Subdivision | Gross Area (ha) | Command Area (ha) | Existing Cropping Intensity (%) | Proposed Cropping Intensity (%) | Existing Fallow Area Intensity (%) | Proposed Fallow Intensity (%) | Existing Cropped Area (ha) | Proposed Cropped Area (ha) | Average Yield (Kg/ha) | Existing Production (000 m.ton) | Proposed Production (000 m.ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aminpur | | | | | | | | | | | |
| Bhagat | 96394 | 75167.27 | 6.40 | 6.40 | 36.00 | 0.00 | 4810.71 | 4810.71 | 2438 | 11.71 | 0.00 |
| Buchiana | 81151 | 64177.76 | 3.20 | 3.20 | 38.00 | 0.00 | 2053.69 | 2053.69 | 2446 | 12.36 | 0.00 |
| Chuharkana | 97417 | 70064.01 | 49.90 | 52.78 | 28.80 | 25.92 | 34961.94 | 36979.78 | 2774 | 96.98 | 102.60 |
| Dhaular | 98000 | 66011.76 | 9.90 | 13.78 | 38.80 | 34.92 | 6535.16 | 9096.42 | 3138 | 20.50 | 28.54 |
| Haveli | | | | | | | | | | | |
| Kanya | 77473 | 56113.92 | 4.50 | 4.50 | 34.40 | 0.00 | 2525.13 | 2525.13 | 1779 | 4.50 | 0.00 |
| Kot Khuda Yar | 81252 | 51289.20 | 3.10 | 8.04 | 49.40 | 44.6 | 1589.97 | 4123.65 | 2537 | 4.03 | 10.46 |
| Mohlan | 112694 | 89537.65 | 26.20 | 29.36 | 31.60 | 28.44 | 23458.86 | 26288.25 | 2298 | 54.00 | 60.41 |
| Pacca Dala | 78108 | 71029.07 | 19.40 | 22.43 | 30.30 | 27.27 | 13779.64 | 15931.82 | 2599 | 35.81 | 41.40 |
| Sagar | | | | | | | | | | | |
| Sangla | 51610 | 40224.70 | 17.90 | 23.03 | 51.30 | 46.17 | 7200.22 | 9263.75 | 4028 | 29.00 | 37.31 |
| Sultanpur | 60629 | 44524.49 | 28.80 | 29.31 | 10.20 | 9.69 | 12823.05 | 13050.13 | 922 | 11.80 | 12.03 |
| Tandlianwala | 110879 | 84752.00 | 3.90 | 5.26 | 27.10 | 25.74 | 3305.33 | 4453.72 | 2933 | 9.70 | 13.06 |
| Tarkhani | | | | | | | | | | | |
| Uqbana | 119053 | 98322.00 | 6.10 | 8.17 | 41.40 | 39.33 | 5998.00 | 8033.00 | 2639 | 15.82 | 21.20 |
| Veryam | 108122 | 94923.90 | 3.00 | 3.00 | 51.70 | 0.00 | 2847.72 | 2847.72 | 2965 | 8.52 | 0.00 |
| Wer | | | | | | | | | | | |

Table 5(d). Distribution of Marginal Improvements to the Sugarcane Crop Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

| Subdivision | Gross Area (ha) | Command Area (ha) | Existing Cropping Intensity (%) | Proposed Cropping Intensity (%) | Existing Fallow Area Intensity (%) | Proposed Fallow Intensity (%) | Existing Cropped Area (ha) | Proposed Cropped Area (ha) | Average Yield (Kg/ha) | Existing Production (000 m.ton) | Proposed Production (000 m.ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aminpur | 92479 | 78103.84 | 14.50 | 20.68 | 24.70 | 18.52 | 11325.06 | 16147.97 | 48149.2 | 545.29 | 777.51 |
| Bhagat | 96394 | 75167.27 | 7.40 | 16.88 | 37.90 | 28.42 | 5562.38 | 12684.48 | 41183.3 | 229.08 | 522.39 |
| Buchiana | 81151 | 64177.76 | 26.00 | 32.55 | 26.20 | 19.65 | 16686.22 | 20889.86 | 45342.9 | 756.60 | 947.21 |
| Chuharkana | 97417 | 70064.01 | 3.30 | 9.03 | 22.90 | 17.17 | 2312.11 | 6323.28 | 46454.8 | 107.41 | 293.75 |
| Dhaular | 98000 | 66011.76 | 20.00 | 22.03 | 8.10 | 6.07 | 13202.35 | 14539.09 | 55734.8 | 735.83 | 810.33 |
| Haveli | | | | | | | | | | | |
| Kanya | 77473 | 56113.92 | 35.20 | 38.48 | 13.10 | 9.82 | 19752.10 | 21589.83 | 46356.0 | 915.63 | 1000.82 |
| Kot Khuda Yar | 81252 | 51289.20 | 28.00 | 35.88 | 31.50 | 23.62 | 14360.98 | 18400.00 | 58686.3 | 842.79 | 1079.83 |
| Mohlan | 112694 | 89537.65 | 18.10 | 20.83 | 10.90 | 8.17 | 16206.31 | 18646.22 | 51067.3 | 827.61 | 952.21 |
| Pacca Dala | 78108 | 71029.07 | 11.70 | 15.60 | 15.60 | 11.70 | 8310.40 | 11080.53 | 52775.2 | 438.58 | 584.78 |
| Sagar | | | | | | | | | | | |
| Sangla | 51610 | 40224.70 | 6.40 | 9.83 | 13.70 | 10.27 | 2574.38 | 3952.08 | 56009.3 | 144.19 | 221.35 |
| Sultanpur | 60629 | 44524.49 | 11.70 | 13.83 | 8.50 | 6.37 | 5209.37 | 6155.51 | 36241.3 | 188.79 | 223.08 |
| Tandlianwala | 110879 | 84752.00 | 21.20 | 24.63 | 13.70 | 10.27 | 17967.42 | 20870.18 | 50144.8 | 900.97 | 1046.53 |
| Tarkhani | 88240 | 67067.83 | 17.80 | 21.33 | 14.10 | 10.57 | 11938.07 | 14302.21 | 56072.7 | 669.40 | 801.96 |
| Uqbana | 119053 | 98322.00 | 20.30 | 25.70 | 21.60 | 16.20 | 19959.37 | 25268.75 | 49024.6 | 978.50 | 1238.80 |
| Veryam | 108122 | 94923.90 | 19.20 | 25.43 | 24.90 | 18.67 | 18225.39 | 24134.40 | 58398.0 | 893.49 | 1183.18 |
| Wer | 93768 | 63683.80 | 27.80 | 30.13 | 9.30 | 6.97 | 17704.10 | 19184.74 | 49420.0 | 1033.88 | 1120.35 |

cotton crop (Table 5(b)), for which the proposed cultivation increases are implied mostly to the tail reach subdivisions of the system, Bhagat Subdivision has the highest estimation for its overall production. For a high consumptive use crop like rice, many of the subdivisions excluded from the list of proposed areal increases for cotton are now prominently included in the proposed estimates of production. From Table 5(c), much of this emphasis in enhanced productivity is limited to the four subdivisions of Chuharkana, Mohlan, Pacca Dala and Sangla. These subdivisions have been the traditional rice growing areas within the LCC system on account of the dual blessings of higher clayey fractions in the soils and their locations near the head reaches of the system.

The sugarcane cultivation, just like wheat, is fairly consistent across all of the subdivisions under the LCC system. Against a 25% areal allocation from the existing Rabi fallow, the proposed cropping intensities are listed in Table 5(d). Here, the trend in increasing levels of the estimated production is the reverse of what was observed for rice, i.e. areas growing rice produce less sugarcane and vice versa. The most prolific potential for higher sugarcane production comes from areas with predominantly medium textured soils (Figures 17(d), 18(d) and 19(d) above).

### 2) Net Economic Returns

The cost effect of marginal improvements to the cultivated regimes of the four major crops appears in Table 6. The calculations derive from the per hectare level gross farm inputs and returns appearing under Tables H2-H5 in Volume Four. From Table 6(a), despite the higher production of the wheat crop in the Chuharkana Subdivision, its overall profits remain lower than the Pacca Dala Subdivision due to relatively higher investments in key input areas of land preparation, fertlizer and irrigation. Unfortunately, these investments are not rewarded in equal measure so as to supercede the average yields in the Pacca Dala Subdivision. Elsewhere, the advantage in higher yields and production is lost in the tail reach Bhagat Subdivision in comparison to Mohlan due to higher costs of irrigation affecting net returns. The highest productive gains in the Aminpur Subdivision (Table 5(a)) are sustained by an equal measure of distinction in both gross income and profits. Its difference vis a vis Bhagat is owed much to the gross receipts for this crop rather than significantly low overall costs. The same analogy could extended to include other subdivisions like Chuharkana, Mohlan, Uqbana and Veryam subdivisions that are similar to Aminpur in terms of the size of the proposed cultivated area. The first two subdivisions are in the head reaches of the LCC, whereas the remaining two are irrigated by the tails of the Rakh and Jhang branches. The overall profits from the wheat crop within the head reach subdivisions, more known for the intensive cultivation of rice, are higher largely because of the difference in gross receipts.

Cotton remains the most rewarding crop for the Bhagat Subdivision, as is evident from Table 6(b). In fact, the lower Rechna subdivisions of Bhagat, Dhaular and Veryam were expected to be favored for its cultivation due to a mix of agroclimatic conditions suitable for

Table 6(a). Distribution of Macro Level Indicators of the Wheat Crop after Marginal Improvement to the Cropping Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Total Proposed Area Under Wheat (ha) | Gross Income | Costs from Total Proposed Area | | | | | | | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cost of Land Preparation | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Total Cost* | |
| Aminpur | 52524.8 | 736.0 | 66.0 | 26.8 | 75.4 | 30.6 | 9.7 | 5.8 | 403.1 | 332.90 |
| Bhagat | 47468.0 | 663.0 | 71.3 | 27.9 | 81.0 | 15.8 | 13.8 | 37.7 | 432.7 | 230.31 |
| Buchiana | 39405.0 | 513.1 | 57.9 | 21.1 | 63.9 | 21.7 | 17.9 | 15.5 | 341.6 | 171.41 |
| Chuharkana | 51602.0 | 673.4 | 78.3 | 27.6 | 78.0 | 30.9 | 19.0 | 28.8 | 457.2 | 216.16 |
| Dhaular | 41092.0 | 460.1 | 49.8 | 24.5 | 75.3 | 9.8 | 4.0 | 36.0 | 321.1 | 139.01 |
| Haveli | | | | | | | | | | |
| Kanya | 34145.0 | 411.7 | 68.7 | 19.4 | 57.3 | 11.6 | 13.2 | 4.1 | 298.6 | 113.12 |
| Kot Khuda Yar | 32953.0 | 383.8 | 48.7 | 19.1 | 58.7 | 15.2 | 2.7 | 18.4 | 273.4 | 110.43 |
| Mohlan | 56364.0 | 669.4 | 82.6 | 31.3 | 79.0 | 11.3 | 20.3 | 32.6 | 432.4 | 236.95 |
| Pacca Dala | 44180.0 | 610.3 | 65.5 | 24.4 | 66.0 | 32.8 | 16.1 | 12.0 | 357.9 | 252.40 |
| Sagar | | | | | | | | | | |
| Sangla | 25764.0 | 290.0 | 45.2 | 14.9 | 38.7 | 19.1 | 4.1 | 4.6 | 198.7 | 91.26 |
| Sultanpur | 31902.0 | 294.6 | 46.9 | 20.4 | 53.5 | 17.1 | 20.6 | 12.6 | 263.4 | 31.17 |
| Tandlianwala | 47419.0 | 567.3 | 68.7 | 25.7 | 67.8 | 21.9 | 14.5 | 13.7 | 380.2 | 187.12 |
| Tarkhani | 35311.0 | 484.7 | 54.4 | 19.8 | 67.9 | 10.0 | 16.7 | 12.9 | 323.0 | 161.80 |
| Uqbana | 52504.0 | 641.0 | 74.0 | 28.6 | 87.0 | 26.46 | 17.32 | 11.18 | 446.20 | 194.8 |
| Veryam | 55198.0 | 608.8 | 73.9 | 31.1 | 93.2 | 23.1 | 9.9 | 15.4 | 440.0 | 168.85 |
| Wer | 29517.0 | 363.1 | 55.0 | 15.1 | 50.4 | 14.6 | 0.0 | 14.4 | 225.8 | 137.31 |

* Total cost also includes the cost of labor.

Table 6(b). Distribution of Macro Level Indicators of the Cotton Crop after Marginal Improvements to Crop Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Proposed Cropped Area (ha) | Costs from Total Proposed Area | | | | | | | | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Gross Income | Cost of Land | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Total Cost* | |
| Aminpur | | | | | | | | | | |
| Bhagat | 30593 | 987.53 | 41.06 | 24.45 | 46.55 | 10.71 | 16.63 | 15.04 | 229.14 | 758.39 |
| Buchiana | 17136 | 395.70 | 29.32 | 6.83 | 28.05 | 11.64 | 17.63 | 12.39 | 139.93 | 255.77 |
| Chuharkana | | | | | | | | | | |
| Dhanlar | 25613 | 964.31 | 27.23 | 12.66 | 31.23 | 10.60 | 37.70 | 23.81 | 212.26 | 752.05 |
| Haveli | | | | | | | | | | |
| Kanya | | | | | | | | | | |
| Mohlan | 3582 | 76.86 | 3.51 | 1.29 | 3.94 | 0.00 | 3.66 | 2.82 | 22.53 | 54.33 |
| Pacca Dala | | | | | | | | | | |
| Sultanpur | 11710 | 209.40 | 18.57 | 4.68 | 11.42 | 7.72 | 6.06 | 9.55 | 86.49 | 122.91 |
| Tandlianwala | 19112 | 528.46 | 25.27 | 7.40 | 32.59 | 8.97 | 48.17 | 6.99 | 180.55 | 347.91 |
| Tarkhani | 22971 | 622.45 | 36.94 | 18.25 | 35.21 | 6.55 | 32.11 | 12.96 | 204.49 | 417.96 |
| Uqbana | | | | | | | | | | |
| Veryam | 20883 | 837.50 | 27.48 | 8.20 | 23.87 | 22.58 | 36.38 | 11.74 | 211.18 | 626.32 |

* Total cost also includes the cost of labor.

Table 6(c). Distribution of Macro Level Indicators of the Rice Crop after Marginal Improvements to Crop Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Proposed Cropped Area (ha) | Costs from Total Proposed Area | | | | | | | | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Gross Income | Cost of Land Preparation | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Total Cost* | |
| Aminpur | | | | | | | | | | |
| Bhagat | | | | | | | | | | |
| Buchiana | | | | | | | | | | |
| Chuharkana | 36979.78 | 568.31 | 57.61 | 3.29 | 62.31 | 21.63 | 12.72 | 79.43 | 332.78 | 235.52 |
| Dhaular | 9096.42 | 130.12 | 11.24 | 1.24 | 9.58 | | 2.78 | 15.24 | 65.58 | 64.54 |
| Haveli | | | | | | | | | | |
| Kanya | | | | | | | | | | |
| Kot Khuda Yar | 4123.65 | 56.80 | 5.47 | 0.33 | 2.16 | 1.95 | 0.72 | 7.00 | 28.03 | 28.77 |
| Mohlan | 26288.25 | 327.03 | 33.86 | 2.34 | 38.12 | 4.55 | 13.70 | 68.56 | 224.32 | 102.71 |
| Pacca Dala | 15931.82 | 218.65 | 23.87 | 1.40 | 23.87 | 9.78 | 7.82 | 15.31 | 119.39 | 99.26 |
| Sagar | | | | | | | | | | |
| Sangla | 9263.75 | 194.03 | 13.40 | 0.85 | 14.82 | 6.86 | 1.15 | 4.04 | 71.15 | 122.87 |
| Sultanpur | | | | | | | | | | |
| Tandlianwala | | | | | | | | | | |
| Tarkhani | | | | | | | | | | |
| Uqbana | 8033.00 | 111.40 | 11.80 | 0.50 | 8.00 | 6.65 | 2.30 | 2.73 | 53.30 | 58.10 |
| Veryam | | | | | | | | | | |
| Wer | | | | | | | | | | |

* Total cost also includes the cost of labor.

Table 6(d). Distribution of Macro Level Indicators of the Sugarcane Crop after Marginal Improvements to Crop Intensities within the Irrigation Subdivisions of the Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Total Proposed Area (ha) | Costs and Income from Total Proposed Area Under Wheat | | | | | | | | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Gross Income | Cost of Land Preparation | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Total Cost* | |
| Aminpur | 16148.0 | 372.2 | 31.1 | 36.1 | 27.6 | 8.6 | 5.5 | 2.3 | 168.5 | 203.7 |
| Bhagat | 12684.5 | 281.1 | 20.5 | 38.1 | 17.1 | 6.8 | 1.8 | 76.5 | 197.6 | 83.4 |
| Buchiana | 20889.9 | 496.5 | 34.7 | 30.0 | 28.0 | 8.8 | 5.1 | 36.1 | 200.2 | 296.3 |
| Chuharkana | 6323.3 | 159.8 | 14.1 | 10.6 | 11.6 | 4.0 | 0.8 | 13.8 | 69.5 | 90.3 |
| Dhaular | 14539.1 | 431.1 | 20.8 | 30.7 | 28.5 | 8.0 | 6.7 | 33.9 | 170.4 | 260.8 |
| Haveli | | | | | | | | | | |
| Kanya | 21589.8 | 534.2 | 37.4 | 22.8 | 47.8 | 17.4 | 4.4 | 6.0 | 182.2 | 352.0 |
| Kot Khuda Yar | 18400.0 | 586.3 | 20.5 | 32.1 | 30.2 | 13.3 | 0.2 | 47.7 | 219.6 | 366.7 |
| Mohlan | 18646.2 | 509.1 | 31.6 | 36.5 | 26.9 | 8.4 | 2.3 | 23.3 | 216.4 | 292.7 |
| Pacca Dala | 11080.5 | 310.5 | 23.8 | 25.2 | 17.3 | 11.2 | 2.2 | 6.8 | 118.1 | 192.4 |
| Sagar | | | | | | | | | | |
| Sangla | 3952.1 | 113.9 | 10.0 | 9.8 | 8.2 | 4.6 | | 1.8 | 45.6 | 68.3 |
| Sultanpur | 6155.5 | 112.9 | 11.5 | 15.2 | 7.2 | 3.0 | | 19.0 | 83.6 | 29.3 |
| Tandlianwala | 20870.2 | 537.0 | 27.3 | 35.8 | 28.7 | 10.8 | 5.7 | 35.9 | 206.7 | 330.3 |
| Tarkhani | 14302.2 | 426.2 | 21.4 | 30.6 | 29.0 | 13.0 | 4.1 | 13.2 | 188.0 | 238.2 |
| Uqbana | 25268.75 | 641.5 | 44.40 | 47.60 | 51.62 | 18.00 | 5.8 | 19.53 | 290.2 | 351.3 |
| Veryam | 24134.4 | 692.9 | 34.0 | 69.7 | 39.7 | 18.6 | 4.0 | 36.5 | 332.5 | 360.4 |
| Wer | 19184.7 | 453.5 | 7.8 | 44.2 | 29.4 | 6.3 | | 35.2 | 196.4 | 257.1 |

* Total cost also includes the cost of labor.

its growth. It is rather surprising to find both Tandlianwala and Tarkhani subdivisions to be significantly behind both in the production and returns despite the largely suitable soils for cotton cultivation. While the low returns from Tarkhani are due to the generally higher costs across all levels of inputs, the gross receipts for Tandlianwala are much less when compared with Veryam that has only a slightly larger area proposed for this crop.

The economic returns from the proposed area under rice cultivation are in tandem with the trends obtained for gross production figures in Table 5(c); the exception being for the Pacca Dala and Sangla subdivisions. The production difference between the two is reversed against the cumulative profits largely because of the lower overall costs within Sangla. These costs are so low that the gross profits supercede the corresponding returns from the much higher production levels in the Mohlan Subdivision.

The estimated production of the sugarcane in Table 5(d) had shown the tail subdivisions of Uqbana, Veryam and Wer to have the highest levels across the LCC system. These levels are sustained largely on the basis of the extensive cultivation of this crop; the subdivisions of Kanya and Kot Khuda Yar are able to match and exceed the profits from these subdivisions on the basis of low overall costs. However, costs are not the only difference towards realization of higher profits; comparisons to this effect are most suitably drawn given nearly equal areas of cultivation and production levels, such as between Kot Khuda Yar (with the highest estimated gross profits) and Wer. The differentiating criteria with the most potent implication is the yield that for Kot Khuda Yar is the highest across the entire LCC system. The tremendous gains in production and profit estimated for Kot Khuda Yar have been realized against an increase in cultivation intensity of less than 8%.

## B. Marginal Improvements to the Resource Potential

The discourse in Section A above has been limited to the production enhancements of major crops that could be effected through selective assimilation of the fallow lands into cultivation across the irrigation subdivisions of the LCC system. This mobilization of the land resource for incremental gains in production represents the *extensive* part of agriculture; comparable gains may also be realized if an *intensive* strategy is adopted whereby more emphasis is accorded to the critical inputs that are significant towards enhancing the existing yields. Based on the IIMI farm survey data, an attempt has been made to arrive at production functions (estimators of productivity per unit area) that best explain the complex interactions amongst the physical and economic constraints across each of the farmholdings. The list of the production functions that most suitably explain the variations in the productivity of major crops has been provided under Tables 10(a)-(d) in Volume Four with concurrent details on their generation appearing in the same document as Appendix I. A pertinent discussion on the significance of the constituting variables appears in Section V of Volume Six. The ensuing discussion here leads to the implied strategy whereby the production functions, with the accompaniments of all of their internal variations, for each of the four major crops, are selectively applied across the irrigation subdivisions of the LCC system.

In this respect, the proposed levels of increase in the productions realized through Section A above have been used as a reference. In other words, the effect of the desired yield increases is being compared in the context of the macro economic indicators of gross income, total costs and profits in what will be a one-to-one comparison against the results achieved under Table 6 above.

As a first step towards accomplishing the targeted/proposed production levels appearing in Table 5 above, the desired increases in yields have been computed for each of the major crops in Tables 7(a)-(d). Exclusions have been made, where necessary, to ensure the appropriate use of the production functions across the subdivisions in lieu of the information on cropping intensities appearing in Table 4 above. In some instances, the desired level of yield is quite extraordinary, as is evident for the Veryam Subdivision in Table 7(b) where a 20% increase in the intensity of cotton has been envisaged. Elsewhere, the resulting increase in yields varies between less than 20% to as much as 250%.

### 1) Choice of the Production Functions

Prior to the applicability of the numerous production functions specific to each crop, the per unit cost effects for each of the significant variables, necessitated by the targeted increase in the yields, have been calculated across all variations in farm sizes. The format of these calculations, presented in Tables 8(a)-(d), is the same as in Tables H2-H5 in Volume Four that were initially used to arrive at the calculations for the macro level economic indicators in Tables 6(a)-(d) above. Hence, the unit costs contained in the Tables H2-H5 have been at the core of the calculations leading to a comparison of the *extensive* vs *intensive* strategies in irrigated agriculture. In Tables 8(a)-(d), only the significant variables of the production functions have been included for the calculation of the per unit gross farm inputs and returns. Since the cultivation of both wheat and sugarcane is an inseparable part of the existing cropping pattern within the LCC system, the production functions for these respective crops have been listed for all of the subdivisions (with known CCAs).

Not all of the listed functional forms could be applied to any subdivision; the reason being that many of these estimators of yield had internal differentiations that were based on the farm-level variations in size, cropping/land use intensities that were not captured as part of the GIS themes latent to the physiography of the regime. Hence, appropriate selections had to be made prior to the multiplication of these unit costs with the area calculations to follow in the next section. These choices were not necessary in cases where the descriptions of the constituting effects of the soils were clearly differentiable so as to avoid overlap in space towards applied area calculations.

### 2) Adjusted Critical Inputs

In the preceding discussion pertaining to the areal adjustments, the proposed cropped area

Table 7(a). Desired Enhancements to the Existing Yields of the Wheat Crop to match the Higher Productions Targets across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Existing Production (000 m.ton) | Production through Additional Cultivated Area (000 m.ton) | Percent Increase in Production (%) | Existing Yield (Kg/ha) | Desired Yield to match the Proposed Production without Increase in Area (Kg/ha) |
|---|---|---|---|---|---|
| Aminpur | 127.75 | 156.49 | 22.50 | 2979.3 | 3649.57 |
| Bhagat | 104.91 | 149.89 | 42.87 | 3157.7 | 4511.51 |
| Buchiana | 87.78 | 111.59 | 27.12 | 2831.8 | 3599.93 |
| Chuharkana | 124.62 | 147.56 | 18.41 | 2859.5 | 3385.97 |
| Dhaular | 98.14 | 104.97 | 6.96 | 2554.4 | 2732.25 |
| Haveli | | | | | |
| Kanya | 80.18 | 89.86 | 12.07 | 2631.6 | 2949.14 |
| Kot Khuda Yar | 63.43 | 84.03 | 32.48 | 2550.1 | 3378.06 |
| Mohlan | 135.96 | 148.85 | 9.48 | 2640.9 | 2891.18 |
| Pacca Dala | 116.44 | 133.14 | 14.34 | 3013.5 | 3445.67 |
| Sagar | | | | | |
| Sangla | 56.21 | 62.94 | 11.97 | 2442.8 | 2735.51 |
| Sultanpur | 62.78 | 66.74 | 6.31 | 2092.1 | 2223.96 |
| Tandlianwala | 109.11 | 124.33 | 13.95 | 2621.9 | 2987.75 |
| Tarkhani | 94.77 | 109.42 | 15.46 | 3098.8 | 3577.81 |
| Uqbana | 115.26 | 144.50 | 25.36 | 2752.2 | 3450.00 |
| Veryam | 106.73 | 135.81 | 27.25 | 2460.4 | 3130.69 |
| Wer | 73.49 | 81.69 | 11.16 | 2767.5 | 3076.12 |

Table 7(b). Desired Enhancements to the Existing Yields of the Cotton Crop to match the Higher Productions Targets across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Existing Production (000 m.ton) | Production through Additional Cultivated Area (000 m.ton) | Percent Increase in Production (%) | Existing Yield (Kg/ha) | Desired Yield to match for the Proposed Production without Increase in Area (Kg/ha) |
|---|---|---|---|---|---|
| Aminpur | 0.46 | | | 494 | |
| Bhagat | 22.22 | 39.83 | 79.30 | 1302 | 2334.42 |
| Buchiana | 4.97 | 17.22 | 246.75 | 1005 | 3484.87 |
| Chuharkana | 2.17 | | | 999 | |
| Dhaular | 18.42 | 36.83 | 100.00 | 1438 | 2876.00 |
| Haveli | | | | | |
| Kanya | 2.70 | | | 1779 | |
| Kot Khuda Yar | | | | | |
| Mohlan | 3.48 | | | 972 | |
| Pacca Dala | 1.50 | | | 1176 | |
| Sagar | | | | | |
| Sangla | | | | | |
| Sultanpur | 7.15 | 8.88 | 24.06 | 758 | 940.35 |
| Tandlianwala | 9.80 | 24.56 | 150.56 | 1285 | 3219.64 |
| Tarkhani | 12.95 | 26.71 | 106.33 | 1163 | 2399.56 |
| Uqbana | 5.49 | | | 1059 | |
| Veryam | 2.94 | 20.55 | 598.63 | 1631 | 11394.71 |
| Wer | | | | | |

Table 7(c). Desired Enhancements to the Existing Yields of the Rice Crop to match the Higher Productions Targets across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Existing Production (000 m.ton) | Production through Additional Cultivated Area (000 m.ton) | Percent Increase in Production (%) | Existing Yield (Kg/ha) | Desired Yield to match for the Proposed Production without Increase in Area (Kg/ha) |
|---|---|---|---|---|---|
| Aminpur | | | | | |
| Bhagat | 11.71 | | | 2438.00 | |
| Buchiana | 12.36 | | | 2446.00 | |
| Chuharkana | 96.98 | 102.60 | 5.80 | 2774.00 | 2934.62 |
| Dhaular | 20.50 | 28.54 | 39.22 | 3138.00 | 4367.15 |
| Haveli | | | | | |
| Kanya | 4.50 | | | 1779.00 | |
| Kot Khuda Yar | 4.03 | 10.46 | 159.55 | 2537.00 | 6578.74 |
| Mohlan | 54.00 | 60.41 | 11.87 | 2298.00 | 2575.15 |
| Pacca Dala | 35.81 | 41.40 | 15.61 | 2599.00 | 3004.43 |
| Sagar | | | | | |
| Sangla | 29.00 | 37.31 | 28.66 | 4028.00 | 5181.80 |
| Sultanpur | 11.80 | 12.03 | 1.95 | 922.00 | 938.15 |
| Tandlianwala | 9.70 | 13.06 | 34.64 | 2933.00 | 3951.20 |
| Tarkhani | | | | | |
| Uqbana | 15.82 | 21.20 | 34.00 | 2639.00 | 3534.70 |
| Veryam | 8.52 | | | 2965.00 | |
| Wer | | | | | |

Table 7(d). Desired Enhancements to the Existing Yields of the Sugarcane Crop to match the Higher Productions Targets across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Existing Production (000 m.ton) | Production through Additional Cultivated Area (000 m.ton) | Percent Increase in Production (%) | Existing Yield (Kg/ha) | Desired Yield to match for the Proposed Production without Increase in Area (Kg/ha) |
|---|---|---|---|---|---|
| Aminpur | 545.29 | 777.51 | 29.87 | 48149.2 | 68653.94 |
| Bhagat | 229.08 | 522.39 | 56.15 | 41183.3 | 93914.84 |
| Buchiana | 756.6 | 947.21 | 20.12 | 45342.9 | 56766.00 |
| Chuharkana | 107.41 | 293.75 | 63.43 | 46454.8 | 127048.45 |
| Dhaular | 735.83 | 810.33 | 9.19 | 55734.8 | 61377.71 |
| Haveli | | | | | |
| Kanya | 915.63 | 1000.82 | 8.51 | 46356 | 50669.04 |
| Kot Khuda Yar | 842.79 | 1079.83 | 21.95 | 58686.3 | 75191.94 |
| Mohlan | 827.61 | 952.21 | 13.09 | 51067.3 | 58755.51 |
| Pacca Dala | 438.58 | 584.78 | 25.00 | 52775.2 | 70367.25 |
| Sagar | | | | | |
| Sangla | 144.19 | 221.35 | 34.86 | 56009.3 | 85981.87 |
| Sultanpur | 188.79 | 223.08 | 15.37 | 36241.3 | 42822.84 |
| Tandlianwala | 900.97 | 1046.53 | 13.91 | 50144.8 | 58245.98 |
| Tarkhani | 669.4 | 801.96 | 16.53 | 56072.7 | 67176.69 |
| Uqbana | 978.50 | 1238.80 | 26.60 | 49024.6 | 62066.00 |
| Veryam | 893.49 | 1183.18 | 24.48 | 58398 | 64919.32 |
| Wer | 1033.88 | 1120.35 | 7.72 | 49420 | 63281.95 |

Table 8(a). Gross Farm Inputs and Returns (per ha) for the Wheat after Yield Adjustments to the Selected Case Definitions for the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(Rupees)

| Subdivision | Yield (Kg/ha) | Case No. | Farm Size (ha) | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Total Cost | Gross Income | Profit |
|---|---|---|---|---|---|---|---|---|---|
| Amirpur | 3630 | II | > 2 | 1532.81 | | 134.70 | 7795.26 | 17166.46 | 9371.20 |
| | | | 2-10 | 1562.50 | | 140.52 | 7830.77 | | 9335.69 |
| | | III | > 2 | 1530.85 | | 133.59 | 7791.69 | | 9374.77 |
| Bhagat | 4512 | II | > 2 | 1924.16 | | 1130.55 | 9668.13 | 19957.80 | 10289.66 |
| | | | 2-10 | 1991.34 | | 1210.55 | 9615.27 | | 10342.53 |
| | | III | > 2 | 1918.59 | | 1115.22 | 9647.29 | | 10310.51 |
| Buchiana | 3600 | II | > 2 | 1733.24 | | 497.73 | 8905.84 | 16551.99 | 7646.15 |
| | | | 2-10 | 1793.65 | | 522.72 | 8971.24 | | 7580.75 |
| | | III | > 2 | 1749.89 | | 492.95 | 8897.72 | | 7654.27 |
| Chuharkana | 3786 | I | > 2 | 1551.36 | | 659.04 | 9002.26 | 13452.51 | 4450.25 |
| | | II | > 2 | 1594.98 | | 659.33 | 9045.40 | | 4407.11 |
| | | | 2-10 | 1630.55 | | 683.45 | 9095.07 | | 4357.44 |
| | | III | > 2 | 1592.86 | | 654.75 | 9038.67 | | 4413.84 |
| | | IV | > 2 | 1721.42 | 370.86 | 585.32 | 9100.57 | | 4351.94 |
| | | V | > 2 | 1878.05 | | 804.05 | 9273.27 | | 4179.24 |
| | | | 2-10 | 2184.17 | | 1591.42 | 10566.66 | | 2885.85 |
| | | VI | All | 1545.64 | 371.70 | 652.44 | 9012.73 | | 4439.78 |
| | | | 2-10 | 1553.90 | 373.38 | 654.13 | 9004.38 | | 4448.13 |
| | | | > 10 | 1676.10 | 366.09 | 627.85 | 9097.00 | | 4355.51 |
| Dhaular | 2732 | I | > 2 | 1851.80 | | 936.12 | 7893.26 | 11976.42 | 4083.16 |
| | | II | > 2 | 1871.09 | | 936.53 | 7912.96 | | 4063.46 |
| | | | 2-10 | 1882.61 | | 950.83 | 7938.79 | | 4037.63 |
| | | III | > 2 | 1870.12 | | 933.80 | 7909.26 | | 4067.16 |
| | | V | > 2 | 1909.17 | | 1022.41 | 8036.92 | | 3939.50 |
| | | | 2-10 | 2341.15 | | 1489.73 | 8726.22 | | 3250.20 |
| | | VI | All | 1857.63 | 96.88 | 932.43 | 7895.77 | | 4080.65 |
| | | | 2-10 | 1852.26 | 97.05 | 933.49 | 7891.36 | | 4085.06 |
| | | | > 10 | 1909.19 | 96.52 | 937.82 | 7932.16 | | 4044.26 |
| Kanya | 2949 | II | > 2 | 1730.23 | | 137.02 | 8818.40 | 13511.04 | 4692.66 |
| | | | 2-10 | 1756.83 | | 136.96 | 8840.36 | | 4670.69 |
| | | III | > 2 | 1736.70 | | 133.76 | 8816.21 | | 4694.83 |
| | | IV | > 2 | 1630.24 | 389.55 | 122.60 | 8901.96 | | 4609.10 |
| Kot Khuda Yar | 3778 | II | > 2 | 1954.51 | | 735.08 | 8647.49 | 15430.13 | 6782.64 |
| | | | 2-10 | 2009.87 | | 777.52 | 8743.09 | | 6687.04 |
| | | III | > 2 | 1950.10 | | 726.98 | 8634.98 | | 6795.15 |
| Mohlan | 2891 | I | > 2 | 1430.74 | | 632.07 | 7745.39 | 13000.54 | 5255.15 |
| | | II | > 2 | 1441.57 | | 631.61 | 7765.96 | | 5234.58 |
| | | | 2-10 | 1453.78 | | 644.66 | 7791.01 | | 5209.53 |
| | | III | > 2 | 1440.56 | | 629.36 | 7762.49 | | 5238.05 |
| | | V | > 2 | 1481.23 | | 708.94 | 7882.75 | | 5117.79 |
| | | | 2-10 | 1722.89 | | 1128.64 | 8544.11 | | 4456.43 |
| | | VI | All | 1427.56 | 362.04 | 628.15 | 7770.08 | | 5230.46 |
| | | | 2-10 | 1421.95 | 362.89 | 629.02 | 7746.22 | | 5254.32 |
| | | | > 10 | 1481.26 | 380.23 | 615.01 | 7788.85 | | 5211.69 |
| Pacca Dala | 3446 | I | > 2 | 1523.02 | | 311.34 | 8169.86 | 15796.99 | 7627.13 |
| | | II | > 2 | 1556.57 | | 320.96 | 8203.22 | | 7593.77 |
| | | | 2-10 | 1576.23 | | 330.12 | 8232.05 | | 7564.94 |
| | | III | > 2 | 1554.94 | | 309.21 | 8199.84 | | 7597.15 |
| | | V | > 2 | 1620.45 | | 345.98 | 8322.12 | | 7474.87 |
| | | | 2-10 | 2009.67 | | 665.35 | 9010.72 | | 6786.28 |
| | | VI | All | 1534.00 | 347.88 | 308.33 | 8180.81 | | 7616.18 |
| | | | 2-10 | 1524.97 | 348.98 | 308.97 | 8173.72 | | 7623.27 |
| | | | > 10 | 1620.49 | | 298.97 | 8255.16 | | 7541.83 |
| Sangla | 2715 | I | > 2 | 1525.30 | | 199.33 | 7760.73 | 12603.13 | 4842.40 |
| | | II | > 2 | 1555.67 | | 199.23 | 7788.63 | | 4814.50 |
| | | | 2-10 | 1572.19 | | 204.23 | 7810.35 | | 4792.78 |
| | | III | > 2 | 1502.02 | | 178.27 | 7734.21 | | 4868.92 |
| | | IV | > 2 | 1637.34 | 159.63 | 383.86 | 7855.91 | | 4747.22 |
| | | V | > 2 | 1609.33 | | 223.27 | 7872.53 | | 4730.61 |
| | | | 2-10 | 1936.25 | | 592.71 | 8362.89 | | 4240.24 |
| | | VI | All | 1536.72 | 159.86 | 197.80 | 7769.45 | | 4833.68 |
| | | | 2-10 | 1539.13 | 160.79 | 196.15 | 7762.69 | | 4840.44 |
| | | | > 10 | 1609.37 | | 192.69 | 7835.98 | | 4767.15 |
| Sultanpur | 2224 | II | > 2 | 1708.99 | | 419.87 | 8314.31 | 9816.68 | 1502.36 |
| | | | 2-10 | 1718.78 | | 425.73 | 8329.88 | | 1486.81 |
| | | III | > 2 | 1706.18 | | 418.73 | 8312.38 | | 1504.30 |
| Tandlianwala | 2988 | II | > 2 | 1488.11 | | 327.55 | 8116.57 | 13635.12 | 5518.55 |
| | | | 2-10 | 1506.41 | | 334.97 | 8144.30 | | 5490.82 |
| | | III | > 2 | 1486.59 | | 323.73 | 8113.26 | | 5521.87 |
| | | IV | > 2 | 1578.63 | 307.36 | 298.61 | 8179.90 | | 5455.22 |
| Tarkhani | 3578 | II | > 2 | 2011.28 | | 420.41 | 9289.97 | 15850.77 | 6560.80 |
| | | | 2-10 | 2038.57 | | 433.64 | 9330.50 | | 6520.27 |
| | | III | > 2 | 2009.00 | | 437.80 | 9285.18 | | 6565.59 |
| | | IV | > 2 | 2144.28 | 475.14 | 379.77 | 9387.32 | | 6463.45 |
| Uchkera | 3450 | II | > 2 | 1782.48 | | 264.53 | 8679.07 | 15915.82 | 7236.75 |
| | | | 2-10 | 1821.08 | | 279.21 | 8730.36 | | 7185.46 |
| | | III | > 2 | 1779.38 | | 264.11 | 8673.45 | | 7242.37 |
| | | IV | > 2 | 1973.37 | 333.26 | 227.56 | 8834.40 | | 7081.42 |
| Veryam | 3131 | II | > 2 | 1826.47 | | 352.97 | 8182.62 | 14036.38 | 5853.76 |
| | | | 2-10 | 1848.76 | | 370.76 | 8242.69 | | 5793.69 |
| | | III | > 2 | 1822.97 | | 349.57 | 8175.71 | | 5860.67 |
| Wer | 3076 | II | > 2 | 1764.23 | | 541.53 | 7759.31 | 13671.72 | 5912.51 |
| | | | 2-10 | 1783.77 | | 554.30 | 7789.30 | | 5882.22 |
| | | III | > 2 | 1764.79 | | 539.09 | 7755.32 | | 5916.40 |

Table 8(b). Gross Farm Inputs and Returns (per ha) for the Cotton after Yield Adjustments to the Selected Case Definitions for the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(Rupees)

| Subdivision | Yield (Kg/ha) | Case | Farm Size (ha) | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Total Cost | Gross Income | Profit |
|---|---|---|---|---|---|---|---|---|---|
| Bhagat | 2334 | I | 2-10 | | | 1150 | 7975 | 57892 | 49917 |
| | | | > 10 | | | 1167 | 7993 | | 49899 |
| | | II | > 2 | | 2026 | 492 | 8799 | | 49093 |
| | | IV | All | | | 1209 | 8035 | | 49857 |
| Buchiana | 3485 | I | 2-10 | | | 3734 | 11004 | 80077 | 69073 |
| | | | > 10 | | | 3813 | 11083 | | 68994 |
| | | II | > 2 | | 9753 | 723 | 16717 | | 63360 |
| | | IV | All | | | 4005 | 11275 | | 68802 |
| Dhaular | 2876 | I | 2-10 | | | 2499 | 9684 | 75292 | 65608 |
| | | | > 10 | | | 2541 | 9725 | | 65567 |
| | | II | > 2 | | 6533 | 930 | 13175 | | 62118 |
| | | III | All | 3260 | | 930 | 10155 | | 65137 |
| | | | > 2 | 3295 | | 930 | 10190 | | 65103 |
| | | IV | All | | | 2641 | 9825 | | 65467 |
| | | V | > 2 | | | 2171 | 9355 | | 65937 |
| | | | 2-10 | | | 2282 | 9467 | | 65826 |
| Sultanpur | 940 | I | 2-10 | | | 1147 | 7544 | 22182 | 14638 |
| | | | > 10 | | | 1155 | 7553 | | 14629 |
| | | II | > 2 | | 945 | 815 | 7641 | | 14541 |
| | | IV | All | | | 1177 | 7574 | | 14608 |
| Tandlianwala | 3220 | I | 2-10 | | | 1295 | 10203 | 69292 | 59089 |
| | | | > 10 | | | 1320 | 10228 | | 59064 |
| | | II | > 2 | | 15565 | 366 | 22319 | | 46973 |
| | | IV | All | | | 1379 | 10287 | | 59005 |
| Tarkhani | 2400 | I | 2-10 | | | 1577 | 9742 | 55906 | 46164 |
| | | | > 10 | | | 1604 | 9769 | | 46137 |
| | | II | > 2 | | 6508 | 564 | 13839 | | 42067 |
| | | IV | All | | | 1668 | 9833 | | 46072 |
| Veryam | 11395 | I | 2-10 | | | 6244 | 15621 | 280213 | 264592 |
| | | | > 10 | | | 6393 | 15771 | | 264443 |
| | | II | > 2 | | 37591 | 562 | 45788 | | 234425 |
| | | IV | All | | | 6756 | 16133 | | 264080 |

Table 8(c). Gross Farm Inputs and Returns (per ha) for the Rice after Yield Adjustments to the Selected Case Definitions for the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(Rupees)

| Subdivision | Yield (Kg/ha) | Case | Farm Size (ha) | Cost of Land | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Total Cost | Gross Income | Profit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chuharkana | 2935 | I | All | | 1722.77 | | 345.22 | 2222.34 | 9527.63 | 16256.20 | 6728.57 |
| | | II | All | 1575.92 | 1721.03 | | | 2229.25 | 9549.19 | | 6707.01 |
| | | IV | All | 1664.86 | 1684.60 | | | 2152.14 | 9524.59 | | 6731.61 |
| | | | 2-10 | 1684.69 | 1684.60 | | | 2155.17 | 9547.45 | | 6708.76 |
| | | V | All | | 1790.46 | | | 2147.92 | 9519.42 | | 6736.78 |
| | | | 2-10 | | 1794.98 | | | 2147.92 | 9523.94 | | 6732.26 |
| | | VI | All | | 1787.96 | 592.69 | 348.98 | 2147.92 | 9530.19 | | 6726.01 |
| | | VII | All | 1608.26 | 1684.60 | | | 2209.36 | 9525.21 | | 6730.99 |
| Dhaular | 4367 | I | All | | 1214.61 | | 314.72 | 2067.48 | 8095.56 | 19905.10 | 11809.54 |
| | | II | All | 1331.30 | 1207.27 | | | 2103.92 | 8211.53 | | 11693.56 |
| | | IV | All | 1808.22 | 1053.26 | | | 1697.28 | 8127.80 | | 11777.30 |
| | | | 2-10 | 1914.53 | 1053.26 | | | 1713.26 | 8250.08 | | 11655.01 |
| | | V | All | | 1500.82 | | | 1675.03 | 7980.38 | | 11924.72 |
| | | | 2-10 | | 1519.93 | | | 1675.03 | 7999.49 | | 11905.60 |
| | | VI | All | | 1490.24 | | 337.33 | 1675.03 | 8001.35 | | 11903.75 |
| | | VII | All | 1504.71 | 1053.26 | | | 1999.04 | 8126.04 | | 11779.05 |
| Kot Khuda Yar | 6579 | I | All | | 852.31 | | 195.37 | 3315.59 | 8970.09 | 35719.91 | 26749.82 |
| | | V | All | | 1432.76 | | | 1697.58 | 7911.76 | | 27808.15 |
| | | | 2-10 | | 1471.51 | | | 1697.58 | 7950.52 | | 27769.39 |
| Mohlan | 2575 | I | All | | 1517.72 | | 525.99 | 2793.08 | 9203.24 | 13939.61 | 4736.37 |
| | | II | All | 1318.24 | 1514.67 | | | 2810.26 | 9242.97 | | 4696.64 |
| | | IV | All | 1468.71 | 1450.48 | | | 2618.63 | 9137.63 | | 4801.98 |
| | | | 2-10 | 1502.25 | 1450.48 | | | 2626.16 | 9178.70 | | 4760.91 |
| | | V | All | | 1637.01 | | | 2608.14 | 9132.98 | | 4806.63 |
| | | | 2-10 | | 1644.98 | | | 2608.14 | 9140.94 | | 4798.67 |
| | | VII | All | 1372.95 | 1450.48 | | | 2760.83 | 9184.07 | | 4755.54 |
| Pacca Dala | 3004 | I | All | | 1589.85 | | 496.38 | 1050.08 | 7962.86 | 15867.94 | 7905.07 |
| | | II | All | 1544.73 | 1585.69 | | | 1058.40 | 8007.57 | | 7860.37 |
| | | IV | All | 1774.96 | 1498.49 | | | 965.59 | 8057.77 | | 7810.16 |
| | | | 2-10 | 1826.27 | 1498.49 | | | 969.24 | 8112.73 | | 7755.20 |
| | | V | All | | 1751.91 | | | 960.51 | 8029.65 | | 7838.29 |
| | | | 2-10 | | 1762.73 | | | 960.51 | 8040.47 | | 7827.46 |
| | | VII | All | 1628.44 | 1498.49 | | | 1034.46 | 7980.13 | | 7887.81 |
| Sangla | 5182 | I | All | | 1779.07 | | 126.19 | 510.08 | 8092.10 | 26947.19 | 18855.10 |
| | | II | All | 1527.45 | 1770.93 | | | 517.00 | 8170.15 | | 18777.04 |
| | | IV | All | 1935.20 | 1599.97 | | | 439.74 | 8329.69 | | 18617.51 |
| | | | 2-10 | 2026.09 | 1599.97 | | | 442.78 | 8423.61 | | 18523.59 |
| | | V | All | | 2096.78 | | | 435.51 | 8332.60 | | 18614.59 |
| | | | 2-10 | | 2117.99 | | | 435.51 | 8353.82 | | 18593.38 |
| | | VII | All | 1675.70 | 1599.97 | | | 497.07 | 8127.52 | | 18819.67 |
| Sultanpur | 938 | I | All | | 2236.69 | | 1069.02 | 233.31 | 7561.72 | 3986.50 | -3575.22 |
| | | V | All | | 2266.68 | | | 230.63 | 7587.47 | | -3600.97 |
| | | | 2-10 | | 2268.68 | | | 230.63 | 7589.48 | | -3602.98 |
| | | VI | All | | 2265.57 | 413.74 | 1072.95 | 230.63 | 7593.74 | | -3607.24 |
| Tandlianwala | 3951 | I | All | | 1870.21 | | 971.66 | 799.27 | 8802.35 | 20742.75 | 11940.40 |
| | | V | All | | 2265.57 | | 947.22 | 662.23 | 9036.23 | | 11706.52 |
| | | | 2-10 | | 2291.97 | | 947.22 | 662.23 | 9062.63 | | 11680.12 |
| | | VI | All | | 2250.97 | | 1033.51 | 662.23 | 9107.92 | | 11634.83 |
| Uqbana | 3534 | I | All | | 1121.47 | | 298.94 | 408.55 | 7250.12 | 18570.04 | 11319.92 |
| | | V | All | | 1354.02 | | | 339.76 | 7406.52 | | 11163.53 |
| | | | 2-10 | | 1369.54 | | | 339.76 | 7422.04 | | 11148.00 |
| | | VI | All | | 1345.43 | 894.22 | 317.57 | 339.76 | 7490.35 | | 11079.70 |

Table 8(d). Gross Farm Inputs and Returns (per ha) for the Sugarcane after Yield Adjustments to the Selected Case Definitions for the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(Rupees)

| Subdivision | Yield (Kg/ha) | Case | Farm Size (ha) | Cost of Land | Cost of Fertilizer | Cost of Irrigation | Gross Income | Total Cost | Profit |
|---|---|---|---|---|---|---|---|---|---|
| Aminpur | 68654 | III | All | 1927.38 | 1713.96 | 141.34 | 32867.35 | 10437.52 | 22429.83 |
| | | | 2-10 | | 1715.00 | | | 10438.5 | 22428.85 |
| | | V | 2-10 | 1931.67 | 1711.34 | 141.83 | | 10439.63 | 22427.72 |
| Bhagat | 93915 | III | All | 1618.51 | 1352.88 | 6036.96 | 50526.27 | 15586.04 | 34940.23 |
| | | | 2-10 | | 1353.70 | 6039.13 | | 15588.98 | 34937.29 |
| | | V | 2-10 | 1622.11 | 1350.81 | 6060.11 | | 15610.68 | 34915.59 |
| Buchiana | 56766 | III | All | 1660.20 | 1344.12 | 1728.41 | 29755.75 | 9584.653 | 20171.09 |
| | | | 2-10 | | 1344.93 | 1729.04 | | 9586.011 | 20169.74 |
| | | V | 2-10 | 1663.90 | 1342.06 | 1735.04 | | 9592.844 | 20162.9 |
| | | VI | All | 1660.79 | 1342.06 | 1727.45 | | 9582.146 | 20173.6 |
| Chuharkana | 127048 | I | All | 2234.35 | 1832.72 | 2174.86 | 69099.24 | 10987.14 | 58112.1 |
| | | III | All | | 1835.53 | 2176.16 | | 10991.28 | 58107.96 |
| | | | 2-10 | | 1836.64 | 2176.94 | | 10993.14 | 58106.11 |
| | | V | 2-10 | 2239.33 | 1832.72 | 2184.50 | | 11001.76 | 58097.49 |
| | | VI | All | 2235.15 | 1832.72 | 2174.94 | | 10988.02 | 58111.23 |
| Dhanlar | 61378 | I | All | 1432.49 | 1958.95 | 2333.04 | 32646.75 | 11717.07 | 20929.68 |
| | | III | All | | 1961.95 | 2334.43 | | 11721.6 | 20925.14 |
| | | | 2-10 | | 1963.14 | 2335.27 | | 11723.49 | 20923.26 |
| | | V | 2-10 | 1435.68 | 1958.95 | 2343.38 | | 11730.6 | 20916.14 |
| Kanya | 50669 | III | All | 1729.70 | 2219.05 | 278.57 | 27046.87 | 8443.461 | 18603.41 |
| | | | 2-10 | | 2220.40 | 278.67 | | 8444.839 | 18602.04 |
| | | V | 2-10 | 1733.55 | 2215.66 | 279.63 | | 8444.922 | 18601.95 |
| | | VI | All | 1730.32 | 2215.66 | 278.41 | | 8440.465 | 18606.41 |
| Kot Khuda Yar | 75192 | III | All | 1111.95 | 1645.57 | 2596.87 | 40824.31 | 11936.91 | 28887.4 |
| | | | 2-10 | | 1646.57 | 2597.80 | | 11938.83 | 28885.48 |
| | | V | 2-10 | 1114.42 | 1643.06 | 2606.83 | | 11946.82 | 28877.49 |
| Mohlan | 58756 | I | All | 1692.64 | 1442.65 | 1251.97 | 31415.51 | 11605.62 | 19809.89 |
| | | III | All | | 1444.86 | 1252.72 | | 11608.61 | 19806.89 |
| | | | 2-10 | | 1445.73 | 1253.17 | | 11609.9 | 19805.61 |
| | | V | 2-10 | 1696.40 | 1442.65 | 1257.52 | | 11614.94 | 19800.57 |
| | | VI | All | 1693.24 | 1442.65 | 1252.02 | | 11606.27 | 19809.24 |
| Pacca Dala | 70367 | I | All | 2147.84 | 1562.41 | 617.75 | 37365.19 | 10660.17 | 26705.02 |
| | | III | All | | 1564.80 | 618.12 | | 10662.99 | 26702.2 |
| | | | 2-10 | | 1565.74 | 618.34 | | 10664.1 | 26701.09 |
| | | V | 2-10 | 2152.62 | 1562.41 | 620.49 | | 10667.69 | 26697.5 |
| | | VI | All | 2148.60 | 1562.41 | 617.77 | | 10660.96 | 26704.23 |
| Sangla | 85982 | I | All | 2536.89 | 2083.88 | 444.78 | 44255.44 | 11533.84 | 32721.61 |
| | | III | All | | 2087.07 | 445.05 | | 11537.29 | 32718.15 |
| | | | 2-10 | | 2088.33 | 445.21 | | 11538.71 | 32716.73 |
| | | V | 2-10 | 2542.54 | 2083.88 | 446.75 | | 11541.45 | 32713.99 |
| | | VI | All | 2537.80 | 2083.88 | 444.80 | | 11534.75 | 32720.69 |
| Sultanpur | 42823 | III | All | 1873.84 | 1171.40 | 3082.35 | 21679.14 | 13590.68 | 8088.465 |
| | | | 2-10 | | 1172.11 | 3083.46 | | 13592.5 | 8086.648 |
| | | V | 2-10 | 1878.01 | 1169.61 | 3094.17 | | 13604.88 | 8074.265 |
| Tandlianwala | 58246 | III | All | 1306.34 | 1376.39 | 1720.84 | 29888.39 | 9906.996 | 19981.39 |
| | | | 2-10 | | 1377.22 | 1721.46 | | 9908.361 | 19980.03 |
| | | V | 2-10 | 1309.24 | 1374.29 | 1727.44 | | 9914.312 | 19974.08 |
| | | VI | All | 1306.80 | 1374.29 | 1719.88 | | 9904.308 | 19984.08 |
| Tarkhani | 67177 | III | All | 1494.00 | 2028.84 | 924.80 | 35697.74 | 13148.57 | 22549.17 |
| | | | 2-10 | | 2030.07 | 925.13 | | 13150.04 | 22547.7 |
| | | V | 2-10 | 1497.33 | 2025.74 | 928.35 | | 13152.25 | 22545.49 |
| Uqbana | 62065 | III | All | 1756.95 | 2044.71 | 773.08 | 32140.92 | 11487.66 | 20653.26 |
| | | | 2-10 | | 2045.95 | 773.36 | | 11489.11 | 20651.82 |
| | | V | 2-10 | 1760.86 | 2041.59 | 776.05 | | 11491.34 | 20649.58 |
| | | VI | All | 1757.58 | 2041.59 | 772.65 | | 11484.66 | 20656.26 |
| Veryam | 64919 | III | All | 1409.16 | 1646.55 | 1512.74 | 31913.93 | 13780 | 18133.93 |
| | | | 2-10 | | 1647.55 | 1513.29 | | 13781.49 | 18132.44 |
| | | V | 2-10 | 1412.29 | 1644.04 | 1518.54 | | 13786.37 | 18127.56 |
| Wer | 63282 | III | All | 403.60 | 1531.89 | 1837.87 | 30269.89 | 10241.64 | 20028.25 |
| | | | 2-10 | | 1532.82 | 1838.53 | | 10243.23 | 20026.66 |
| | | V | 2-10 | 404.49 | 1529.55 | 1844.92 | | 10247.25 | 20022.64 |

calculated in Table 5 was subsequently multiplied with the unit costs/returns as per Tables H2-H5 to arrive at the gross figures (in millions of Rupees) for the macro level economic indicators listed in Table 6. Similar calculations for the yield intensive strategy require the per unit calculation of the significant variables in Table 8 to be multiplied with the *effective area* over which the selected production function needs to be applied. To arrive at this *effective area*, the determination of the total applied area specific to each of the production functions within the subdivision is essential. These calculations have been performed under Table 9 for each of the four major crops across the LCC subdivisions. The results so obtained borrow from the descriptions of the physical regime for each of the production functions provided under Appendix I, Volume Four. Finally, the effective area is arrived at by multiplying the applied area with the existing cropping intensity of the four major crops across each of the subdivisions (Tables 10(a)-(d)). The calculations for the insignificant variables has borrowed from the original values of the same appearing under Tables H2-H5.

## C. Evaluation of the Resource Potential: Extensive Vs. Intensive Strategies

### 1) Subdivision Level

The results of the calculations performed under Tables 6 and 10 are of penultimate nature, wherein the final evaluation hinges solely on the comparison of the two strategies explained above. This comparison, in terms of the gross incomes, total costs and profits has been made in Tables 11(a)-(d) for the four major crops across all of the subdivisions of the LCC system. In general, while the gross incomes and the total costs are higher for the area-intensive strategy, it is the all important profits that are higher in many of the subdivisions across all the major crops. For the wheat crop (Table 11(a)), it is only the tail subdivisions of Dhaular and Wer in the Jhang Canal command that favor resorting to extensive irrigated agriculture; elsewhere, despite higher gross incomes, the profits are almost invariably high for investments towards yield increases. In fact, for the subdivisions like Chuharkana, Mohlan, Sangla, Tandlianwala and Tarkhani, and against no significant difference in gross incomes, the rewards in terms of higher profits are amply clear in favor of higher farm inputs. Overall, the profits are highest for the Bhagat Subdivision; however, on the gross income side, the extensive agriculture gives the highest net difference for the Buchiana Subdivision.

For the cotton crop, extensive irrigated agriculture is most suited for the subdivisions of Dhaular, Mohlan (yield increase option not implied), Sultanpur and Veryam (Table 11(b)). With the exception of Mohlan, the other subdivisions are part of the lower Rechna Doab belt where cotton cultivation is comparatively more prolific. Elsewhere, the difference in profits is not as large as for the wheat crop.

Rather surprisingly, for the Chuharkana Subdivision, well known for the highest cropping intensities of rice, the gross incomes and the profits from extensive use of the land are much higher than comparable returns from investments in yield enhancements (Table

Table 9(a). Magnitude of the Spatial Regime Corresponding to each of the Selected Case Definitions for the Wheat Crop within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Case No I | Percentage of Area | Applied Area (ha) |
|---|---|---|---|
| Chuharkana | | 0.35 | 24522.4035 |
| Dhaular | | 0.25 | 16502.94 |
| Mohlan | | 0.7 | 62676.355 |
| Pacca Dala | | 0.3 | 21308.721 |
| Sangla | | 0.2 | 8044.94 |
| Aminpur | Case No.II | 0.85 | 66388.264 |
| Bhagat | | 0.9 | 67650.543 |
| Buchiana | | 0.8 | 51342.208 |
| Chuharkana | | 0.45 | 31528.8045 |
| Dhaular | | 0.6 | 39607.056 |
| Kanya | | 0.9 | 50502.528 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.295 |
| Pacca Dala | | 0.65 | 46168.8955 |
| Sangla | | 0.7 | 30168.525 |
| Sultanpur | | 0.85 | 37845.8165 |
| Tandlianwala | | 0.8 | 67801.6 |
| Tarkhani | | 0.9 | 60361.047 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.315 |
| Wer | | 0.8 | 50947.04 |
| Aminpur | Case No III | 0.85 | 66388.264 |
| Bhagat | | 0.9 | 67650.543 |
| Buchiana | | 0.8 | 51342.208 |
| Chuharkana | | 0.45 | 31528.8045 |
| Dhaular | | 0.6 | 39607.056 |
| Kanya | | 0.9 | 50502.528 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.295 |
| Pacca Dala | | 0.65 | 46168.8955 |
| Sangla | | 0.75 | 28157.525 |
| Sultanpur | | 0.85 | 37845.8165 |
| Tandlianwala | | 0.8 | 67801.6 |
| Tarkhani | | 0.9 | 60361.047 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.315 |
| Wer | | 0.8 | 50947.04 |
| Chuharkana | Case No IV | 0.2 | 14012.802 |
| Kanya | | 0.4 | 22445.568 |
| Sangla | | 0.2 | 8044.94 |
| Tandlianwala | | 0.25 | 21188 |
| Tarkhani | | 0.1 | 6706.78 |
| Chuharkana | Case No V | 0.35 | 24522.4035 |
| Dhaular | | 0.25 | 16502.94 |
| Mohlan | | 0.7 | 62676.355 |
| Pacca Dala | | 0.3 | 21308.721 |
| Sangla | | 0.2 | 8044.94 |
| Chuharkana | Case No VI | 0.35 | 24522.4035 |
| Dhaular | | 0.25 | 16502.94 |
| Mohlan | | 0.7 | 62676.355 |
| Pacca Dala | | 0.3 | 21308.721 |
| Sangla | | 0.1 | 4022.47 |

Table 9(b). Magnitude of the Spatial Regime Corresponding to each of the Selected Case Definitions for the Cotton Crop within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Case No I | Percentage of Area | Applied Area (ha) |
|---|---|---|---|
| Aminpur | | 0.85 | 66388.264 |
| Bhagat | | 0.9 | 67650.543 |
| Buchiana | | 0.8 | 51342.208 |
| Chuharkana | | 0.45 | 31528.8045 |
| Dhaular | | 0.6 | 39607.056 |
| Kanya | | 0.9 | 50502.528 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.295 |
| Pacca Dala | | 0.65 | 46168.8955 |
| Sangla | | 0.75 | 30168.525 |
| Sultanpur | | 0.85 | 37845.8165 |
| Tandlianwala | | 0.8 | 67801.6 |
| Tarkhani | | 0.9 | 60361.047 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.315 |
| Wer | | 0.8 | 50947.04 |
| Aminpur | Case No.II | 0.85 | 66388.264 |
| Bhagat | | 0.9 | 67650.543 |
| Buchiana | | 0.8 | 51342.208 |
| Chuharkana | | 0.45 | 31528.8045 |
| Dhaular | | 0.6 | 39607.056 |
| Kanya | | 0.9 | 50502.528 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.295 |
| Pacca Dala | | 0.65 | 46168.8955 |
| Sangla | | 0.75 | 30168.525 |
| Sultanpur | | 0.85 | 37845.8165 |
| Tandlianwala | | 0.8 | 67801.6 |
| Tarkhani | | 0.9 | 60361.047 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.315 |
| Wer | | 0.8 | 50947.04 |
| Chuharkana | Case No III | 0.35 | 24522.4035 |
| Dhaular | | 0.25 | 16502.94 |
| Mohlan | | 0.7 | 62676.355 |
| Pacca Dala | | 0.3 | 21308.721 |
| Sangla | | 0.2 | 8044.94 |
| Aminpur | Case No IV | 0.85 | 66388.264 |
| Bhagat | | 0.9 | 67650.543 |
| Buchiana | | 0.8 | 51342.208 |
| Chuharkana | | 0.45 | 31528.8145 |
| Dhaular | | 0.6 | 39607.056 |
| Kanya | | 0.9 | 50502.528 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.295 |
| Pacca Dala | | 0.65 | 46168.8955 |
| Sangla | | 0.75 | 30168.525 |
| Sultanpur | | 0.85 | 37845.8165 |
| Tandlianwala | | 0.8 | 67801.6 |
| Tarkhani | | 0.9 | 60361.047 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.315 |
| Wer | | 0.8 | 50947.04 |
| Chuharkana | Case No V | 0.35 | 24522.4035 |
| Dhaular | | 0.25 | 16502.94 |
| Mohlan | | 0.7 | 62676.355 |
| Pacca Dala | | 0.3 | 21308.721 |
| Sangla | | 0.2 | 8044.94 |

Table 9(c). Magnitude of the Spatial Regime Corresponding to each of the Selected Case Definitions for the Rice Crop within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Case No I | Percentage of Area | Applied Area (ha) |
|---|---|---|---|
| Aminpur | | 0.85 | 66388.264 |
| Bhagat | | 0.9 | 67650.543 |
| Buchiana | | 0.8 | 51342.208 |
| Chuharkana | | 0.45 | 31528.8045 |
| Dhaular | | 0.6 | 39607.056 |
| Kanya | | 0.9 | 50502.528 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.295 |
| Pacca Dala | | 0.65 | 46168.8955 |
| Sangla | | 0.75 | 30168.525 |
| Sultanpur | | 0.85 | 37845.8165 |
| Tandlianwala | | 0.8 | 67801.6 |
| Tarkhani | | 0.9 | 60361.05 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.32 |
| Wer | | 0.8 | 50947.04 |
| Chuharkana | Case No.II | 0.35 | 24522.4 |
| Dhaular | | 0.25 | 16503 |
| Mohlan | | 0.7 | 62676.36 |
| Pacca Dala | | 0.3 | 21308.72 |
| Sangla | | 0.2 | 8045 |
| Chuharkana | Case No IV | 0.35 | 24522.4 |
| Dhaular | | 0.25 | 16503 |
| Mohlan | | 0.7 | 62676.36 |
| Pacca Dala | | 0.3 | 21308.72 |
| Sangla | | 0.2 | 8045 |
| Aminpur | Case No V | 0.85 | 66388.26 |
| Bhagat | | 0.9 | 67650.54 |
| Buchiana | | 0.8 | 51342.21 |
| Chuharkana | | 0.45 | 31528.8 |
| Dhaular | | 0.6 | 39607.06 |
| Kanya | | 0.9 | 50502.53 |
| Kot Khuda Yar | | 0.8 | 41031.4 |
| Mohlan | | 0.3 | 26861.3 |
| Pacca Dala | | 0.65 | 46168.9 |
| Sangla | | 0.75 | 30168.52 |
| Sultanpur | | 0.85 | 37845.82 |
| Tandlianwala | | 0.8 | 67801.6 |
| Tarkhani | | 0.9 | 60361.05 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.32 |
| Wer | | 0.8 | 50947.04 |
| Aminpur | Case No VI | 0.85 | 66388.3 |
| Bhagat | | 0.9 | 67650.54 |
| Buchiana | | 0.8 | 51342.21 |
| Chuharkana | | 0.45 | 31528.8 |
| Dhaular | | 0.6 | 39607.06 |
| Sultanpur | | 0.85 | 37845.82 |
| Tandlianwala | | 0.8 | 37801.6 |
| Tarkhani | | 0.9 | 60361.05 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.32 |
| Wer | | 0.8 | 50947.04 |
| Chuharkana | Case No VII | 0.35 | 24522.4 |
| Dhaular | | 0.25 | 16503 |
| Mohlan | | 0.7 | 62676.36 |
| Pacca Dala | | 0.3 | 21308.7 |
| Sangla | | 0.2 | 8045 |

Table 9(d). Magnitude of the Spatial Regime Corresponding to each of the Selected Case Definitions for the Sugarcane Crop within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivision | Case No I | Percentage of Area | Applied Area (ha) |
|---|---|---|---|
| Chuharkana | | 0.35 | 24522.41 |
| Dhaular | | 0.25 | 16503.00 |
| Mohlan | | 0.55 | 49245.70 |
| Pacca Dala | | 0.3 | 21308.70 |
| Sangla | | 0.2 | 8045.00 |
| Uqbana | Case No.II | 0.04 | 3933.00 |
| Aminpur | Case No III | 0.85 | 66388.26 |
| Bhagat | | 0.9 | 67650.54 |
| Buchiana | | 0.7 | 44924.43 |
| Chuharkana | | 0.45 | 31528.81 |
| Dhaular | | 0.6 | 39607.06 |
| Kanya | | 0.9 | 50502.53 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.30 |
| Pacca Dala | | 0.55 | 39066.00 |
| Sangla | | 0.65 | 26146.00 |
| Sultanpur | | 0.85 | 37846.00 |
| Tandlianwala | | 0.8 | 67801.60 |
| Tarkhani | | 0.9 | 60361.05 |
| Uqbana | | 0.95 | 93406.0 |
| Veryam | | 0.85 | 80685.32 |
| Wer | | 0.8 | 50947.04 |
| Aminpur | Case No V | 0.85 | 66388.26 |
| Bhagat | | 0.9 | 67650.54 |
| Buchiana | | 0.8 | 51342.21 |
| Chuharkana | | 0.45 | 31528.80 |
| Dhaular | | 0.6 | 69607.06 |
| Kanya | | 0.9 | 50502.53 |
| Kot Khuda Yar | | 0.8 | 41031.36 |
| Mohlan | | 0.3 | 26861.30 |
| Pacca Dala | | 0.65 | 46169.00 |
| Sangla | | 0.75 | 30168.52 |
| Sultanpur | | 0.85 | 37845.80 |
| Tandlianwala | | 0.8 | 67801.60 |
| Tarkhani | | 0.9 | 60361.05 |
| Uqbana | | 0.95 | 93406.00 |
| Veryam | | 0.85 | 80685.32 |
| Wer | | 0.8 | 50947.04 |
| Buchiana | Case No VI | 0.3 | 19253.33 |
| Chuharkana | | 0.2 | 14013.00 |
| Mohlan | | 0.15 | 13430.64 |
| Pacca Dala | | 0.15 | 10654.36 |
| Sangla | | 0.15 | 5485.20 |
| Tandlianwala | | 0.2 | 16950.40 |
| Uqbana | | 0.05 | 4916.00 |

Table 10(a). Distribution of Macro Level Economic Indicators for the Wheat Crop after Yield Adjustments within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Applied Area x Existing Cropping Intensity (ha) | Gross Income | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Cost of Land Preparation | Total Cost* | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| Aminpur | 36,447 | 626 | 19 | 56 | 21 | 7 | 5 | 46 | 284 | 341 |
| Bhagat | 29,902 | 597 | 18 | 57 | 10 | 9 | 33 | 45 | 289 | 309 |
| Buchiana | 24,798 | 411 | 13 | 43 | 14 | 11 | 12 | 36 | 221 | 190 |
| Chuharkana | 43,580 | 674 | 23 | 70 | 26 | 16 | 28 | 66 | 394 | 279 |
| Dhaular | 32,656 | 391 | 20 | 61 | 8 | 3 | 30 | 40 | 258 | 133 |
| Kanya | 27,423 | 370 | 16 | 48 | 9 | 11 | 4 | 55 | 242 | 129 |
| Kot Khuda Yar | 19,900 | 307 | 12 | 39 | 9 | 1 | 15 | 30 | 172 | 135 |
| Mohlan | 51,484 | 669 | 29 | 74 | 10 | 18 | 33 | 75 | 399 | 270 |
| Pacca Dala | 36,708 | 580 | 20 | 57 | 27 | 14 | 11 | 54 | 301 | 279 |
| Sangla | 23,009 | 290 | 13 | 35 | 17 | 3 | 4 | 41 | 178 | 112 |
| Sultanpur | 25,508 | 251 | 16 | 44 | 13 | 16 | 11 | 38 | 212 | 38 |
| Tandlianwala | 41,613 | 568 | 23 | 63 | 19 | 13 | 13 | 60 | 338 | 229 |
| Tarkhani | 30,583 | 485 | 17 | 62 | 9 | 15 | 13 | 47 | 285 | 200 |
| Uqbana | 39,791 | 633 | 22 | 71 | 20 | 13 | 11 | 56 | 345 | 288 |
| Veryam | 36,873 | 518 | 21 | 67 | 16 | 6 | 13 | 49 | 302 | 216 |
| Wer | 21,245 | 291 | 11 | 38 | 10 | 0 | 12 | 40 | 165 | 126 |

* Total cost also includes the cost of labor.

Table 10(b). Distribution of Macro Level Economic Indicators of the Cotton Crop after Yield Adjustments within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Applied Area x Existing Cropping Intensity (ha) | Gross Income | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Cost of Land Preparation | Total Cost* | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| Bhagat | 15,357 | 889 | 12 | 23 | 5 | 8 | 18 | 21 | 123 | 767 |
| Buchiana | 3,953 | 317 | 2 | 6 | 3 | 4 | 16 | 7 | 45 | 272 |
| Dhaular | 10,885 | 820 | 5 | 13 | 4 | 16 | 27 | 12 | 106 | 714 |
| Sultanpur | 8,023 | 178 | 3 | 8 | 5 | 4 | 9 | 13 | 61 | 117 |
| Tandlianwala | 6,102 | 423 | 2 | 10 | 3 | 15 | 8 | 8 | 62 | 361 |
| Tarkhani | 10,020 | 560 | 8 | 15 | 3 | 14 | 16 | 16 | 98 | 462 |
| Veryam | 1,533 | 430 | 1 | 2 | 2 | 3 | 10 | 2 | 24 | 406 |

* Total cost includes the cost of labor.

Table 10(c). Distribution of Macro Level Economic Indicators of the Rice Crop after Yield Adjustments within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Applied Area x Existing Cropping Intensity (ha) | Gross Income | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Cost of Land Preparation | Total Cost | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| Chuharkana | 27,969 | 455 | 2 | 48 | 16 | 9 | 62 | 44 | 267 | 188 |
| Dhaular | 5,555 | 111 | 1 | 8 | 0 | 2 | 9 | 8 | 45 | 66 |
| Kot Khuda Yar | 1,272 | 45 | 0 | 2 | 1 | 0 | 2 | 2 | 10 | 35 |
| Mohlan | 23,459 | 327 | 2 | 35 | 4 | 12 | 63 | 34 | 215 | 112 |
| Pacca Dala | 13,091 | 208 | 1 | 20 | 8 | 6 | 13 | 21 | 105 | 103 |
| Sangla | 6,840 | 184 | 1 | 12 | 5 | 1 | 3 | 10 | 55 | 129 |
| Tandlianwala | 2,644 | 55 | 0 | 6 | 0 | 2 | 2 | 3 | 24 | 31 |
| Uqbana | 5,698 | 139 | 0 | 8 | 6 | 2 | 3 | 11 | 54 | 85 |

* Total cost includes the cost of labor.

Table 10(d). Distribution of Macro Level Economic Indicators of the Sugarcane Crop after Yield Adjustments within the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Applied Area x Existing Cropping Intensity (ha) | Gross Income | Cost of Seed | Cost of Fertilizer | Cost of FYM | Cost of Plant Protection | Cost of Irrigation | Cost of Land Preparation | Total Cost* | Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| Aminpur | 9,626 | 316 | 21 | 17 | 5 | 3 | 1 | 19 | 100 | 216 |
| Bhagat | 5,006 | 253 | 15 | 7 | 3 | 1 | 30 | 8 | 78 | 175 |
| Buchiana | 16,686 | 497 | 24 | 22 | 7 | 4 | 29 | 28 | 160 | 337 |
| Chuharkana | 2,312 | 160 | 4 | 4 | 1 | 0 | 5 | 5 | 25 | 134 |
| Dhaular | 11,222 | 366 | 24 | 22 | 6 | 5 | 26 | 16 | 132 | 235 |
| Kanya | 17,777 | 481 | 19 | 39 | 14 | 4 | 5 | 31 | 150 | 331 |
| Kot Khuda Yar | 11,489 | 469 | 20 | 19 | 8 | 0 | 30 | 13 | 137 | 332 |
| Mohlan | 16,206 | 509 | 32 | 23 | 7 | 2 | 20 | 28 | 188 | 321 |
| Pacca Dala | 8,310 | 311 | 19 | 13 | 8 | 2 | 5 | 18 | 89 | 222 |
| Sangla | 2,574 | 114 | 6 | 5 | 3 | 0 | 1 | 7 | 30 | 84 |
| Sultanpur | 4,428 | 96 | 11 | 5 | 2 | 0 | 14 | 8 | 60 | 36 |
| Tandlianwala | 17,967 | 537 | 31 | 25 | 9 | 5 | 31 | 24 | 178 | 359 |
| Tarkhani | 10,744 | 384 | 23 | 22 | 10 | 3 | 10 | 16 | 141 | 242 |
| Uqbana | 19,959 | 641 | 38 | 41 | 14 | 5 | 15 | 35 | 229 | 412 |
| Veryam | 15,492 | 494 | 45 | 26 | 12 | 2 | 23 | 22 | 214 | 281 |
| Wer | 14,163 | 429 | 33 | 22 | 5 | 0 | 26 | 6 | 145 | 284 |

* Total cost also includes the cost of labor.

Table 11(a). Differences in the 'Extensive' vs 'Intensive' Irrigated Agriculture Strategies towards Production Increases in the Wheat Crop across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Gross Income | Total Cost | Profit |
|---|---|---|---|
| Aminpur | 110 | 119.1 | -8.1 |
| Bhagat | 66 | 143.7 | -78.69 |
| Buchiana | 102.1 | 120.6 | -18.59 |
| Chuharkana | -0.6 | 63.2 | -62.84 |
| Dhaular | 69.1 | 63.1 | 6.01 |
| Kanya | 41.7 | 56.6 | -15.88 |
| Kot Khuda Yar | 76.8 | 101.4 | -24.57 |
| Mohlan | 0.4 | 33.4 | -33.05 |
| Pacca Dala | 30.3 | 56.9 | -26.6 |
| Sangla | 0 | 20.7 | -20.74 |
| Sultanpur | 43.6 | 51.4 | -6.83 |
| Tandlianwala | -0.7 | 42.2 | -41.88 |
| Tarkhani | -0.3 | 38 | -38.2 |
| Uqbana | 8 | 101.2 | -93.2 |
| Veryam | 90.8 | 138 | -47.15 |
| Wer | 72.1 | 60.8 | 11.31 |

\+ Means higher values for *area intensive* strategy.
\- Means higher values for *yield intensive* strategy.

Table 11(b). Differences in the 'Extensive' vs 'Intensive' Irrigated Agriculture Strategies towards Production Increases in the Cotton Crop across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Gross Income | Total Cost | Profit |
|---|---|---|---|
| Bhagat | 98.53 | 106.14 | -8.61 |
| Buchiana | 78.7 | 94.93 | -16.23 |
| Dhaular | 144.31 | 106.26 | 38.05 |
| Mohlan* | 76.86 | 22.53 | 54.33 |
| Sultanpur | 31.4 | 25.49 | 5.91 |
| Tandlianwala | 105.46 | 118.55 | -13.09 |
| Tarkhani | 62.45 | 106.49 | -44.04 |
| Veryam | 407.5 | 187.18 | 220.32 |

+ Means higher values for *area intensive* strategy.
- Means higher values for *yield intensive* strategy.
* Yield intensive option not applied.

Table 11(c). Differences in the 'Extensive' vs 'Intensive' Irrigated Agriculture Strategies towards Production Increases in the Rice Crop across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Gross Income | Total Cost | Profit |
|---|---|---|---|
| Chuharkana | 113.31 | 65.78 | 47.52 |
| Dhaular | 19.12 | 20.58 | -1.46 |
| Kot Khuda Yar | 11.8 | 18.03 | -6.23 |
| Mohlan | 0.03 | 9.32 | -9.29 |
| Pacca Dala | 10.65 | 14.39 | -3.74 |
| Sangla | 10.03 | 16.15 | -6.13 |
| Tandlianwala* | -55 | -24 | -31 |
| Uqbana | -27.6 | -0.7 | -26.9 |

+ Means higher values for ***area intensive*** strategy.
- Means higher values for ***yield intensive*** strategy.
* Area intensive option not applied.

Table 11(d). Differences in the 'Extensive' vs 'Intensive' Irrigated Agriculture Strategies towards Production Increases in the Sugarcane Crop across the Irrigation Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Subdivision | Gross Income | Total Cost | Profit |
|---|---|---|---|
| Aminpur | 56.2 | 68.5 | -12.3 |
| Bhagat | 28.1 | 119.6 | -91.6 |
| Buchiana | -0.5 | 40.2 | -40.7 |
| Chuharkana | -0.2 | 44.5 | -43.7 |
| Dhaular | 65.1 | 38.4 | 25.8 |
| Kanya | 53.2 | 32.2 | 21 |
| Kot Khuda Yar | 117.3 | 82.6 | 34.7 |
| Mohlan | 0.1 | 28.4 | -28.3 |
| Pacca Dala | -0.5 | 29.1 | -29.6 |
| Sangla | -0.1 | 15.6 | -15.7 |
| Sultanpur | 16.9 | 23.6 | -6.7 |
| Tandlianwala | 0 | 28.7 | -28.7 |
| Tarkhani | 42.2 | 47 | -3.8 |
| Uqbana | 0.5 | 61.2 | -60.7 |
| Veryam | 198.9 | 118.5 | 79.4 |
| Wer | 24.5 | 51.4 | -26.9 |

\+ Means higher values for ***area intensive*** strategy.
\- Means higher values for ***yield intensive*** strategy.

11(c)). In fact, the figure on gross incomes is disproportionately higher in comparison to the other subdivisions. Elsewhere, the traditional rice growing subdivisions have only slightly higher gross profits accruing from investments towards higher inputs. Of particular interest is the Uqbana Subdivision where the returns (against a negligible difference in costs amongst the two strategical options) is totally in favor of a yield intensive strategy.

### 2) Canal Command Level

The implications of the observations made at the subdivisional level are more emphatically underscored in the context of the larger canal commands where decisions pertaining to resource allocations are much easier to mobilize and implement. For the Rechna Doab, the administrative unit of the LCC (East) Circle covers the commands of the Gugera Branch, whereas the LCC (West) Circle is exclusively responsible for the commanded regime under the Jhang Branch (see Figure 14, Volume Two for spatial separations of the commanded regimes). A summation of the macro economic indicators at this scale presents a cumulative picture of investments and returns that could be expected in the context of the dual production intensive strategies explained above. Table 12 summarizes the essential constructs of this comparison (differences in the magnitudes of the macro economic indicators) in the context of the four major crops considered for production enhancement within the LCC system. It is only the wheat crop for which the pattern of investments and returns is consistent across both of the Circles and also matches the general observations at the subdivisional level. While the profits are higher from the yield intensive option in the LCC (East), the gross incomes have more than double the difference across the LCC (West) where the proposed increase in the area under this crop (45795 ha) is just 75% of the corresponding increase in the LCC (East). The total costs are about the same against either of the strategies.

The cotton crop is predominanlty favored against the *extensive* option within the LCC (West); the difference in profits favoring the *intensive* option is not substantial for the LCC (East). The lower cost differences amongst the options in the LCC (West) result probably from the efficiencies in its cultivation across the tail subdivisions of the Jhang Branch that have had traditionally higher cropping intensities of cotton. Regardless, the gross income differences are clearly in favor of utilization of the lands being currently left fallow for want of surface irrigation or useable groundwater supplies. The overwhelmingly large cultivations of rice in the LCC (East) are universally higher in returns (and also in costs) for the LCC (East) given the rather wide margins for areal expansion against existing levels of fallowing. Understandably, the cultivations in the LCC (West) would likely take more advantage of the benefits accruing from key inputs to their not so extensive reliance on boosting productivity, a situation that is reflected in the difference of nearly 41 million rupees in net profits in favor of the *intensive* option.

Finally, for the sugarcane, two contrasting situations emerge vis a vis the two options for enhancing production. The higher values of the total costs and profits for the intensive

Table 12. Differences in the 'Extensive' vs 'Intensive' Irrigated Agriculture Strategies towards Production Increases in the Major Crops across the Canal Commands of the LCC System, Rechna Doab, Punjab, Pakistan.

(million Rupees)

| Irrigation Circle | Crop | Gross Income | Total Costs | Profit |
|---|---|---|---|---|
| LCC East | Wheat | 282.50 | 606.00 | -322.56 |
| | Cotton | 453.40 | 474.13 | -12.73 |
| | Rice | 68.99 | 65.49 | 3.49 |
| | Sugarcane | 139.30 | -313.70 | -353.10 |
| LCC West | Wheat | 426.80 | 604.30 | -176.44 |
| | Cotton | 551.81 | 293.44 | 258.37 |
| | Rice | 13.35 | 54.06 | -40.72 |
| | Sugarcane | 462.40 | 543.20 | 125.30 |

gains in the LCC (East) Circle are completely reversed in the LCC (West); the gross incomes in either case remaining in favor of the *extensive* option. The tendency for the sugarcane cultivations across the LCC (West) Circle to be prone towards the extensive gains in irrigated agriculture is similar to the one for rice in the LCC (East), the difference being just in the magnitude of returns.

## D. Cost Effect of Marginal Improvements in Critical Inputs

Tables 11 and 12 have shown the cumulative mutual differences in the macro economic parameters leading to the choice of the most appropriate strategy to implement preset gains in the agricultural productivity of the major crops. Nowhere has it been implied that the comparative differentiations rendered against the extensive and the intensive options are the only feasible alternatives towards raising the current levels of agricultural production. Perhaps there are combinations thereof that would be most suitable towards adoption of a suitable strategy. The scope of such a discussion would be beyond the mandate of the current study that essentially is not unmindful of the deleterious impacts of salinity on the current levels of production that are rather inconsistently distributed in space. In this respect, the generation, and subsequent application, of the production functions (Table 10, Volume Four) has included the component effects of the water and soil related constraints that are most representative of the growing conditions for the major crops. Much of the comparison above has not only shown substantial benefits by pursuing an *intensive* irrigated agriculture strategy, but also has been revealing on the marginal differentiations of doing so. Hence, the concommitant conclusions must then identify the measure of investments for those key supplements that would be essential to achieve the desired levels of inputs. Again, these assimilations must distinguish between the geographic scales at both the subdivision and the canal command level to be consistent with the format of deliverables in the preceding discussions. Tables 13 lists the desired incremental investments (those exceeding the 100% figure) at the subdivision level in terms of the most dominant significant variables of the respective production functions for each of the four major crops. For the wheat crop (Table 13(a)), only modest enhancements to fertilizer and irrigation supply are required to meet the production targets across each of the subdivisions. This situation contrasts with that of cotton where only irrigation supplies need to be enhanced between 17-350% over the current levels to achieve the desired targets (Table 13(b)). The case for Veryam is different, where an increase in cropping intensity from the current 1.9% to 22% is envisaged to achieve consistency across the lower reaches of the LCC system; hence, the over eight fold increase in irrigation supplies.

For rice, only Uqbana Subdivision shows the need for higher investments across all of the three key areas of inputs, including fertilizer (Table 13(c)); the other two subdivisions requiring significant improvements in fertilizer applications are Dhaular and Kot Khuda Yar. Except for the Uqbana, almost everywhere the exisitng irrigation applications are sufficient to meet the consumptive use requirements of this crop. The sugarcane crop shows almost no need for incremental investments in irrigation and fertilizer applications across the entire

Table 13(a). Incremental Investment in Critical Inputs of Wheat Crop for the Intensive Irrigated Agriculture Strategy across the Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivisions | Existing Costs (million Rupees) | | | Anticipated Costs After Yield Adjustment (million Rupees) | | | Incremental Investment (percentage) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation |
| Aminpur | 61.617 | 7.938 | 4.720 | 56 | 7 | 5 | 90.884 | 88.182 | 105.933 |
| Bhagat | 56.619 | 9.625 | 26.418 | 57 | 9 | 33 | 100.673 | 93.511 | 124.916 |
| Buchiana | 50.233 | 14.060 | 12.171 | 43 | 11 | 12 | 85.600 | 78.234 | 98.593 |
| Chuharkana | 65.942 | 16.049 | 24.336 | 70 | 16 | 28 | 106.154 | 99.692 | 115.057 |
| Dhaular | 70.366 | 3.724 | 33.667 | 61 | 3 | 30 | 86.690 | 80.566 | 89.109 |
| Kanya | 51.127 | 11.822 | 3.626 | 48 | 11 | 4 | 93.884 | 93.047 | 110.320 |
| Kot Khuda Yar | 44.320 | 2.015 | 13.853 | 39 | 1 | 15 | 87.996 | 49.639 | 108.279 |
| Mohlan | 72.136 | 18.523 | 29.740 | 74 | 18 | 33 | 102.584 | 97.177 | 110.963 |
| Pacca Dala | 57.691 | 14.104 | 10.549 | 57 | 14 | 11 | 98.802 | 99.263 | 104.275 |
| Sangla | 34.580 | 3.661 | 4.098 | 35 | 3 | 4 | 101.216 | 81.955 | 97.609 |
| Sultanpur | 50.306 | 19.408 | 11.849 | 44 | 16 | 11 | 87.465 | 82.439 | 92.835 |
| Tandlianwala | 59.448 | 12.730 | 11.981 | 63 | 13 | 13 | 105.976 | 102.122 | 108.505 |
| Tarkhani | 58.854 | 14.446 | 11.171 | 62 | 15 | 13 | 105.345 | 103.836 | 116.373 |
| Uqbana | 69.404 | 13.822 | 8.922 | 71 | 13 | 11 | 102.300 | 94.052 | 123.297 |
| Veryam | 73.199 | 7.758 | 12.048 | 67 | 6 | 13 | 91.531 | 77.343 | 107.900 |
| Wer | 45.348 | | 12.949 | 38 | | 12 | 83.796 | | 92.671 |

Table 13(b). Incremental Investment in Critical Inputs of Cotton Crop for the Intensive Irrigated Agriculture Strategy across the Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivisions | Existing Costs (million Rupees) | | | Anticipated Costs After Yield Adjustment (million Rupees) | | | Incremental Investment (percentage) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation |
| Bhagat | 25.919 | 9.264 | 8.379 | 23 | 8 | 18 | 88.738 | 86.355 | 214.835 |
| Buchiana | 8.096 | 5.089 | 3.576 | 6 | 4 | 16 | 74.108 | 78.597 | 447.451 |
| Dhaular | 15.598 | 18.836 | 11.900 | 13 | 16 | 27 | 83.341 | 84.944 | 226.883 |
| Sultanpur | 9.197 | 4.877 | 7.688 | 8 | 4 | 9 | 86.982 | 82.019 | 117.065 |
| Tandlianwala | 13.048 | 19.286 | 2.801 | 10 | 15 | 8 | 76.638 | 77.778 | 285.613 |
| Tarkhani | 17.105 | 15.599 | 6.293 | 15 | 14 | 16 | 87.694 | 89.751 | 254.250 |
| Veryam | 2.106 | 3.209 | 1.035 | 2 | 3 | 10 | 94.976 | 93.477 | 965.820 |

Table 13(c). Incremental Investment in Critical Inputs of Rice Crop for the Intensive Irrigated Agriculture Strategy across the Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivisions | Existing Costs (million Rupees) | | | Anticipated Costs After Yield Adjustment (million Rupees) | | | Incremental Investment (percentage) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation |
| Chuharkana | 58.920 | 12.029 | 75.110 | 48 | 9 | 62 | 81.466 | 74.820 | 82.545 |
| Dhaular | 6.915 | 2.010 | 11.000 | 8 | 2 | 9 | 115.684 | 99.522 | 81.816 |
| Kot Khuda Yar | 0.823 | 0.274 | 2.661 | 2 | | 2 | 243.112 | 0.000 | 75.167 |
| Mohlan | 34.029 | 12.227 | 61.206 | 35 | 12 | 63 | 102.853 | 98.143 | 102.931 |
| Pacca Dala | 20.592 | 6.749 | 13.210 | 20 | 6 | 13 | 97.126 | 88.897 | 98.410 |
| Sangla | 11.493 | 0.891 | 3.132 | 12 | 1 | 3 | 104.413 | 112.273 | 95.792 |
| Sultanpur | 28.481 | 13.689 | 2.964 | 6 | 2 | 2 | 21.067 | 14.611 | 67.487 |
| Uqbana | 5.938 | 1.751 | 2.039 | 8 | 2 | 3 | 134.733 | 114.200 | 147.117 |

Table 13(d). Incremental Investment in Critical Inputs of Sugarcane Crop for the Intensive Irrigated Agriculture Strategy across the Subdivisions of the LCC System, Rechna Doab, Punjab, Pakistan.

| Subdivisions | Existing Costs (million Rupees) | | | Anticipated Costs After Yield Adjustment (million Rupees) | | | Incremental Investment (percentage) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation |
| Aminpur | 19.385 | 3.863 | 1.598 | 17 | 3 | 1 | 87.695 | 77.650 | 62.597 |
| Bhagat | 7.498 | 0.799 | 33.483 | 7 | 1 | 30 | 93.358 | 125.126 | 89.598 |
| Buchiana | 22.361 | 4.049 | 28.776 | 22 | 4 | 29 | 98.385 | 98.789 | 100.777 |
| Chuharkana | 4.198 | 0.284 | 4.981 | 4 | | 5 | 95.281 | 0.000 | 100.373 |
| Dhaular | 25.863 | 6.073 | 30.801 | 22 | 5 | 26 | 85.062 | 82.331 | 84.413 |
| Kanya | 43.775 | 4.069 | 5.492 | 39 | 4 | 5 | 89.092 | 98.296 | 91.047 |
| Kot Khuda Yar | 23.625 | 0.173 | 37.314 | 19 | | 30 | 80.424 | 0.000 | 80.399 |
| Mohlan | 23.353 | 2.007 | 20.262 | 23 | 2 | 20 | 98.489 | 99.664 | 98.708 |
| Pacca Dala | 13.007 | 1.665 | 5.146 | 13 | 2 | 5 | 99.943 | 120.086 | 97.157 |
| Sangla | 5.374 | | 1.147 | 5 | | 1 | 93.047 | | 87.151 |
| Sultanpur | 6.075 | | 15.997 | 5 | | 14 | 82.309 | | 87.519 |
| Tandlianwala | 24.670 | 4.902 | 30.883 | 25 | 5 | 31 | 101.336 | 102.005 | 100.380 |
| Tarkhani | 24.182 | 3.426 | 11.029 | 22 | 3 | 10 | 90.975 | 87.575 | 90.671 |
| Uqbana | 40.757 | 4.611 | 15.429 | 41 | 5 | 15 | 100.596 | 108.445 | 97.222 |
| Veryam | 29.927 | 3.022 | 27.524 | 26 | 2 | 23 | 86.877 | 66.184 | 83.562 |
| Wer | 27.066 | | 32.496 | 22 | | 26 | 81.284 | | 80.009 |

LCC system. In fact, the values for these variables are less than 100% meaning that there may be an over-application of these resources that averages between 15-20%. At the Irrigation Circle level, interesting comparisons are obtained for the incremental investments against each of the four major crops. From Table 14, for the irrigated commands within the LCC (East) Circle (Gugera Branch), an 11.4% increase in irrigation supplies is needed for the wheat crop as compared to a 133% increase desired for the cotton crop to achieve the required production targets through extensive irrigated agriculture. It seems that the current investments in plant protection for both rice and cotton are already beyond the essential levels as determined by the production functions in the yield intensive strategy. The higher consumptive use crops, like rice and sugarcane, do not show the need for tangible investments, over and above the existing, to overcome higher production targets through exclusive reliance on yield increases. For the LCC (West) Circle, rice cultivation would benefit from a 19% investment in fertilizer use above the current levels, whereas the cotton crop requires an increase of upto 186% to overcome not only the target production levels but also to overcome the surface irrigation shortages that have been the major drawback to the farming potential of the tail subdivisions of the Jhang Branch. Taken in the context of the information in Table 12, the existing investments in fertilizer and plant protection for cotton crop are in excess of the essential requirements as determined by the production functions applied to this area.

## IV. MAJOR CONCLUSIONS

The foregoing discussion in this Volume has been a descriptive account of both the physiographic and the farming constraints of irrigated agriculture across the 1.561 Mha of gross commanded regime within the LCC system. The description has also encompassed the over 98,600 ha of gross area that extends beyond the intersection of the Haveli Canal to the confluence of the Ravi and the Chenab rivers. The discussion, emanating from extensive rendering of the thematic profiles, pertaining to both soil and water resources, has been abetted by data obtained from both public sources and IIMI's own surveys. The intention to pursue a descriptive style, rather than GIS-assisted quantifications of the physical regime, has been necessitated largely by the tremendous variability in the interactive mix of constraints that collectively influence the farming traditions that are at the heart of the hundred years of irrigated agriculture within the Rechna Doab. Perhaps, there are still many peculiarities of the system that have not been captured suitably across time and space; accomplishing such an ordeal would defy many of the constraints to information shortcomings that are unlikely to be overcome in real life. What has transpired, as a result of the inter-netting of the variant forms of information, is the potent realization of the rewards (to both the gross agricultural GDP and the farm gate) if the system were to be managed only slightly more efficiently.

Table 14. Incremental Investment in Critical Inputs for the Intensive Irrigated Agriculture Strategy across the LCC System, Rechna Doab, Punjab, Pakistan.

| Irrigation Circle | Crops | Existing Costs (million Rupees) | | | Anticipated Costs After Yield Adjustment (million Rupees) | | | Incremental Investment (Percentage) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation | Cost of Fertilizer | Cost of Plant Protection | Cost of Irrigation |
| LCC-East | Wheat | 522.357 | 130.767 | 141.840 | 518.00 | 123.00 | 158.00 | 99.166 | 94.060 | 111.393 |
| | Cotton | 73.366 | 54.114 | 28.736 | 62.00 | 45.00 | 67.00 | 84.508 | 83.157 | 233.154 |
| | Rice | 142.022 | 44.694 | 152.490 | 109.00 | 29.00 | 140.00 | 76.749 | 64.886 | 91.810 |
| | Sugarcane | 169.120 | 21.201 | 156.049 | 160.00 | 21.00 | 149.00 | 94.607 | 99.051 | 95.483 |
| LCC-West | Wheat | 398.834 | 38.917 | 90.256 | 367.00 | 33.00 | 90.00 | 92.018 | 84.797 | 99.716 |
| | Cotton | 17.704 | 22.045 | 12.936 | 15.00 | 19.00 | 37.00 | 84.725 | 86.186 | 286.028 |
| | Rice | 25.168 | 4.926 | 18.832 | 30.00 | 5.00 | 17.00 | 119.197 | 101.506 | 90.272 |
| | Sugarcane | 171.997 | 17.742 | 146.309 | 152.00 | 15.00 | 122.00 | 88.373 | 84.547 | 83.385 |

In leading to the discussion on the fundamental choices between *extensive* and *intensive* irrigated agriculture strategies, the intention is not to be exacting on the deliverables but to assist towards those strategic policy choices that are needed for potent and sustainable gains in irrigated agriculture. Ordinarily, decisions pertaining to increases in the existing cropping potential oversight the resource potential of the regime and the reigning offsets of land degradation caused by soil salinization and poor drainage. The current study has not been oblivious to this emergent threat, and, in arriving at aspects of resource mobilization, the core issues of water scarcity, key agricultural inputs and the recurrent impact of soil salinization have been taken into account. In building up to the final set of strategic choices, there remain gaps in information coverage; perhaps, subsequent studies may be able to enforce the constraints to the existing farming potential in a manner that is more cogent in space and time.

Final conclusions, ***leading to sector level decision making***, may be drawn in the context of the information already presented in Tables 12 and 14. The targeted achievements, in terms of the proposed production levels, are defined exclusively by the extensive irrigated agriculture strategy in Table 5. The quantum increases in the cultivated areas and production at the Irrigation Circle level are summarised in Table 15. Larger cultivation extents have been devoted to the wheat, cotton and sugarcane crops in the LCC (East) Circle vs rice in the LCC (West). The lesser areal increase for rice in the LCC (East) is primarily due to the already high cropping intensities prevailing in this area.

The respective values of the cumulative area and production for both of the strategies appear under Tables 16 and 17. It should be obvious by now that the area devoted to the major crops under the 'extensive' irrigated agriculture strategy has to be larger than the corresponding figures under the 'intensive' strategy. Under the 'intensive' option, the total effective area for cotton and rice crops across both of the Circles is less than the corresponding values in the 'extensive' option applied across the LCC (East) Circle alone. Considering this small area of utilization under the 'intensive' option, the significance of its impact on the macro economic indicators under Table 12 is very impressive. There, cotton shows higher profits in the LCC (East) Circle, whereas rice accomplishes the same in the LCC (West) Circle. For ease of reference, comparisons against both area and yield related figures in Tables 16 and 17 have been summarised in Table 18. The consistently high values of the gross income in Table 12 under the 'extensive' option are because of the larger extents of the major crops (Table 18(a)) and the higher gross production (Table 18(b)) in both of the Irrigation Circles. However, the '-' sign for the profits in Table 12 for three of the four major crops in the LCC (East) Circle and two crops in the LCC (West) Circle indicates that despite these gaps in the gross production, the economic returns at the farm gate are superior for the 'intensive' irrigated agriculture strategy.

The foregoing analysis has been based on data that should suffice for comparisons at the reconnaissance level, such as for the Rechna Doab. Improvements in the respective levels of detail would necessitate cognizance of the physical constraints in a manner that would be very difficult to collect and verify towards emergent decision making in real life.

Table 15(a). Proposed Areal Increases for the 'Extensive' Irrigated Agriculture Option within the respective Canal Circles of the LCC System, Rechna Doab, Punjab, Pakistan.

(hectares)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 59950 | 45795 |
| Cotton | 51315 | 23603 |
| Rice | 8375 | 9193 |
| Sugarcane | 28598 | 24275 |

Table 15(b). Proposed Production Increases for the 'Extensive' Irrigated Agriculture Option within the respective Canal Circles of the LCC System, Rechna Doab, Punjab, Pakistan.

(000 tons)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 164.83 | 129.41 |
| Cotton | 60.11 | 36.02 |
| Rice | 21.21 | 28.16 |
| Sugarcane | 1338.66 | 1257.38 |

Table 16(a). Proposed Cumulative Area for the 'Extensive' Irrigated Agriculture Option within the respective Canal Circles of the LCC System, Rechna Doab, Punjab, Pakistan.

(hectare)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 387797 | 289554 |
| Cotton | 110067 | 43083 |
| Rice | 106093 | 33365 |
| Sugarcane | 132542 | 121627 |

Table 16(b). Proposed Cumulative Production from the 'Extensive' Irrigated Agriculture Option within the respective Canal Circles of the LCC System, Rechna Doab, Punjab, Pakistan.

(0 0 0 metric tons)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 1081 | 770 |
| Cotton | 117 | 57 |
| Rice | 230 | 98 |
| Sugarcane | 6373 | 6431 |

Table 17(a). Effective Area for the 'Intensive' Irrigated Agriculture Option within the respective Canal Circles of the LCC System, Rechna Doab, Punjab, Pakistan.

(hectares)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 311599 | 209849 |
| Cotton | 43455 | 12418 |
| Rice | 67163 | 19365 |
| Sugarcane | 99436 | 84525 |

Table 17(b). Cumulative Production from the 'Intensive' Irrigated Agriculture Option within the respective Canal Circles of the LCC System, Rechna Doab, Punjab, Pakistan.

(000 metric tons)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 1018.45 | 670.22 |
| Cotton | 100.85 | 48.77 |
| Rice | 192.26 | 88.21 |
| Sugarcane | 6106.63 | 5575.60 |

Table 18(a). Differences in Irrigated Extents of Major Crops for the 'Extensive' and 'Intensive' Options within the respective Canal Circles of the LCC System, Rechna Doab, Pakistan.

(hectares)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 76198 | 79705 |
| Cotton | 66612 | 30665 |
| Rice | 38930 | 14000 |
| Sugarcane | 33106 | 37102 |

Table 18(b). Differences in Production of Major Crops for the 'Extensive' and 'Intensive' Options within the respective Canal Circles of the LCC System, Rechna Doab, Pakistan.

(000 metric tons)

| Crops | Administrative Circles | |
|---|---|---|
| | East | West |
| Wheat | 62.55 | 99.78 |
| Cotton | 16.15 | 8.23 |
| Rice | 37.74 | 9.79 |
| Sugarcane | 266.37 | 855.4 |

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