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WATERLOGGING AND SALINITY MANAGEMENT IN THE SINDH PROVINCE

Volume
One

The Irrigated Landscape: Resource Availability across the Hydrological Divides

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WATERLOGGING AND SALINITY MANAGEMENT IN THE SINDH PROVINCE

Volume I

THE IRRIGATED LANDSCAPE: RESOURCE AVAILABILITY ACROSS THE HYDROLOGICAL DIVIDES

I. PREAMBLE

The discrepancy between stagnant agricultural production and an increasing demand for food products has been well documented (World Bank, 1994), and is clearly an important issue in the agenda of policy makers and funding agencies in Pakistan. With the irrigation sector catering to over 90 percentof the exports of agricultural products, much attention has been given to potential improvements in water availability for corresponding increases in yield and production in the past. In the 1960s and early 1970s, strategy and investment in irrigation and drainage in Pakistan was mainly focused on three activities, i.e. construction of major storages, barrages and link canals; control of increasing waterlogging and salinity through drainage (public tile and tubewell drainage projects); and expansion of water supplies by new storages and public tubewell schemes. During the 1970s, the strategy was changed due to:

- high cost of additional stored water;
- the faltering performance of the surface irrigation system (especially inadequate maintenance leading to operational problems); and
- problems of sustainable realizations from public sector tubewells.

The Revised Action Program (RAP) for Irrigated Agriculture of 1979, however, switched the emphasis from improving system efficiency through rehabilitation and upgrading to small-scale physical investments (private tubewells, watercourse improvements and soil reclamation). The new strategy so adopted focused on better utilization of existing infrastructure, especially at the watercourse level, the "savings" of surface water "losses" from channels, and improved management of water from the irrigation command level down to the farm. Furthermore, RAP estimated that saving water by increasing water efficiency (i.e. reducing "losses") cost about a quarter that of developing new irrigation supplies.

Towards the end of the 1980s decade, many of the irrigation sector expansion and rehabilitation programs were either operationally mature or were in an advanced stage of implementation. This also marked the turning point in what was an impressive expansion of the agriculture land. Thereonwards, the *area* sown to important crops has seen minimum increase (Figure 1) because of continuing stress on the distribution of existing irrigation

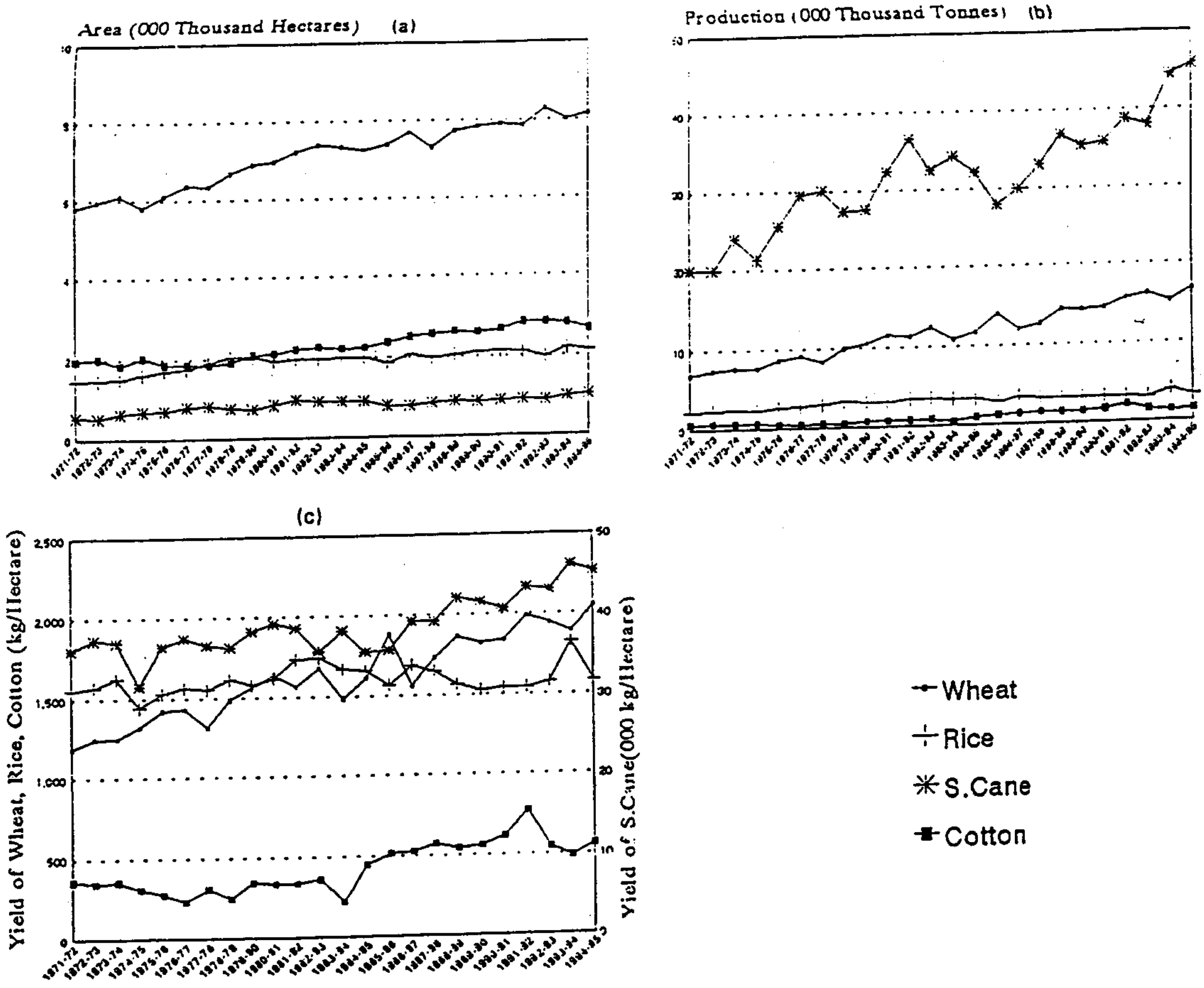

Figure 1. Historical Trends in Area Production and Yield of Major Crops in Pakistan.

supplies beset with a low level of irrigation efficiency and structural incapacity for additional mobilization. In comparison to the last population census growth rate of 3.1 percent (1981), the annual rates of increase in the cultivable and cropped areas have been under 1 percent. Well worth considering is that population density per square kilometer of cropped area has already increased from 26.25 in 1951 to 51.2 in 1989, a rise of about 95 percent, despite substantial expansion in cropped area. At the same time, according to agricultural censuses, the total number of farms in the country increased from 3.762 million in 1972 to over 44 million in 1980, with a corresponding decrease in farm size from 5.27 ha to 4.68 ha; in other words, the land fragmentation has increasingly rendered the farm holdings uneconomic.

The National Commission on Agriculture (NCA) Report (1988) estimates that the present rate of agricultural growth must rise by an average of 5 percent per annum (4% for crops) to keep up with the population demand. This is still too conservative of an estimate as it has been projected for a population of 140 million by the year 2000 instead of the 148 million by the Planning Commission. Except for cotton, which experienced a high rate of yield increase ***over the past decade***, the rate of annual yield growth of all other crops has been about 2 percent or less. It is not possible to say how much of the yield increase has resulted from increased water supply per irrigated hectare over the period, which on the average was about 7 percent (WSIP, 1990; 2.4% when comparing for 1965-88). However, these low yields per unit area, to some extent, mask the actual efficiency in using scarce irrigation water, which is relatively high among the better farmers.

About two-thirds of the wheat production increase during the last 15 years has come from improvements in yield and the balance from areal expansion; comparative figures for cotton and rice are 50 percent and 25 percent, respectively, while the yield increase for sugarcane has been much less. When compared against the targeted growth rates of 4.45 percent for wheat and 4.07 percent for rice in the 6th Five Year Plan (1983-88), achievements were 0.43percent and 1.19 percent, respectively. During the same period, the overall investment in the water sector was 17 percent below WAPDA's Revised Action Plan recommendations of 1979. With the near-levelling off of the availability of irrigation water per hectare of cultivated land, and evidence of a sharp decline in the marginal returns to further increases in the use of fertilizer, doubts begin to emerge about the ability to sustain current levels of productivity.

The WSIP study ascribes the low crop yields primarily to low fertilizer use efficiency, inefficient on-farm water delivery and management, and inadequate transfer of available technology, particularly to small-scale traditional farmers. With proper agronomic practices and the use of inputs in a timely and proper proportion, average farm productivity can easily improve by 15-20 percent. In short, the existing yields are almost half of the possible yields that can be achieved through improved management practices.

All these factors make a strong case for continued water sector investments to minimize land deterioration, increase water supplies per cropped hectare, or at least to improve the timeliness of water deliveries for consumptive use. Given the very low volume of irrigation supplies available to the farmers, even marginal levels of salinity could build up to larger concentrations. Irrigation practices would have to change to achieve the dilution, meaning significantly more water per unit area of crop (thus reducing the cropped area) or supplying more water at the farmgate, either of which is difficult to achieve at present. The problem is not just maintaining a salt balance in the root zone, but disposal of the additional salinity picked up from the huge reservoir of salt through which drainage flows pass, especially sub-surface drainage flows. The Staff Appraisal Report (SAR) of the National Drainage Program (NDP) mentions that a 25 percent reduction in the production of our major crops is attributed to salinity alone.

In the Sindh Province where the problem is much more severe, the impact may be closer to 40-60 percent in saline groundwater areas. The impact of waterlogging on yields is as startling. The agricultural census of 1990 shows that out of the total farm area of 3.48 Mha, about 0.57 Mha is classified as culturable waste areas (CWA) and about 50 percent of the area under CWA is due to waterlogging and salinity.

As the downstream riparian, the Lower Indus Basin plays host to a rather complex set of relationships in the physical environment that remain largely elusive in the absence of a basin-wide management plan. Over the last 30 years, the region has seen a spate of both large and small public sector land rehabilitation schemes implemented from Guddu to Kotri commands that have yielded site-specific solutions through capital investments. These investments are equivalent to more than 40 percent of the total irrigated area rehabilitation expenditure within the country. The latest completion amongst a host of portfolio items in water sector reforms has been the Left Bank Outfall Drain Project covering some 0.5 Mha of irrigated area across two major canal systems of Rohri and Nara. Its drainage-works, comprising drainage/seepage wells that discharge into a network of surface drains and a 250 km-long main drain, is reckoned to be the largest such undertaking in the world. However, periodic monitoring of the performance of public sector schemes indicates the emergent need for imperative system rehabilitation needs that are different from the purely engineering focus of more than three decades ago. Management-led reforms must then attend to removing the principal constraint plaguing the irrigation system, the distribution and utilization of scarce irrigation supplies against an expanding farming system.

Field research conducted by the International Irrigation Management Institute (IIMI) since 1987 has been suggestive of delinking the irrigation supplies from the outdated objectives of system-wide equity criteria and its utilization from the sustainability point of view. This realization, in the absence of stringent distribution controls, will largely dictate the optimal allocation of scarce irrigation supplies coming forth through an ageing distribution system already stressed by extended full supply operations.

In the future, there will be a need to focus on more efficient use of inputs rather than increased levels of inputs as the major source of growth. Hence, the best strategy is to look for widely appropriate system interventions such as deep tillage methods to conserve moisture in drier areas, a new fodder crop to relieve fodder constraints, a new cash crop suited to local conditions, or a new early maturing variety of a staple food crop to promote an increased cropping intensity. In addition, these interventions will have to be evaluated for their impacts on the total farming system, since their effects are not just crop specific.

Study Background

Under a bilateral grant agreement between the Government of Pakistan and The Royal Netherlands Government, funds have been provided to the International Irrigation Management Institute to conduct research in Pakistan towards identifying sustainable options in irrigated agriculture. The first five-year phase of research ended in 1993 that emphasized the impact of waterlogging and salinity in the context of known inequities in the distribution of irrigation supplies across watercourse and distributary commands in selected areas of the Punjab Province. The second 5-year phase of the project includes the current study that focuses on the basin level investigations for sustainable irrigated agriculture across the main hydrological divides of the Sindh Province. This activity comprises the use of spatial information systems as the backdrop to an integrated assessment of salinity and waterlogging that serves as a capping effort for much of the research conducted during the previous phase of funding focused exclusively in the Punjab Province. The study is meant to be multidisciplinary in the wake of inputs catering to both the physical and farming regime of the entire province. Extensive surveys have been conducted across sample sites distributed over the major canal commands to include valuable information on the prevailing status of farming and constraints thereof. Alongside this primary data collection, secondary data on cropping, canal flows, extent of waterlogging and soil salinization, and associative profiles of soils and their characteristics has also been collected. Analysis has been aided and supplemented by the use of a spatial information system that allows convenience of resampling for diverse data sets across the hydrological divides. The major component activities of this study are related to:

i. establishment of a spatial database on the physiography and land use of the regime;
ii. impact assessment for groundwater hydrology in the context of changes to prevailing cropping patterns;
iii. economic survey and analysis to explore alternatives to the prevailing cropping pattern and comparative returns to scale; and
iv. determination of the water balance at the root zone as a result of the reallocation of surface water supplies across the hydrological divides.

The salient issues, addressed as part of the management interventions package, include:

- potential gains from culturable waste area;
- farming practices attuned to the suitability of soils for crop growth;
- expanded reliance on usable groundwater quality extractions during water-scarce periods;
- gaps in the optimum vs average yields; and

- impact of variations in cropping pattern on the availability of irrigation supplies across distinct hydrological divides.

Objectives

The following objectives were established for this investigation of waterlogging and salinity management in the Sindh Province:

1. Investigate major physical and economic constraints affecting the irrigated agriculture; to identify the current physical and agricultural resource base in the province (to include drainage, irrigation supplies, crop acreage, and environmental constraints);

2. To identify gaps in public sector planning and project prioritization/execution to establish the framework for IIMI's own observations/investigations;

3. Ascertain subsystem-wide (canal command level) adequacy of irrigation supplies for sustainable production;

4. Comparison of economic benefits by exploring the horizontal and vertical linkages in the concurrent utilization of the resource base (to include integration of physical information on the system versus farm-level interaction for agricultural practices);

5. Predict long-term impact of remedial measures on agricultural production; and

6. Identify subsystem-wide improvements towards alleviation of waterlogging and salinity; devise and recommend an implementation strategy for sustainable irrigated agriculture in the Sindh Province.

The implementation strategy, together with the basic elements of data collection and organization, is discussed in Section VI. This section also summarizes the specific methodology adopted for the inputs to this study and the format of deliverables native to each component of investigation. The following section details the salient features of the history of irrigated agriculture within the Lower Indus Basin Plain and the operational constructs of the hydrological system in the present environment.

II. EVOLUTION OF IRRIGATED AGRICULTURE IN THE LOWER INDUS BASIN

Astride the River Indus, the province of Sindh extends southwards from the head of the Lower Indus Plain, just above the Guddu Barrage, some 500 km in the southwest to the

Arabian Sea, and in the south-east to the border with India in the Rann of Kutch. The alluvial plain, through which the river follows a course roughly like an open letter S (Figure 2), for the most part is productive, or potentially productive agricultural lands. This physiography (Figure 3) is in sharp contrast to the bare Kirthar mountain range that forms the western boundary with Baluchistan Province and the Thar Desert that stretches along the entire eastern boundary with India.

Restricted irrigation, based on the seasonal rise of the Indus River, has been available to this area since the Moenjo Daro era almost 5,000 years ago. Until relatively recent times, the whole of the Lower Indus Basin was irrigated merely by floods from the river Indus. The river, which normally flows on a raised channel formed by its own deposits inundated the surrounding plain during summer. In years of high flood, the sheet of water tended to flow first along the main valley lines and meander channels formed by the previous courses of the river. With the passage of time, controlling and channelizing these natural meanders of flood waters by constructing parallel banks became possible. This marked the beginning of the first inundation canals across the Lower Indus Plains. Their parallel alignment along the valleys sustained maximum withdrawals from the river without causing flood damage to the surrounding land. Later, other inundation canals were built with offtakes to circumvent topographic limitations hindering access to lands not covered by valley alignments. At the turn of the century, some 19 large inundation canals had been built, but the condition of most of the canals deteriorated soon after.

These early canals had no permanent structures, and relied on cuts in the bank for the distribution of water. In the latter half of the 19th century, these inundation canals were enlarged, straightened and extended, their commands increased and head regulators constructed. Cross regulators and watercourse outlet structures were also constructed; the canal system was properly designed and maintained.

During low river flows, the performance of the irrigated agriculture suffered drastically as the canals were unable to operate on the run of the river. The seasonal inundations were supplemented by lift irrigation using Persian wheels. By 1850, inundation canals supplied irrigation water to about 10 percent of the area for Kharif crops. A major program of improvement and construction of new inundation canals was undertaken in the latter half of the 19th century, but it was not until 1932 that barrage-commanded irrigation was introduced with the construction of the Sukkur Barrage system commanding a gross area of some 3.25 million ha on the left and right banks of the river Indus. Later, two other barrages, Kotri (1.25 Mha, 1955) and Guddu (1 Mha, 1962) completed the system as it is today (Figure 4). The irrigated area increased substantially with the advent of the barrage-controlled canals and currently accounts for 5.485 Mha of CCA on either side of the river Indus (6.025 Mha GCA). On these barrages depends largely, but not wholly, the agricultural future of the province. Outside the barrage-commanded area, cultivation falls into two groups: rainfall and flood-irrigated. In general, there is insufficient rainfall for normal cropping.

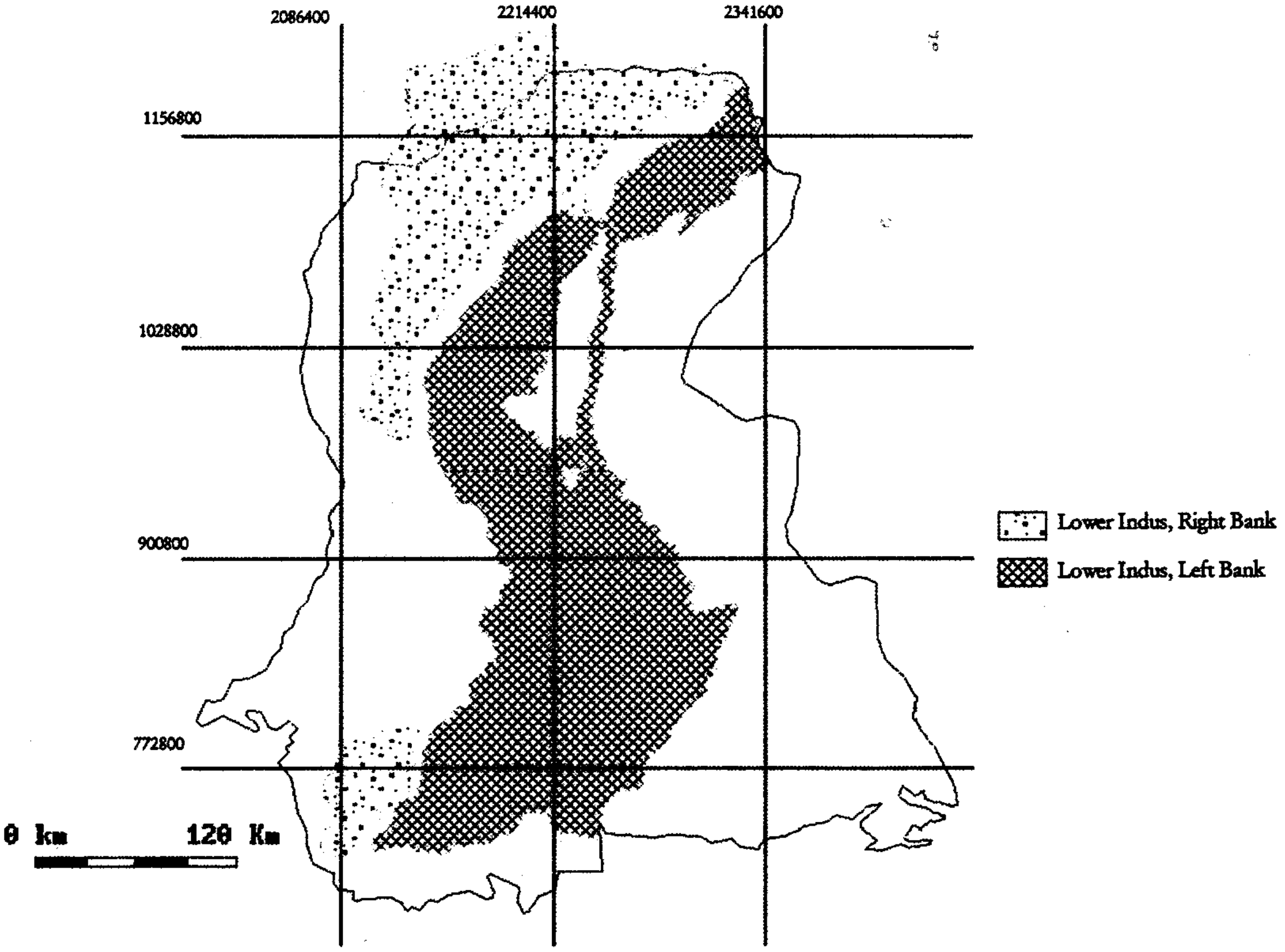

Figure 2. The Commanded Regime within the Lower Indus Basin Irrigation System.

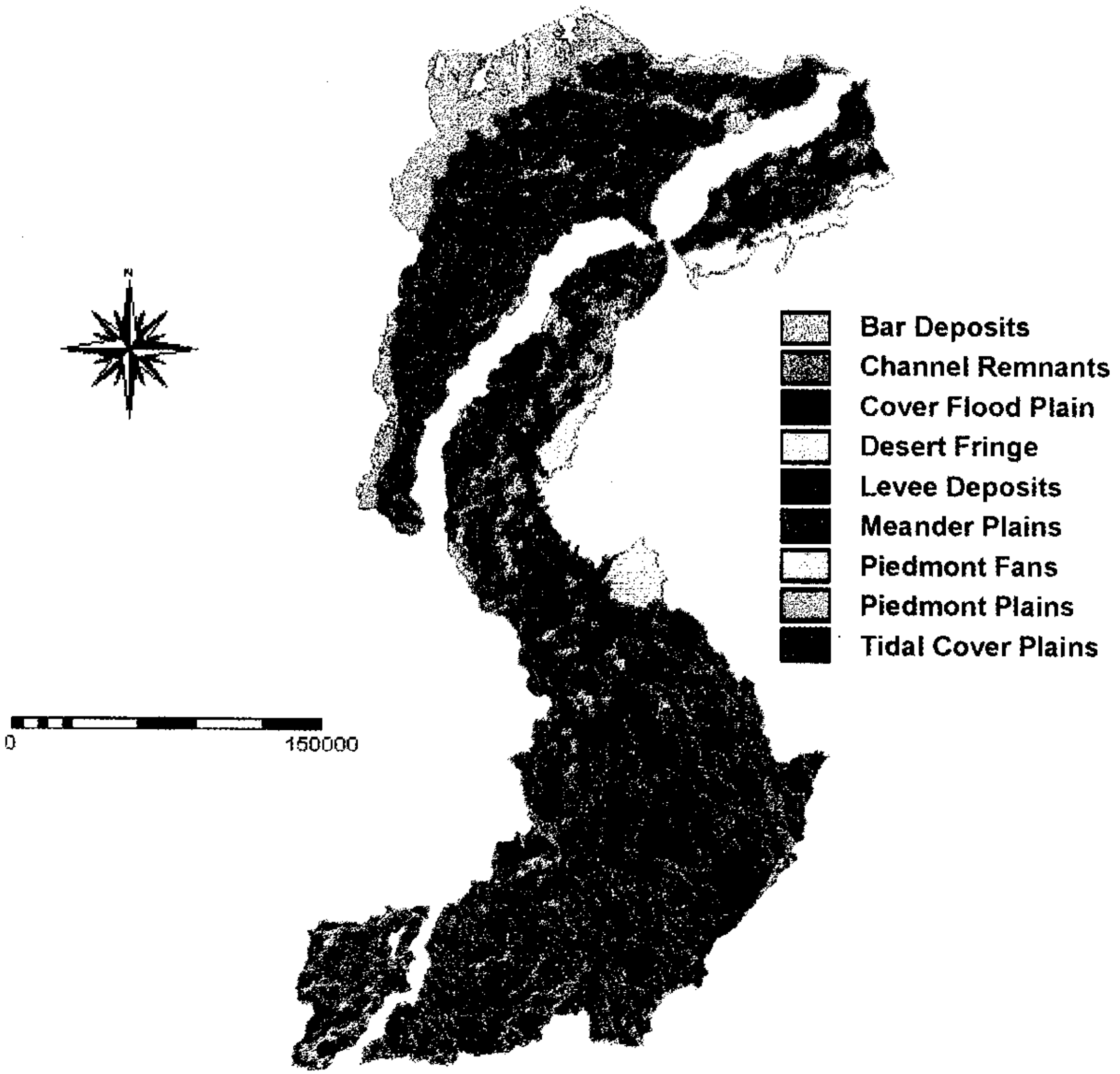

Figure 3. Physiography of the Lower Indus Basin Plain, Sindh Province, Pakistan.

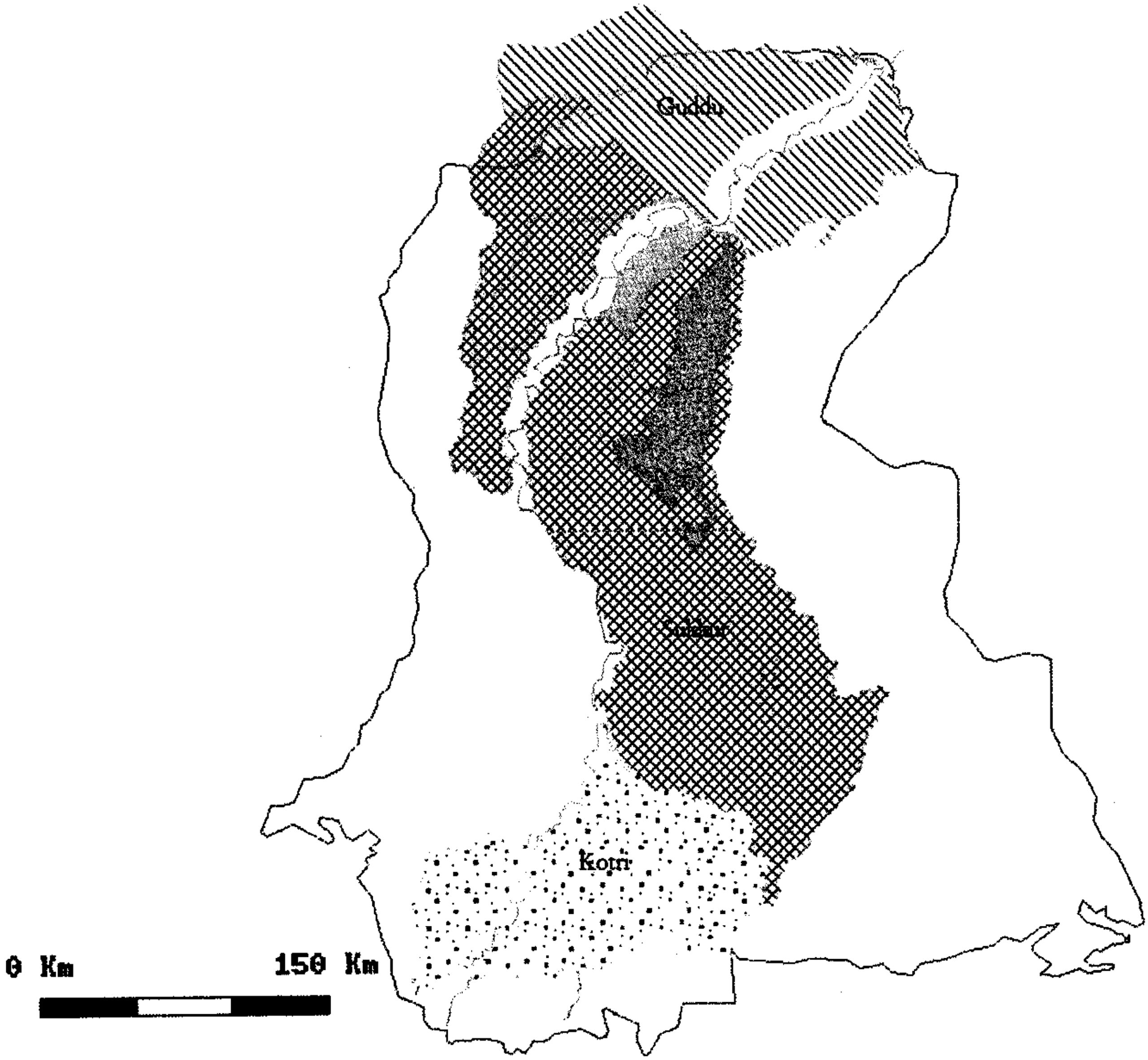

Figure 4. Geographical Expanse of the Barrage Commands within the Lower Indus Basin.

The Sukkur Barrage was commissioned in 1932 and remains the largest barrage system in Pakistan; the Rohri command, with its main canal stretching the 320 km from Sukkur to Hyderabad, is one of the largest single irrigation systems in the world. Prior to the commissioning of the Kotri Barrage in 1955, some 40 percent of its command was irrigated from inundation canals, much of which was affected by salinity. A major development effort has been concentrated on these commanded areas in the form of the Kotri Surface Drainage Project.

Concurrent with the expansion of the controlled irrigated area environment has been the emphasis on the protection of the irrigation system on either side of the Indus River. The threat of yearly flooding has been curtailed to a large extent with the construction of the continuous flood protection *bunds* along the entire 800 km length of the Indus River from Guddu to the sea. The embankments have caused flood season flows to pass more quickly to the sea with no major river course shift, apart from less critical movements in the lower delta south of Kotri.

The canal diversions are designed for continuous operation at or near full capacity. The amount of flow cannot be regulated on demand except within very narrow parameters. Water flows continuously from canals into distributaries, then through ungated concrete modular outlets (*moghas*) into watercourses, and finally into farmers' ditches and fields. The *mogha* is designed to deliver a fixed quantity of water when the canal is flowing at full capacity based on the area commanded.

The Provincial Irrigation Departments (PIDs) are responsible for operating and maintaining the system downward from the barrages to the *moghas*. Thereonwards, the watercourse is legally the responsibility of the farmers who own land in the command area. The water distribution was deliberately designed by the British to command the maximum area possible (0.21 lps/ha) with a minimum of management necessary up to the *mogha*. Despite major remodelling at the macro level, canals are still operated according to the principles established by the British.

A major adverse effect of barrage-controlled irrigated agriculture in the absence of drainage has been the rise in watertables and a consequential increase in soil salinity. As a result, crop yields have been affected by waterlogging and salinity and cultivated land has been progressively abandoned. Although the need for drainage was recognized at the time of designing the Sukkur Barrage (in the late 1920s), the watertable at that time was deep, and it was rightly considered that drainage construction, and the costs thereby incurred, could be deferred until drainage becomes necessary. However, the IInd World War and the subsequent establishment of the state of Pakistan delayed the provision of drainage. In 1959, after waterlogging and salinity had become a serious problem, the Water and Power Development Authority (WAPDA) instituted initial investigations into the control of waterlogging and into the overall development of agriculture in the provincial area.

A. Climate

The climate of Sindh can simply be described as arid and hot; based on the data available from the meteorological stations scattered all over the province (Figure 5), nowhere in the province does the average rainfall exceed 260 mm. The summer maximums exceed 100° F. Rainfall from December to February is generally less than 250mm. The hottest period is March to June when winds are rather variable. Humidity is low, but increases as the sea breeze becomes dominant. The monsoon season is between July and mid-September. Heavy rains are generally rare in the north which receives little influence either from the monsoon currents in the south or from those that come up from the Ganges Valley to the northern Indus Plains. Mid-September to November is the period when sea breezes are replaced by the north-easterly winds. The high temperatures, low rainfall and low humidities prevalent throughout the province provide a natural constraint to agricultural development in the absence of irrigation, and their effect is enhanced in the southern part of the province by the high winds that blow for the better part of the year.

B. Farming

There are two cropping seasons in the Lower Indus Plain: Kharif, the summer season from mid-April to mid-October, and Rabi the winter season, from October to mid-April. Crops grown in Kharif include rice, cotton, sorghum and millet; in Rabi, wheat and oilseeds are the principal crops. Certain crops, such as sugarcane and fruit, span both seasons. Rice has limited cultivation potential in perennial areas for two reasons. Firstly, it is difficult to design and operate canals to supply both the large amount of water needed for rice cultivation and manage the comparatively small quantities needed by the Rabi crops, and secondly, rice creates waterlogging problems.

C. Groundwater

The native groundwater in the Lower Indus Basin probably originated from the river system, which has been flowing through the valley since late tertiary times. Data concerning the distribution of saline groundwater zones and their chemical character when examined in the context of probable pre-irrigation groundwater flow patterns and the geologic history, indicate that there can be neither a single cause or source of the saline water, nor a single theory that can adequately explain their origin. The native groundwater quality, when examined in the light of the physographic features of the area and the possible pre-irrigation groundwater circulation pattern, indicates that fresh groundwater is generally associated with the active and recent meander flood-plains. However, in a few cases, saline groundwater has been found even in areas adjacent to the river. WAPDA conducted extensive water quality sampling across the entire Lower Indus Basin during 1976-1980 as part of the Master Planning and Review Division surveys for the Revised Action Plan. The groundwaters were classified into usable, marginal and fresh categories on the basis of specific measurements

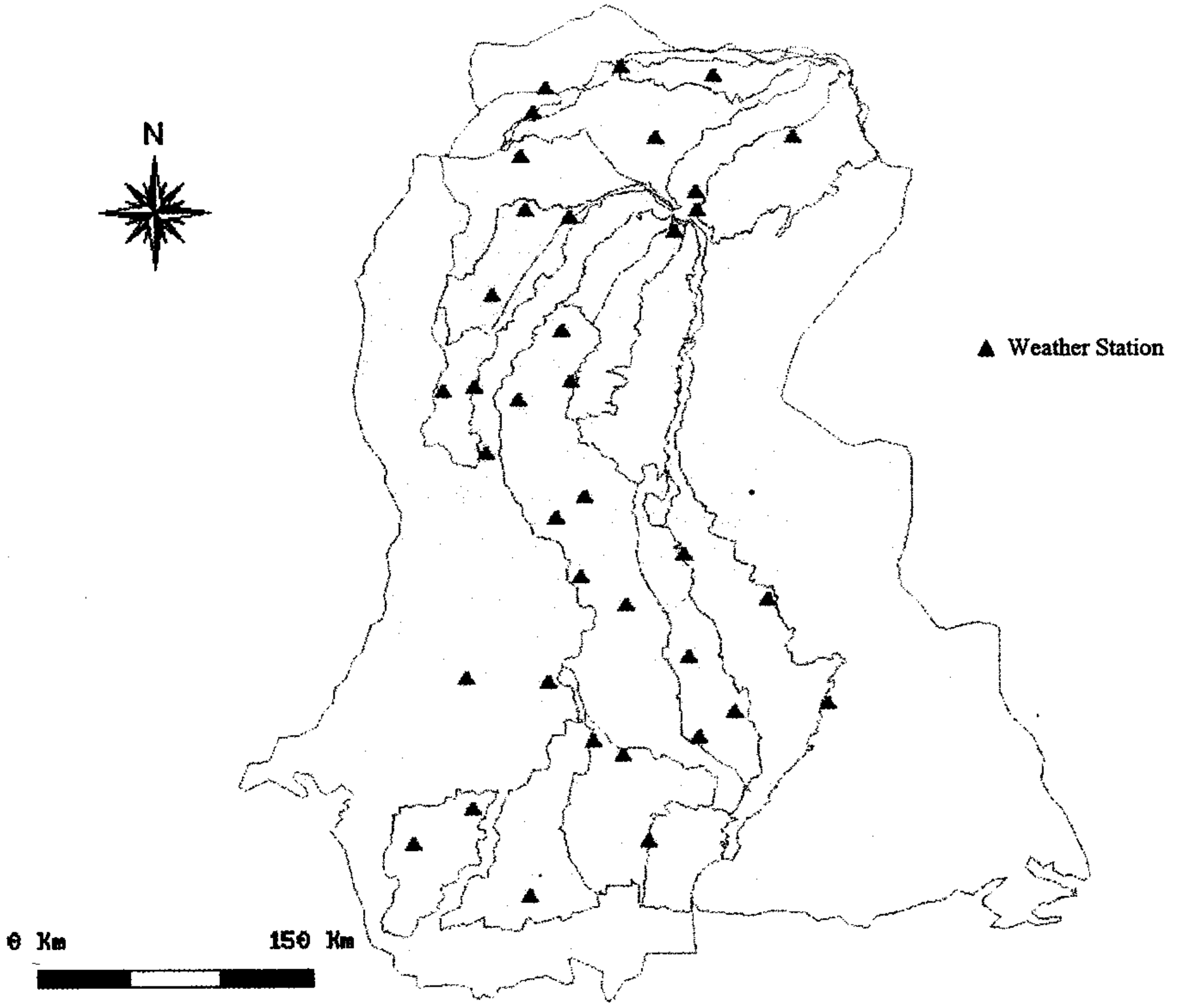

Figure 5. Location of Weather Stations across the Canal Commands of the Sindh Province.

pertaining to the electrical conductivity, SAR and TDS contents. Figure 6 shows the distribution of the sample points across the canal commands of the Sindh Province based on the classification of the TDS into three categories of < 1500, 1500-3000 and > 3000 parts per million. Overall, 25 percent of the samples that were reported to be usable, 16 percent marginal and the remainder as hazardous.

Extensive irrigation development, together with recharge from rivers and large canals, has caused a steady rise in watertables in nearly all areas. For Nawabshah, on the left bank of the Indus River, the deepest level of groundwater before the commencement of canal irrigation in 1932 was reported to be 12 m. Subsequent increases in watertables from depths deeper than 6 m was more or less linear at many sites. At a depth of 3 m, the upward rise slowed down and at about 1.5 m the table stabilized. At this depth, the fluctuations follow the monsoon supplies with a rise of 0.6 to 0.9 m and a gradual lowering thereafter due to natural drainage until June, when base levels are attained once more.

D. Barrage-controlled Irrigation System

The respective proportions of the commanded areas for each of the three barrages appear in Figure 7. The commanded areas of these barrages extend on either side of the river Indu;, however, the entire northern Indus Right Bank, being 30.4 percent of the total irrigated area within the Lower Indus Basin, is made up of the Guddu and Sukkur commands. Amongst them, these barrages cover four distinct agroclimatic zones of which the Indus Right Bank is only one. The huge expanse of the barrage commands is further divided into hydrological regimes with distinct variations in soils, cropping intensities and seasonal diversions. Figure 8 shows the geographical distribution of the major canal commands on either side of the River Indus. The Rohri and Nara Canals are the two largest outlets across the system and constitute 54 percent of the commanded area on the Left Bank. Larger still is the coverage of the Sukkur Barrage that not only contains these two principal canals, but extends to cover 57 percent of the total commanded area within the Lower Indus Basin (40.65% on the Right Bank and 65% on the Left Bank). The proportions of the gross and culturable commanded areas are shown in Figure 9.

The latest available information from the Sindh Irrigation and Power Department (IPD) shows that Sukkur Barrage withdrawals were 55 percent of the total diversions during 1995-96 (Table 1). This compares well with the proportion of the gross and commanded area statistics provided under Figure 9 above. Rabi withdrawals are, in all cases, much less than those for Kharif, being 26 percent of the latter at Guddu, 67 percent at Sukkur and 52 percent at Kotri Barrages. In lieu of these substantially less than total withdrawal capacities and potential irrigation demands, careful allocation of water supplies is enforced. The magnitude of this can be grasped from the comparison of sanctioned allocations and average withdrawals in Figure 10 for the Lower Indus barrages during the pre-Water Apportionment Accord years.

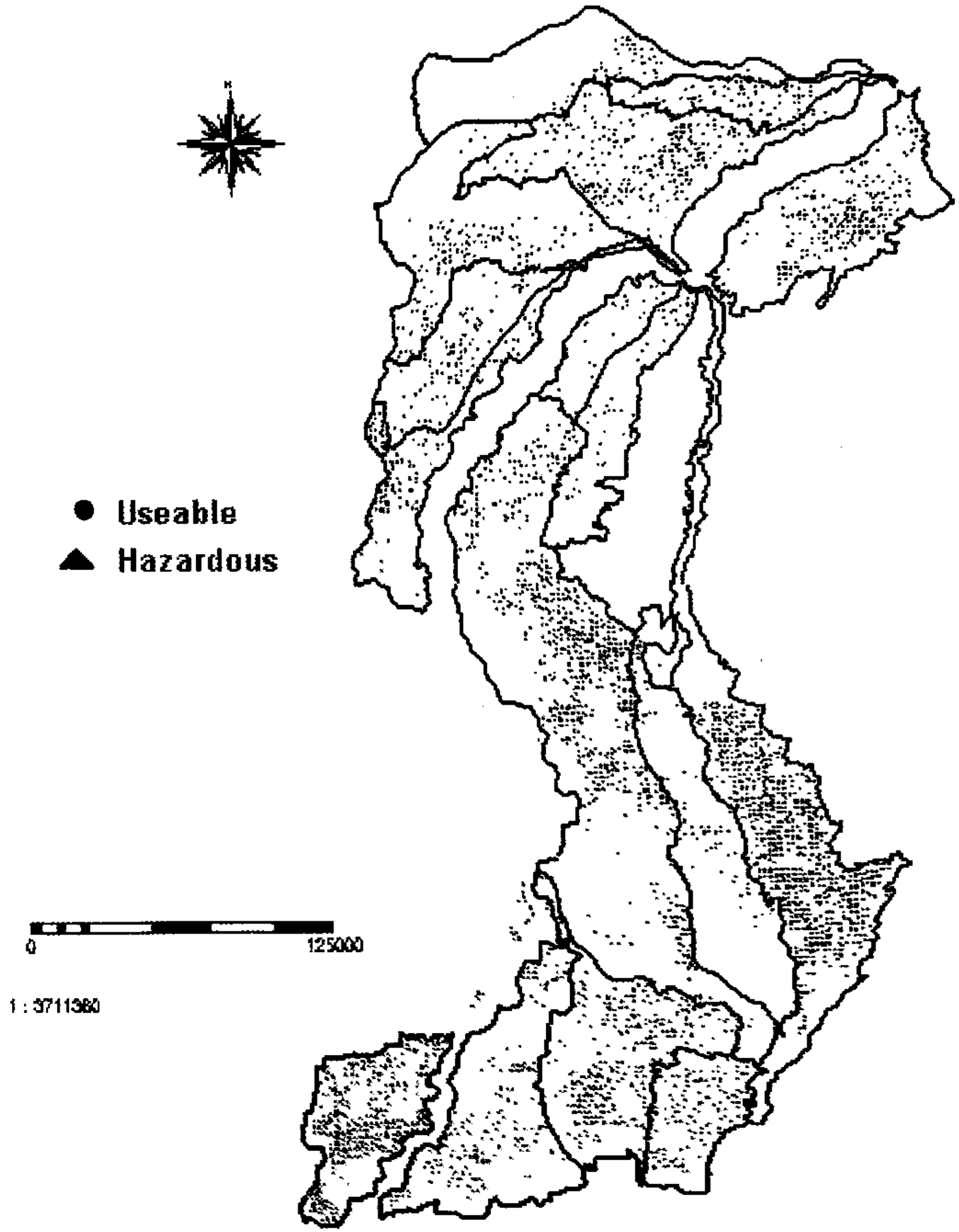

Figure 6. Distribution of Groundwater Sample Sites, WAPDA Master Planing and Review Division, 1976-79, Lower Indus Basin.

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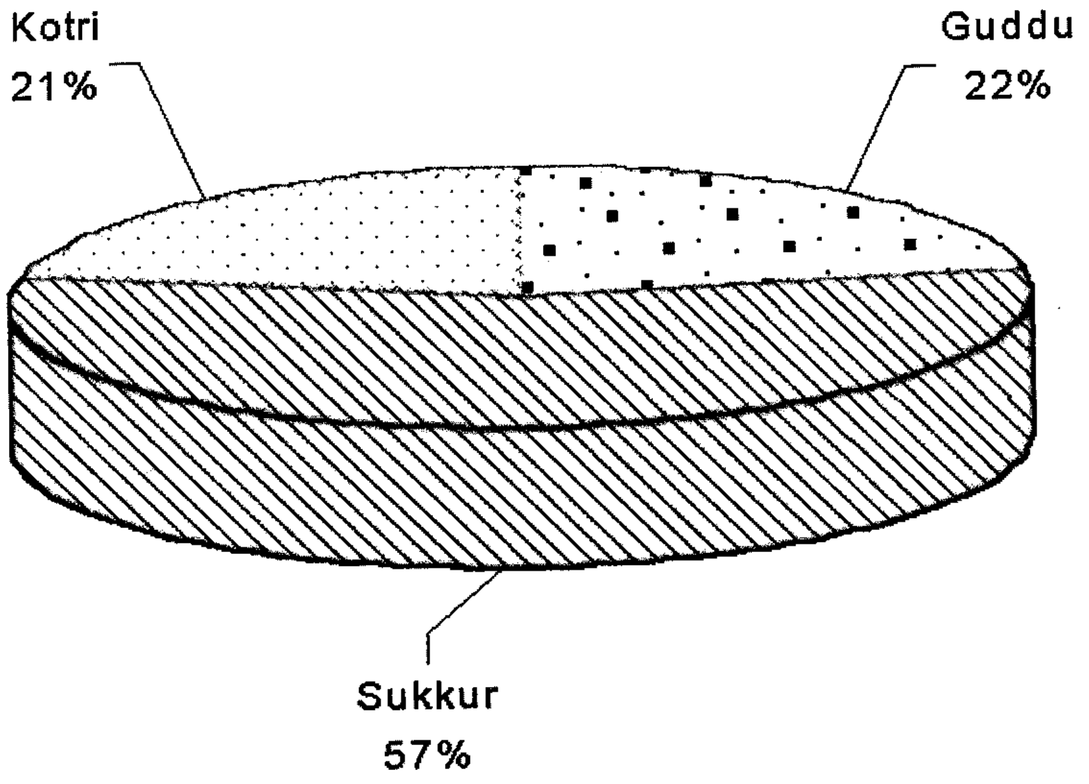


Figure 7. Proportion of Barrage Commanded Areas within Lower Indus Basin Plain, Sindh Province, Pakisatn.

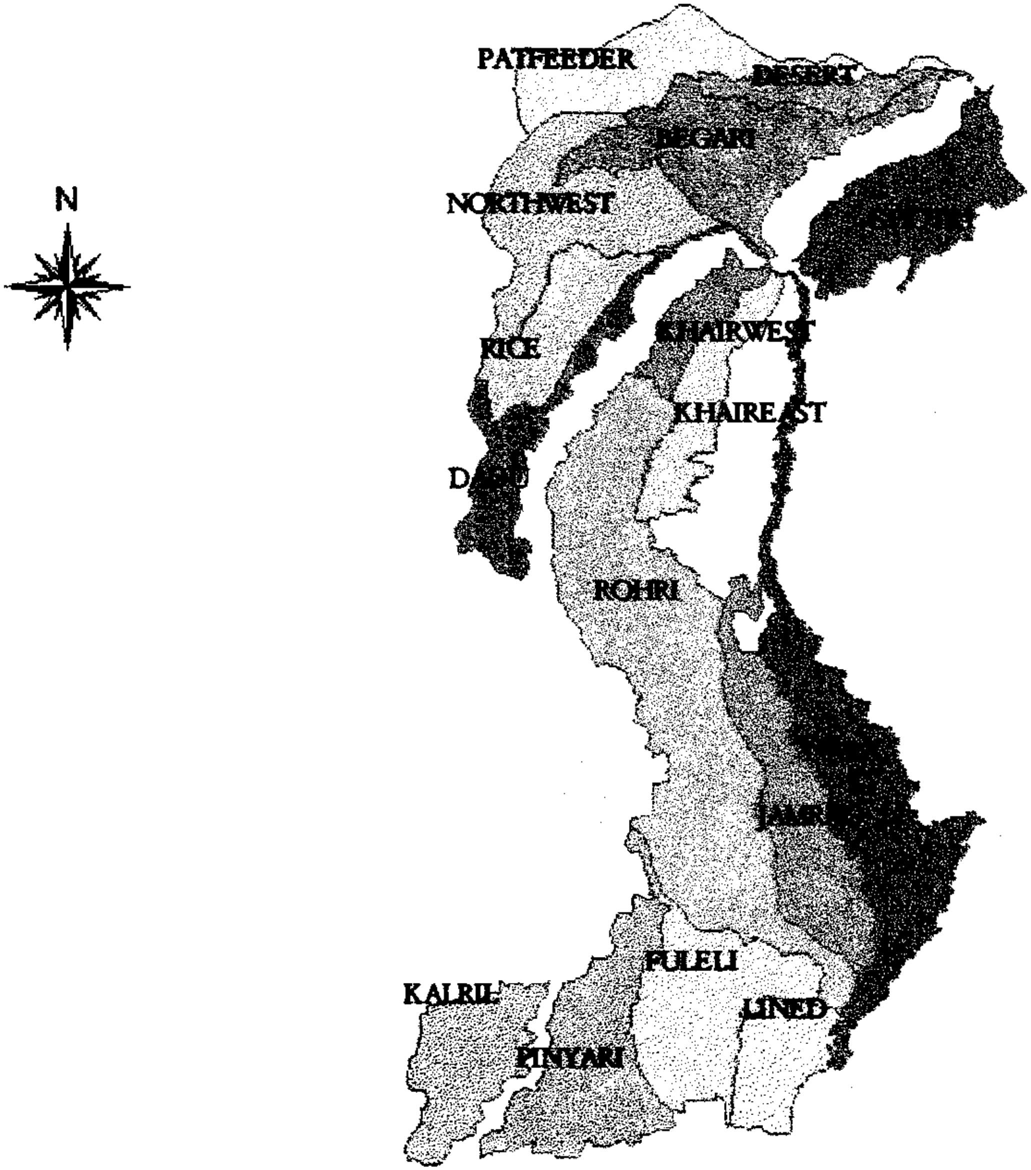
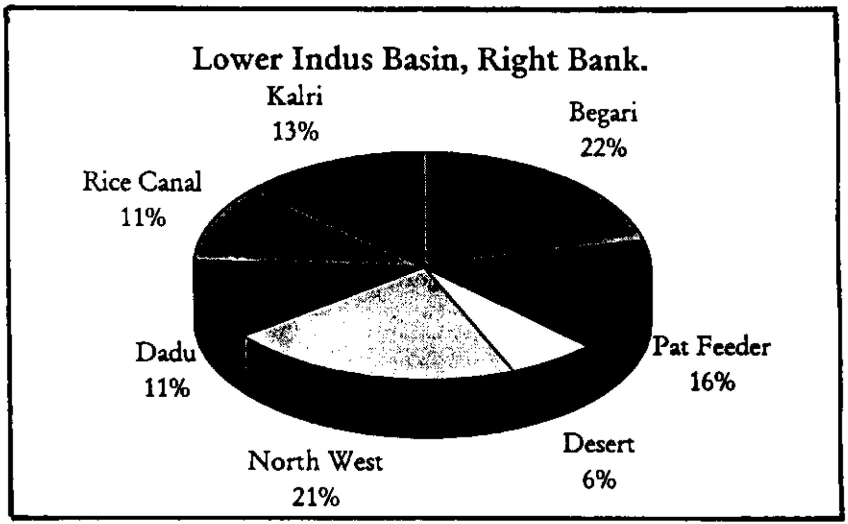
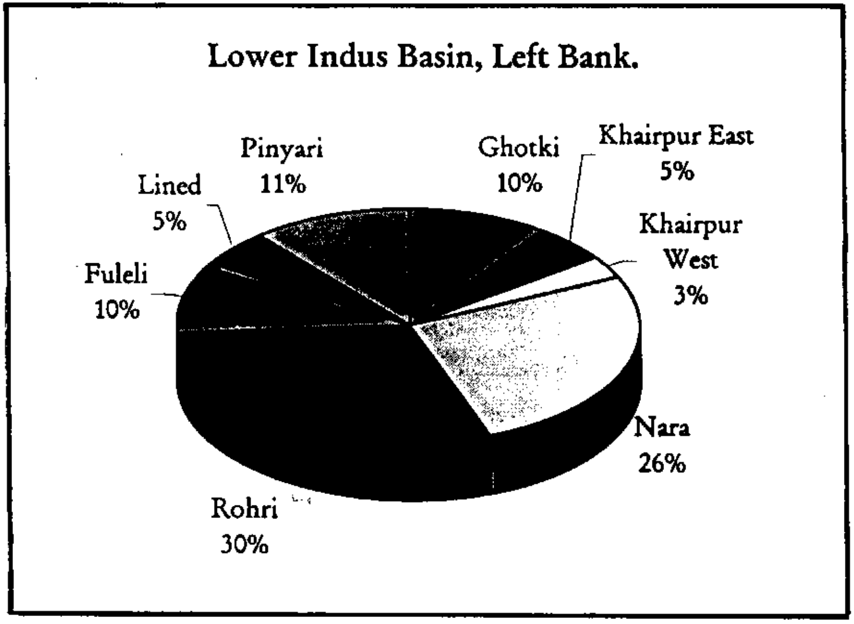


Figure 8. Canal Command Map of Lower Indus Basin Irrigation System, Sindh Province, Pakistan.

Canal Commands	Area (ha)
Right Bank	
Begari	441663
Pat Feeder	337117
Desert	129853
North West	437608
Dadu	235246
Rice Canal	233082
Kalri	273899
Left Bank	
Ghotki	381237
Khairpur East	207938
Khairpur West	124177
Nara	1047946
Rohri	1156530
Fuleli	405285
Lined	187263
Pinyari	444693

Barrage-wise Gross Area (ha)	
Guddu	1289870
Sukkur	3442526
Kotri	1311140
Gross Area	6043536


Lower Indus Basin, Right Bank.


Lower Indus Basin, Left Bank.

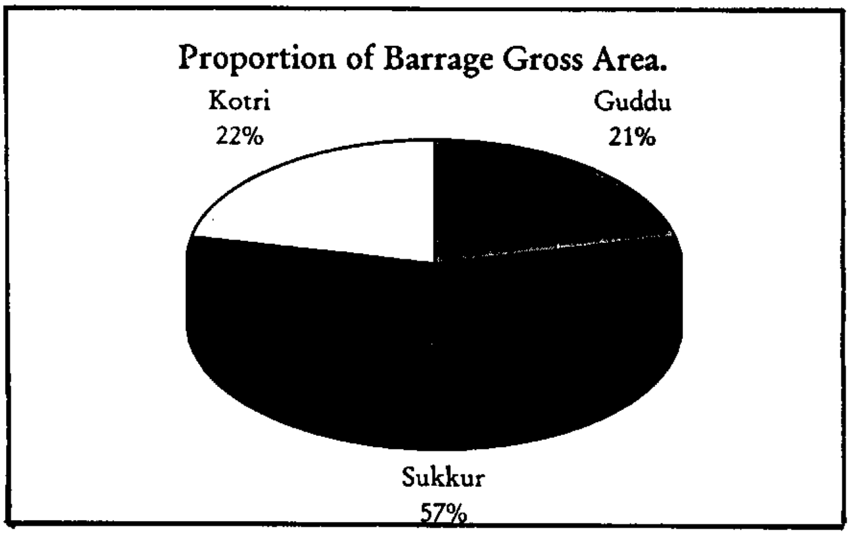
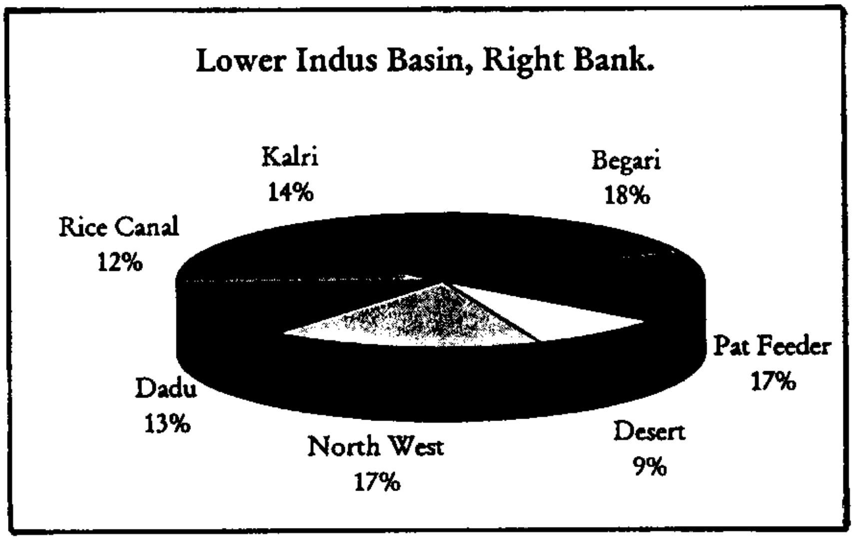
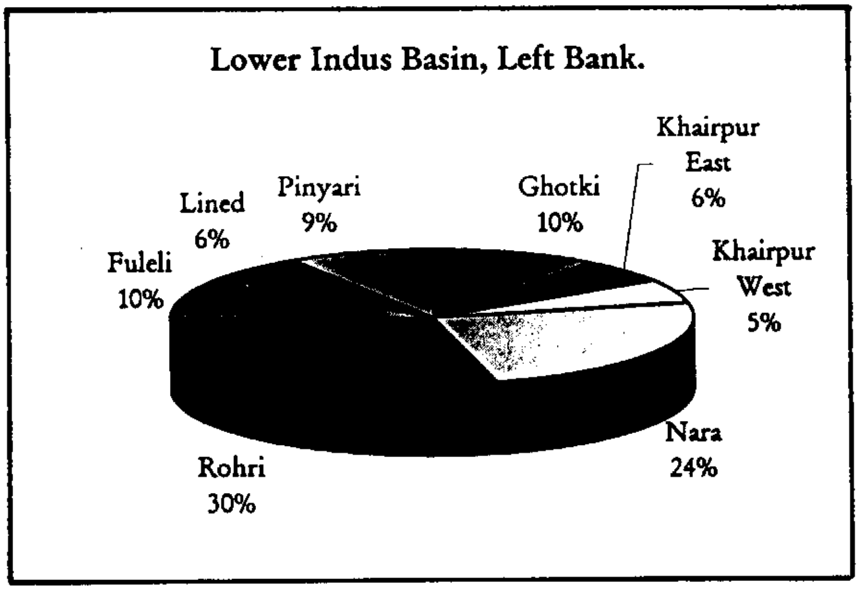

Proportion of Barrage Gross Area.

Figure 9a. Gross Area Statistics of the Irrigation System in the Lower Indus Basin Plain.

Canal Commands	Area (ha)
Right Bank	
Begari	340753
Pat Feeder	302306
Desert	157831
North West	309187
Dadu	244840
Rice Canal	210036
Kalri	257386
Left Bank	
Ghotki	368272
Khairpur East	218940
Khairpur West	195467
Nara	882639
Rohri	1045326
Fuleli	360583
Lined	220154
Pinyari	323351

Barrage-wise Commanded Area (ha)	
Guddu	1169162
Sukkur	3106435
Kotri	1161473
Gross Area	5437070





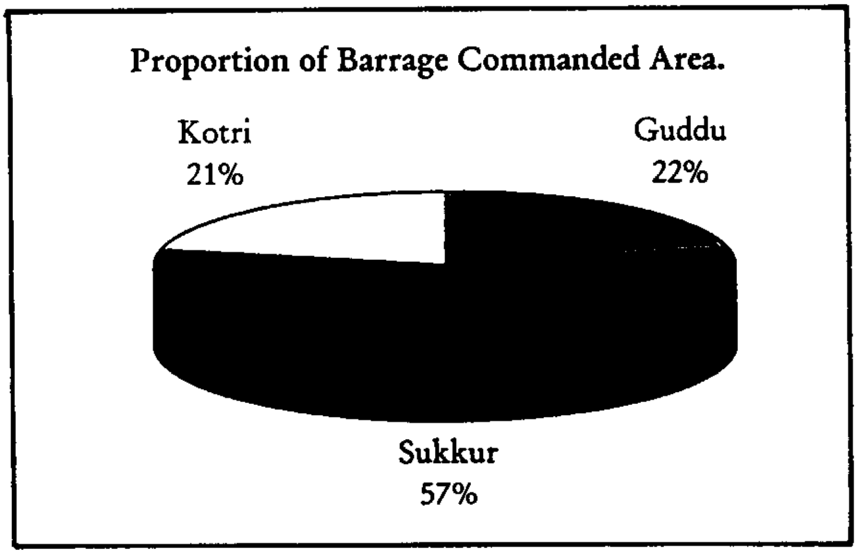


Figure 9b. Canal Commanded Coverage of the Irrigation System in the Lower Indus Basin Plain.

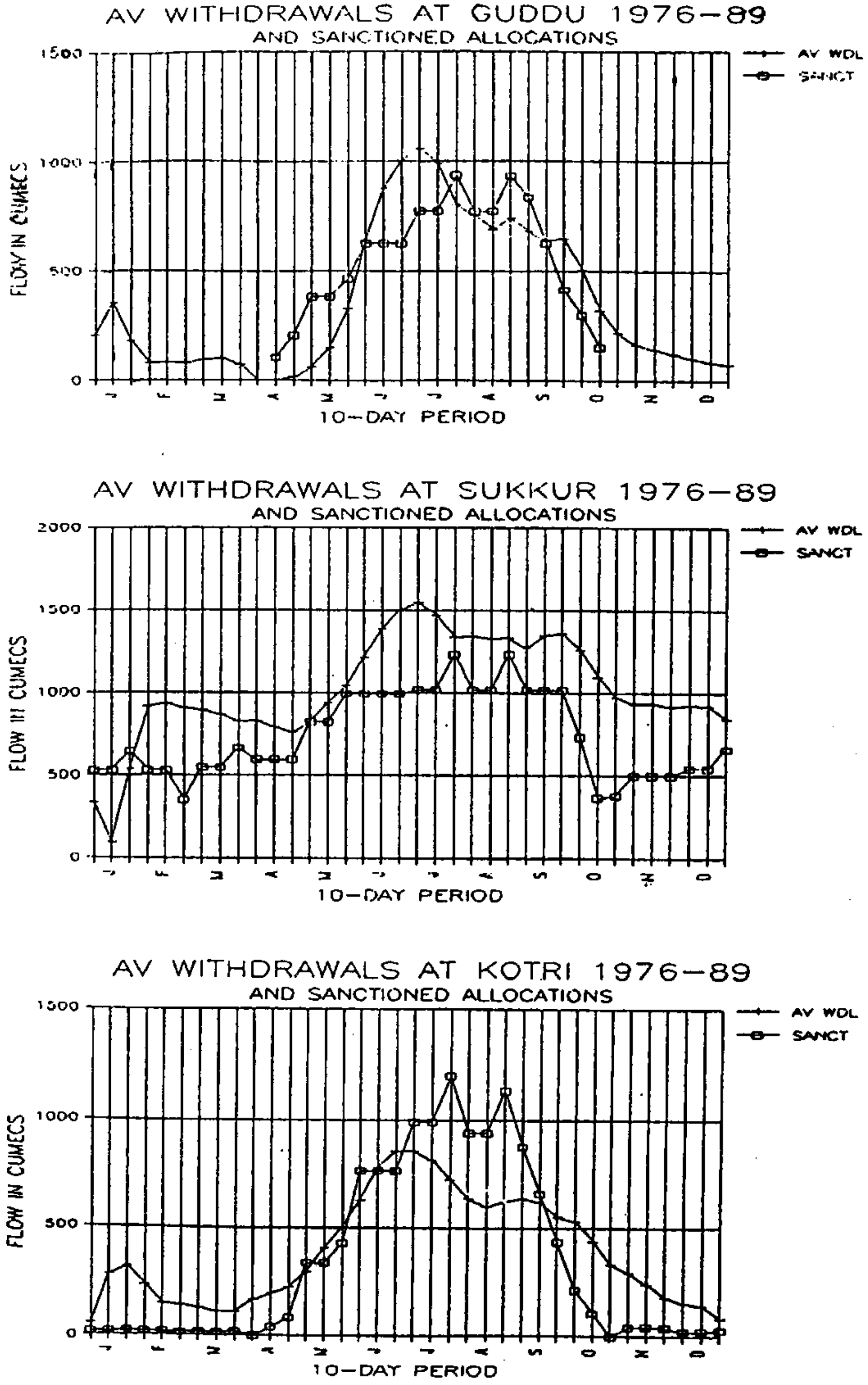


Figure 10. Sanctioned Allocations and Average Withdrawls at Lower Indus Barrage Commands.

Table 1. Barrage Withdrawals and corresponding Seasonal Cropping Intensities in the Sindh Province.

Barrage Command	Farm Area Cropping Intensities (1997-98)		Withdrawals (Mhm) (1995-96)	
	Kharif	Rabi	Kharif	Rabi
Guddu	85.0	79.0	0.841	0.222
Sukkur	61.9	61.7	1.794	1.202
Kotri	38.0	23.4	0.91	0.473

Notwithstanding the excess withdrawals in years of abundance within the averages, both, the Guddu and Kotri Barrages are badly affected given the critical state of early Kharif flows relative to sanctioned allocations. Mid-Kharif allocations are not fully utilized at either barrage, but is the result of prevailing canal capacities or needs rather than inadequate river Indus flows. For the Desert-Pat Feeder combine, the canal capacities have been increased, but elsewhere improved water availability can come from better water distribution, improved water management and cropping practices. This is not to say that there has been no incremental improvement to the sanctioned canal withdrawals. The historic withdrawals at the Guddu and Sukkur Barrages had risen steadily since their construction, even during declining periods, until a distinct levelling-off during the 1980s. The situation is summarized in Table 2.

Table 2. Comparison of Post-Commissioning and Current Irrigation Withdrawals from the Lower Indus Basin Barrage Controls.

Barrage	Post-commissioning Diversions (Mhm)		Current Diversions (Mhm) (average for 1990-96)		Peak Diversion Recorded (1990-96)	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Guddu	0.666	0.074	0.841	0.222	1.045 (1994-95)	0.311 (1992-93)
Sukkur	1.356	0.986	1.794	1.202	2.126 (1991-92)	1.321 (1991-92)
Kotri	0.41	0.021	0.91	0.473	1.083 (1993-94)	0.510 (1991-92)

The temporal variations in barrage head diversions since the beginning of this decade are best illustrated in Figure 11. The Rabi season withdrawals for both the Guddu and Kotri Barrages have been fairly stable, whereas releases at the Sukkur Barrage are on a downslide since the Water Apportionment Accord. The Kharif situation for the Sukkur Barrage is also dismal with very large variations. These variations were synchronized to the releases from the Guddu and Kotri Barrages until about 1995, wherein the discharge pattern reversed for the Guddu Barrage.

Also, from Table 2 above, the total Kharif cropping intensities are only marginally higher than Rabi areas in the case of the Guddu and Sukkur Barrages, but the substantially lower values for Rabi cropping at the Kotri Barrage is because water shortages are quite typical of the system (for additional details, see Annex-I). Even against these substantial shortages in the system, crops can benefit from the residual moisture in the soils left over from the Kharif. Also, there is a less frequent need for irrigation due to low evapotranspiration rates during the winter.

The major crop areas for all the three barrages appear in Figure 12. There are wide variations across the comparison period for 1990-96; wheat has actually registered a 17 percent decline in the Sukkur command, whereas both rice and cotton have increased. The rice area has increased enormously in both the Guddu and Kotri commands, which is substantiated in Table 2 for the relatively large value of the Kharif withdrawals for these two barrages. Relatedly, it is not unexpected to find diminishing acreage under cotton in the Kotri command area due to the rather acute drainage situation wherein farming is in the process of adjusting to high delta crops of rice and sugarcane.

E. Administrative Divides for Barrage-controlled Irrigation

The command and gross area statistics for the major canal commands already appear in Figure 9 above. The major perennial canals are the Northwest and Dadu on the Right Bank and all the Left Bank canals (see Figure 8 on canal commands). With the exclusion of the Pat Feeder canal system (offtaking from Guddu) and the Kirthar Branch (tail branch offtake from the North West Canal), the remaining area on the Right Bank is exclusive to the Sindh Province. The cropping on either side of the river Indus is quite diverse and is basically controlled by the water duties available to the areas. In general, surface irrigation supplies are more scarce on the Left Bank where cotton-wheat cropping is significant, but not dominant. In contrast, the entire Indus Right Bank is dominated by rice-wheat cultivation. This difference in cultivation clearly rests on the Kharif diversions made available to the commands on the Right Bank. Table 3 shows the emergent differences in irrigation volumes made available to the commanded regime on either side of the river.

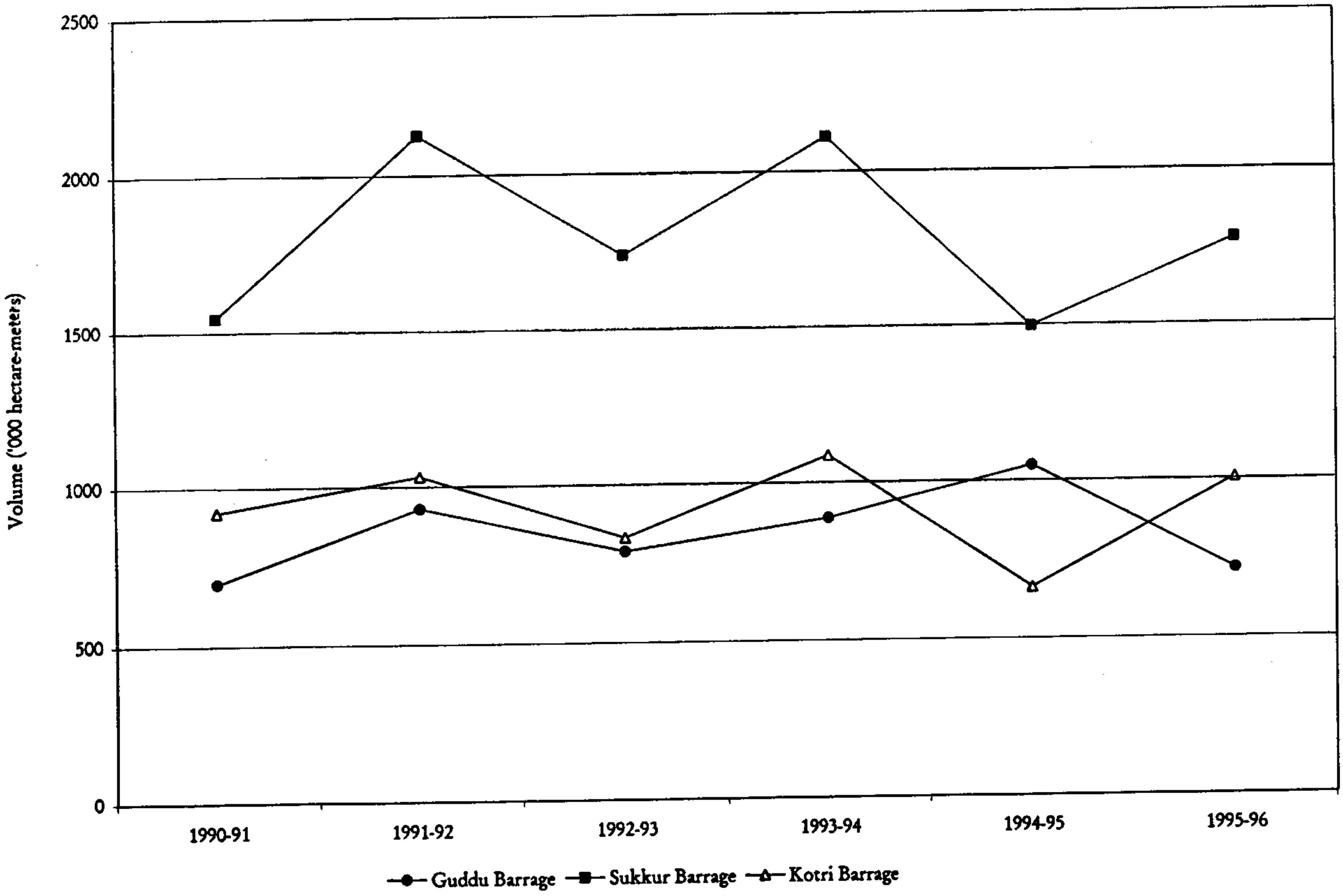


Figure 11a. Cumulative Canal Head Diversions during Kharif Season across the Lower Indus Basin Barrage Controls.

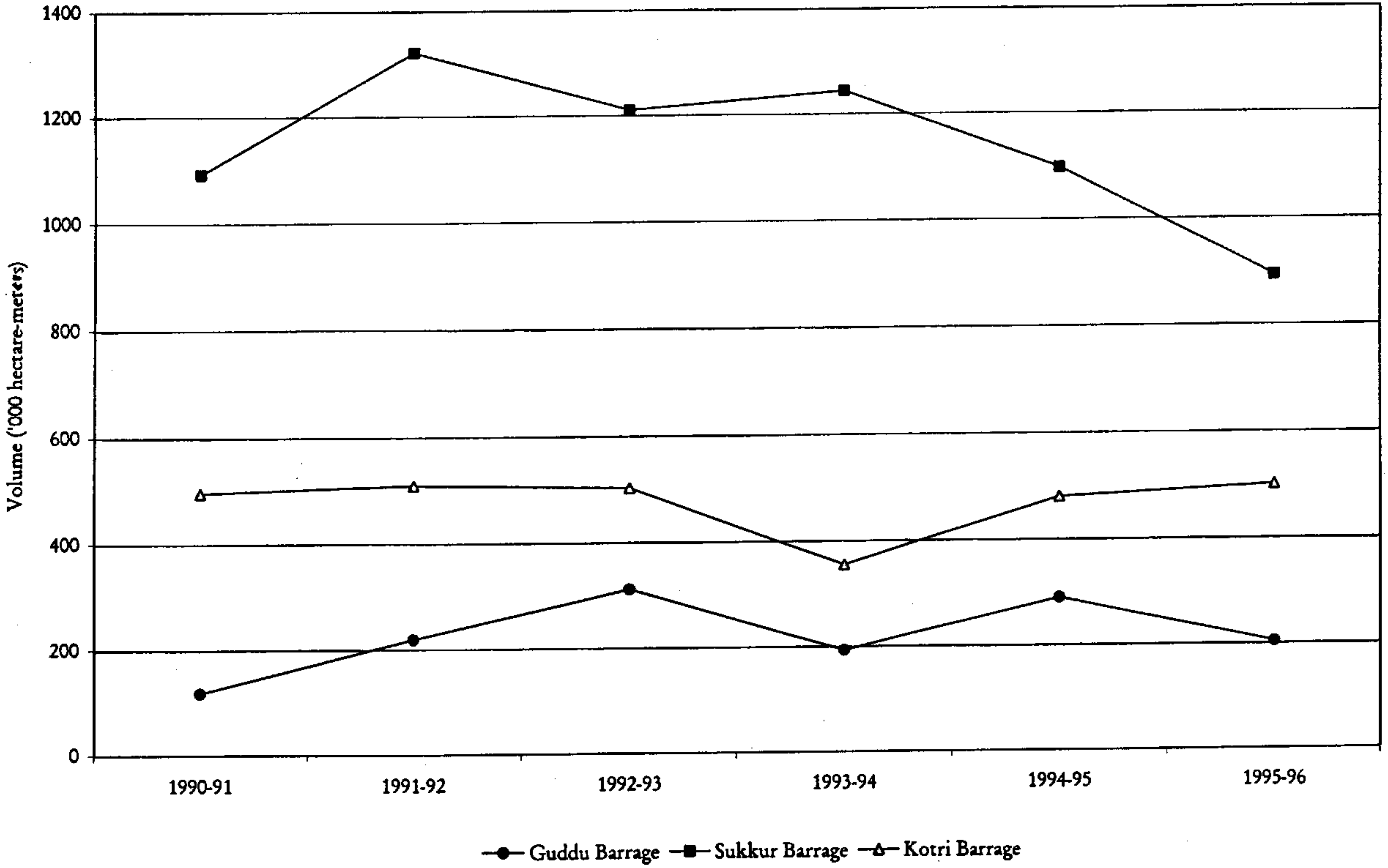


Figure 11b. Cumulative Canal Head Diversions during Rabi Season across the Lower Indus Basin Barrage Controls.

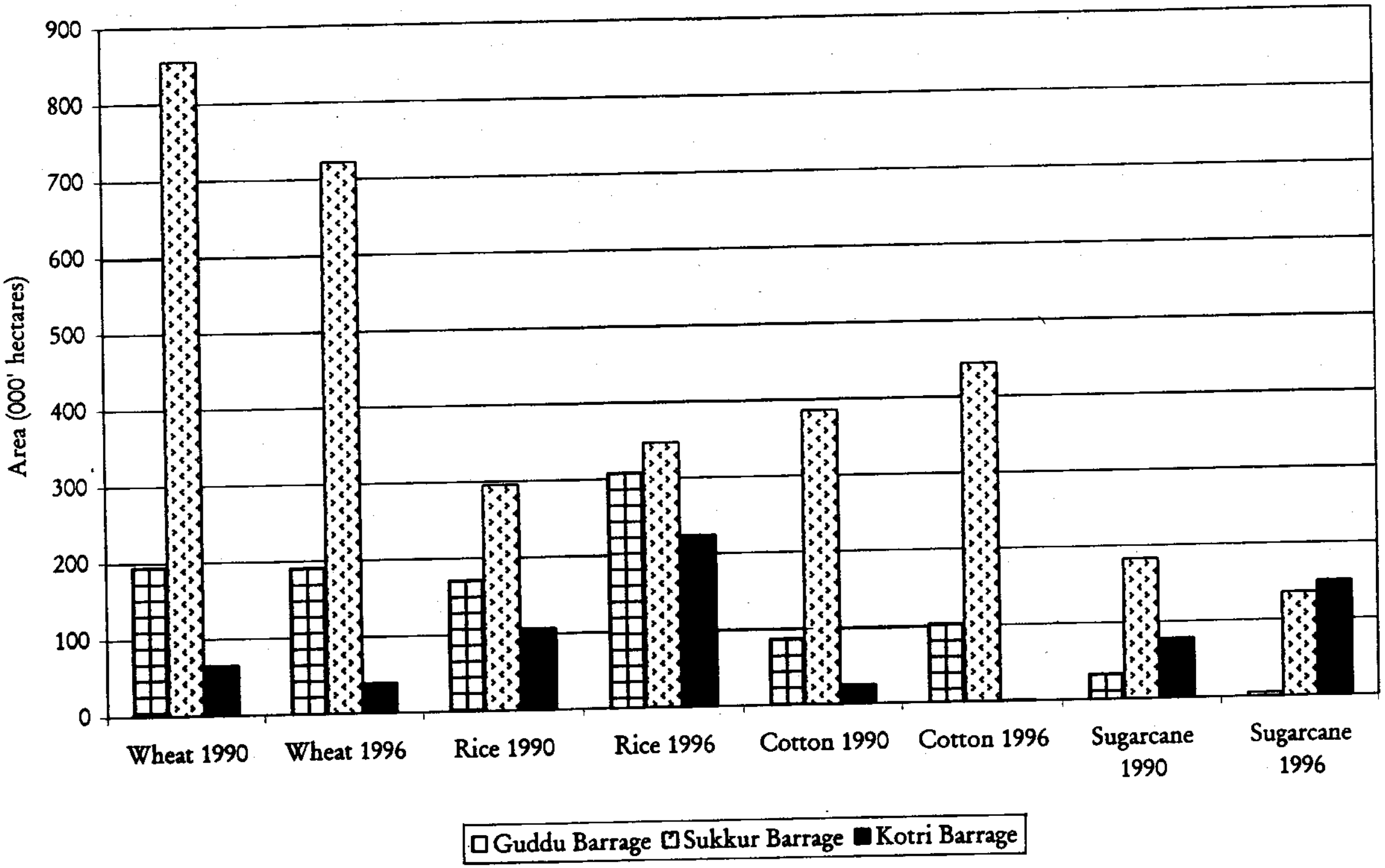


Figure 12. Barrage-wise Comparison of Major Crop Area across the Sindh Irrigation System.

Table 3. The Distribution of Surface Irrigation Volumes with respect to the Proportion of Culturable Commanded Area across the Lower Indus Left and Right Banks.

Irrigated Regime (Sindh Province)	Proportion of Culturable Commanded Area (%age)		Proportion of Surface Irrigation Volumes (%age)			
	1990	1995	1990		1995	
			Rabi	Kharif	Rabi	Kharif
Indus Right Bank	30.96	29.82	21.84	44.76	27.11	45.15
Indus Left Bank	69.03	70.17	78.16	55.24	72.89	54.85

The Rice Canal remains almost entirely a Kharif offtake, but the Northwest and Dadu canals deliver about 2/3rds of their Kharif rate during Rabi. Rabi withdrawals from the Rice Canal have remained small throughout its history. All Right Bank canals are normally closed in April/May when there is little flow in the river and available supplies are diverted to the Left Bank to facilitate cotton cultivation. The Sukkur Barrage canals are also closed in January for maintenance and at that time the Begari and Desert Canals receive water.

I) Command Area Expansion

Together with the consistent increase in canal diversions, there has been an expansion in the culturable commanded area (CCA). Ten out of the fourteen major canal commands have experienced this expansion in recent times. The net recorded increase across the 1990-96 comparison is 75,000 ha (Table 4).

The canal commands of Begari, North West, Rice and Kalri Beghar canals have experienced a decrease in their CCA, which is also reflected in the lower Rabi cropping intensities during 1995-96 (Figure 13a). In fact, with the exception of the Desert, Dadu and Lined Channel (Akram Wah) commands, all other hydrological divides suffered a decrease in their Rabi cropped areas. The Kharif cropping intensities showed improvement across much of the Right Bank (as much as double in the Rice Canal command) and areas southwards of Khairpur commands on the Left Bank (Figure 13b). Recent sample surveys by IIMI during 1997-98 have indicated that the crop area decline, especially during Rabi 1995-96, is not a progressive phenomenon and that such variations are largely in response to crop water availability. As an example, benchmark data for the Right Bank cropping shows that the statistics for the year 1995-96 probably correspond to a one-time low and that the seasonally cropped areas have reached a near level rate of expansion during Rabi and an all-time high during Kharif (Figures 14a & b). Expansion in the rice area has had a consistent trend line for Dadu, Desert and North West canal commands, whereas both the Rice and Begari canal

Table 4. Comparison of the Culturable Commanded Area across the Sindh Canal Commands.

Canal Command	Culturable Commanded Area (000 ha)	
	1990	1996
Desert	133	158
Begari	405	341
Ghotki	347	368
North West	331	309
Rice	210	210
Dadu	236	245
Khairpur West	169	195
Khairpur East	151	182
Rohri	1036	1045
Nara	881	883
Kalri Beghar	240	257
Akram Wah	203	220
Fuleli	373	361
Pinyari	307	323

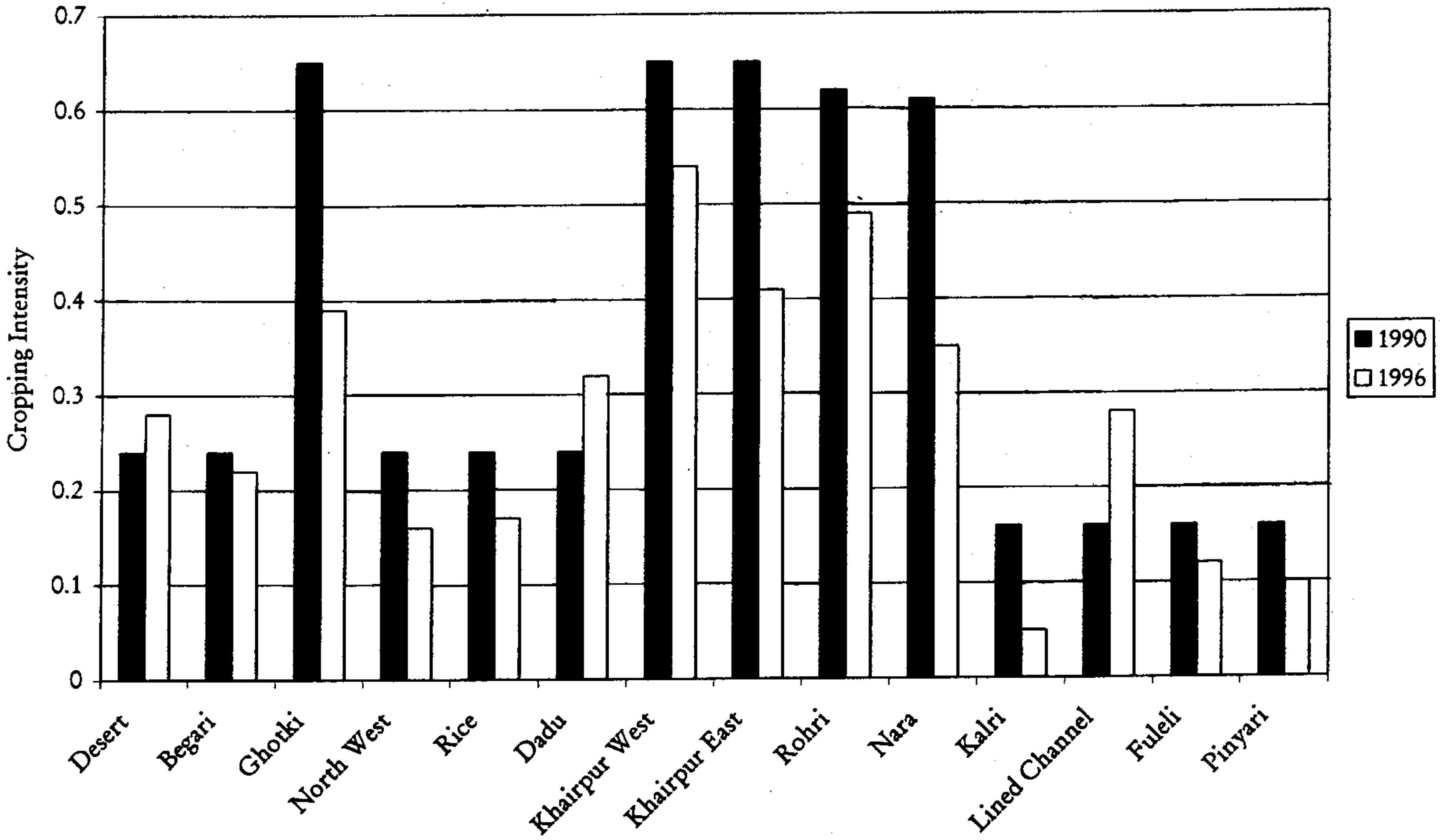


Figure 13a. Rabi Season Cropping Intensities across the Canal Commands of the Sindh Irrigation System.

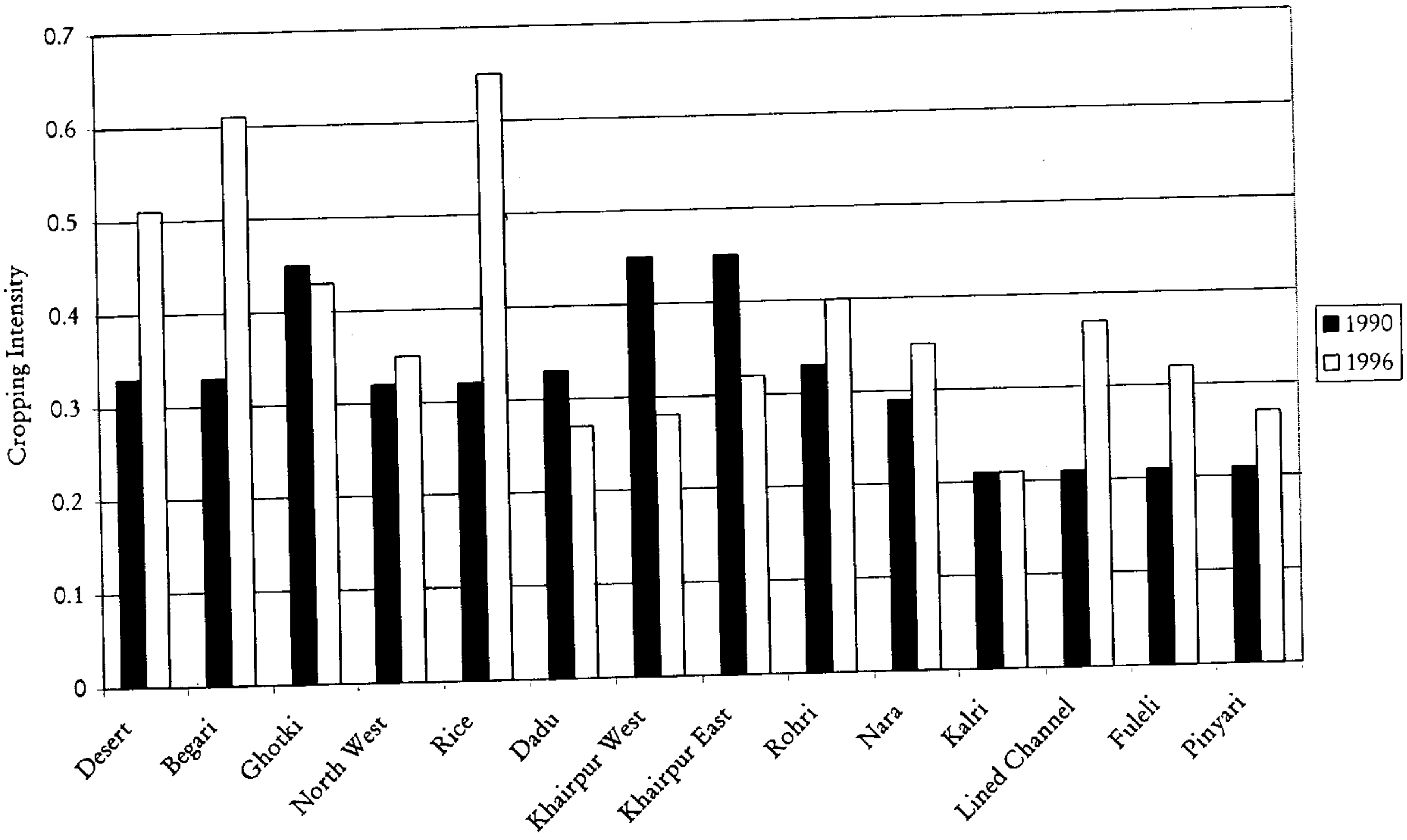


Figure 13b. Kharif Season Cropping Intensities across the Canal Commands of the Sindh Irrigation System.

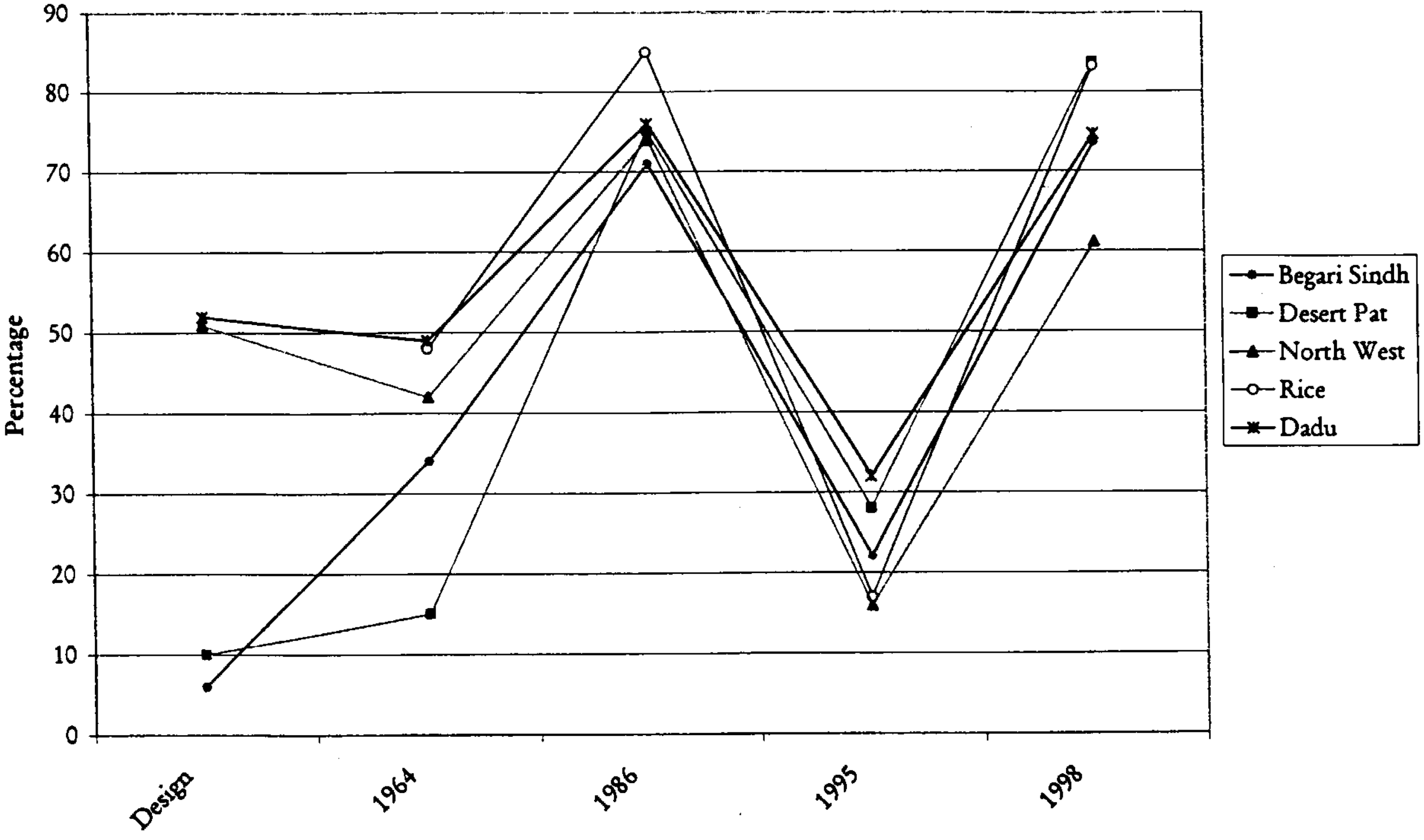


Figure 14a. Historical Changes in Rabi Cropping Intensities across the Right Bank of the Lower Indus Basin Plain.

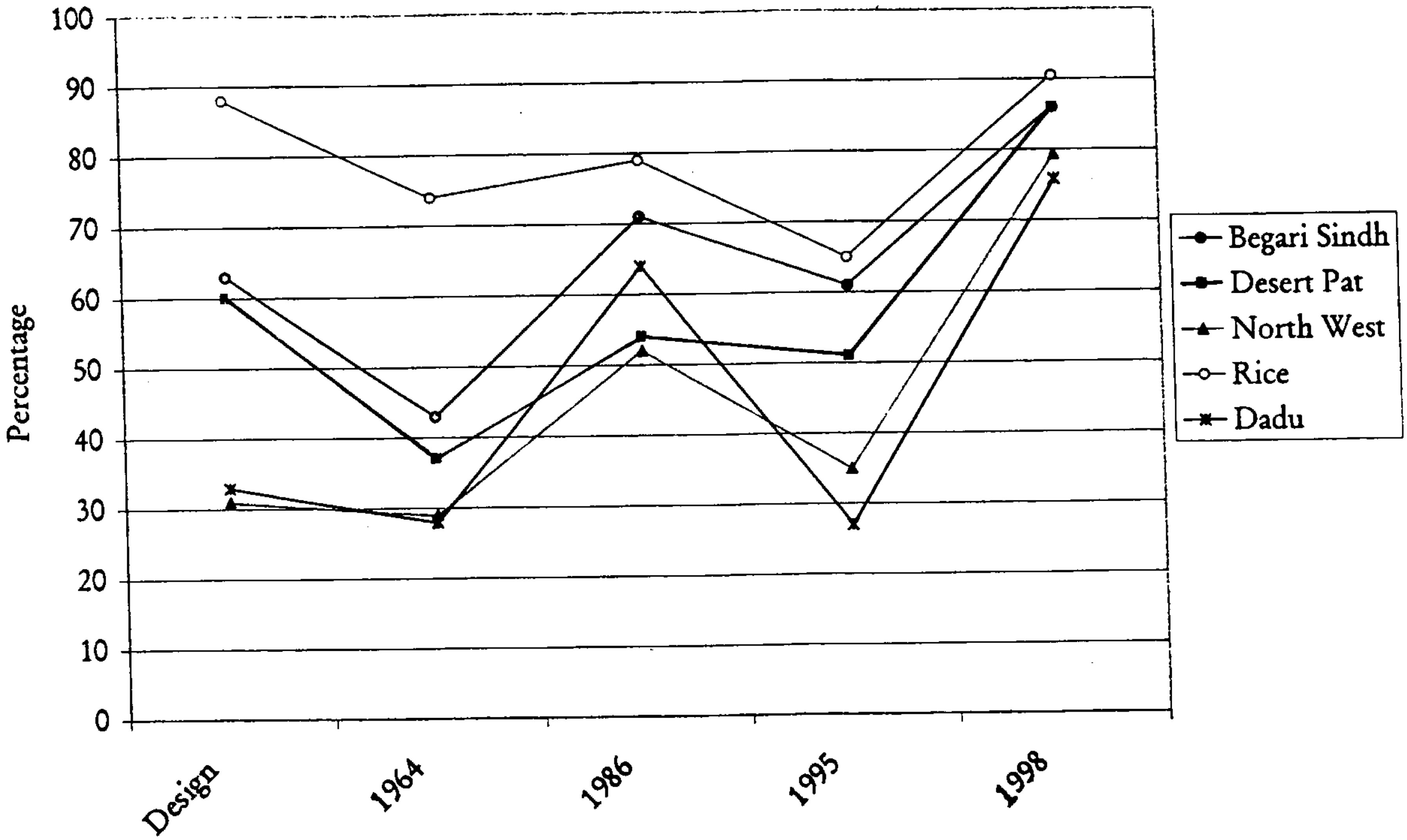


Figure 14b. Historical Changes in the Kharif Cropping Intensities across the Right Bank of the Lower Indus Plain.

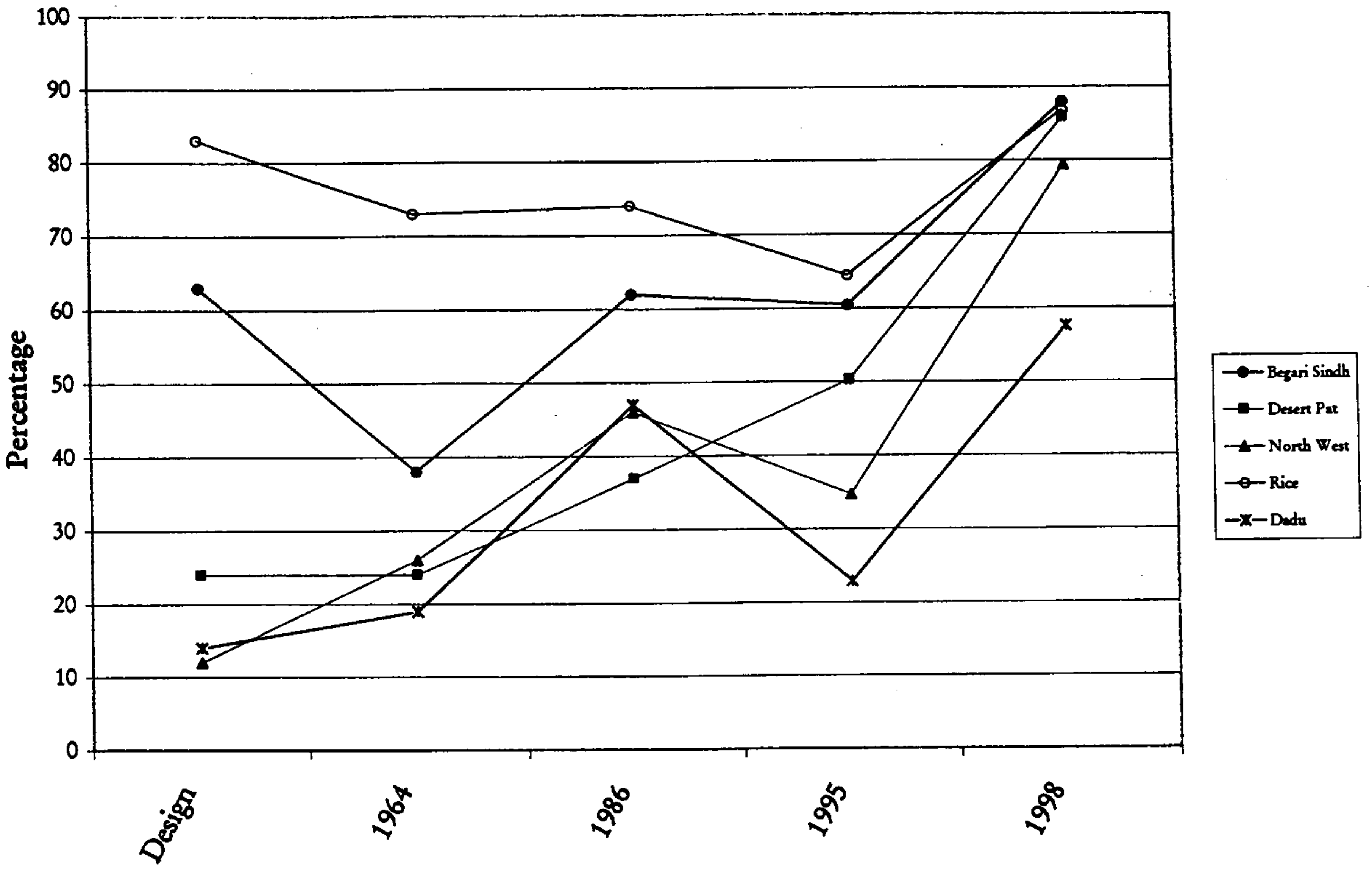


Figure 14c. Historical Changes in Rice Crop Intensities across the Right Bank of the Lower Indus Plain.

commands have stabilized and matched the expansion elsewhere since the mid-1980s (Figure 14c).

2) Major Crop Intensities

The IIMI farm sample surveys also provided comparable figures for major crop intensities to match those available from the Irrigation Department for the period 1995-96 (Figure 15). These statistics are meant to enable individual crop area comparisons in a manner that obviates the slant in sampling accuracy or the reconciliation of figures to correspond to wanton under-reporting by the official staff. Moreover, the period of comparison is just 2 years apart, which is small enough to isolate any large variations in cropping intensities. For example, in Figure 15b there is a considerable difference in the intensity of cotton across the Ghotki Feeder command. Here, the official figure of 31 percent is too low for a traditionally strong cotton-growing area that would also include the Khairpur East Canal command. The same holds true for rice in areas of the Right Bank where there is a blanket preference for this crop. Clearly, a 35 percent officially-reported intensity of rice in the North West Canal is not tenable; the same holds true for the Begari, Desert and to a lesser extent in the Dadu canal commands (Figure 15c).

With the construction of the Piyaro Goth sugar mill, the sugarcane cultivation has increased tremendously in recent years across the Dadu Canal command (Figure 15d). This fact was noted in the Right Bank Master Plan Report (a composite irrigation and drainage related project prepared by WAPDA, discussed under Section V of this report) wherein it was observed that an increase in the Kharif supply to the Dadu Canal could jeopardize production of non-rice crops, like sugarcane, due to the rise in water levels. The official figures on sugarcane cultivation do not show the rather large increase in area recorded since the last decade. The same discrepancy has been observed for both Khairpur East and West canal commands.

The Ghotki and Khairpur East canal commands are suspected of showing the same pattern of under-reporting for the wheat as was previously noted for cotton (Figure 15a). Elsewhere, the piedmont plains of the Desert, Begari and North West canal commands have experienced a tremendous increase in wheat cultivation during the last decade. This increase in cultivated area also extends into the Pat Feeder command of the Baluchistan Province. For these areas, the official figures seem to be grossly low in estimates. Areas further south in the Right Bank, commanded by the Rice and Dadu Canals, are known to have significant cultivations of wheat, more so in the latter where persistent water shortages during early Kharif have stimulated the cultivation of dry foot crops and winter wheat that benefits from residual moisture made available from excess supplies during late Kharif.

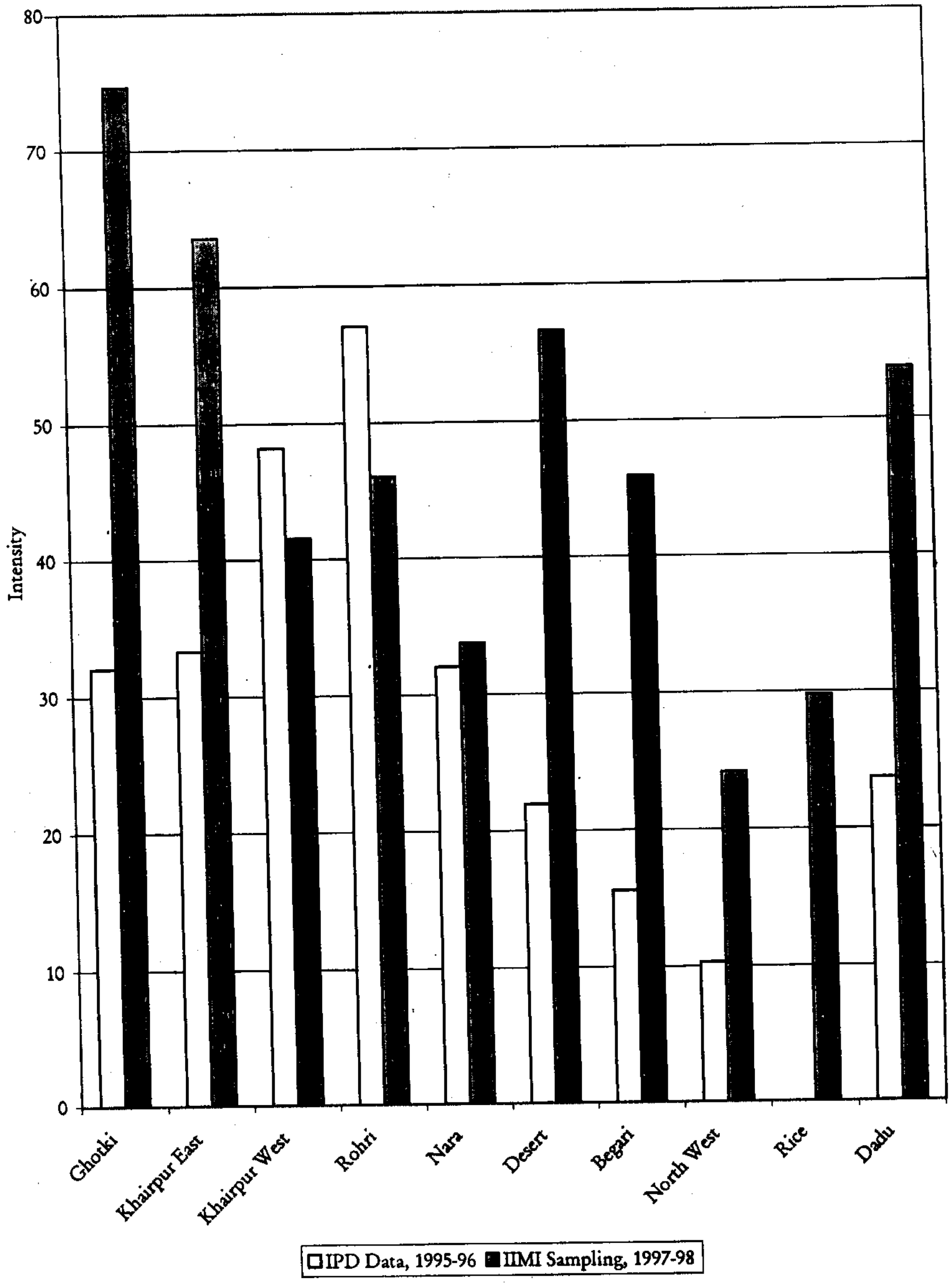


Figure 15a. Comparison of Wheat Cropping Intensity based on IPD Data, 1995-96 & IIMI Sampling, 1997-98.

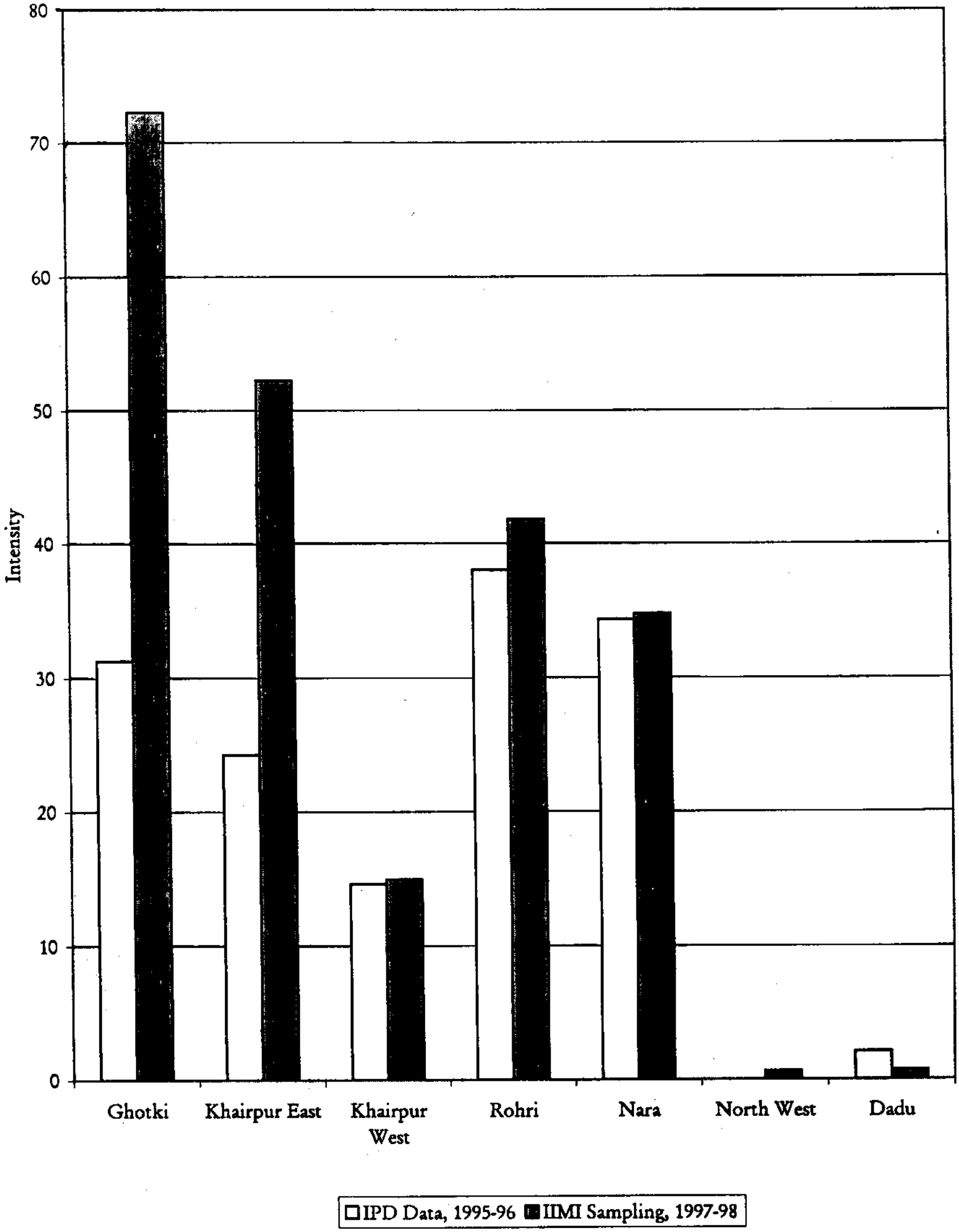


Figure 15b. Comparison of Cotton Cropping Intensity based on IPD Data, 1995-96 & IIMI Sampling, 1997-98.

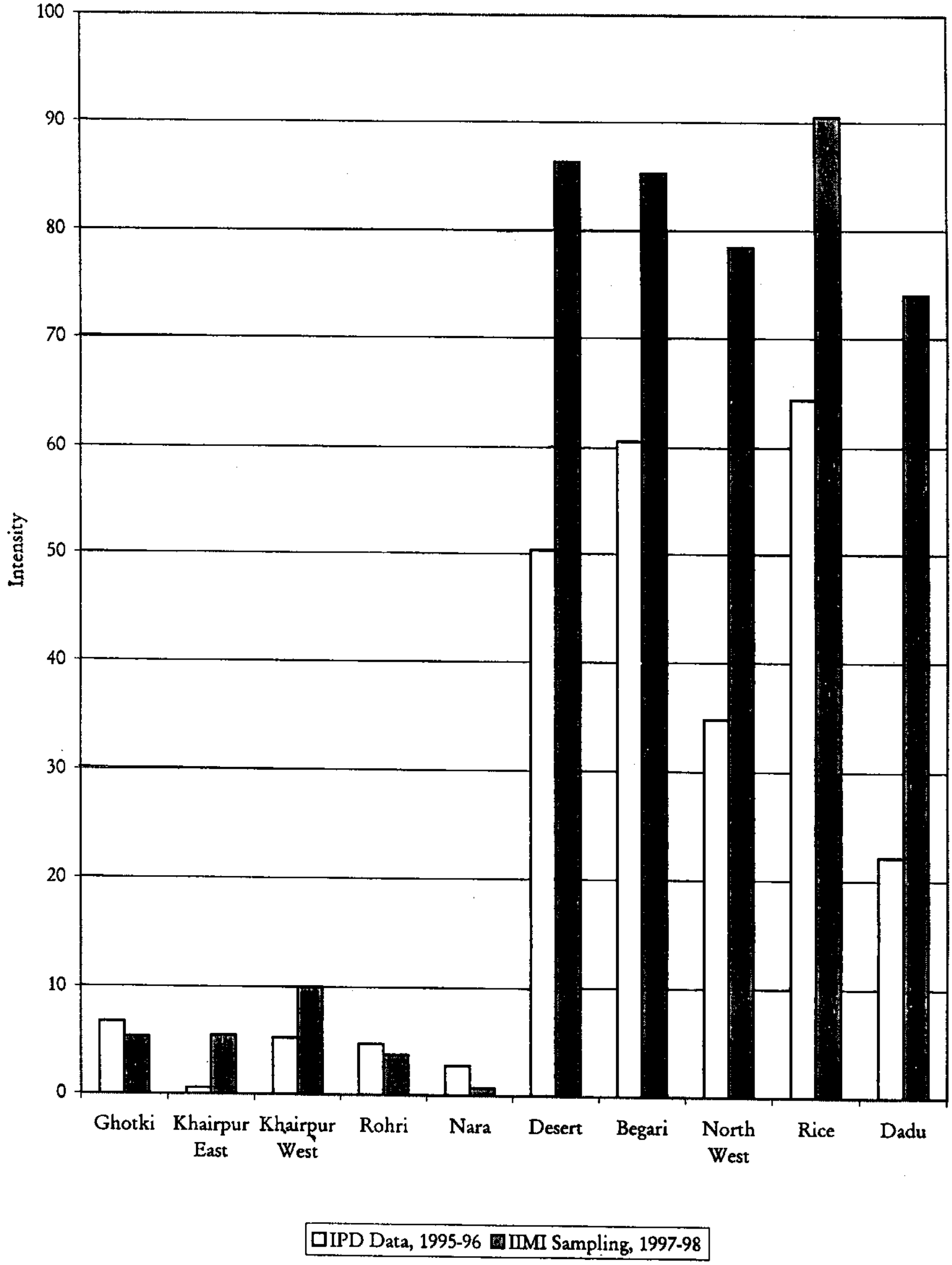


Figure 15c. Comparison of Rice Cropping Intensity based on IPD Data, 1995-96 & IIMI Sampling, 1997-98.

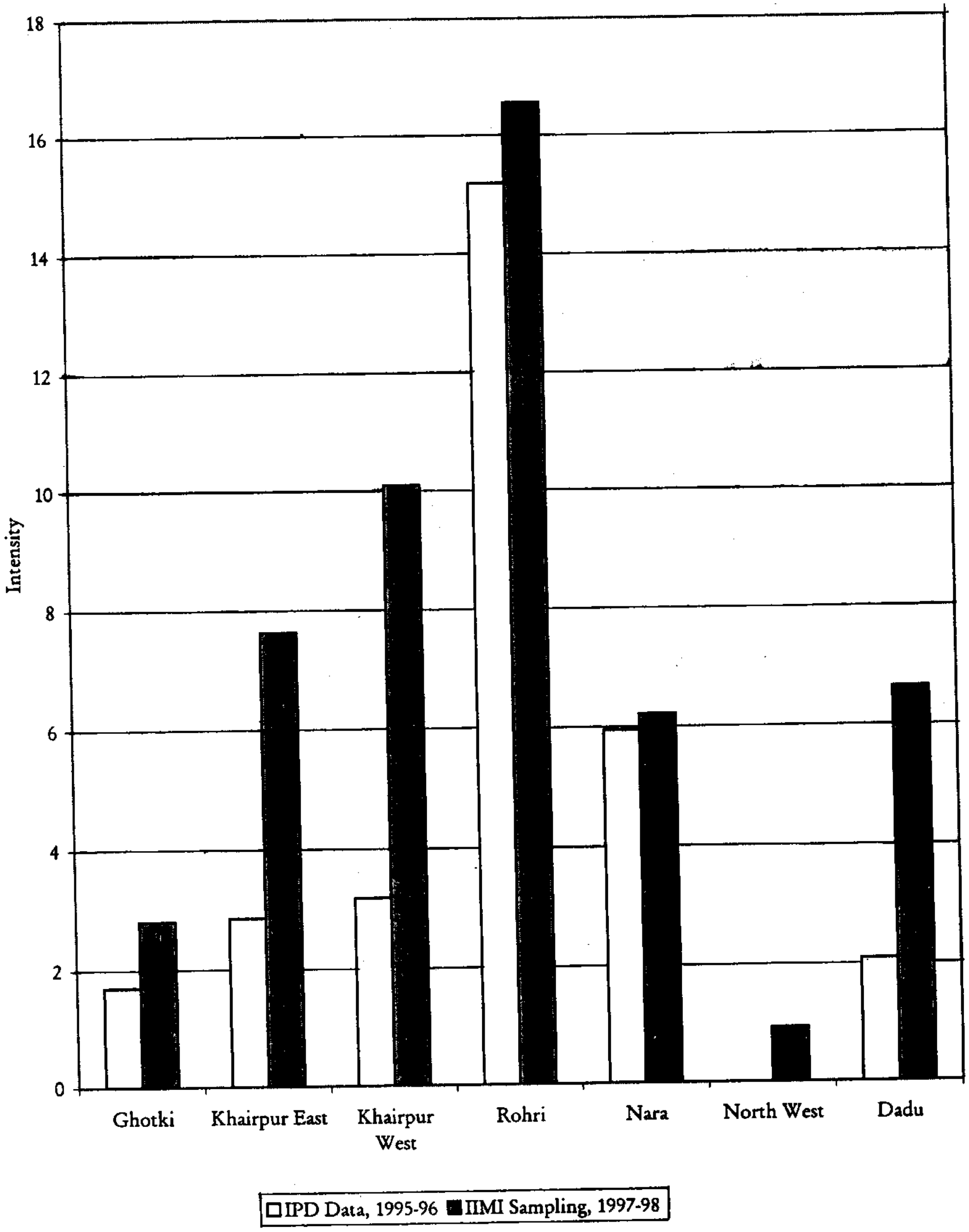


Figure 15d. Comparison of Sugarcane Cropping Intensity based on IPD Data, 1995-96 & IIMI Sampling, 1997-98.

3) Discharges

The discharges across the Sindh irrigation canal commands are known to vary greatly from year to year. This fact has already been illustrated in Figure 11 above, where temporal comparison of total diversions at the respective barrage heads has been shown for the period 1989-90 to 1995-96. Moreover, following the continuing emphasis since the early 1970s to intensify agriculture, there has been no let-up in the demand for increased water supplies, especially in areas where farming has reconciled in favor of high consumptive use crops. In the foreseeable future, canals are likely to be operated in a manner that will leave little scope for management interventions slated for improved distribution of supplies and channel maintenance. Most of the deficiencies in surface water delivery stems from the way the system is operated at the main system level, the emphasis being solely on achieving, maintaining and more often even surpassing full supply levels. Documenting these abuses in a sustained manner is not possible; however, some inference may be drawn from the records maintained by the IPD on canal head discharges. For the purpose of documentation, this study has provided a simple collation of statistics on the ten-daily, monthly and annual flows that are attached as Annex-II. The sheer volume and unresolved discrepancies in this data prevent a fulsome discussion on the prevailing idiosyncracies across each canal command. The graphs for the statistics have all been calculated from the data on daily diversions available at the barrage head for the period 1994-96 and are supposed to be indicative of the short term variations in flows specific to the operating conditions of a canal command; these variations are not readily contrasted within volumetric calculations that tend to mask significant slips in water delivery and maintenance of full supply levels.

In comparison to the above statistics on monthly and yearly flow calculations and the volume of ten-daily flows for the period 1994-96, additional calculations on yearly averages of canal diversion volumes are also provided for the period 1990-91 to 1995-96. Annex-III accounts for figurative comparison of the Rabi, Kharif and annual volumes specific to each canal command. This detail is supplemental to the previous statistics whereby long term trends in water availability have been exposed. For many canal commands, water year 1993-94 marks a high point in water diversions with respect to the Kharif supplies and a general and progressive decline in the volumes of water made available across the respective barrage heads in the aftermath of the Water Apportionment Accord.

4) Water Balance

Based on the data for canal head releases corresponding to the years 1990 and 1996, and after accounting for delivery losses and supplemental pumpage in fresh groundwater zones, comparisons have been made for seasonal differences in the *surface water balance* at the root zone across each canal command. Figures 16a-d show the results for the fourteen major canals in the Sindh Province. Data for the comparison period indicates that the Rabi season crop water availability in the Guddu command is lower than the demand; despite the irrigation demand in the Ghotki Feeder command actually having reduced during this time.

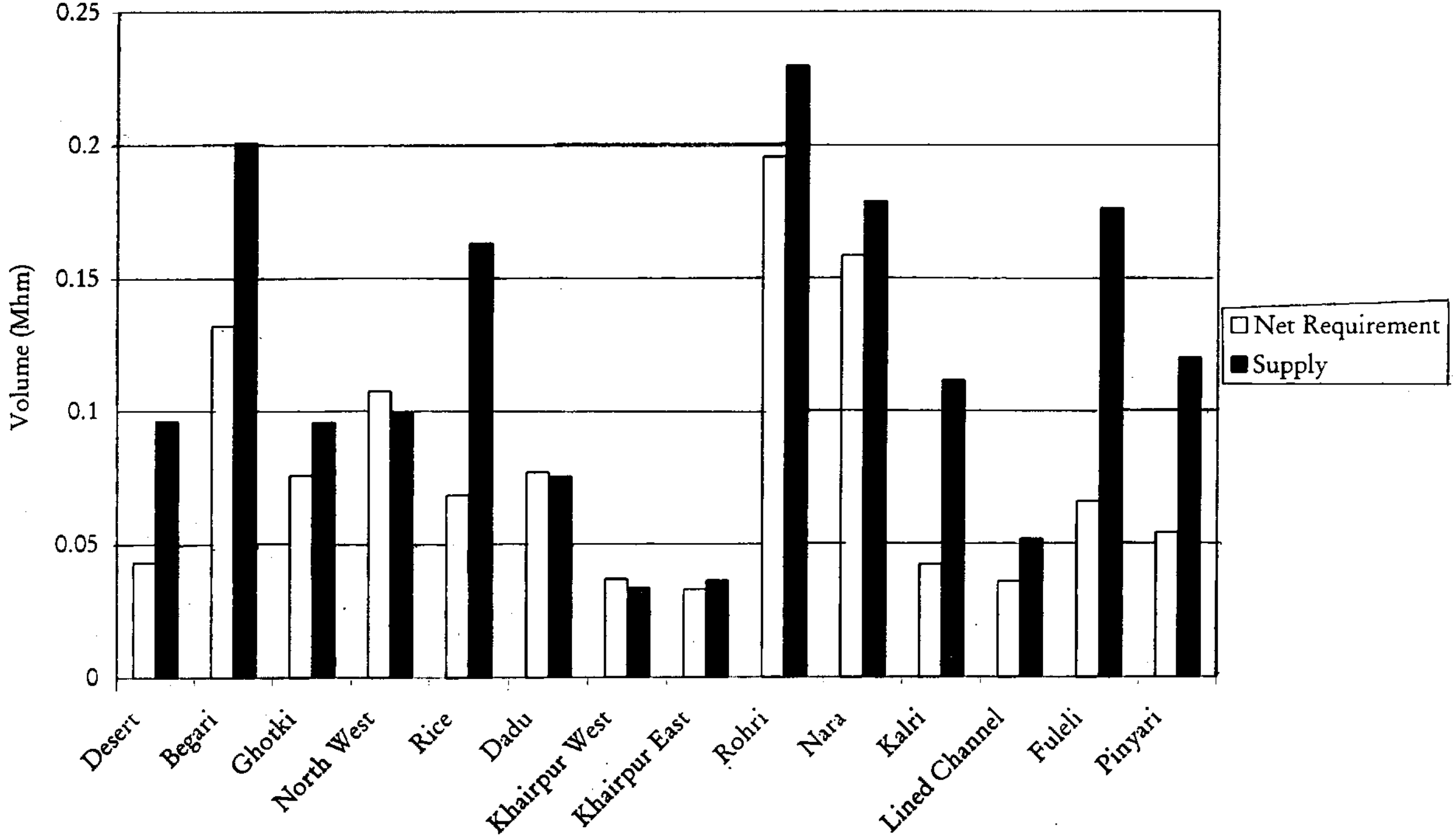


Figure 16a. Surface Water Balance at the Root Zone during Kharif 1990 for Sindh Canal Commands.

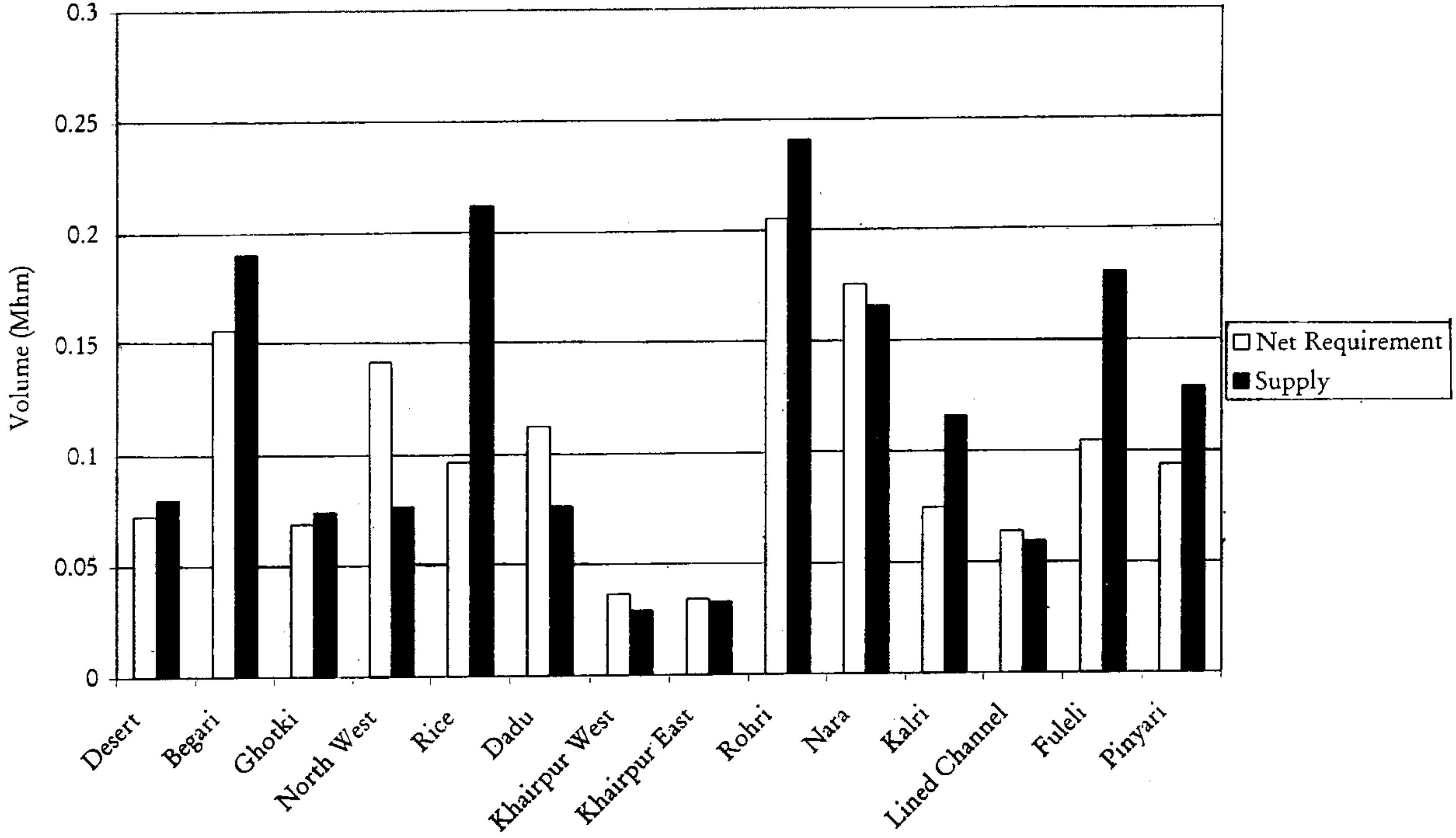


Figure 16b. Surface Water Balance at the Root Zone during Kharif 1996 for Sindh Canal Commands.

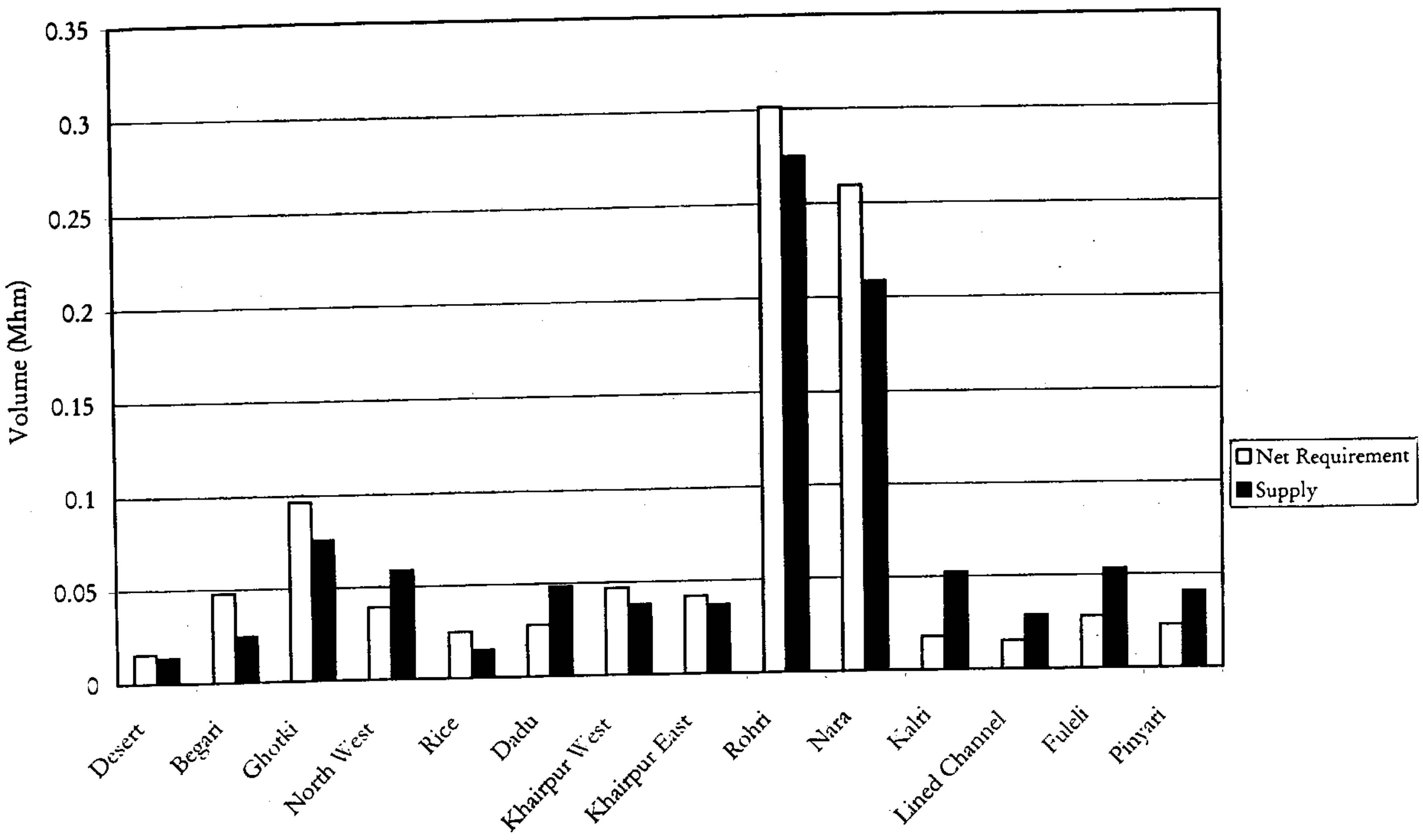


Figure 16c. Surface Water Balance at the Root Zone during Rabi 1990 for Sindh Canal Commands.

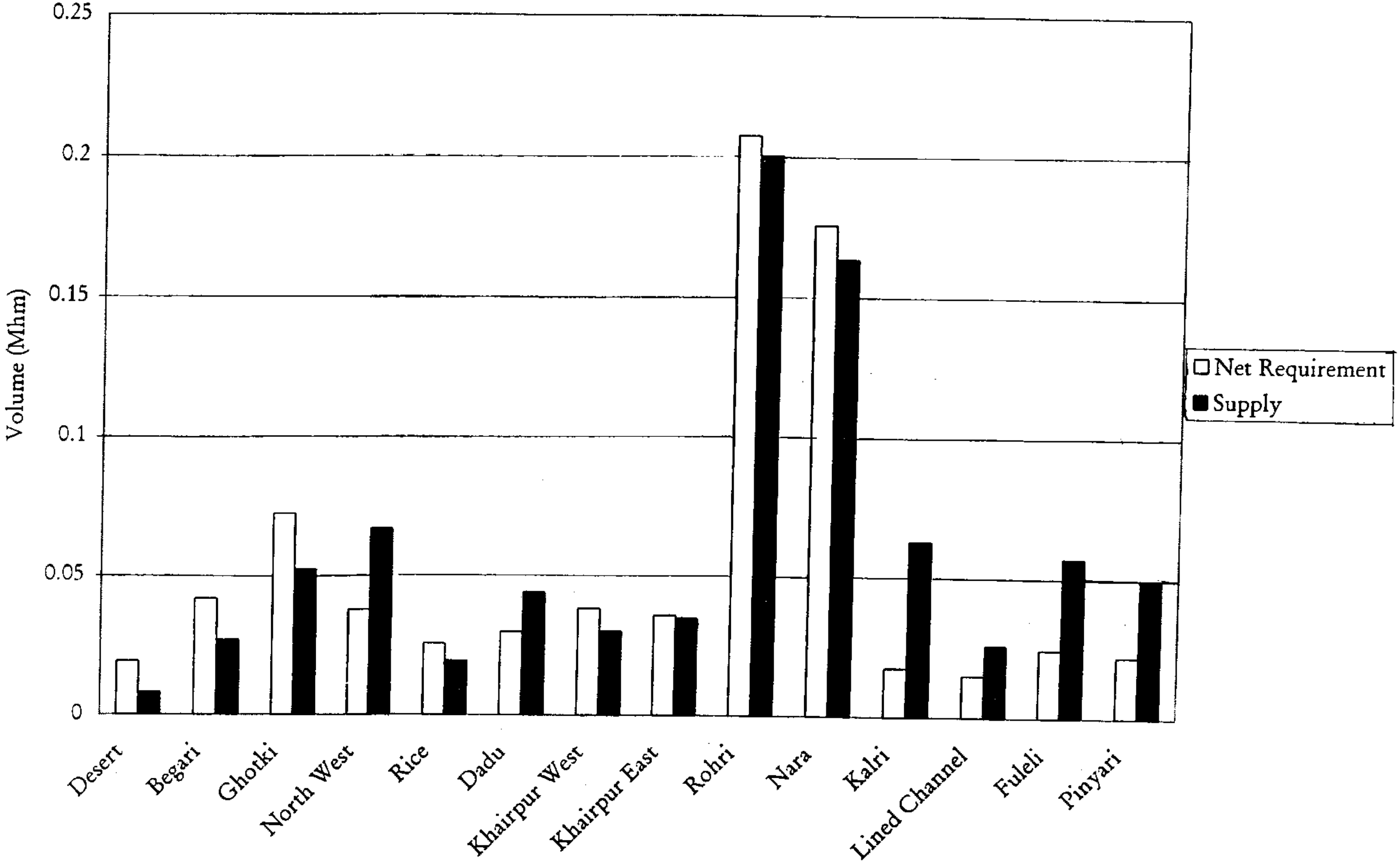


Figure 16d. .Surface Water Balance at the Root Zone during Rabi 1996 for Sindh Canal Commands.

In contrast, the irrigation surplus has increased in the North West system. On a larger scale, the surpluses have become much more pronounced across all of the Kotri canal commands.

The Kharif water availability has also declined for the Guddu canal commands, by as much as 17 percent for the Desert, 6 percent for Begari and 23 percent for Ghotki canals. The rice cultivation requirements for water within the North West have increased tremendously, to as much as 32% during 1995. This is similar to the trend in the Dadu Canal command, but opposite to the persistent near-double the requirement (surplus) conditions in the Rice Canal command. Elsewhere, across the Kotri Barrage commands, the surpluses have reduced significantly (40% for Kalri Beghar, 30% for Fuleli, 47% for Pinyari and a passover to a deficit for the Akram Wah). Figures 17a & b summarize this overall reduction in available surpluses across all the Sindh canal commands for both Rabi and Kharif, respectively. Barr the North West and Dadu canal systems on the Right Bank, the remainder of the canal commands within the two northern barrages are in deficit during Rabi. There is some consolation, however, in that although deficits have not been eliminated, the magnitude has decreased, noticeably for Rohri and Nara canal commands.

The Kharif season comparison in Figure 17b indicates that only the Rice and Rohri canal commands have had an increase in their respective irrigation supplies and all the remaining canal commands have experienced reduction, especially in the Guddu Barrage command (the reduction in surplus being more than 7 times within the Desert Canal).

The groundwater balances have to be seen in the context of fresh and saline zone differentiation. Much of the canal commanded area within the Sindh Province has saline groundwaters, especially in areas away from the direct recharge zone of the river Indus. However, there are significant fresh groundwater pockets where public sector schemes have been undertaken to harvest usable to marginal groundwaters through tubewells. Also, the last two decades have seen considerable development of private tubewells in these exploitable zones, and hence, the need to assess groundwater balances separately.

Groundwater balance comparisons for the years 1990 and 1996 *in fresh groundwater quality zones* show net increases via recharge for all canal commands across both time periods (Figures 18a & b). The decrease in inflows is significant only for the Begari, Ghotki and Rohri commands; however, there has also been a decrease in the related abstractions during this period. The *saline groundwater zones* for the Rohri and Nara canal commands show a decrease in inflows over the 1990 situation, however, the Kotri Barrage commands have experienced a concommitant increase (Figures 19a & b). Overall, like the fresh water zone, all the canal commands in the saline zone show net recharge entering the aquifer during both time periods. Figures 20a & b show the net groundwater balances for all the canal commands in both fresh and saline groundwater zones, respectively. Rather alarming to note is that the net recharge in the Rohri and Nara canal commands is quite high when compared to other commands. The persistence of this trend across the period of comparison indicates that over the long term the continuing recharge may contribute to a rather adverse rise in water levels that may imperil productive cultivation, especially in those

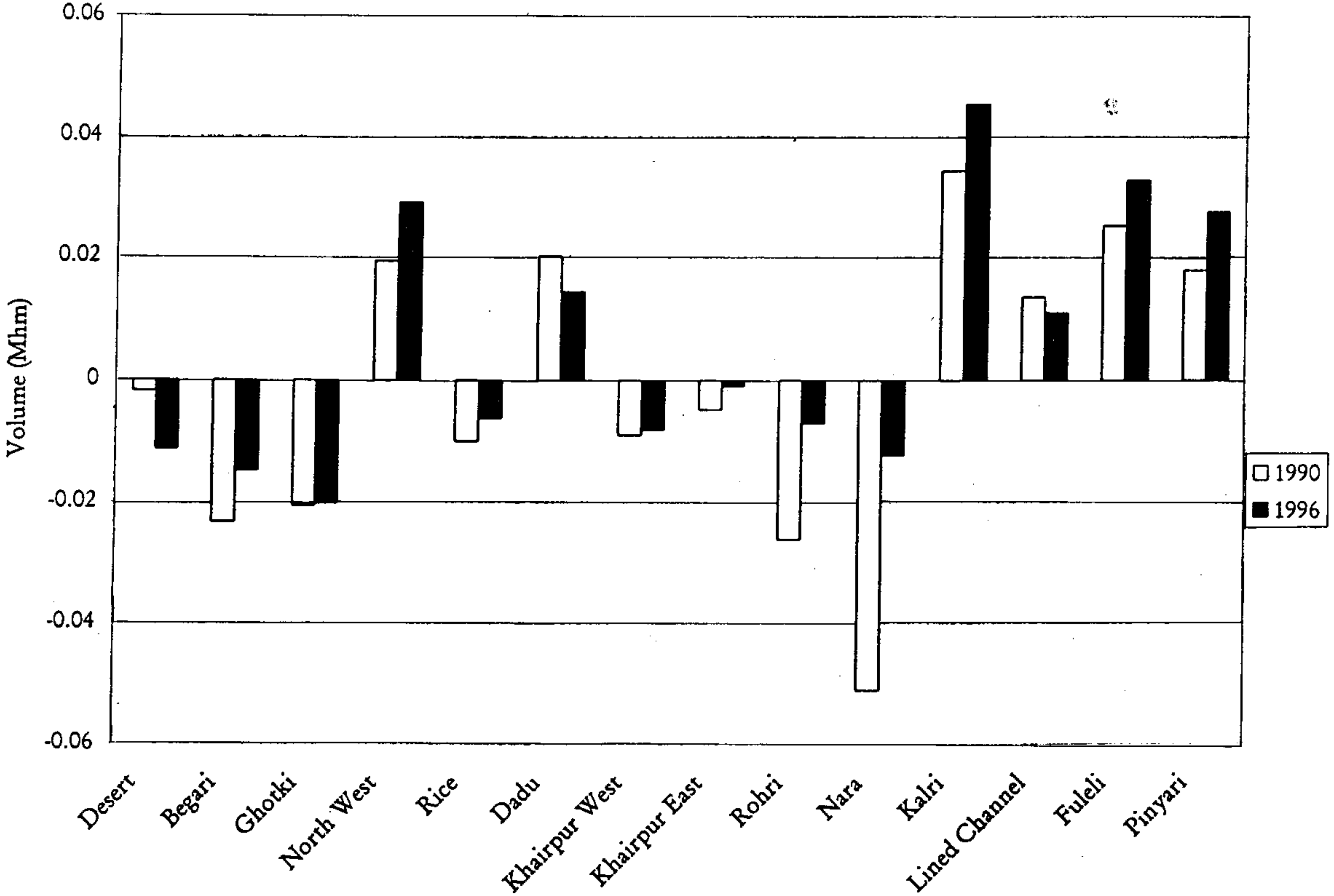


Figure 17a. Canal Command Level Availability of Surplus Irrigation Waters During Rabi Season at the Root Zone, Sindh Irrigation System.

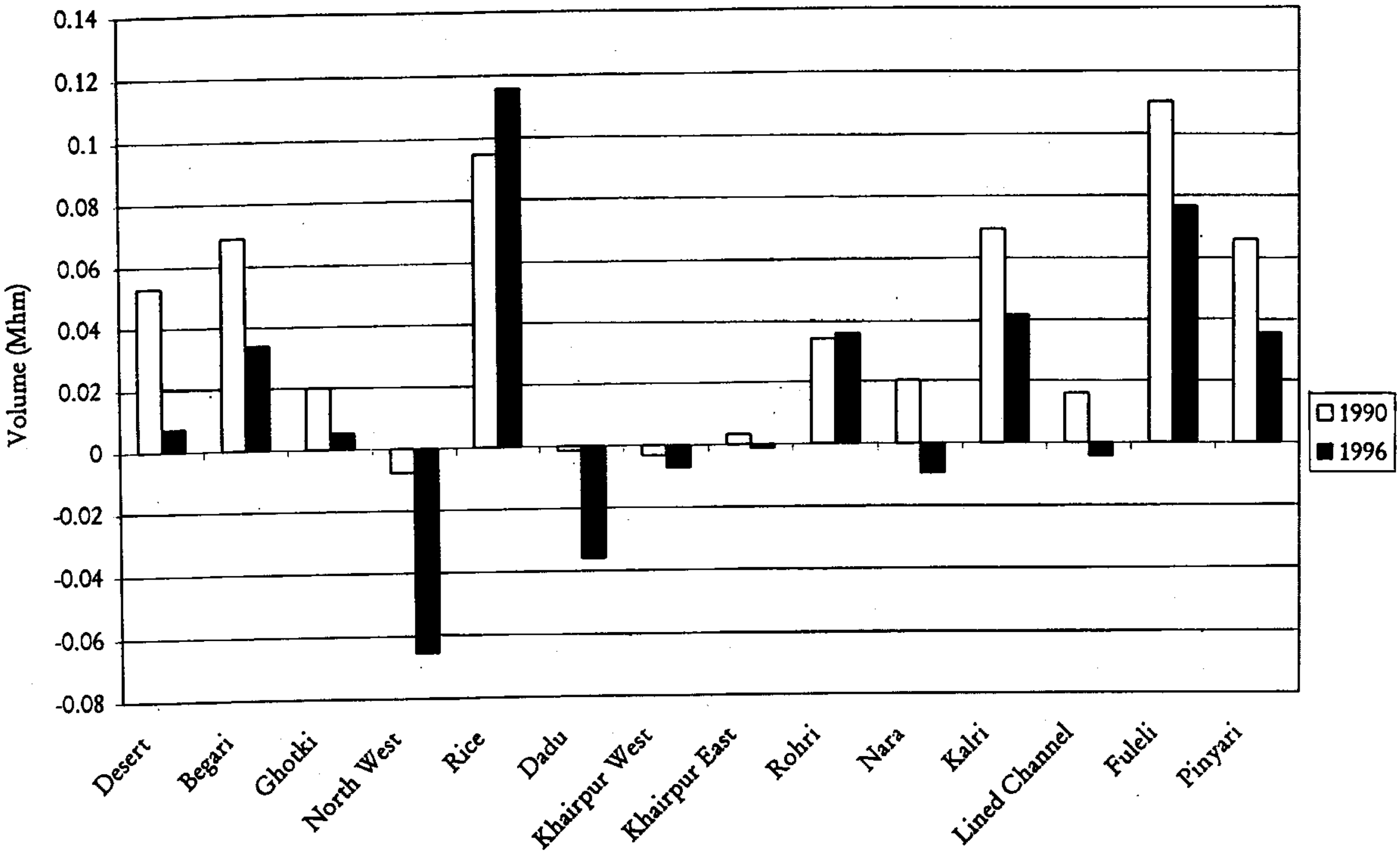


Figure 17b. Canal Command Level Availability of Surplus Irrigation Waters During Kharif Season at the Root Zone, Sindh Irrigation System.

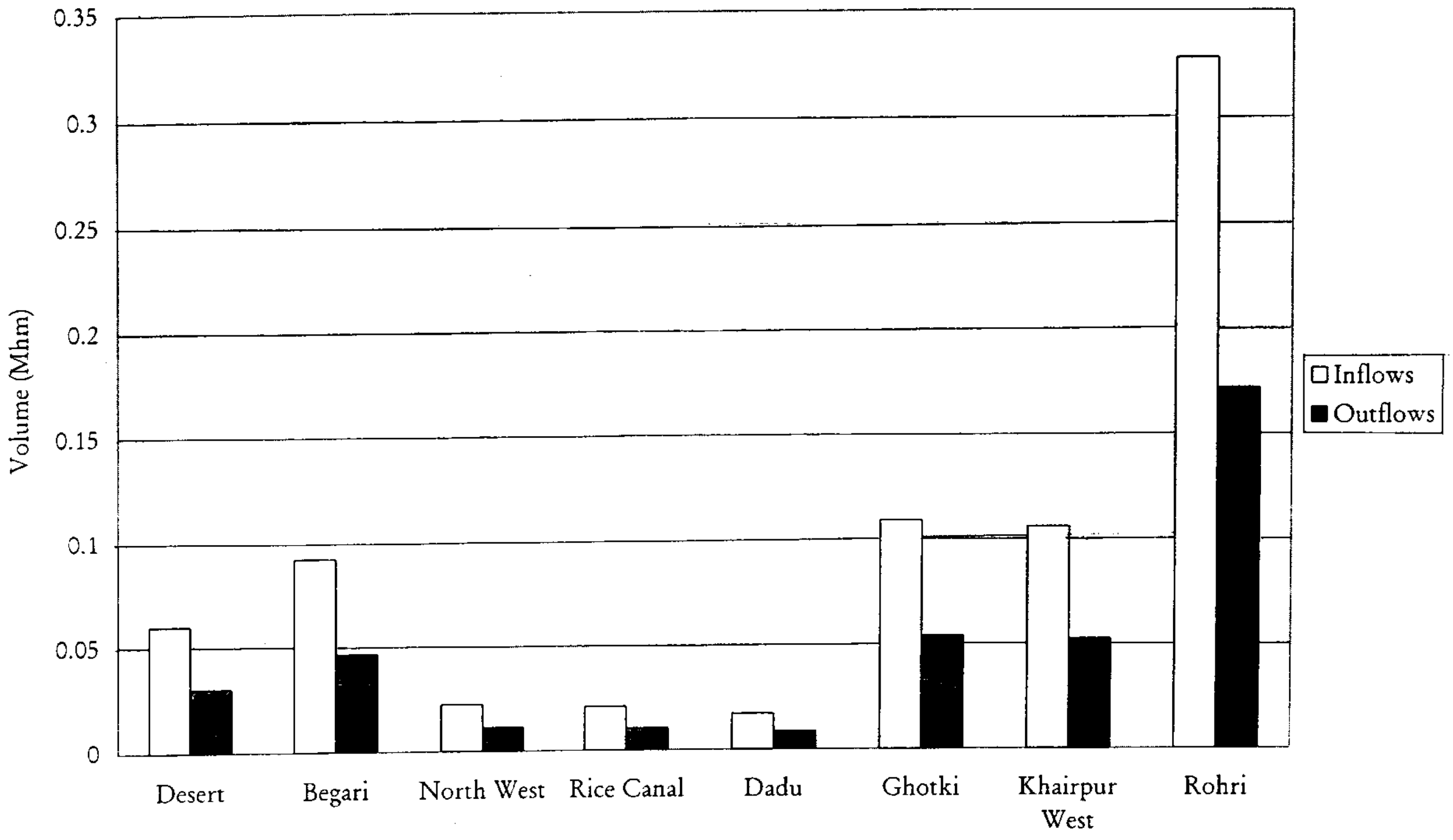


Figure 18a. Comparison of Annual Groundwater Balance for the Year 1990 for Sindh Canal Commands, Fresh Groundwater Zone.

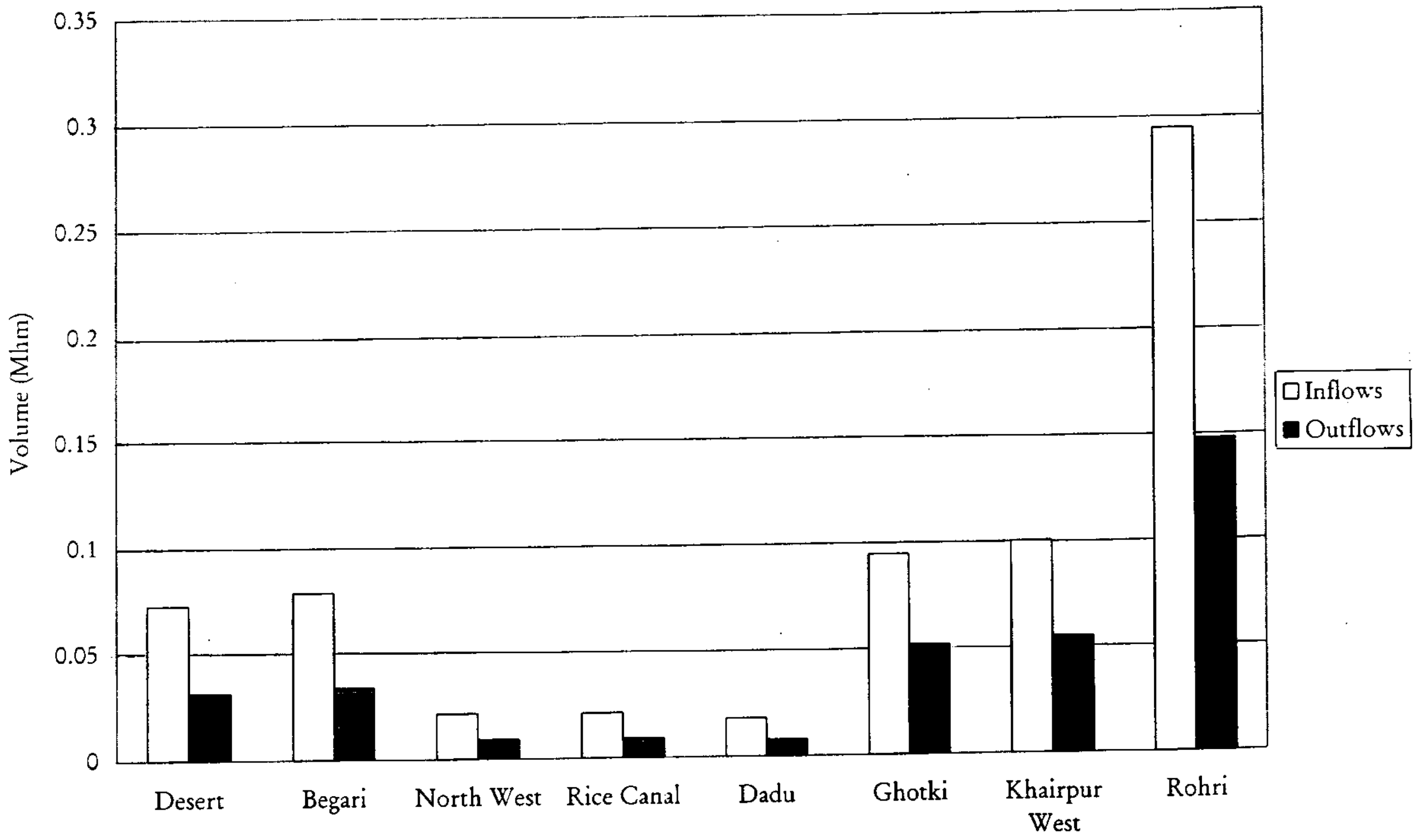


Figure 18b. Comparison of Annual Groundwater Balance for the Year 1996 for Sindh Canal Commands, Fresh Groundwater Zone.

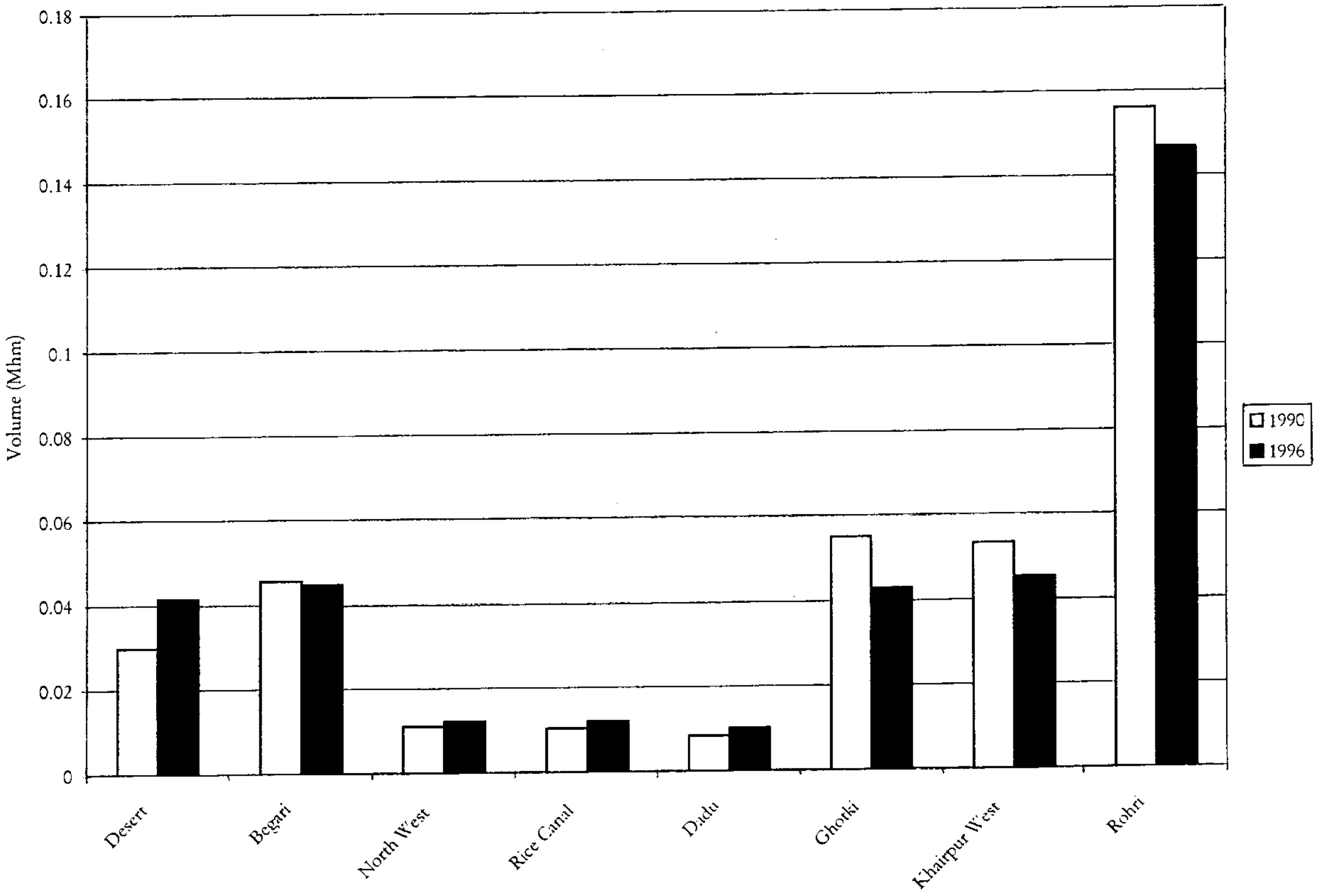


Figure 20a. Temporal Comparison of Net Annual Groundwater Balance for the Sindh Canal Commands, Fresh Groundwater Zone.

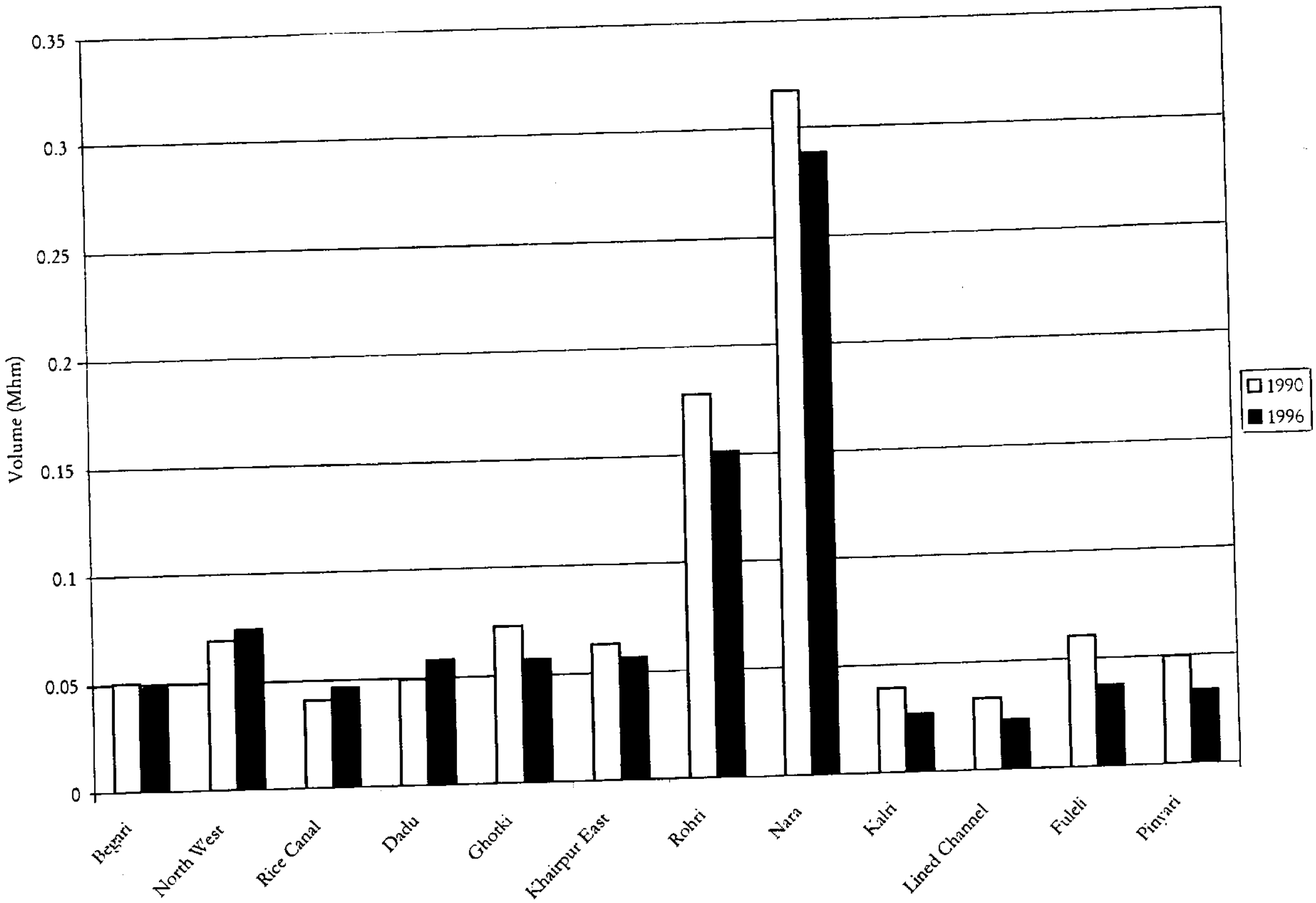


Figure 20b. Temporal Comparison of Net Annual Groundwater Balance for the Sindh Canal Commands, Saline Groundwater Zone.

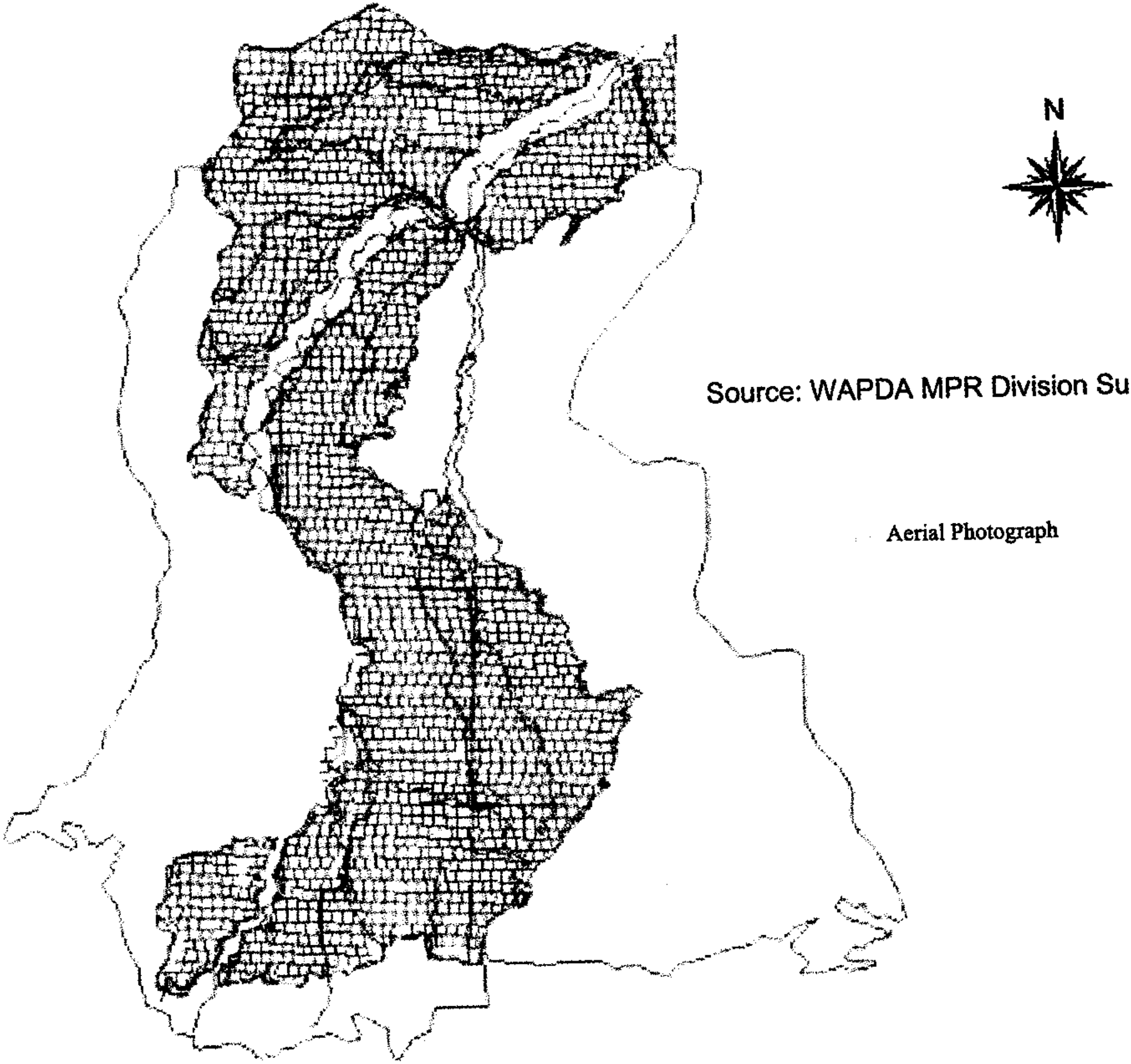
areas of these two canal commands where farmers have shown an acute preference for high delta crops.

F. Waterlogging and Salinity

Integrated reporting of the extent of land mass affected by waterlogging and soil salinity has only been done twice; once as early as the mid-sixties under the aegis of the Lower Indus Plan (LIP) Report, which was comparatively much less detailed with respect to the subsequent WAPDA Master Planning and Review (MPR) Division surveys completed with the help of aerial photo interpretations during 1976-79 (Figure 21). Other than these instruments of comprehensive project planning, detailed surveys on concurrent assessment of both waterlogging and soil salinity have been done for much smaller areas, like the planning for the Right Bank Master Plan (RBMP) study and under individual WAPDA Project Planning Reports for various SCARPs implemented since the original recommendations of the LIP Report. Since these individual reports are published disproportionately across time, one-time integrated assessments remain elusive. WAPDA MPR surveys provide map-level details (1:250,000 scale) on the distribution of varying degrees of waterlogging and soil salinization across the entire Lower Indus Basin. This information is inclusive of areas that were relatively immune from the debilitating effects of this phenomenon.

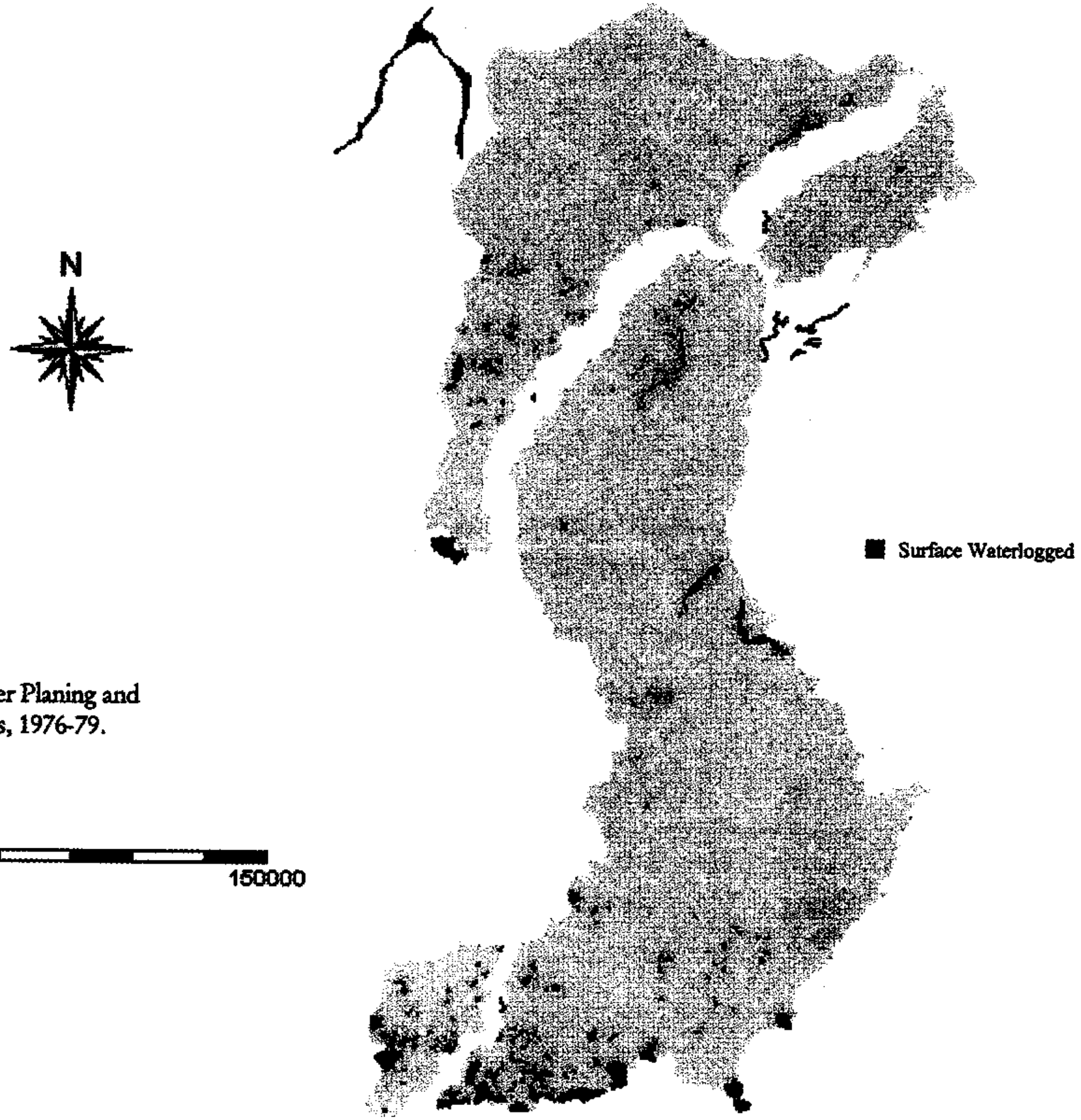
A representation of the most affected areas at that time has been isolated in Figures 22a-c to coincide with the extents of surface waterlogged, critically waterlogged and severely salinized areas, respectively. Surface waterlogged (ponded regimes) were most numerous along the Right Bank of the river Indus and in the then drainage-less commands of the Rice and Dadu Canals having near-exclusive rice cultivation during Kharif. Other ostensibly affected areas were in the commands of the Khairpur East Canal, the Jamrao head and fairly significant patches within the Kotri Barrage command. The near-surface, or critically, waterlogged areas predominate the poor permeability Piedmont alluvials on the Right Bank and a continuous belt stretching across the commands of the Khairpur East, North Rohri, Jamrao head and Main Nara canal commands. This phenomenon was mapped to be quite discontinuous and scattered across the Kotri Barrage command, the suppressed intensity being largely related to the then yet to emerge pattern of sugarcane and rice cultivations within the Fuleli, Akram Wah and Kalri Beghar Feeder canal commands (see Table 1 for the low intensity of crop cultivations within the Kotri commands). Overall, the mapping accounted for 3 percent of the gross area of the Left Bank as permanently waterlogged and a corresponding 6 percent on the Right Bank (Figures 23a & b).

The WAPDA S4 class of soil salinity dominated the most intensively cultivated areas on the Indus Right Bank, much of the Ghotki Feeder command (then a water scarce environment), and the majority of the Nara and Kotri Barrage commands. Few areas were mapped to be affected by extreme soil salinization within the Rohri and Northern Sukkur Barrage commands. Proportionately, from Figure 23, 11 percent of the area was affected on the



Source: WAPDA MPR Division Surveys, 1976-79

Figure 21. Aerial Photo Coverage for the Lower Indus Basin, Sindh, Pakistan.



Source: WAPDA Master Planing and Review Surveys, 1976-79.

Figure 22a. Surface Waterlogged Area within Lower Indus Basin Irrigation System, Sindh Province, Pakistan.

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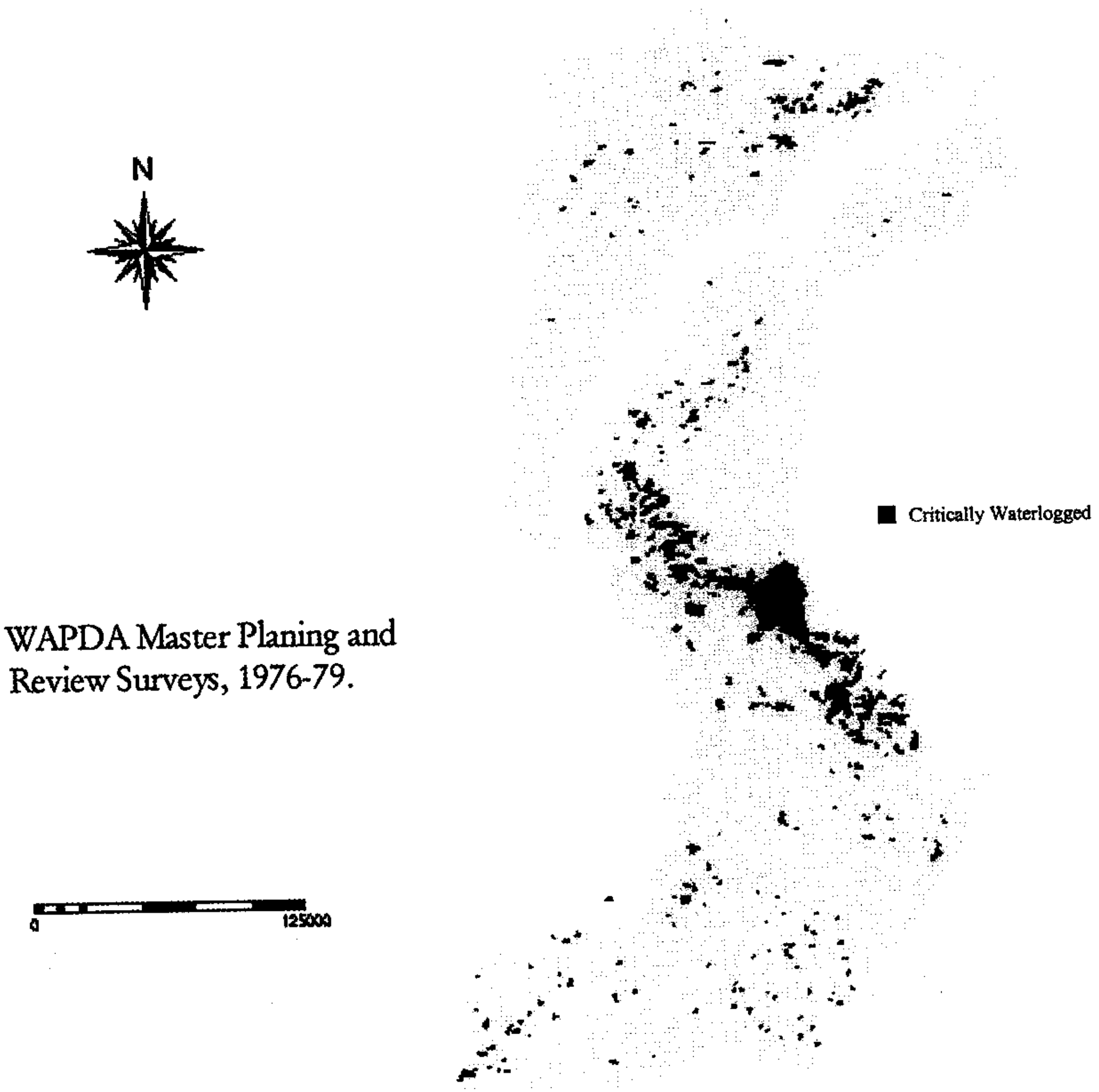
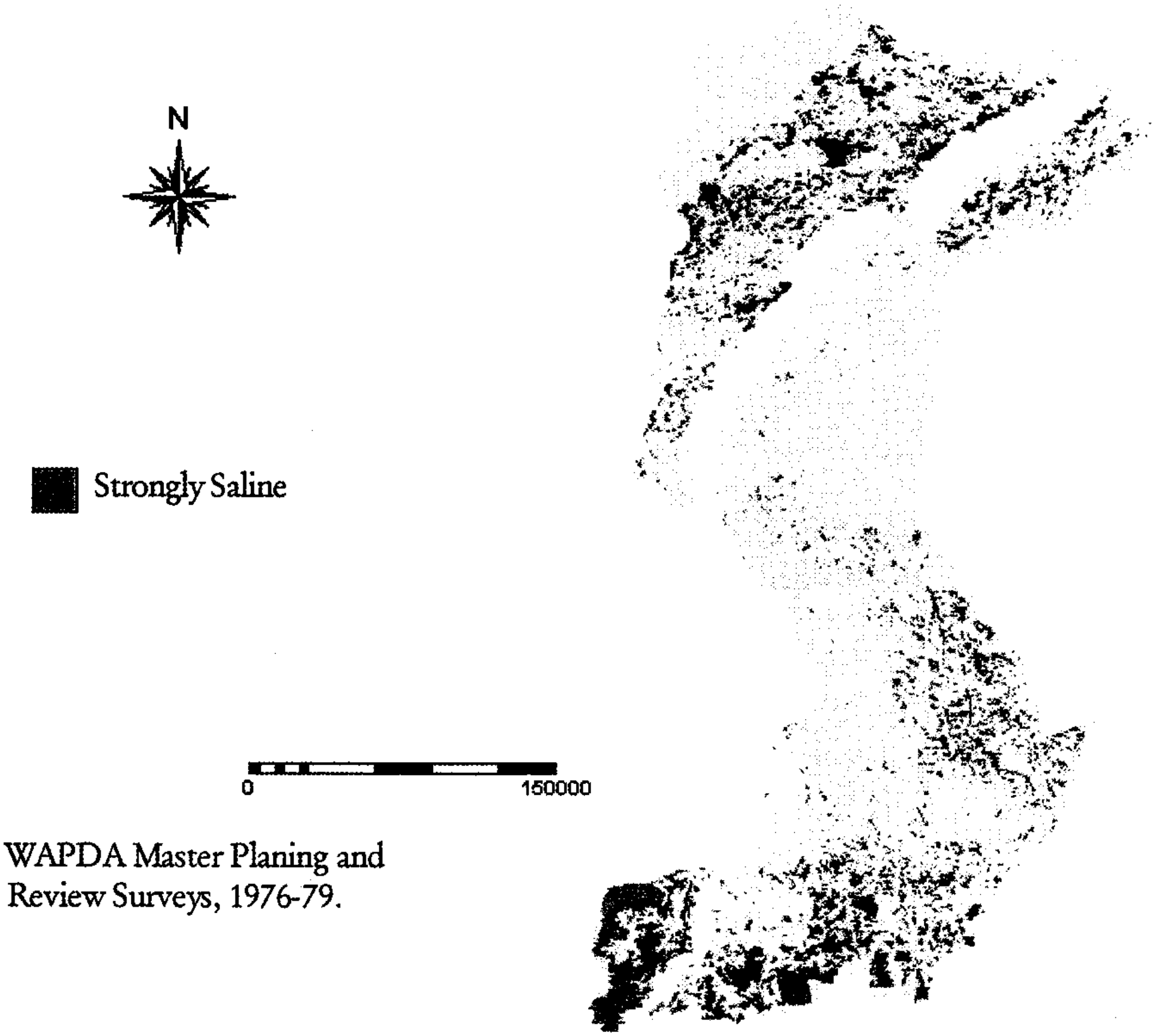


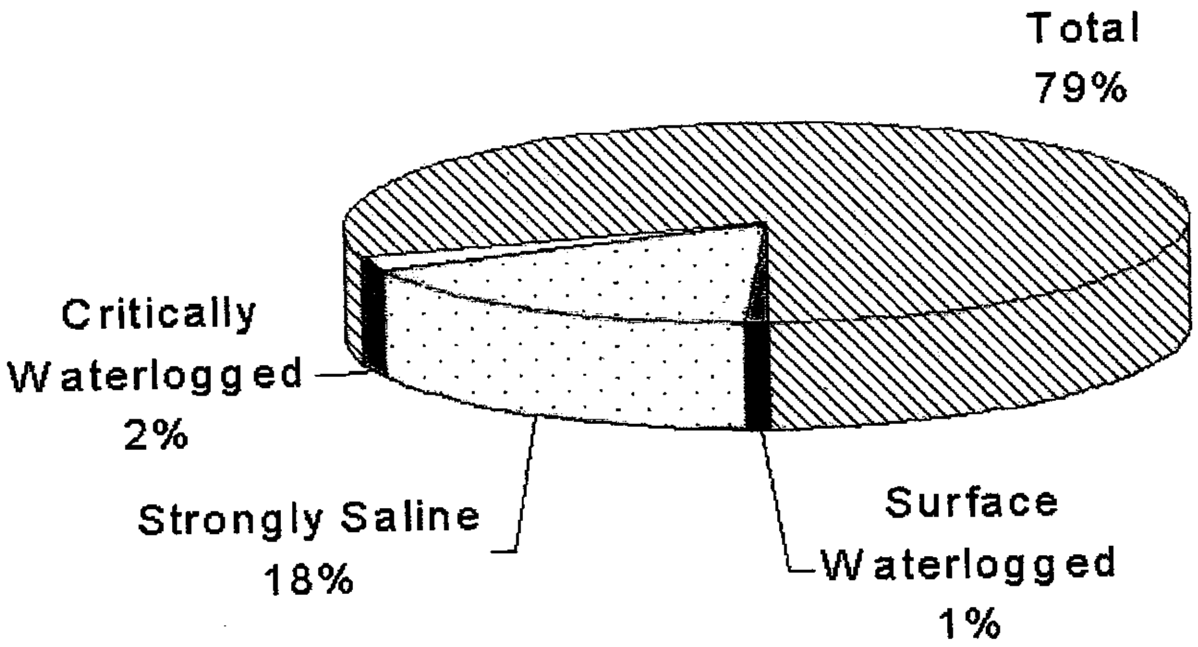
Source: WAPDA Master Planing and Review Surveys, 1976-79.

Figure 22b. Distribution of Critically Waterlogged Areas within Lower Indus Basin Irrigation System, Sindh Province, Pakistan.



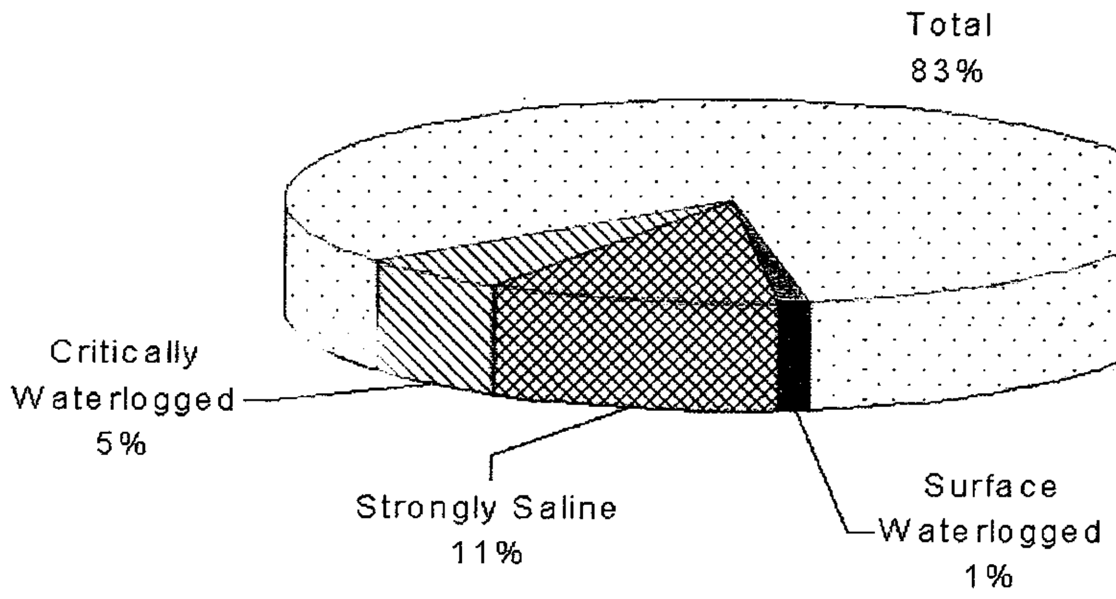
Source: WAPDA Master Planing and
Review Surveys, 1976-79.

Figure 22c. Distribution of Severely Salinized Areas within Lower Indus Basin, Irrigation System, Sindh Province, Pakistan.



Source: WAPDA MPR Division Survey, 1976-79

Figure 23a. Proportion of Degraded Land within Lower Indus Basin Plain, Left Bank, Sindh Province, Pakistan.



Source: WAPDA MPR Division Survey, 1976-79

Figure 23b. Proportion of Degraded Land within Lower Indus Basin Plain, Right Bank, Sindh Province, Pakistan.

Indus Right Bank and a much larger 18 percent (with a lion's share belonging to the Kotri command) on the Left Bank.

G. Irrigation Land Suitability

Following the Colombo Plan era aerial photography of the Lower Indus Basin during 1954-55, the first reconnaissance level soil surveys describing the associative aspects of the soil series with respect to local topographic variations was initiated in 1967. About 18 different reports were produced by the Soil Survey of Pakistan describing aspects of drainability, salinity, land and crop suitability of the soils. All these reports were appended with maps that showed the distribution of the respective associative groups across the Lower Indus regime. A composite classification of these attributes comprises close to 200 soil associations, all scattered in spatial units of various scales across the different reports.

Subsequent to these aerial photo interpretations, there have not been integrated assessments to account for the changes brought about by population pressures to increase cultivated extents, and thereby change the productivity ranking of the soils. Moreover, as already stated above, increased canal supplies have facilitated the extension of cultivated tracts to areas previously classified as marginal to not suitable lands due to high watertables and extreme soil salinization. Recent sample surveys by IIMI, of nearly 800 sites distributed across the entire Sindh Province (Figures 24 and 25; circa 1997-98 and described in detail in Section VI) have shown that the proportion of SI lands comprised 51 percent of the total currently productive irrigated areas and that the majority of the constraint derivatives (comprising less than 1/3rd of the total area) are owed to moderate to high water levels and mostly moderate levels of salinization (Figure 26). These constraints are further offset by rather low soil permeabilities that restrict drainage and hinder workability. Clearly, with the bulk of the emphasis being drawn towards limiting conditions for drainage, it is not difficult to infer that either existing trends towards high consumptive use crops will need to be curtailed or else phenomenal investments in drainage will need to catch up with the foreseable rise in drainage surpluses.

Annex-I lists the proportional distribution of the IIMI sample sites corresponding to broad categorizations of irrigation suitability rankings. Detailed subsets of classification, with explanatory notes and areal determinants, are given in Annex-IV where canal command-wise maps have also been attached as plates for spatial reference. An exhaustive discussion on the significance of the distribution of different suitability rankings for each canal command is beyond the scope of this study, however, Tables 5 and 6 provide the information matrix to the dominant and aggregate occurrence of suitability rankings across the hydrological units of the Sindh irrigation system.

The following discourse dwells on the Right Bank of the Lower Indus Basin Plain where a significant mass of the historic public sector land reclamation schemes were undertaken in the past, and is also home to the most integrated development plan ever proposed within

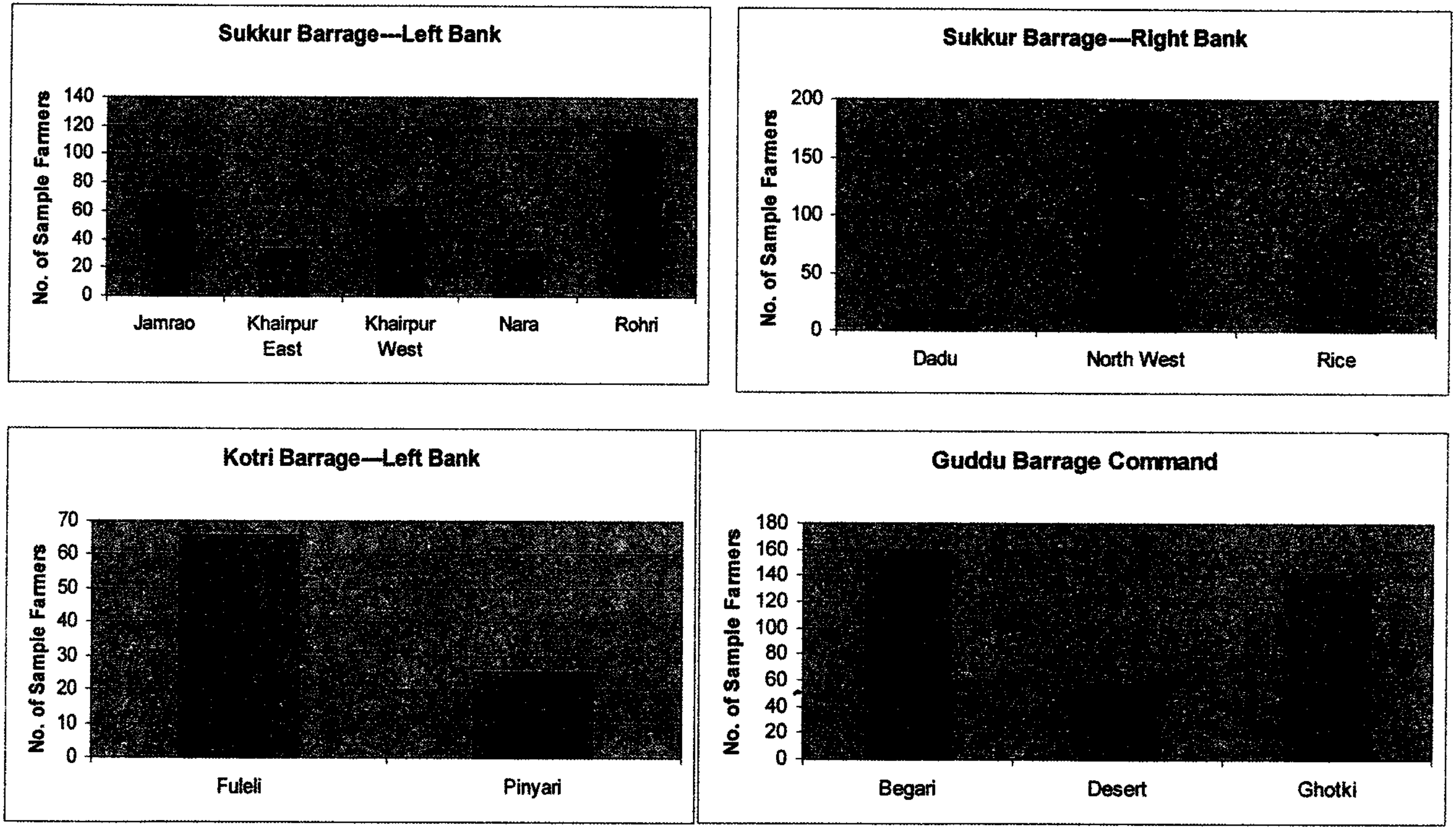


Figure 24. Barrage Command-wise Distribution of IIMI Sample Farmers within the Sindh Irrigation System.

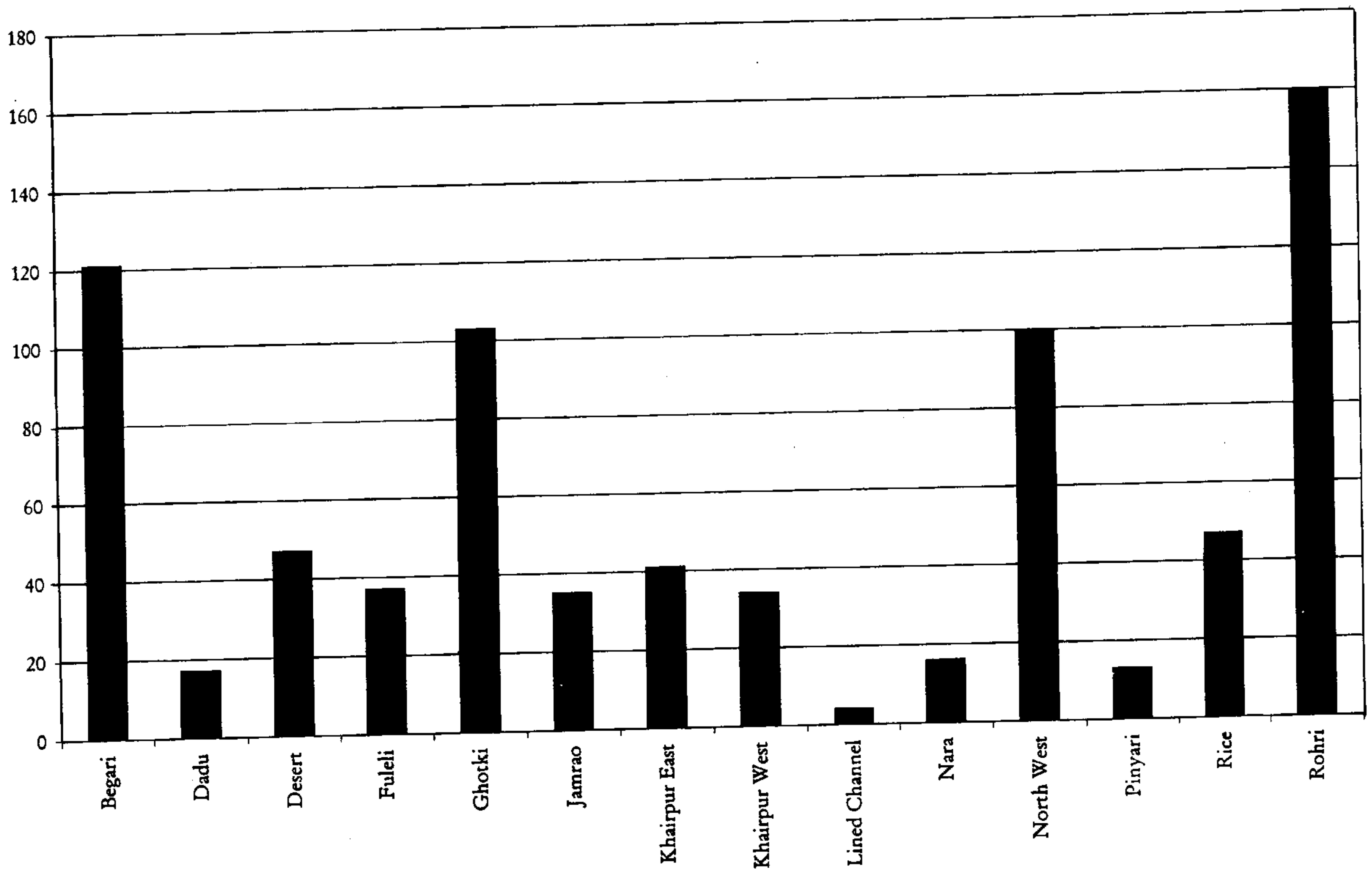
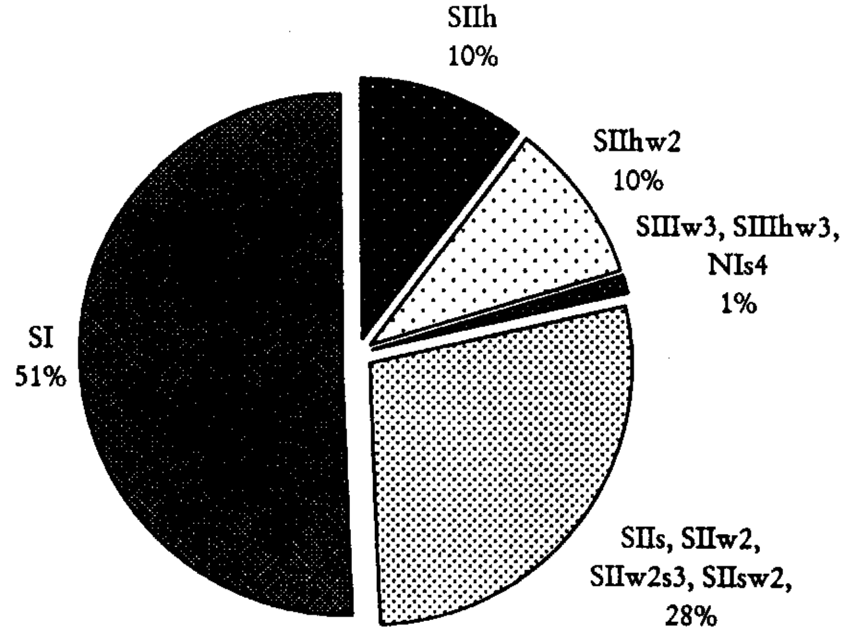


Figure 25. Distribution of IIMI Sample Sites for Farm and Physical Surveys within the Sindh Irrigation Canal Commands, 1997-98.



Key to Land Use Suitability Classification of IIMI Sample Sites	
Suitability Class	*Description*
SI	Highly suitable land.
SIIh	Moderately suitable clayey land due to low permeability and workability.
SIIs	Moderately suitable land due to shallow depth (18-50 cm).
SIIs3	Moderately suitable land due to moderate salinity.
SIIw2	Moderately suitable land due to high watertable (90-200 cm).
SIIhw2	Moderately suitable clayey land due to low permeability and workability and high watertable.
SIIsw2	Moderately suitable land due to moderate depth to sand and high watertable.
SIIs3w2	Moderately suitable land due to moderate salinity associated with high watertable.
SIIIs4w2	Marginally suitable land due to high watertable (9-200 cm) and severe salinity.
SIIIs	Marginally suitable land due to very sandy nature and complex topography.
SIIIhw3	Marginally suitable clayey land due to low permeability, workability and very high watertable (30-90).
SIIIhs4w2	Marginally suitable clayey land due to low permeability, workability, high watertable and severe salinity.
NIs4	Currently not suitable land due to severe salinity / sodicity and low permeability.

Figure 26. Proportions of Updated Land Suitability Classification based on IIMI Surveys in 1997-98 within the Lower Indus Basin Plain, Sindh Province.

Table 5. Dominant Occurance of land suitability classification map units by canal commands.

Sr. #	Suitability Class	Begari	Pinyari	Lined Channel	Fuleli	Rice Canal	Jamrao	Ghotki	Khairpur West	Khairpur East	Dadu	Northwest	Nara	Desert	Rohri
1	SI	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2	SIIhw2	x	x	x	x			x	x	x	x		x		x
3	SIIs3	x				x			x				x	x	x
4	SIIhs3	x				x	x		x		x		x	x	x
5	SIIIs	x	x		x	x		x	x	x	x	x		x	x
6	NIhs4	x	x												
7	NII	s,w	w-g	w	sw	swg	sw	sw	sw	swg	sw	sw	sw	sw	sw
8	SIIIs4w2		x	x	x										x
9	SIIIhw3		x	x	x	x					x				x
10	SIIIhs4w2				x			x		x		x	x		
11	SIIh					x	x				x	x	x	x	
12	SIIs3w2						x	x		x	x	x	x		
13	SIIw2								x				x		x
14	NIhs4														x

Table 6. Aggregate Occurance of land suitability classification map units by canal commands.

Sr. #	Suitability Class	Pinyari	Lined Channel	Fuleli	Khairpur West	Khairpur East	Dadu	North West	Rice Canal	Desert	Rohri	Ghotki	Nara	Jamrao	Begari
1	SI	x	x		x	x			x	x	x	x	x		
2	SIIh-SIIhw2	x	x					x		x				x	
3	SIIs4w2-SIIw2	x	x	x							x				
4	SIIIhw3	x	x	x			x		x		x				
5	SIIIs-SIIs	x		x	x	x	x	x	x	x	x	x			x
6	NIIwg,s	x	x	x	x	x	x	x	x	x	x	x	x	x	x
7	SIIw2-SIIIs4w2		x						x					x	
8	SIIhw2-SIIw2			x											
9	SIIw2-SIIIhs4w2			x								x			
10	SI-SIIw2				x	x	x	x	x		x		x	x	x
11	SI-SIIhs3				x										
12	SI-SIIs3				x				x	x	x		x		x
13	SI-SIIhw2				x	x					x	x			x
14	SI-SIIs3w2					x		x				x	x		
15	SIIh-SIIIhs4w2					x		x						x	
16	SIIh						x								
17	SIIhw2-SI						x								
18	SIIh-SIIhs3						x		x	x	x				x
19	SIIs3w2-SI						x								
20	SI-SIIh								x						
21	NIhs4										x				x
22	SIIw2-SIIhw2												x		
23	SIIh-NIIs												x		
24	SIIs3-NIIs												x		
25	SIIhs3-NIIs												x		

the country. The sheer volume of investigations from the operative and proposed public sector projects provides an excellent opportunity to arrive at a better understanding of the prolific water use in this area. The often wasteful irrigation practices for rice cropping have put the farming options into a virtual strait jacket, for which implementing alternatives seem hard.

III. LOWER INDUS BASIN---RIGHT BANK

A. Climate

The Lower Indus Right Bank is in a region of very low and sporadic rainfall, with average annual rainfall as low as 75-100 mm. Driest is the eastern fringe along the Indus River from the Guddu to Sukkur Barrages. Towards the west the rainfall gently increases, reaching about 150 mm along the western boundary. Given the rather high temperatures and the minimal cloud cover prevailing for much of the year, the evapotranspiration rates exceed 2000 mm each year. Consequently, the extensive cropping, which is the major source of both employment and income, is dependent almost entirely on irrigation water originating from outside the area. In comparison to these barrage diversions, much smaller contributions come from groundwater supplies, and even this is dependent on the Indus flows percolating into the aquifers. The groundwater is largely located in the heads of canal systems where surface water is readily available. A major value of groundwater is its storage potential to enable Kharif flood water to be stored and used during Rabi.

B. Soils

The two principal soil types are distinct with respect to their physical characteristics, soils chemistry and soils and land drainability (Figure 27). The Indus alluvials cover 70 percent of the area and comprise an intricate pattern of riverine geomorphic features, derived mainly from deposits laid down by the river Indus. In fact, the Indus River has been the single-most instrumental source in carving the existence of the various agroecological zones covering the Right Bank. The distribution of these zones was mapped as part of the investigations conducted by the RBMP study (Figure 28).

The Indus alluvials consist largely of permeable silt loams, loams and silty clay loams. The Piedmont alluvials are sediments derived from the adjacent highlands and are fine-textured, deeply homogeneous weakly structured clays with little evidence of stratification, and very slow permeabilities. The Piedmont alluvials are more fertile than the Indus alluvials.

The watertable is raised to the surface for rice cultivation on the Indus alluvials. Thus, soil profiles of all textural groups are saturated throughout their depth and varying degrees of

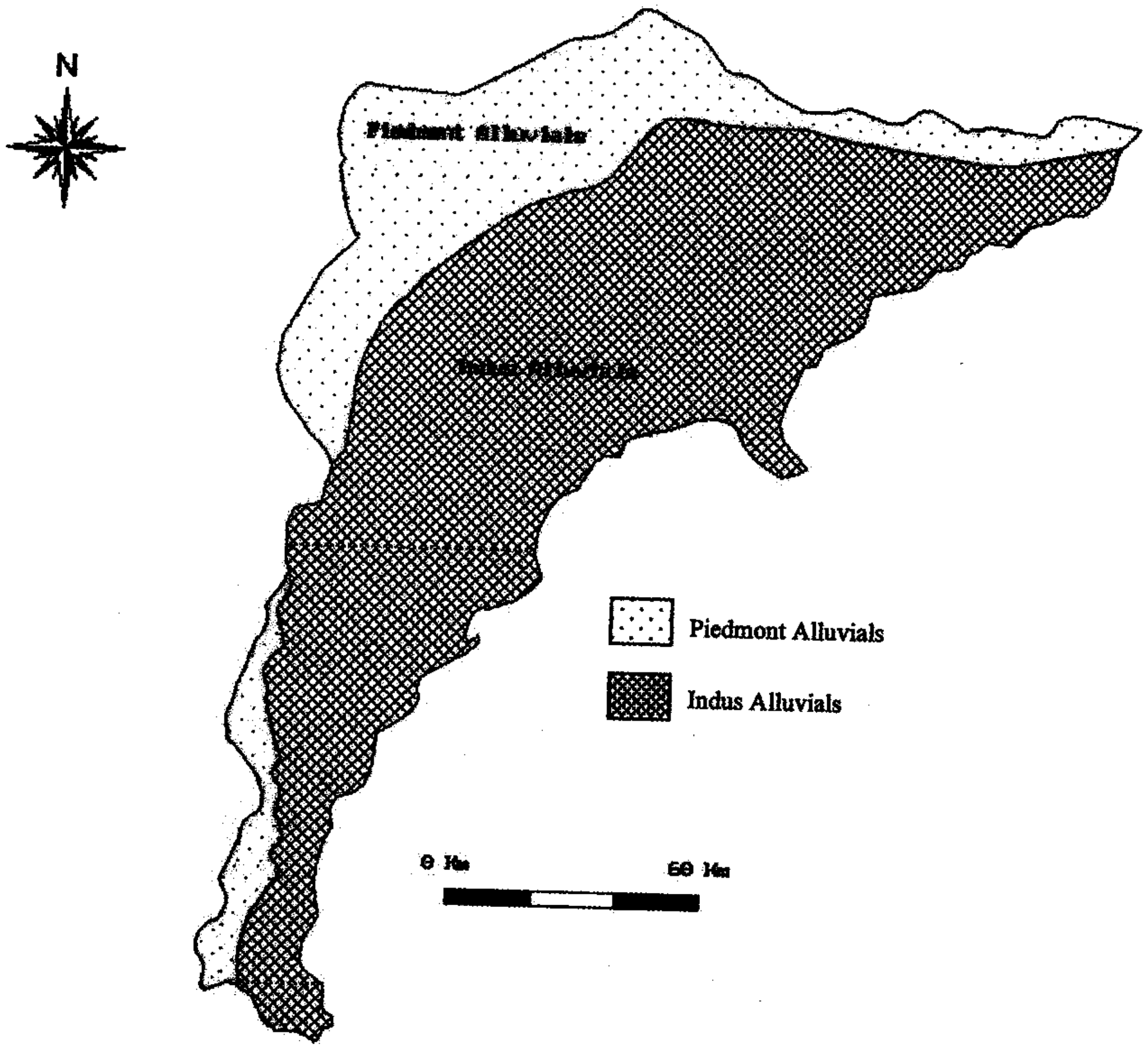


Figure 27. Major Soil Types across the Lower Indus Basin, Right Bank.

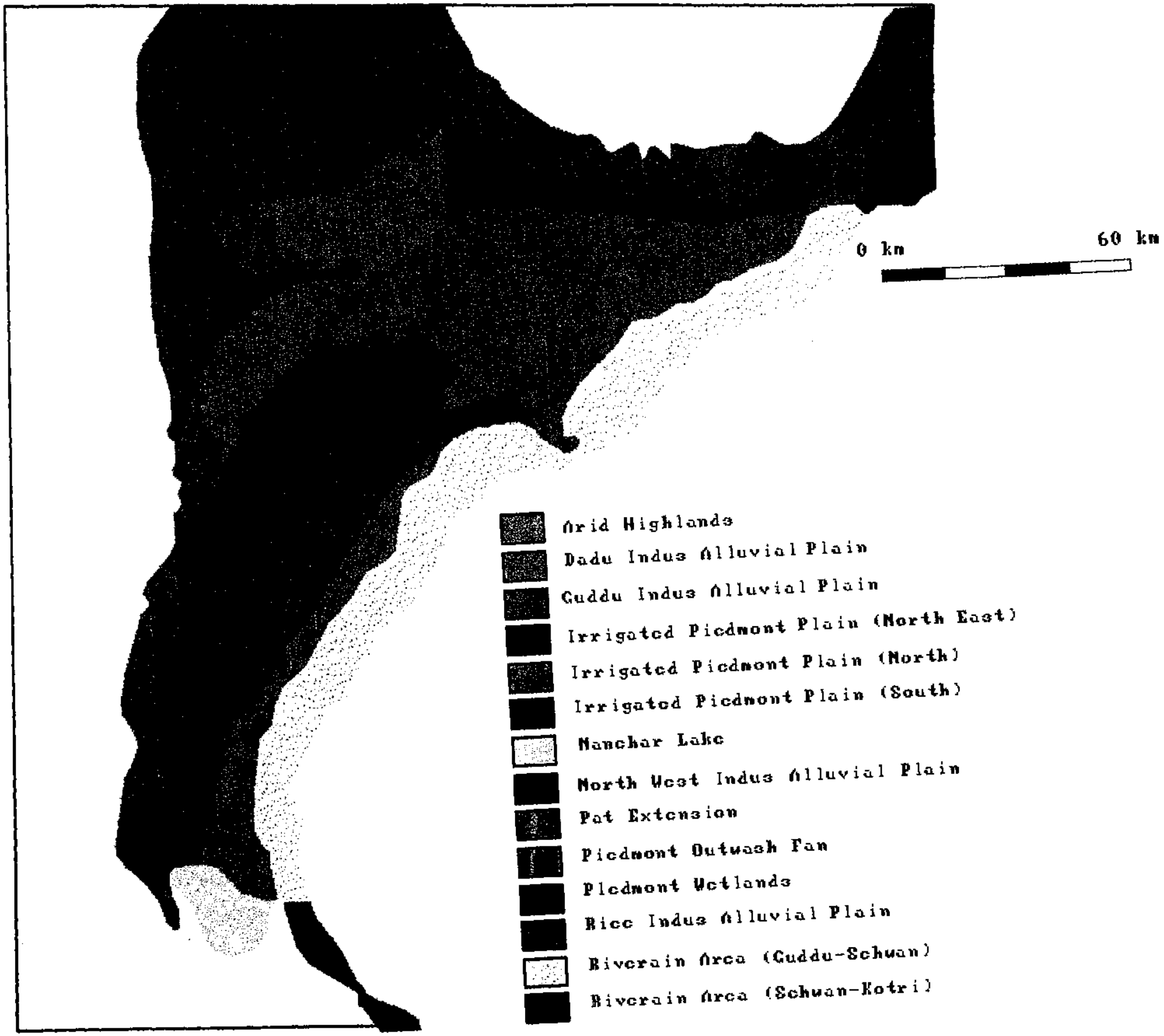


Figure 28. Distribution of Agroecological Zones in the Indus Right Bank, Right Bank Master Plan Study.

flooding occur in shallow land depressions. Soil moisture retention characteristics, depth to watertable and the rate of capillary flux influence water availability for Rabi cropping on these soils. In contrast, water is easily ponded for rice cultivation because of their low permeabilities on the Piedmont alluvials. The watertable remains at depth and there are minimal losses to deep percolation.

Some Piedmont alluvials are virtually undrainable since they have low hydraulic conductivity and infiltration rates. As a result, pre-wetting of land for wheat cultivation commences well before the sowing time: water stands on the field for several days after irrigation, resulting in high evaporative losses.

Consideration of the large volumes of water used to raise the watertable to the surface require that the suitability of the soils for rice production be assessed assuming that this practice was to be discontinued. For this situation, the RBMP classifications for permanent limitations to rice production take cognizance of the presence of perched watertables and soils, which could, if necessary, be easily puddled and have low hydraulic conductivity. Results specific to this classification indicate 21 percent of the area being most suitable for rice production. These areas were associated with deep and very fine piedmont soils, including those considered uneconomic to drain for other arable crops. Of the remaining area, 60 percent are moderately suitable and the remaining marginal to unsuitable. However, if current practices of rice cultivation are retained then the areas highly suitable for rice increase to 54 percent; the increase being exclusive to the alluvials and not the piedmonts, where allocating a greater proportion of the most suitable soils to rice would necessitate more stringent control on both water and salinity management.

C. Farming

The Indus Right Bank has aproximately 9 percent of the country's irrigated area and grows at least 40 percent of the overall production of rice and 6 percent of wheat. Relatively smaller contributions are made towards cotton (< 1% of the national cropped area) and sugarcane (< 2% of the national cropped area). Historically, the areas under major crops have increased in lieu of the increased availability of supplies from the canal system, as explained above. The temporal comparison for this areal expansion, accompanied by concurrent yield increases, is shown in Table 7. The related impact on increased production is owed largely to these areal increases, but there are other factors such as extensive adoption of high yielding varieties, the wider use of agricultural chemicals, widespread use of mechanization for land preparation and threshing, and changes in canal operating periods. The high rate of population growth has provided a powerful stimulus to more intensive agriculture.

Table 7. Temporal Changes in the Average Yield of Major Crops on the Indus Right Bank.

Area in 000 ha, Yield in Kg/ha

Crop	1963/64		1989/90		1997/98 (IIMI Sample Survey)	
	Area	Yield	Area	Yield	Area	Yield
Wheat	219.9	995	552.9	1430	435	1344
Cotton	1.1	415	17.11	760	6.5	-
Rice	530.1	1750	807.9	3360	1008	3794
Sugarcane	4.7	18400	4.5	38000	42.7	50243

The farming zones identified in the Right Bank Master Plan study are characterized by high rice and wheat cropping intensities in the head reaches of the canal systems where timely and adequate supplies are favorably ensured. Tail portions of the Dadu Canal command benefit from available Rabi supplies to the extent that seasonally cultivated areas are higher than in Kharif, whence dry foot crops are grown, including sugarcane and cotton. Increasing Kharif supply to the Dadu Canal could jeopardize production of non-rice crops in Kharif due to rise in the water levels. Farming zones further west suffer from late and erratic supplies that prevents extensive rice cropping with a concurrent impact on Rabi cropping. These are the areas where oilseeds could be promoted in preference to sorghum and fodder crops, particularly in Piedmont alluvials where low hydraulic permeabilities would inhibit post-rice cultivations. Additionally, soil salinity in these soils could be overcome through frequent, but relatively small applications of irrigation waters to promote slow but persistent leaching of salts.

Rice is the predominant Kharif crop on the Guddu Sukkur Right Bank, with a cropping intensity exceeding 77 percent (IIMI Survey, 1998). Wheat dominates Rabi cropping because of favorable financial returns and because it is an important staple crop. Minor Rabi crops include oilseed, chick peas, field peas, leguminous fodder and vegetables. The entire *Rabi* cropping benefits from the residual moisture from the preceding Kharif season cultivation of rice. Minor crops predominate the Rice canal command, while wheat is largely grown where Rabi water is supplied (Begari, Desert and North West canal commands). The Kharif and Rabi farm level cropping intensities are 84 percent and 72 percent, respectively. The comparable figure for the Kharif cultivation intensity, as determined for the RBMP Study through image interpretation, is 79 percent (Figure 29).

Water requirements in Kharif are dominated by the cultural practices associated with rice, in particular the raising of the watertable to ground level in the Indus alluvials to create ponded conditions. Figure 30 shows the watertable fluctuation in a wheat and rice cropped field in the North West Canal command. The watertable is typically maintained at ground level from July-October through high water applications, then allowed to decline. Profile filling (in the Indus alluvials) in early Kharif and crop consumptive use are the major

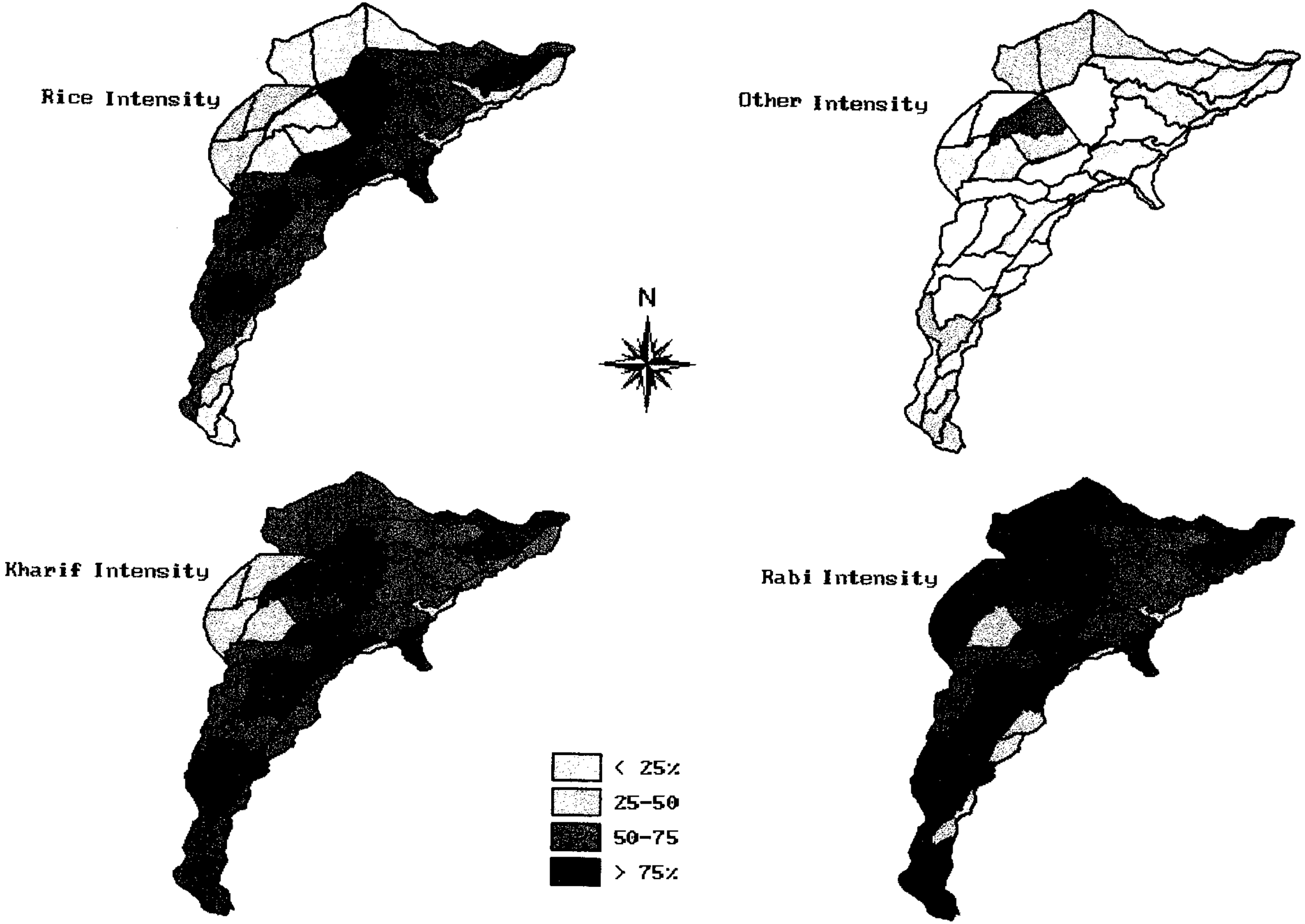


Figure 29. Cropping Intensities During 1989 across the Lower Indus Basin, Right Bank

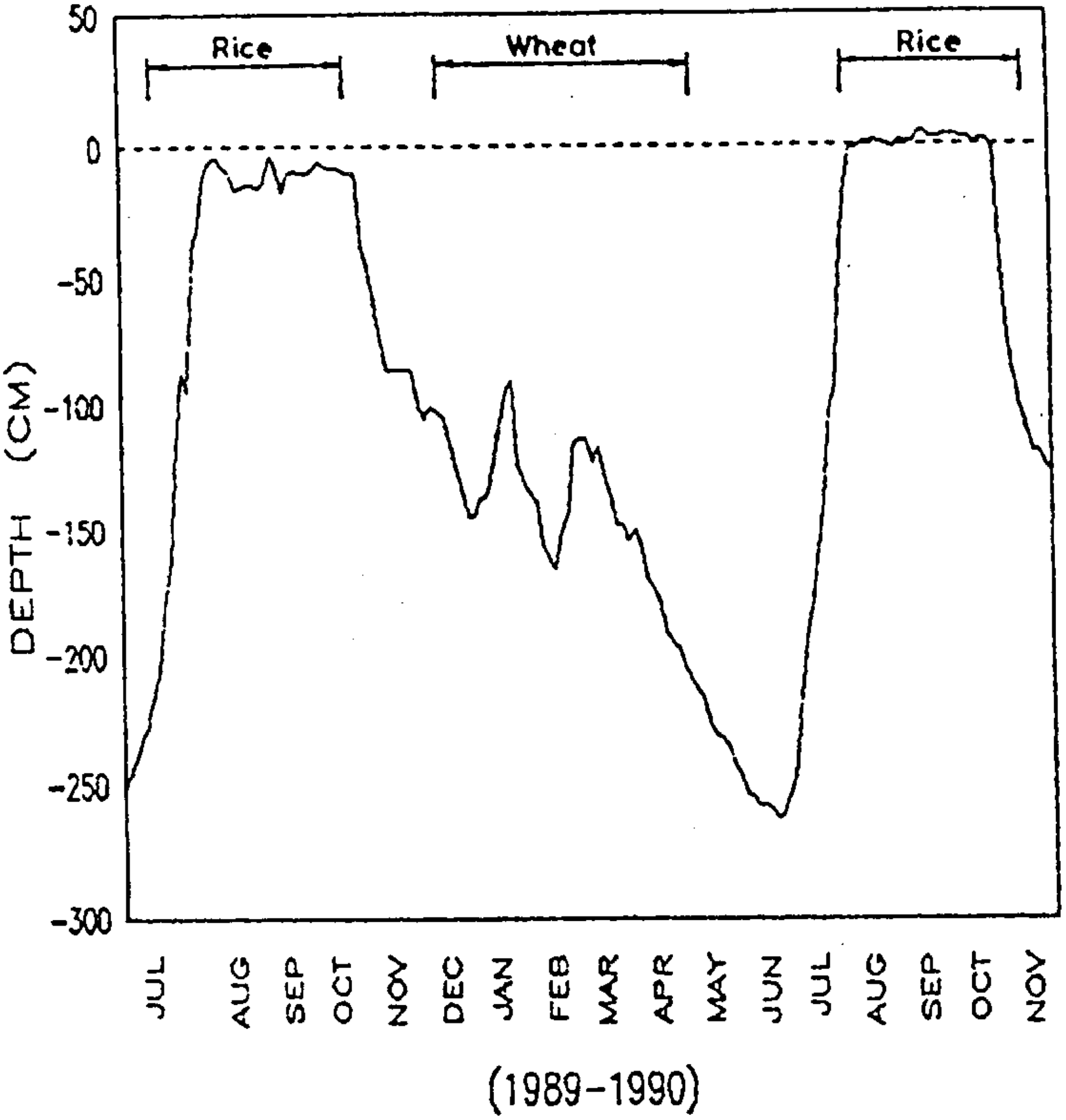


Figure 30. Typical Watertable Fluctuations in the Indus Alluvials.

components of rice water requirements. In the Piedmont alluvials, profile filling is not required to create ponding, but sustained deep percolation losses do occur. Their initial infiltration rates are high, averaging from 1-5 mm/hr over the first four hours due to adsorption and disappearance/lateral flow of water into surface cracks; swelling of the clays then causes the rate to drop rapidly.

Under the existing system of farming and support services, there is less reason to believe that the rice-wheat cropping will change in favor of other rotations. Farmers respond to their local circumstances in terms of both the potential of their lands and their prevailing economic situations. A consideration is that diversification away from existing cropping patterns will come about only when farmers are made more aware of alternative crops combined with the provision of input supply and marketing services that compete favorably with those of rice and wheat.

D. Subsurface Water Levels

Based on the bi-annual monitoring of piezometers for both pre- and post-monsoonal changes in the depth of watertables, the fluctuations generally remain within 1.5-3.0 meters. Deeper watertables are found in the piedmont areas where the seasonal rise is usually below the root zone. Critically waterlogged regimes occur within the Shahdadkot/Ratodero area, Warah and South Dadu areas in the Sukkur command and Hairdin in the Guddu command. The geographic distribution of these variations is accounted for in the temporal comparison of average yearly waterlevels occurring within the Watertable Units defined for the RBMP study. These Watertable Units (Figure 31) were delineated closely along irrigation subdivision level administrative divides on the Right Bank. This data was provided by the IPD (at an observation density of 1 site per 10 sq. km) and WAPDA SM (South) (density between 15-100 sq. km per observation point). Not only is the network of these observation points sparsely distributed (Figure 32), but the frequency of sampling also leaves remissions towards adequate coverage across time. This can be judged from Figure 33's histogram of past biannual observations by the SM (South) between Oct. 1984-Aug. 1997 for the entire Sindh Province. For the RBMP, this lack of coverage was made up by grouping the observations provided by both the IPD and WAPDA within the Watertable Units. Figure 34 illustrates these changes at five-year intervals, which indicates that there was a rise in the watertables until around 1980, particulalrly in the Bhan and Sehwan Units in the Dadu command. This data could be benchmarked against previous reconnaissance level surveys by WAPDA MPR Division between 1976-79, wherein both surface and critically waterlogged areas had been delineated (see Figures 22 and 23 above).

E. Soil and Groundwater Salinity

Soil salinity conditions are different in the two types of soils within the Right Bank, i.e. the Indus alluvials and the Piedmonts further to the north and west (see Figure 27 above).

Figure 31. Watertable Units in the Right Bank Master Plan Study, Lower Indus Basin.

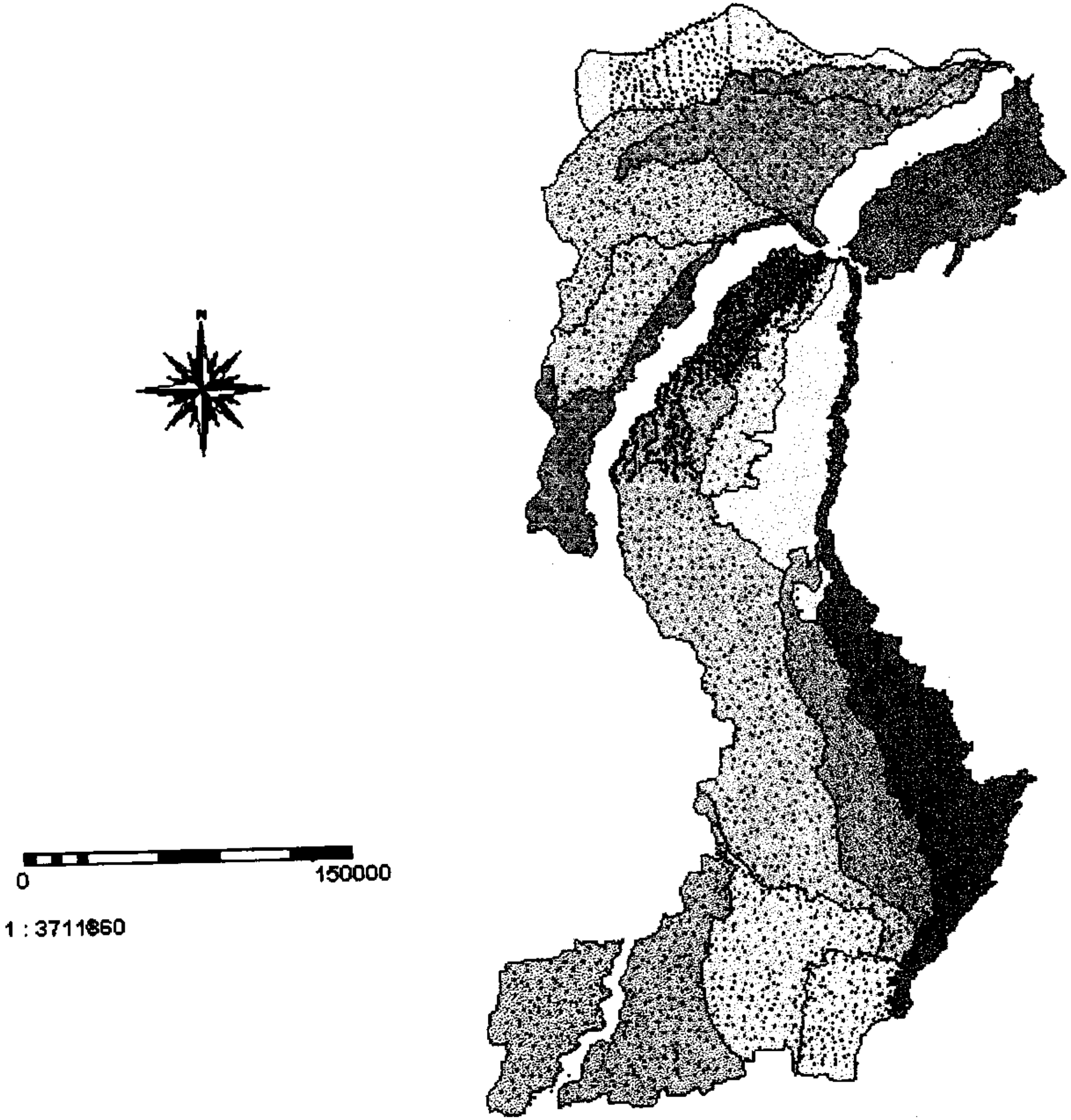


Figure 32. Location of WAPDA Installed Piezometers within the Lower Indus Basin Irrigation System, Sindh Province, Pakistan.

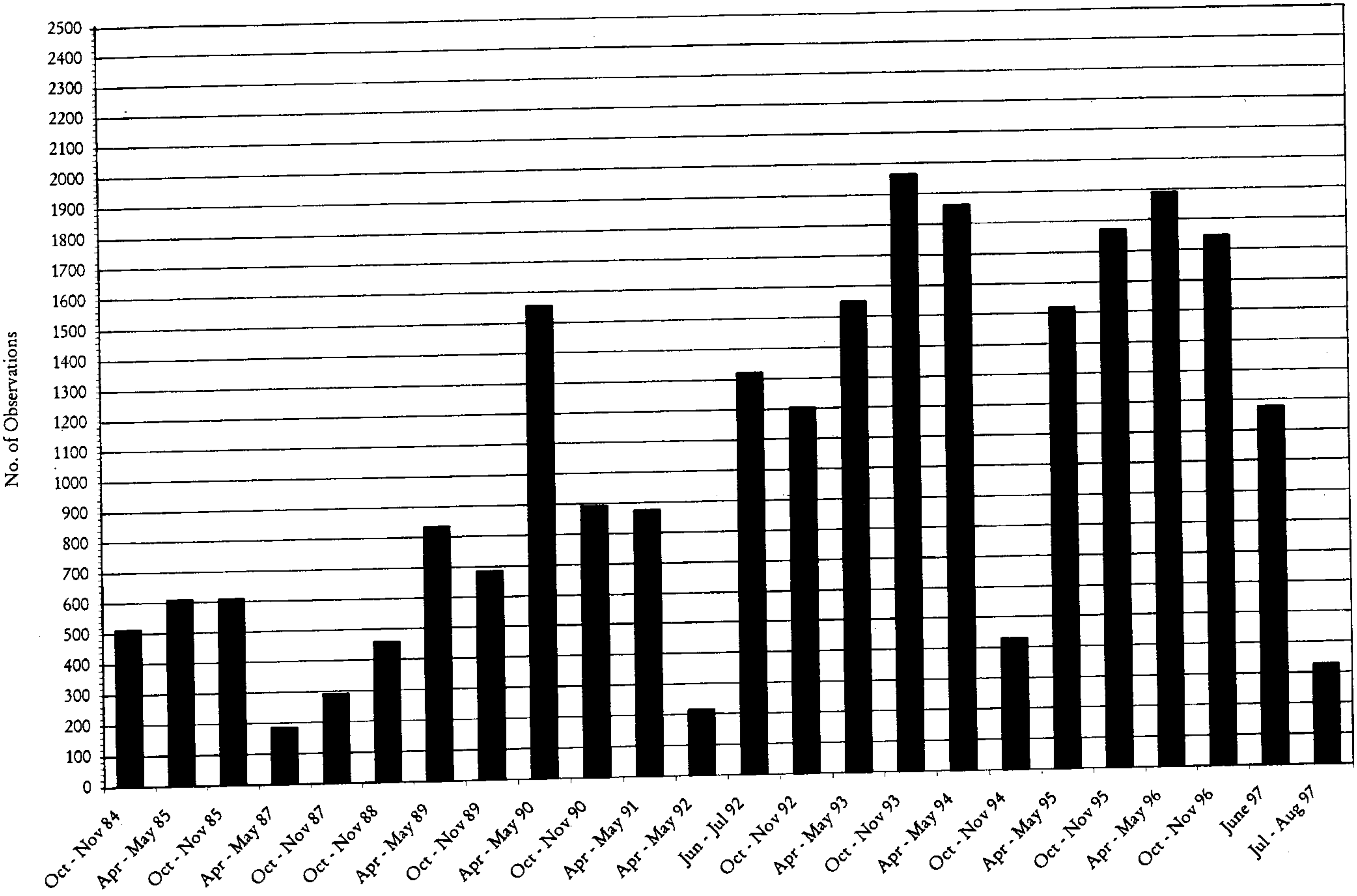


Figure 33. Frequency of Sampling across the Installed Base of WAPDA SCARPs Monitoring (South) Piezometers within the Sindh Province.

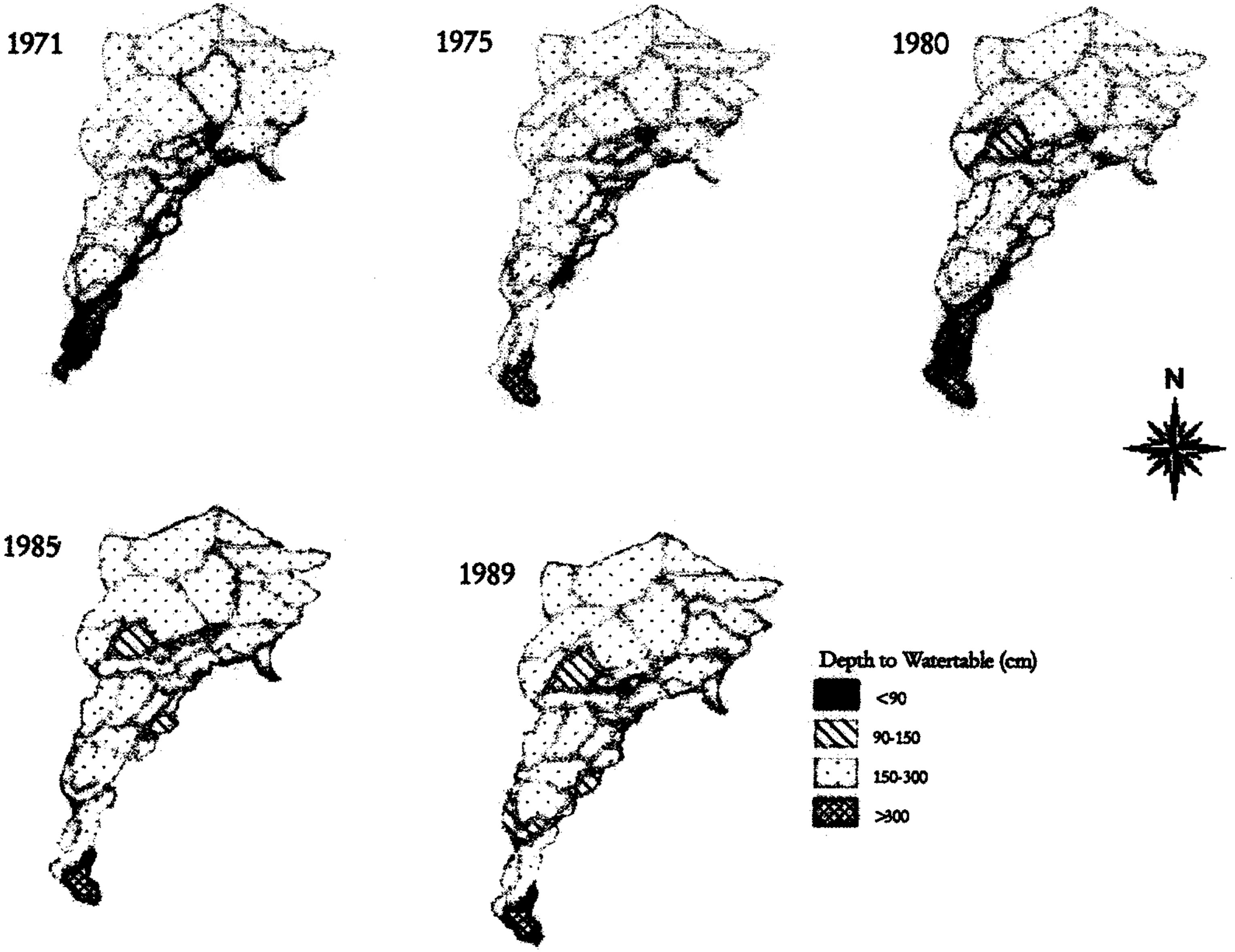


Figure 34. Temporal Comparison of Mean Annual Depth to Watertable across wer Indus Basin,Right Bank, Sindh , Pakistan.

Salinity in the Indus alluvials arises from secondary salinization caused by capillary rise from the watertable. Salt concentrations, therefore, are highest at the surface and decrease with depth. By contrast, the Piedmonts are naturally saline as a result of salt depositions from the surrounding hills. Salt concentrations in these soils increase with depth from recurrent leaching. As part of the RBMP study, satellite image interpretation of SPOT multispectral data for the year 1987 is given in Figure 35. Land use interpretations show the incidence of abandoned lands to be strongly correlated to high levels of soil salinity.

Contiguously irrigated areas are less likely to suffer from salt build-up due to continuous leaching enforced by rice cropping during Kharif; each irrigation leaches salts and increases the availability of soil moisture to the crop. One Rabi irrigation in December or February, where there was none before, would boost the wheat yield by 200-300 kg of grain/ha (MMP/HTS, 1990). Data from the RBMP Study watercourses has shown that a pre-irrigation was necessary and was always supplied where a fallow wheat rotation was practiced, but was rare for a rice-wheat rotation.

The Right Bank alluvials are underlain by an areally extensive, fairly homogenous unconfined sand aquifer that reaches a depth of more than 300 meters near the river. Aquifer storage coefficients vary widely, ranging from 0.005 to 0.43, and indicating the local occurrence of semi-confined aquifer conditions. The aquifer is overlain by a surface layer of between 3-5 meters of variable material with silt and clay predominating. The lower surface of the aquifer is formed by impermeable tertiary clay and limestone formations. In between, the proportion of sand predominates to 80 percent or more throughout the area. Near the river, surface clays rarely attain a thickness of > 3 m, whereas 7-13 m thicknesses are more common elsewhere. Maximum clay thicknesses occur at the margins in the north (> 15 m) and in the isolated pockets in the south near Nasirabad, Mehar and to the west of Dadu (20-30 meters). The salinity of the aquifer increases with depth and distance from the Indus River; however, within the fresh groundwater zone, there are areas where the salinity is as high as 3.5 mS/cm. As an exception to the geographical distribution, fresh groundwater lenses occur within an otherwise saline groundwater environment of the Begari Canal command.

Exploratory drilling has confirmed the presence of saline groundwaters throughout the Right Bank; fresh water zones are typically associated with the river Indus (Figure 36). The quality becomes worse with increasing depth in the alluvial sequence and with distance from the river. The saline groundwater is NaCl type and is unsuitable for irrigation or for drinking purposes; the fresh groundwater comprises the bicarbonates of Ca/Mg/Na with the proportions of cations being quite variable. The occurrence of clay and gravel horizons in the profile locally create anomalous vertical transitions, either in the form of extreme increases in salinity over relatively short depth intervals or the occurrence of less saline water beneath more saline.

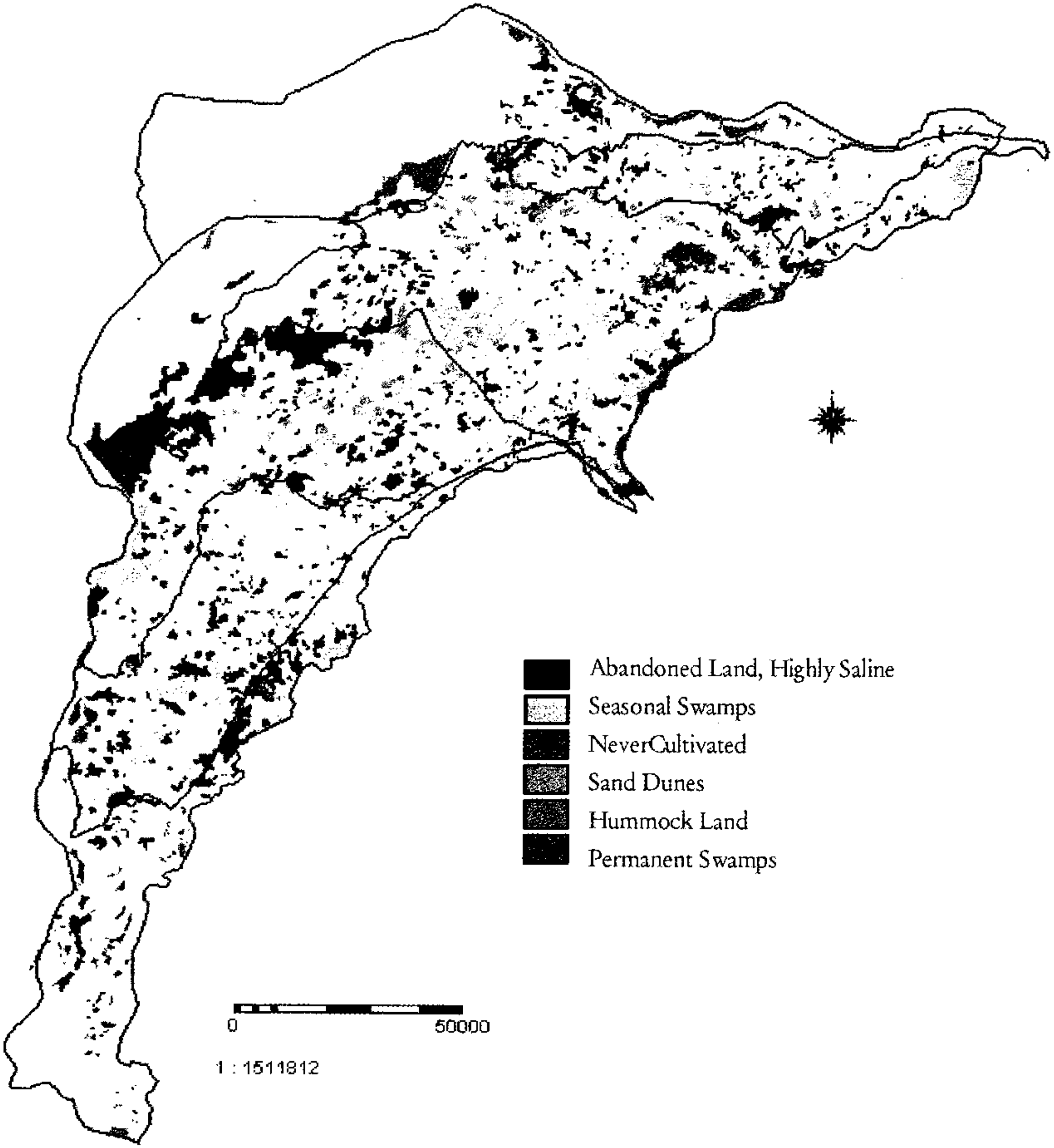


Figure 35. Land Use Interpretation of Spot Multispectral Image Data Coverage for the Year 1987, Right Bank Master Plan Study , Lower Indus Basin.

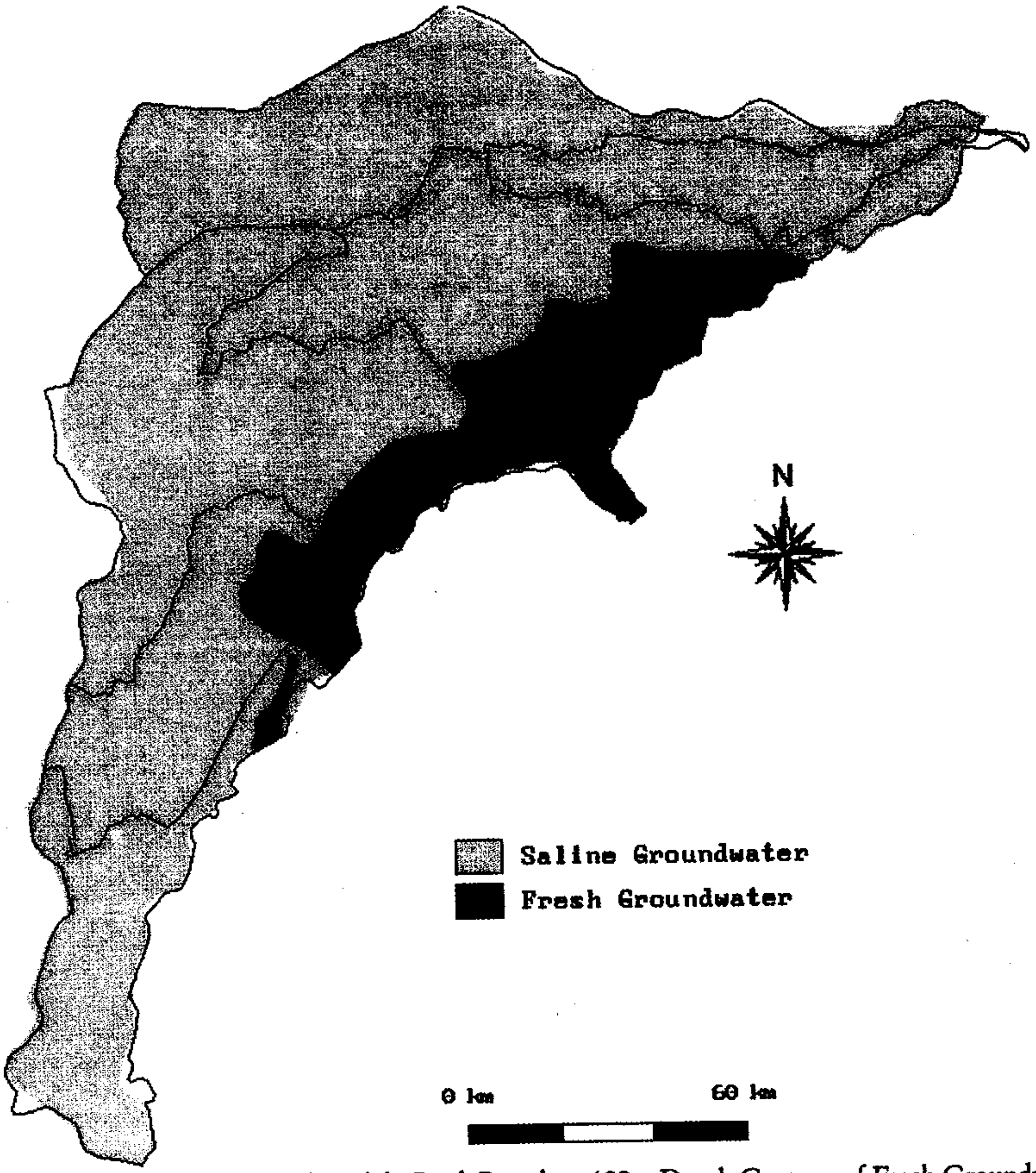


Figure 36. Groundwater Quality Distribution in the Indus Right Bank Based on 100m Depth Contour of Fresh Groundwater Zone.

F. Groundwater Development

The total volume of deep, shallow and marginal FGW areas is estimated to be 13.4 Mhm. Prospects for significant fresh groundwater development within the Right Bank are, to a large extent, dependent upon sustained recharge and the ability of the aquifer to transmit the displaced water. The lenses that are associated with major irrigation canals have developed under concentrated line recharge sources in highly transmissive aquifer sections. The earliest public sector ventures towards fresh groundwater harvest for irrigation, land and urban drainage started during the 1970s. These were based on the geographical distribution of the recommended development plan in the LIP Report (Figure 37). Schemes like Kandhkot, Sukkur, Shikarpur, Larkana and Ratodero comprise tubewells typically of 56 lps capacity. With time, the abstractions from over 500 SCARP wells have continuously been on the decline and is expected to be between 12,000-14,000 Hm.

With the exception of wells installed near towns to protect building foundations, it appears that SCARP tubewells in the Guddu-Sukkur Right Bank have not been very successful (many of the wells have had utilization fators < 20%; see discussion on pilot projects). Reliable figures on the number of private tubewells operating withtin the Right Bank are not available; at the time of the RBMP study, some 4,000 private wells were in operation, each servicing an area of about 5 ha. This development has been stimulated largely by the perceived benefits of establishing rice nurseries early, in advance of surface water availability. Supplying the small quantities of water required for nurseries for 20-30 days in early Kharif is not possible through the canal system due to difficulties of command and equitable conveyance when flows are smaller than designed for. The private wells' average discharges are about 21 lps with an operating factor of 16 percent.

Whilst all public tubewells have been constructed essentially within deep FGW areas, many of the private tubewells extend into shallow and even marginal areas. Although tubewells are typically < 30 m in depth, no widespread deterioration in water quality, such as might be expected from upconing, has been reported. Increased anisotropy, between 30-50 m is the likely cause for the suppression of upconing. In general, moderate to high lateral permeabilities and cumulative sand thicknesses within the uppermost 65 m of the aquifer are favorable to efficient and large scale abstraction by tubewells.

Unfortunately, area with the greatest FGW development potential is largely coincident with areas that have maximum benefit from the available surface water supplies. Conversely, tail areas of canal commands have limited or no access to fresh groundwater. Hence, in the absence of any control on water use or the balancing of groundwater and surface water resource exploitation, whereby there are benefits to be had from early rice transplants and cultivation of Rabi cash crops, it is likely that the current mode of operation of private tubewells will remain.

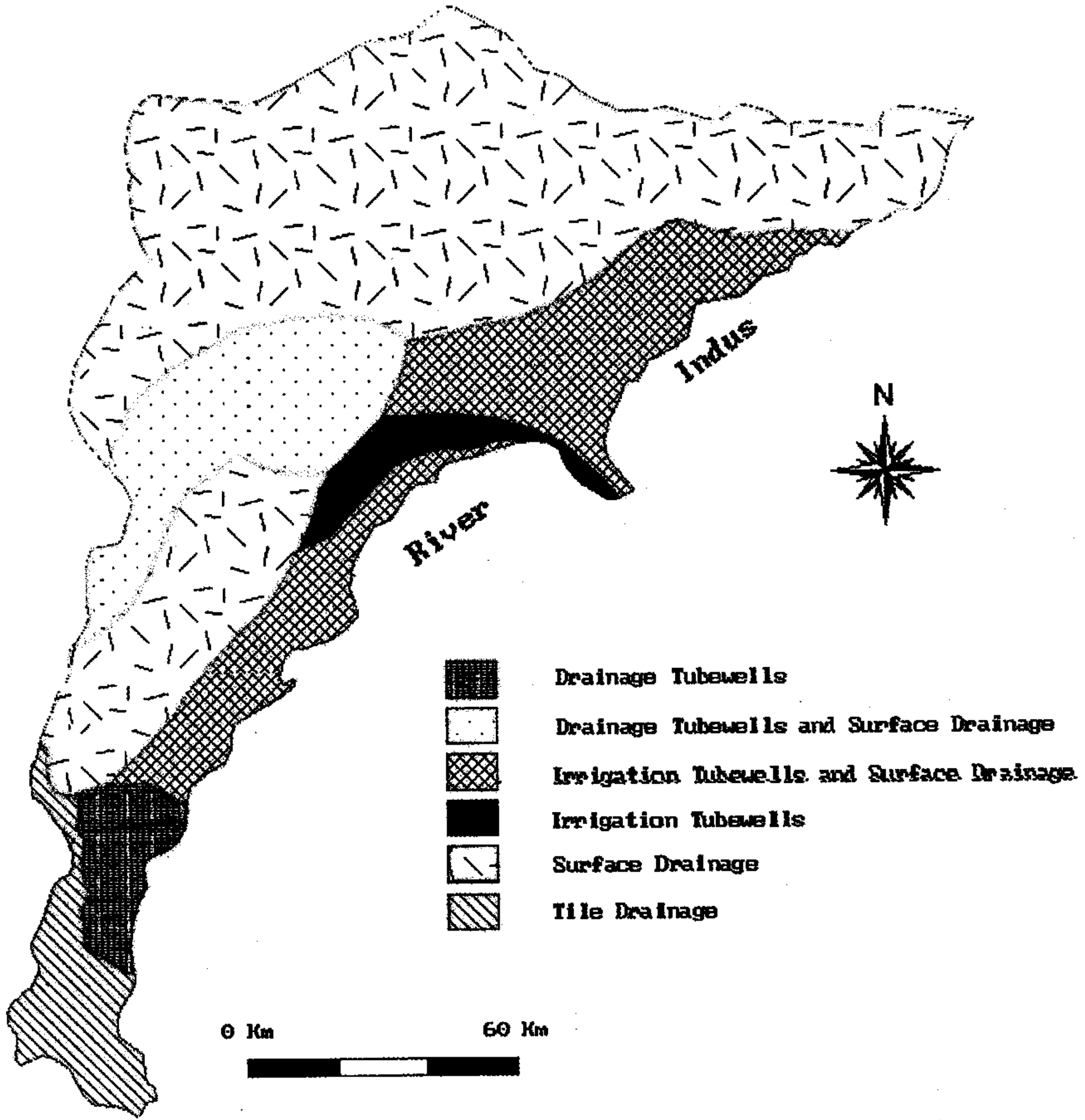


Figure 37. Drainage Strategy for the Indus Right Bank Based on the Recommendation of the Lower Indus Plan Report, 1966.

G. Drainage

To date, the major planning initiative for drainage on the Right Bank is the LIP Report. In the early sixties, rice cultivation was limited principally to the Rice canal command. In other areas, other Kharif crops were more significant. The Report put great emphasis on the provision of drainage for dry food crops. For dry food crops it was observed that a fixed depth to watertable should be maintained by means of controlled drainage to achieve maximum yields. This would be achieved by means of sub-surface drainage. A generalized safe watertable depth was adopted for each major crop, as given below. The additional requirement was to minimize salinization in fallow lands.

Wheat	1.05 m
Cotton	2.10
Sorghum	0.90

Surface drainage was deemed to provide major benefits to the rice growing areas where the yields were affected by both saline groundwater and stagnant surface waterlogging that preempted application of flushing doses of irrigation waters. Minimizing stormwater drainage was seen as a second, but major justification for surface drainage. Consequently, the LIP drainage strategy encompassed the following:

> *For perennial areas, tubewell installations to maintain the watertable at a depth of seven feet, or tile drainage to achieve a minimum depth to the watertable of 4 feet.*
>
> *For rice growing areas, surface drainage with a capacity of 1.5 cusecs per sq. mile.*

In the years subsequent to the planning contained for drainage in the LIP, rice has emerged as the major cash crop of the entire Lower Indus Right Bank. Consequently, the stress on waterlogging, being the bearer of depressed crop yields, has given way to the removal of excess irrigation and storm water, and improving the soil water conditions in the root zone.

IV. IRRIGATION MANAGEMENT---THE GROWING IMBALANCE

A. The Nemesis of Intensive Agriculture

As already stated, it was known in 1932 that the Sukkur Barrage command would eventually require drainage, but with the deep watertables prevailing at that time, it was not an immediate consideration. By 1959, however, the situation had become serious and consultants were engaged to study the position in Khairpur, the northern-most area of the command. Concurrent relief was also to be provided to areas in the Kotri command where a surface drainage system was subsequently constructed. Following completion of the consultant's report, a drainage project was undertaken with the assistance of the World Bank. The study area was extended to eventually cover the whole of the Sindh Province in what became known as the Lower Indus Plan, a comprehensive examination of irrigated agriculture in Sindh.

The LIP Report consists of a Main Report comprising the regional development plan and an analysis of its costs and benefits. The supplementary volumes contain the data collected during the investigations and the supporting volumes analyze this data to develop the criteria on which the development plan is based. The plan provides for extensive remodeling of the canal systems and pumping of fresh groundwater for the increased supplies to meet intensified cropping. The increased water applications to the land in turn make the planned provision of drainage essential even where salinity and waterlogging are not a problem at present. Where there is a suitable aquifer and the groundwater is fresh, increased irrigation supplies are provided by the installation of tubewells pumping directly into the irrigation system. These tubewells provide the required drainage. Where the groundwater is saline and cannot be re-used for irrigation, tubewells still provide the most economical means of drainage. The whole area is divided into 28 parts (Figure 38) under the following categories:

i) Perennial fresh groundwater;
ii) Non-perennial fresh groundwater;
iii) Perennial saline water; and
iv) Non-perennial saline water;

Figure 39 shows the salient features of the development plan for the Left Bank in terms of estimated targets for the cropping intensity, watercourse head discharges and drainable surplus. These are the Left Bank areas where nearly two decades later one of the most ambitious public sector drainage projects was undertaken in the form of the Left Bank Outfall Drain (see Supplement I.D of this report). Meanwhile, in the years subsequent to the LIP-recommended strategy for development (Figure 40), the GoP completed drainage works in many of the areas, the need being governed mostly by the progressive threat of waterlogging and salinization that seemed to have exacerbated with time. Table 8 gives a list of the completed drainage projects on the Right Bank. A brief discussion on some of the more important of these completed drainage schemes is provided in Section V.

Priority was given to the projects in fresh groundwater areas, where tubewells could be easily installed to provide both, increased irrigation water and drainage, and concurrently realize large and early increases in production. The fresh groundwater projects completed subsequent to the LIP Report include the North and South Rohri SCARPs, SCARP Khairpur, Ghotki, Sukkur Right Bank and pilot projects of Larkana, Kandhkot, Sukkur and Shikarpur. Intrusion of saline groundwater into shallow fresh groundwater zones often resulted in the closure of tubewells, since its quality prevented further use for irrigation. Moreover, the decrease in the well pumpage capacity, on average 5 percent per annum,

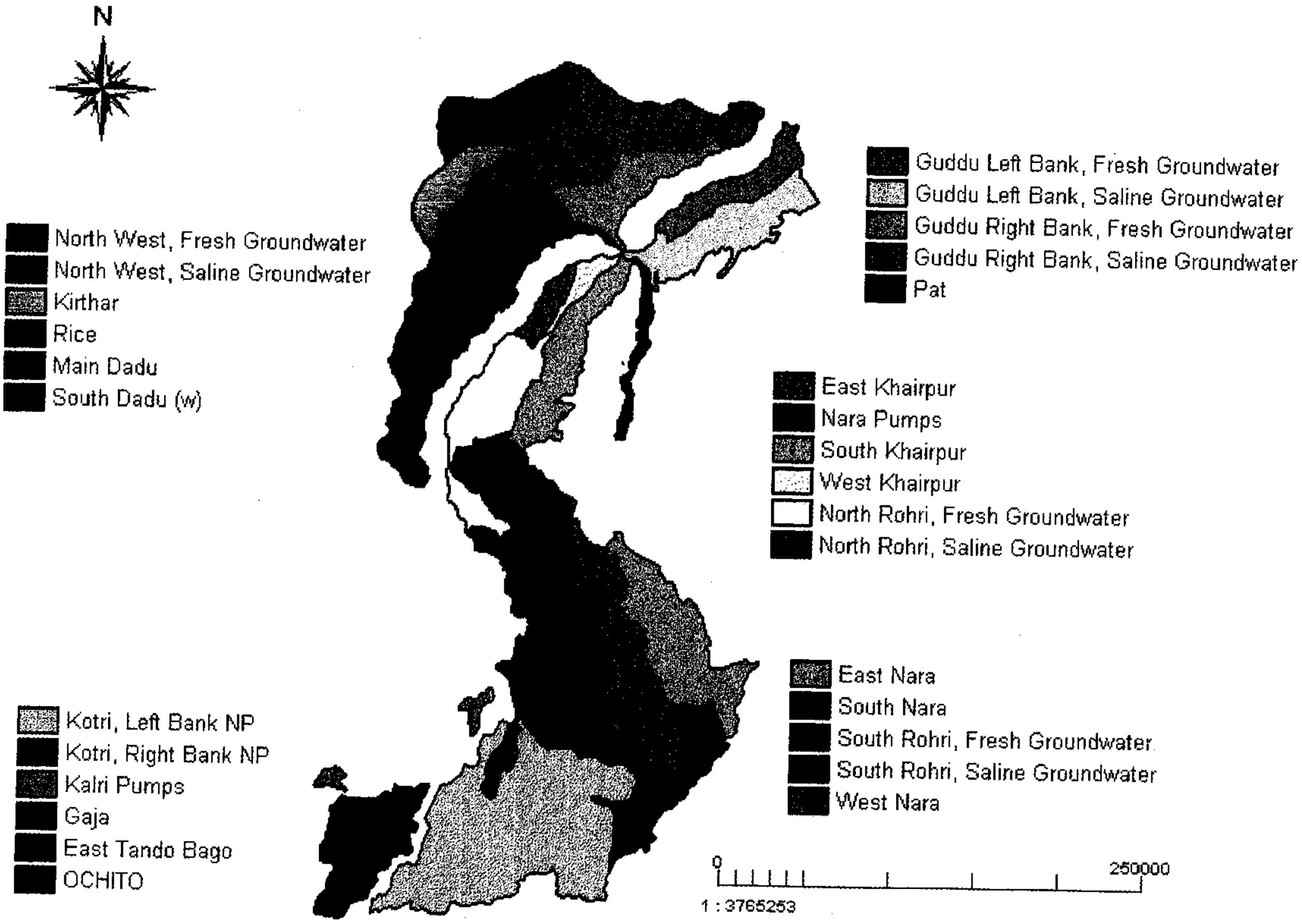


Figure 38. Proposed Irrigation System Development Projects in the Lower Indus Basin, Sindh Province, Pakistan.

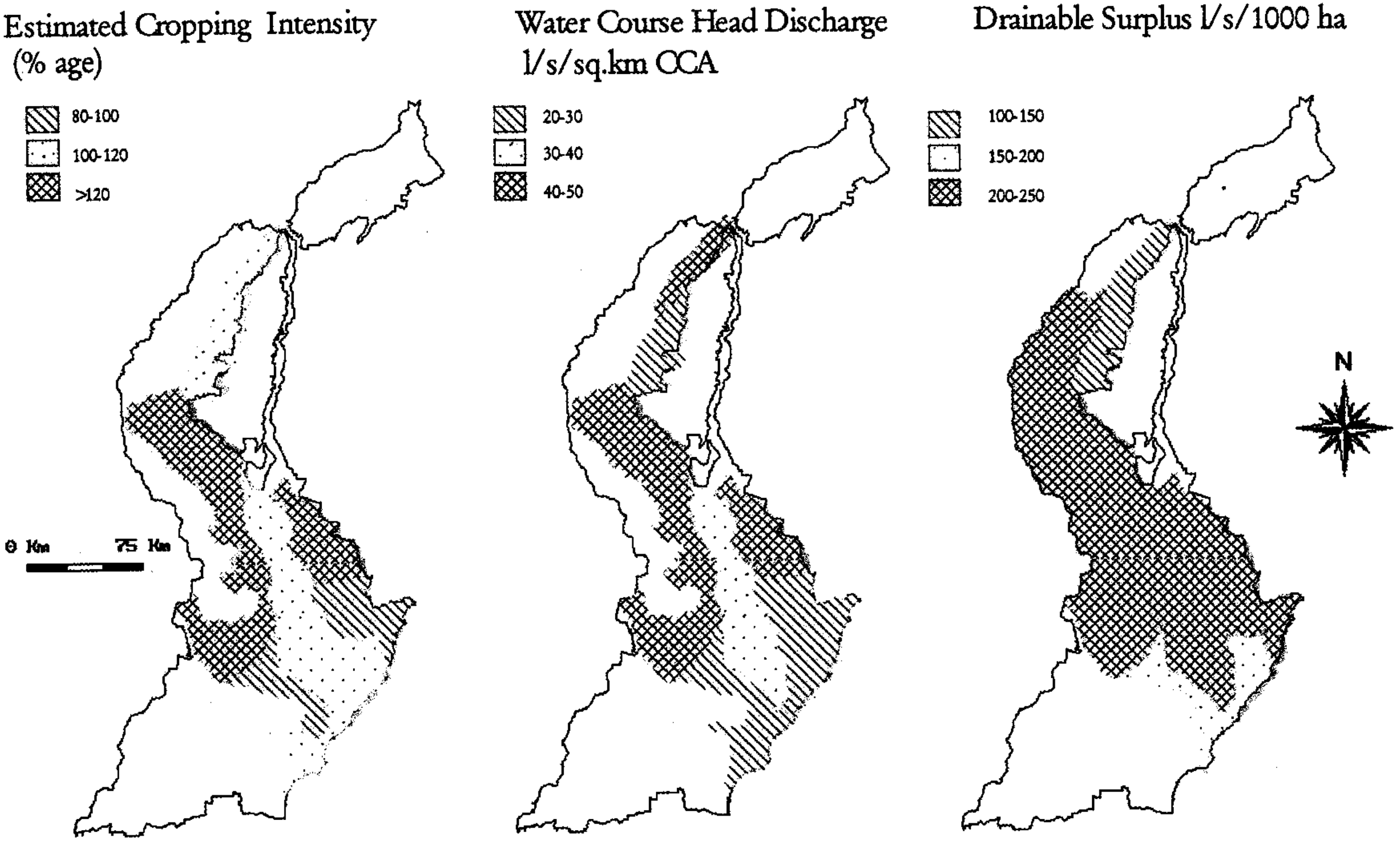


Figure 39. Salient Features of Full Project Development Plan for the Lower Indus Basin, Left Bank, as per Recommendations of the LIP Report, 1966.

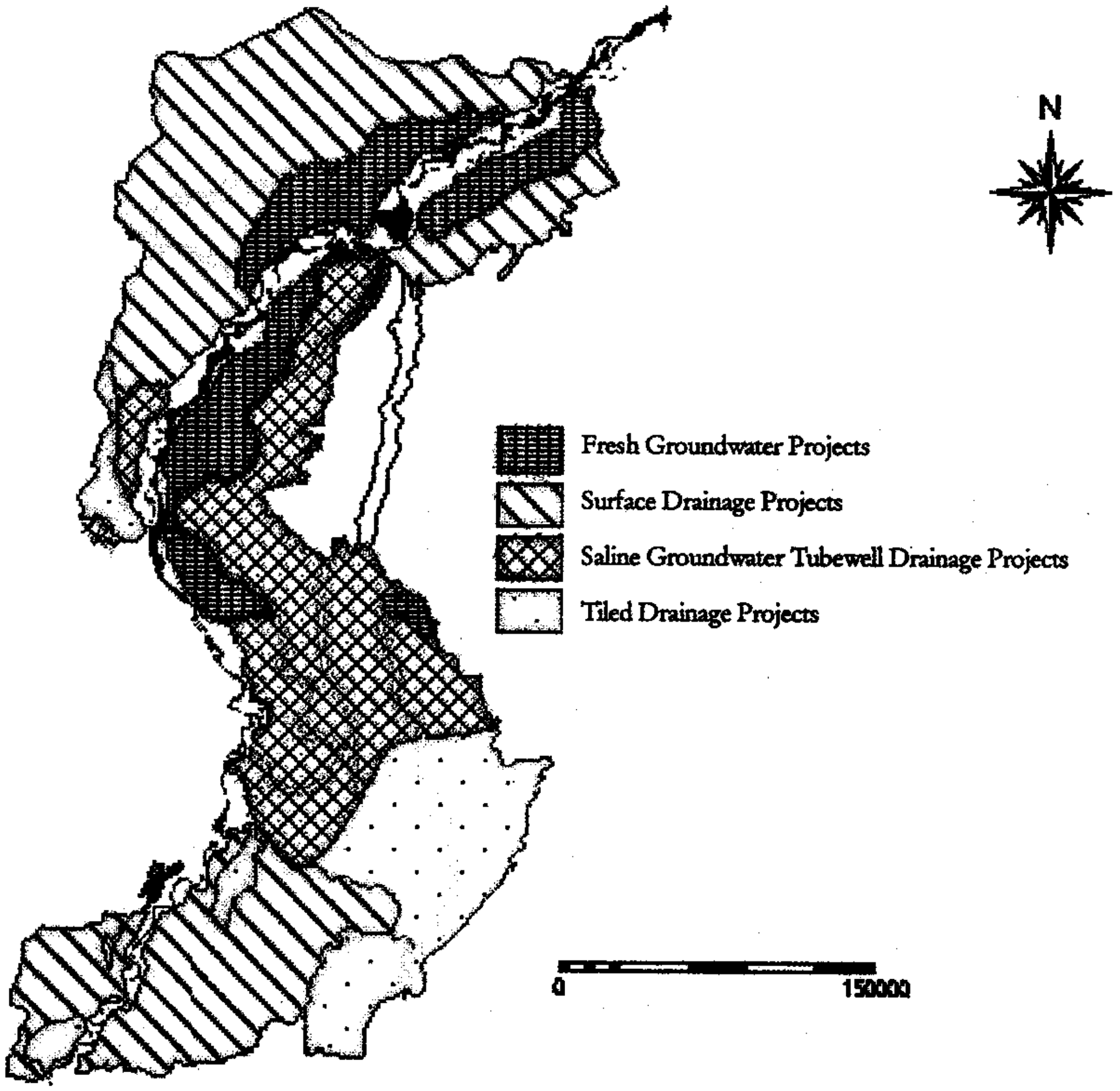


Figure 40. Lower Indus Plan Recommendations for Area Development in the Lower Indus Basin.

Table 8. Public Sector Land Reclamation Schemes in the Lower Indus Basin, Right Bank.

Drainage Scheme	Description
Larkana-Shikarpur Surface Drainage Project	Surface drainage for rice, gross area of 283, 386 ha.
Sukkur Right Bank FGW Tubewell Project	408 tubewells 43 to 85 lps capacity in an area of 60, 703 ha.
Kandhkot Pilot Project	Provision of 26 tubewells of 56 lps capacity and 3 surface drain pump stations for lowering the watertable in an area of 3, 480 ha around Kandhkot town.
Shikarpur Pilot Project	Provision of 50 tubewells 56 lps capacity and 1 surface drain pump stations for lowering the watertable for an area of 7, 071 ha in and around Shikarpur town.
Sukkur Pilot Project	Provision of tubewells for controlling the watertable and supplementing irrigation for an area of 2, 023 ha 6.5 kms northwest of Sukkur.
Larkana Pilot Project	Provision of 35 tubewells of 56 lps capacity for lowering the watertable in an area of 3, 159 ha around Larkana.
Mohen-jo Daro Project	Provision of 26 tubewells of 56 lps capacity to protect the ancient ruins.
Pat Feeder Rehabilitaion and Improvement Project	Provision of surface and sub-surface drainage.
Hairdin Surface Drainage Project I & II	Surface drainage for a gross area of 71, 427 ha (gross area of 75, 677 ha).
North Dadu Surface Drainage Project	Surface drainage for a gross area of 202, 347 ha.
Kandhkot-Thul-Shahdadkot Surface Drainage Project	Surface drainage for a gross area of 859,657 ha of predominantly rice growing land.
Planned Projects	
South Dadu Project	Deep drainage for a gross area of 161, 875 ha.
Warah Surface Drainage Project	Surface drainage for a gross area of 51, 782 ha.
Dokri Surface Drainage Project	Surface drainage for an area of 45, 991ha land between Dadu and Rice canals.
Guddu Right Bank FGW	Development of tubewells for irrigating a gross area of 48, 433 ha which includes part of the Larkana-Shikarpur Surface Drainage Project.

necessitated replacement in some cases within 8 years of original installation; this put the O&M costs at a premium (revenue receipts from reclamation cess were only 20% of the annual O&M). Underfunding of these requirements resulted in further deterioration of the SCARPs performance.

B. Drainage Performance

In addition to the manifest requirements for improved drainage necessitated by the intensified cropping system, the canal network itself has interfered with natural drainage lines and has resulted in the formation of extensive internal drainage basins. A temporally persistent example of this phenomenon occurs in areas of the Indus Right Bank between Shikarpur and Kandhkot and in the vicinity of Mehar. Also, the performance of the drainage infrastructure has been questionable in lieu of poor design, construction and maintainance. The calculations for drainable surplus have had to be revised over the initial constructions (e.g. the Larkana Shikarpur surface drainage has been remodelled to accommodate a four-fold increase in design capacity). Such examples stem from the little or total absence of consultation, between farmers and the agency vested with drainage works, on the typical requirements for drainage. This appears odd given the responsibility of the farmers for field drain construction and maintenance. In practice, field drains are rarely constructed due to a prevailing practice of sequential passover of irrigation flows across contiguous fields.

Management of completed drainage projects and disposal of saline effluent is an issue dealt with separately from the operational aspects of the irrigation network. Often, the distinction between the two is blurred when the effluent is recycled back to the irrigation system. This is typical of the Larkana Shikarpur Surface Drainage Project, where up to 30 percent of the effluent is mostly recycled into the North West Canal, while the remainder is disposed of through the flood protection *bund* at Miro Khan into the Hamal Lake. Less acceptable, is the practice of pumping saline effluent from the Hairdin drainage scheme into the Kirther Branch (off taking from North West Canal). Water users downstream often complain of the poor canal water quality. Issues such as these result in poor coordination between the irrigation and drainage divisions, especially when excess canal flows are being passed over to the drains.

The conventional O&M emphasis is on the operation of the pumping stations; surface drains are difficult to maintain due to a lack of regulating structures. In fact, under the circumstances, such a control would be undesirable since it would add to the complexity of operation in the wake of minimal allocations for O&M (typically < 1% of capital cost). This is compounded by the poor initial standard of construction, so that even the optimal maintenance budgets (estimated to be 2% of the capital cost) are insufficient to keep the infrastructure in an acceptable condition.

C. Coping with High Consumptive Use

For the Right Bank commands, there is generally an adequate supply of water in the river to allow sanctioned allocations to be met during the main Kharif season when the Indus River is in flood. However, during the important early Kharif there is often a serious failure to meet sanctioned allocations, whereby cropping schedules have to be delayed. Part of the problem pertains to the withdrawals that have been checked considerably since the last decade. This is reflected in the share of command deltas for major canal systems in the Sindh Province for the period 1990-96 (Figure 41).

Against these diminishing supplies in a supply-oriented delivery system, the tail portions have been the worst sufferers due to a steady increase in the upstream offtakes, some illegal. Although the IPD operates the main canals to maintain full supply water levels from the head downwards, head end farmers can regulate their water supply by manipulating outlets. In areas of rice cultivation, this practice is rampant and fairly competitive towards the early Kharif soil profile filling requirements (from mid-May up to mid-June at the earliest and up to late July at the latest). This causes gross inequalities of distribution since only the surplus flow (during late Kharif) is passed downstream to the lower riparians. For example, insufficient supply to the Dadu Canal in early Kharif results in significant head/tail inequalities, as supplies decrease significantly towards the tail of the system. Tail farmers have adjusted to this situation by adopting Kharif crops other than rice. Dadu Canal has a good Rabi supply that exceeds requirements; the result is higher annual cropping intensities.

To overcome these shortfalls, greater upstream storage seems to be the only possibility. Otherwise, with diminishing capacity of the existing storages and consolidation of the upstream irrigation schemes, these shortfalls are only likely to exacerbate (Figure 42).

Water management studies, conducted as part of the proposed Right Bank Master Plan, have shown that outflow from the ponded fields was not a legitimate rice crop water requirement. Poor ponded depth control was more significant in reducing potential yield than salinity, and outflows did more to reduce than raise overall crop yields. This is corroborated by the data on Kharif 1990 rice yields in the heads of the Guddu-Sukkur Right Bank systems that were lower (3.6-3.7 t/ha) than in the tails (3.9-4.3 t/ha), the loss being primarily attributed to the flooding in the low-lying fields of the head reaches directly affected by excessive application of water. The shortage of water at the tails meant that most of the high-lying fields were irrigated first where excess waters could be drained to lower-lying fallow or abandoned areas. Thus, the system operation, which reduced the supply to head-enders or persuaded farmers to use less water, should, therefore, increase the average head yield by 0.1-0.3 t/ha. Surface drainage and canal escapes would then alleviate storm water flooding at the tail of the system.

Moreover, increasing intensities of rice cultivation are associated with lesser wastage of water in raising the watertables across the non-cropped, fallow or abandoned land. This

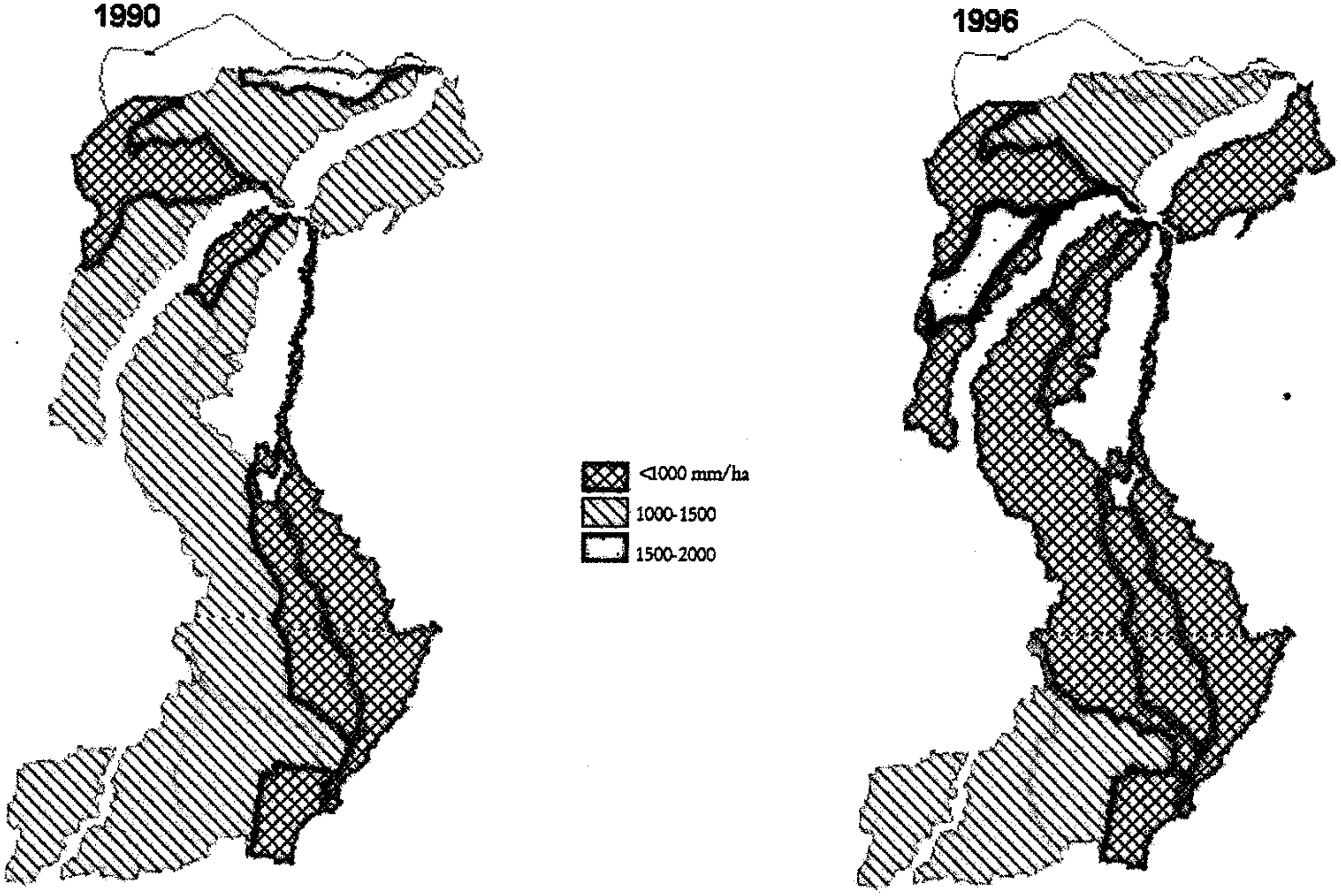


Figure 41. Temporal Comparison of Command Delta in the Lower Indus Basin Plain.

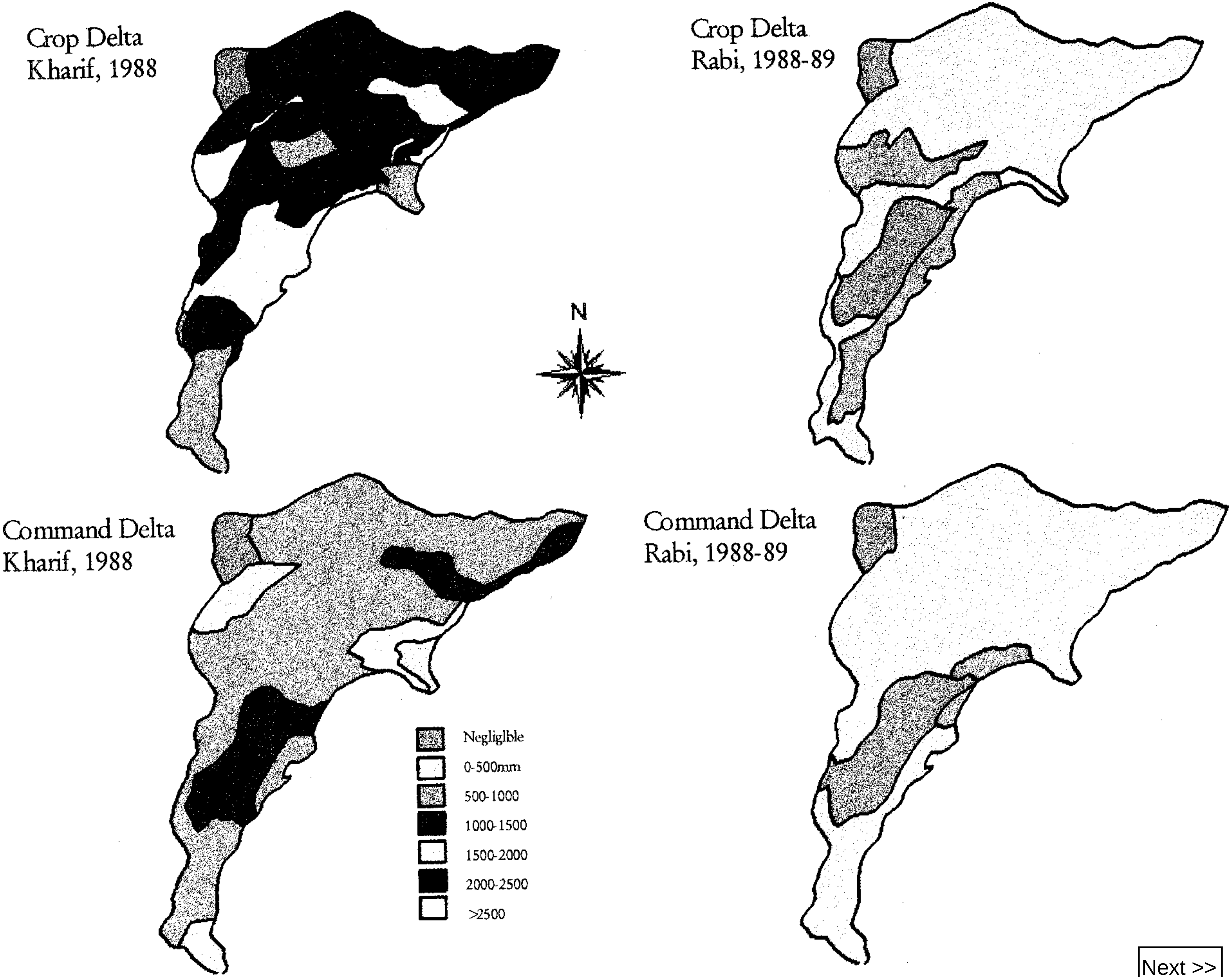


Figure 42. Command and Crop Deltas during 1988-89, Lower Indus Basin, Right Bank.

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would imply that higher irrigation efficiencies tend to be associated with higher cropping intensities of rice across the Indus alluvials during soil profile filling. The estimate is that for a rice cropping intensity of only 30 percent, the total water requirement is 1.93 m (over the cropped area), declining to 1.65 m for an 80 percent cropping intensity. For the Piedmont alluvials, however, the increase is gradual, from 1.62 m (over cropped area) at 80 percent intensity to 1.76 m at 30 percent. This is largely because of the watercourse conveyance losses associated with long lengths of channels that form a greater proportion of water requirement as the cropping intensities decrease.

Throughout the season, 200 mm of water was estimated as required to establish and re-establish ponded conditions, 100 mm of which was subsequently used by the crop and the remainder was released as surface flow. Generally, the perennial canal commands require less water for filling due to Rabi irrigations. Following soil profile filling, seepage from the rice basins to lower-lying non-cropped areas continues. The hydraulic head and soil textures control the rate of seepage or wastage, which can be as much as 20 percent of the net requirements. Figure 43a shows the component-wise breakdown up of the total crop water requirement for rice on *Indus alluvials* at the watercourse head. These calculations are for a cropping intensity of 70 percent over loam soils. The same may be compared with Figure 43b for the *Piedmont soils*, where 100 mm are required for ponding and 890 mm for consumptive use for fairly early planting.

In marked contrast to other Right Bank canal commands, it is the Rabi rather than Kharif water that enters storage. Also, in these tail areas, the sowing of the Rabi crops is not delayed pending drying of the soil profile, especially for areas left fallow during the preceding Kharif season. Both the Begari and North West canal commands suffer from a double disbenefit in that not only are they receiving late and excess supplies during Kharif but there is also the Rabi supplies that further soak up the already wet root zone. This delivery mismanagement is largely thought to be responsible for the depressed agricultural production across these canal commands.

Across the Indus alluvials, for high-lying fields, the watertable declines rapidly at the end of Kharif in November. Here, a quick turn-around from rice into wheat is necessary to optimize the use of stored soil moisture. Labor and/or lack of farm mechanization is a major constraint to a quick turn-around. Many farmers, therefore, over-irrigated rice at the end of Kharif to delay the decline of the watertable towards improving soil moisture availability across time. The converse applies for the low-lying fields (and the Piedmont alluvials), where standing water delays planting of wheat beyond late November with consequent losses of yield.

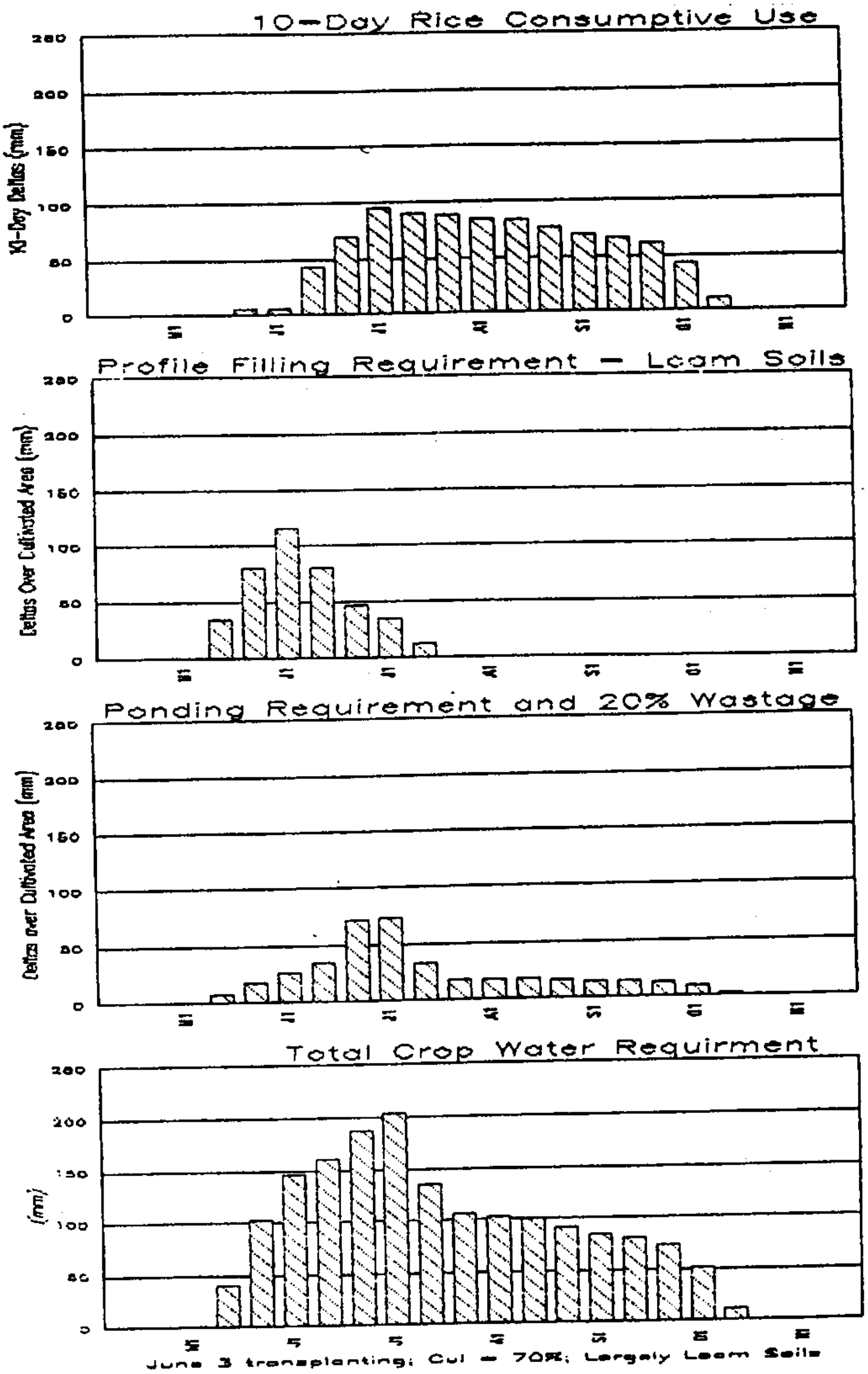


Figure 43a. Crop Water Requirements for Rice on Indus Alluvials, Indus Right Bank.

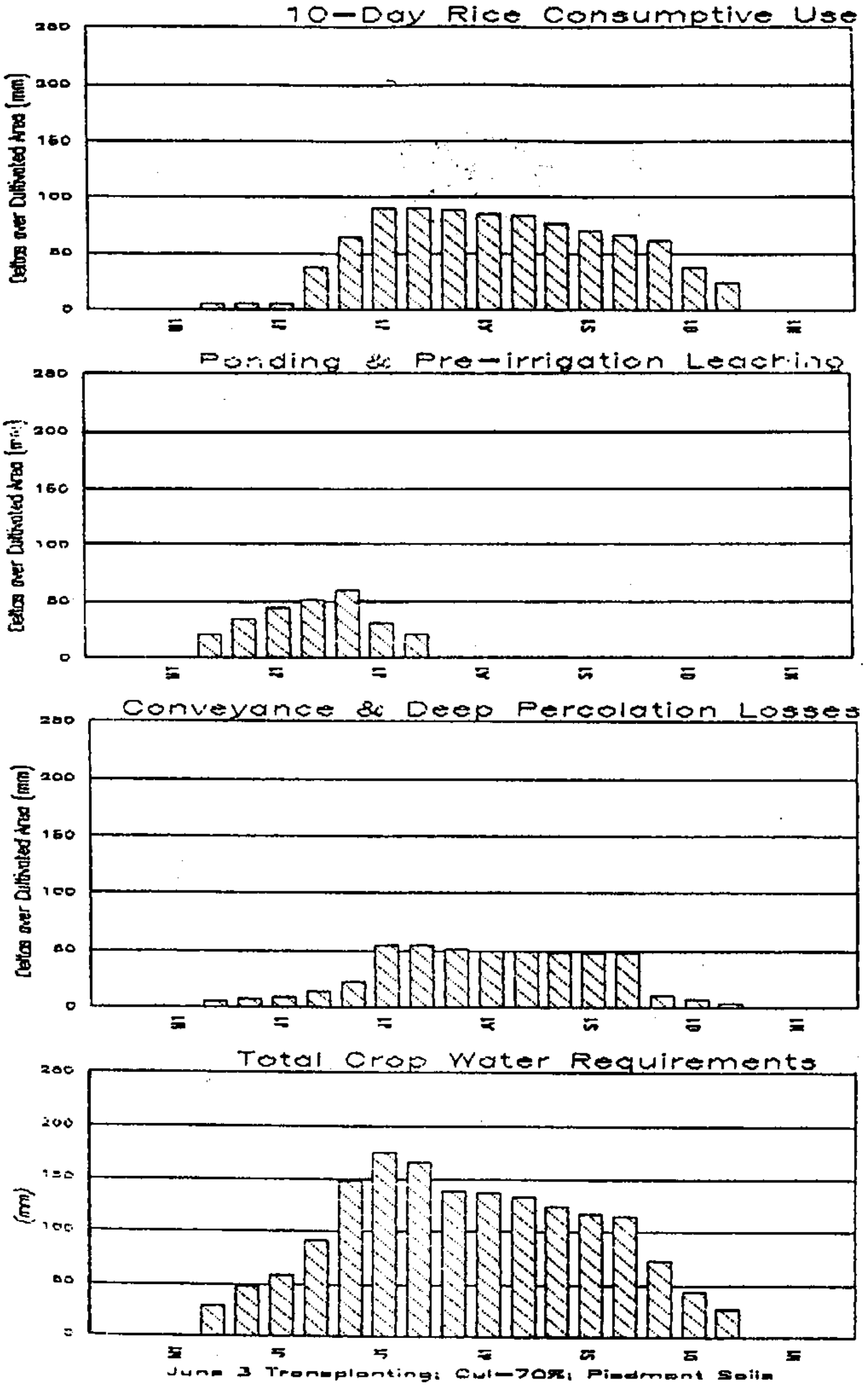


Figure 43b. Crop Water Requirements for Rice on Piedmont Soils, Indus Right Bank.

V. PUBLIC SECTOR LAND RECLAMATION AND DRAINAGE SCHEMES

A. North Rohri Fresh Groundwater Project

The planning for the North Rohri area was provided in the LIP, whereby the fresh groundwater resources were to be harvested towards bolstering the then rather dismal annual cropping intensities of 95 percent. Additional water requirements are also necessitated by the rather dry climatological conditions for the major part of the year; rainfall is limited to the months of July and August (5 cms in the north to 12.5 cms in the south). Since feasibility for the project promised a high rate of return, priority was given to this project that covered a gross area of 321,000 ha (CCA 277,770 ha) (Figure 44). Surface irrigation supplies to the area come from the Rohri and Khairpur West Feeder.

The project was consructed in two phases; Phase I started in August 1969 and was completed by September 1974, and involved the installation of 566 tubewells. Construction for Phase II was initiated in 1975 and completed in June 1978, and involved the installation of an additional 626 tubewells. Of these, 78 tubewells were installed outside the project command area for drainage of effluent through the Rohri Canal. The details on these contruction works appear in Table 9.

Table 9. Construction Units of the North Rohri Fresh Groundwater Project, Lower Indus Basin, Left Bank.

Location	Development Unit	Area (ha)	Installed Tubewells				
			56 lps	86 lps	114 lps	142 lps	Total
North Rohri	Kandiaro	29,664	-	32	36	44	112
	Tharushah	55,848	-	60	68	84	212
	Padidan	51,882	81	62	46	58	247
	Moro	63,537	193	68	40	50	351
	Sakrand	38,446	44	61	32	41	178
Khairpur Extension		24,039	-	27	31	38	96
Total		263,416	318	310	253	315	1196

The project's tubewells have been provided with turbine pumps and fiber glass strainers. The acceptance tests on tubewells in Phase-I were carried out between Nov. 1970-May 1971, whereas for Phase-II wells, the period was July 1974-April 1977. Since these acceptance tests, the cumulative pumping capacities decreased from 106 cumecs to 50 cumecs in 1989, with a related decrease in the specific capacity and discharge of 36 percent and 28 percent,

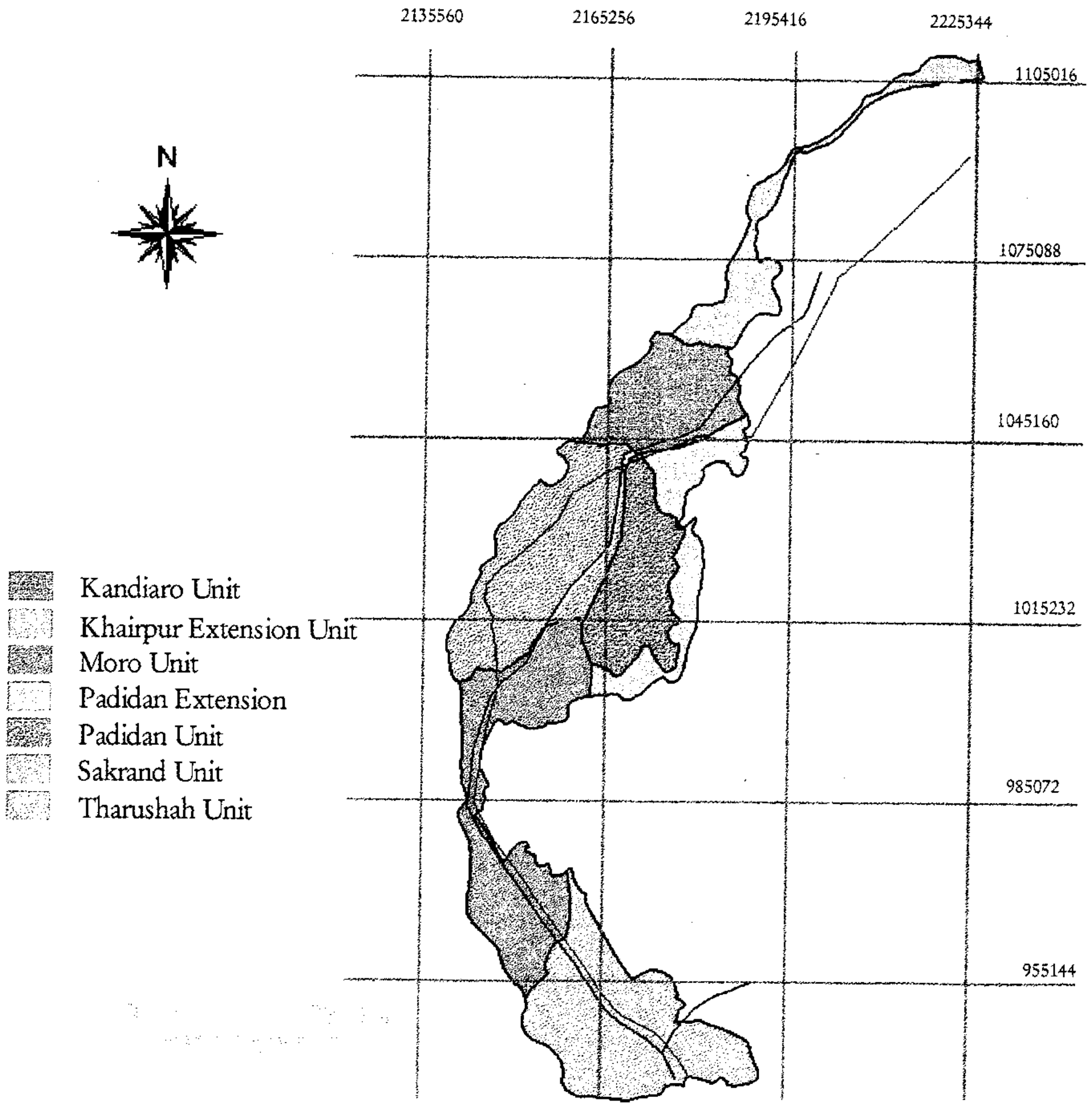


Figure 44. Location Map of SCARP North Rohri Development Units, Lower Indus Basin, Left Bank.

respectively. By this time, the annual pumpage volume was estimated at 104,779 hm (35.73% of the design capacity). The quality of this pumpage is summarzied below in Table 10.

The test holes drilled in the project area, to depths ranging from 135-400 meters, gave no evidence of bedrock. However, in the region outside the project area, there are outcrops indicative of limestone formations underneath. Exploratory drilling has shown that these limestones are overlain by thin beds of shales and clay indicating that the basement underlying the alluvium is generally impermeable. The bulk of the upper alluvium deposited by the river is typical of the sediments carried by the river over great distances. They are well sorted, fine to medium micaceous sands with bands and lenses of silt and silty clay. The deposits are extremely variable and the variation in lithology is so intense that it is difficult to correlate the strata found in two adjacent boreholes. However, relative percentages of sand and clay bands are remarkably constant over large areas. Sand is generally the predominant material. Resultantly, the aquifer is highly transmissive and has non-artesian characteristics.

Prior to the inception of canal irrigation, the groundwater system was in a state of dynamic equilibrium. Since the earliest recorded watertable elevations in 1932 (due to the commissioning of the Sukkur barrage), there has been a gradual increase in the subsurface water levels. By April 1966, watertables were known to be 3-5 meters higher, especially in the lower half of the project area. The mean depth to watertables for April 1966 (Figure 45), however, show the situation to be distinctly the opposite of this historic rise wherein the northern part of the project area was affected the most due to rising watertables. This was due to the groundwater flow pattern, which, in recent times, has been considerably different from that prevailing in the pre-irrigation period. The historic pattern of flow was from the river towards the groundwater trough in the center of the area (with gradually diminishing loss along the flow path due to evaporation and transpiration); lately, this has been superseded by a pattern of seepage from the canals with more or less evenly distributed upward losses or discharge from the area. Thus, both the discharge and sources of seepage are now distributed more evenly over the area than in the pre-irrigation period (Figure 46). Most recent data on interseasonal groundwater fluctuations, as monitored by SM (South), WAPDA, shows that variations have been mostly confined to depths below the root zone (Figure 47).

Over the project area, the quality of water varies with depth as well as with distance from the river. Based on the results of the drilling data available from LIP investigations (LIP Supplement 6.1.4, 1966), the transition from fresh to saline water is generally fairly sharp, both vertically and laterally. The northern part of the project, being adjacent to the river, has good groundwater quality with TDS < 500 ppm to depths of 175 meters or so. In such waters, the bicarbonates constitute between 50-60 percent of the total anions. Although sodium salts predominate, the Na : (Ca+Mg) ratios are not sufficiently high to make the waters potentially unsafe only on the basis of the SAR.

Table 10. Temporal Comparison of the Pumpage Quality in the Tubewell Units of North Rohri Fresh Groundwater Project, Lower Indus Basin, Left Bank.

Location	Quality of Tubewell Pumpage during 1979-80				Quality of Pumpage during 1987-89			
	# of Samples	Useable percent	Marginal percent	Hazardous percent	# of Samples	Useable percent	Marginal percent	Hazardous percent
Kandiaro	107	100	-	-	103	100	-	-
Tharushah	203	88.7	9.8	1.5	194	90.7	7.2	2.1
Padidan	201	64.7	26.9	8.4	165	76.3	17.6	6.1
Moro	172	63.9	28.5	7.6	147	63.3	31.3	5.4
Sakrand	148	66.8	27.7	5.5	170	63.0	31.8	5.2
Khairpur Extension	86	93	7.0	-	72	95.8	4.2	-
Total	917	76.9	18.5	4.6	851	79.2	17.2	3.6

Source: Water Quality of Tubewells in SCARP North Rohri, 1987-89, SM (South), WAPDA.

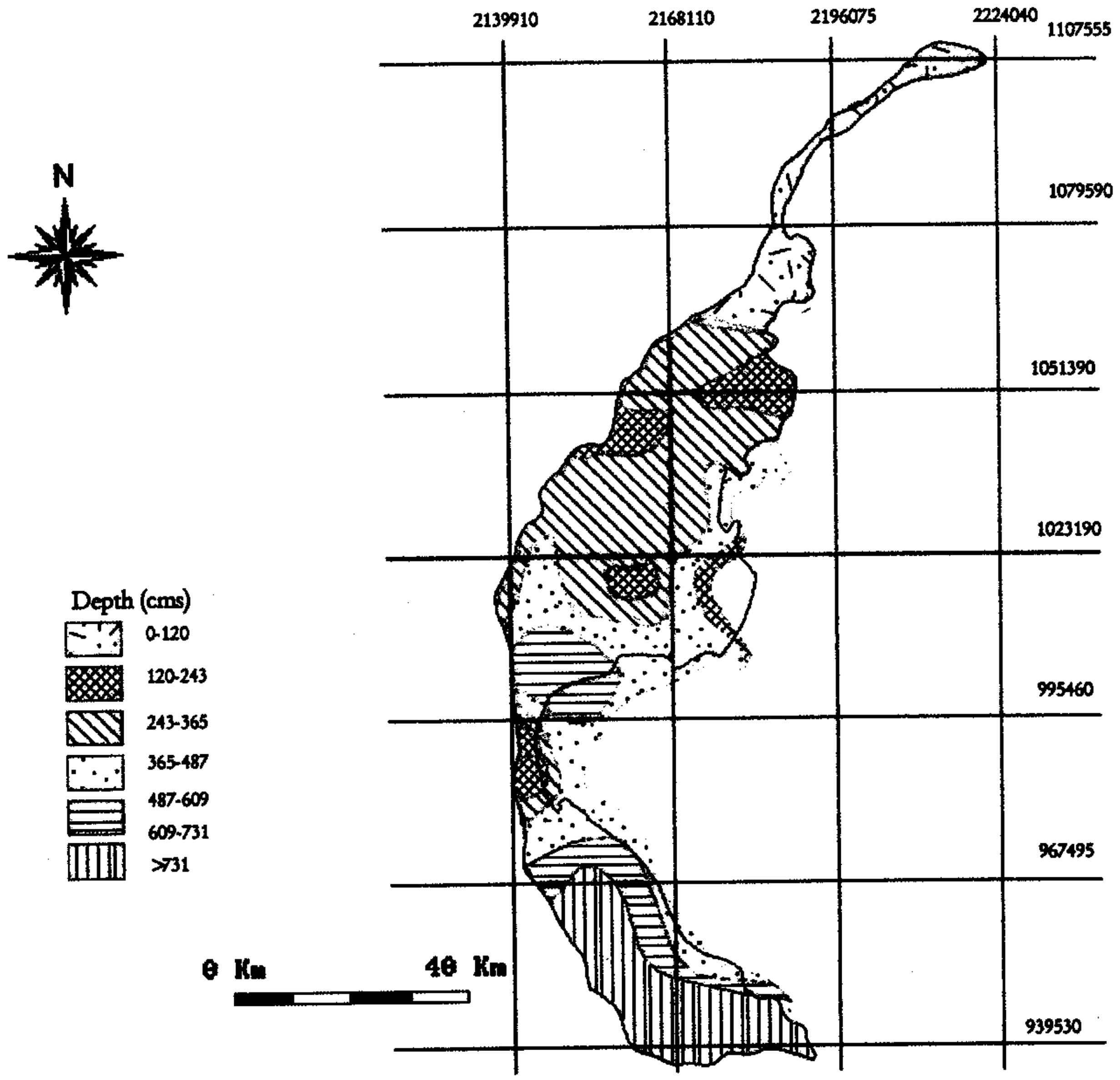


Figure 45. Depth to Watertable in SCARP North Rohri Project during April 1966, Lower Indus Basin, Left Bank

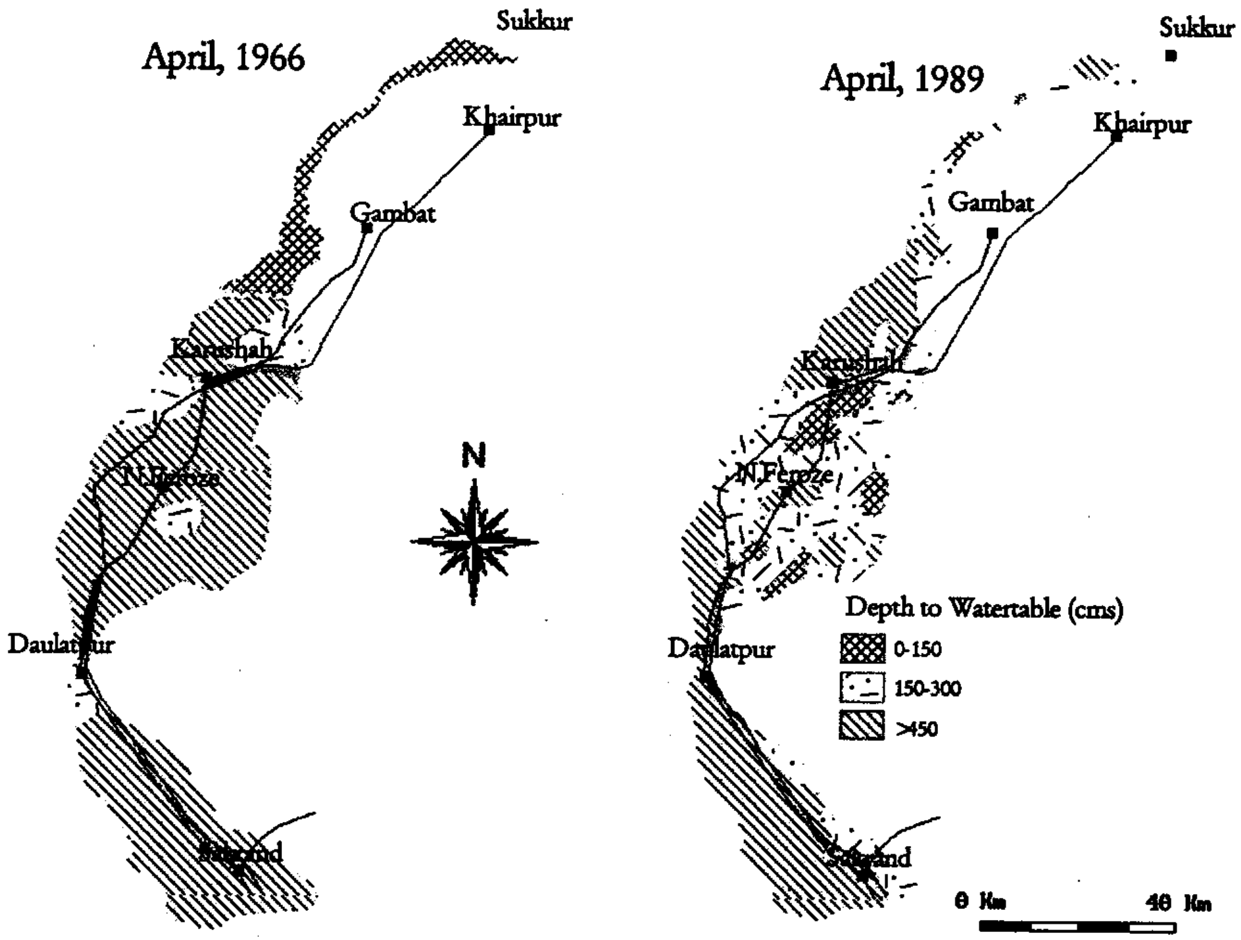


Figure 46. Comparison of Pre-Monsoonal Depths to Watertable within SCARP North Rohri, Lower Indus Basin, Left Bank.

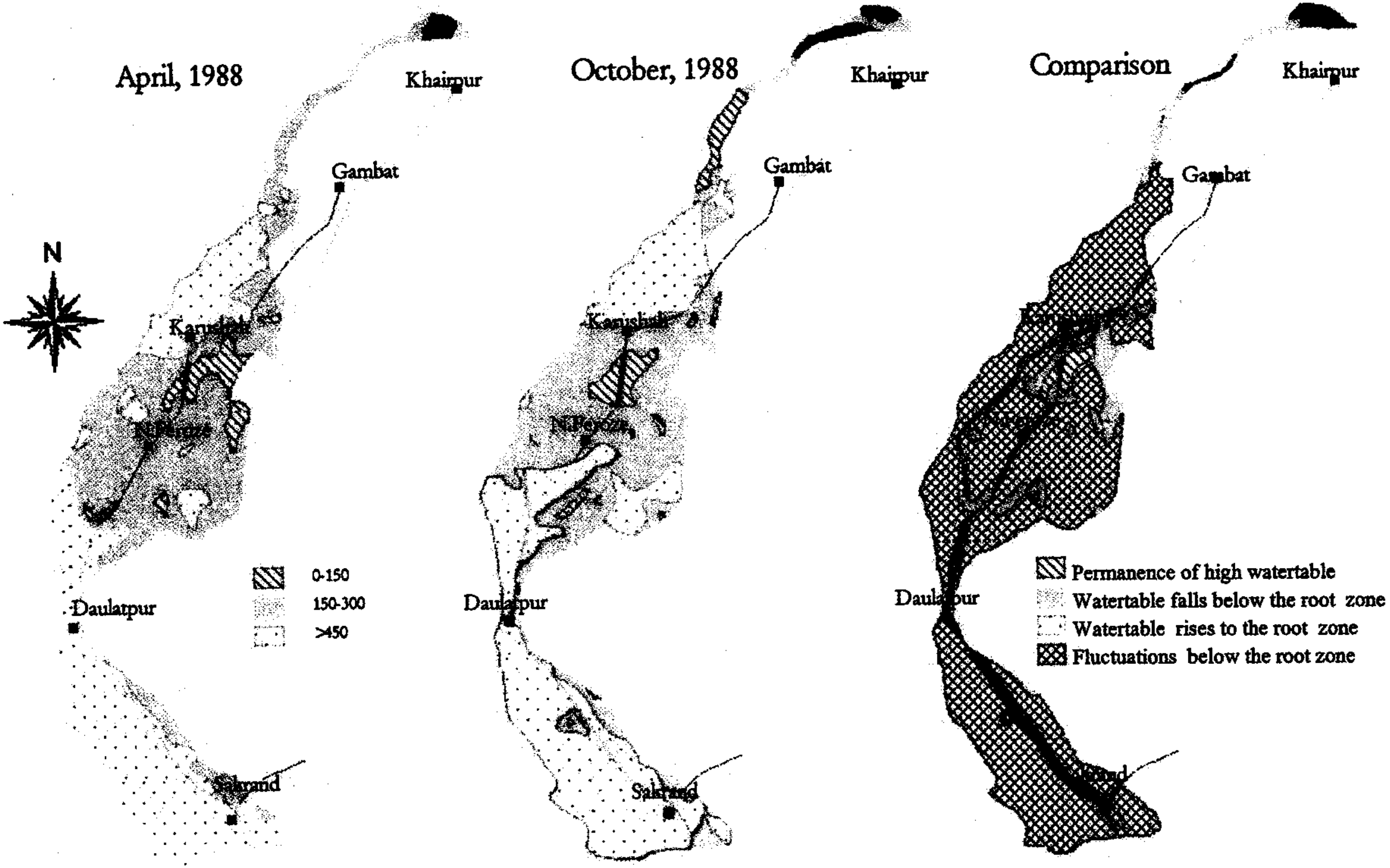


Figure 47. Seasonal Comparison of Pre- and Post Monsoonal Depths to Watertable during 1988 within SCARP North Rohri, Lower Indus Basin, Left Bank.

In waters containing TDS between 500-1000 ppm concentrations, the chloride and sulphate salts of sodium predominate. TDS concentrations beyond 1500 ppm may prove potentially hazardous due to rather high values of SAR (ranging between 2.7-19).

At the time of project planning in 1967, the implementation strategy entailed three sequential stages in deliverables. The first stage covered the initial 10 years of project life wherein the targeted cropping intensity was assumed to reach 136 percent, based on incentive supplies to the cultivators through tubewell pumpage. The annual operating factor of the wells was estimated to be 0.3. The intermediate stage was to represent the period between the 10th and the 23rd year when the cultivation intensities were to rise further to 148 percent. The annual pumpage was to increase to keep pace with supplemental irrigation requirements to an extent whereby the groundwater recharge would have been exceeded in the fifth year of the period. The estimated volume of pumpage for the 23rd year was 0.117 Mhm, involving nearly 1.5 meters of aquifer mining. The annual operation factor would increase slightly to 0.32.

The third and final stage, covering the period between the 24th and the 30th year of operation, assumed completion of the remodeling for the North Rohri Canal system (then not deemed necesary until 1985) and the tubewell operations being confined mostly to the Rabi season. The annual pumpage was estimated to reach 0.121 Mhm at an operation factor of 0.36.

The canal system remodeling permits all Kharif season requirements to be met from surface supplies that, in turn, would recharge the watertable enough to facilitate Rabi season extractions. Thus, the Rabi season surface supplies would have been diverted to saline groundwater zones to bolster irrigation-related potential for cropping. The expected benefits from the project, at the time of project planning, are summarized in Figure 48.

The operation factor of the tubewells was in line with the balanced recharge concept, which avoids the dangers of salt infiltration and the high cost of deep pumping and limits the total pumpage to the available recharge.

B. South Rohri Fresh Groundwater Project

The South Rohri Project forms part of a comprehensive development plan that was presented in the LIP Report. This was the third and the last in a series of projects for the development of fresh groundwater areas on the Left Bank of the Sukkur Barrage. The first two projects were the SCARP Khairpur and North Rohri. These fresh groundwater areas constituted the priority ranking under the LIP recommendations for development through tubewells. Beyond the southern and eastern boundary of the project, the groundwaters become saline. The project works aimed to enhance irrigation supplies and provide subsurface drainage to control waterlogging and salinity. The cropping intensities were to be raised from 86 percent prevailing in the mid-1960s to 150 percent in a period of 40 years.

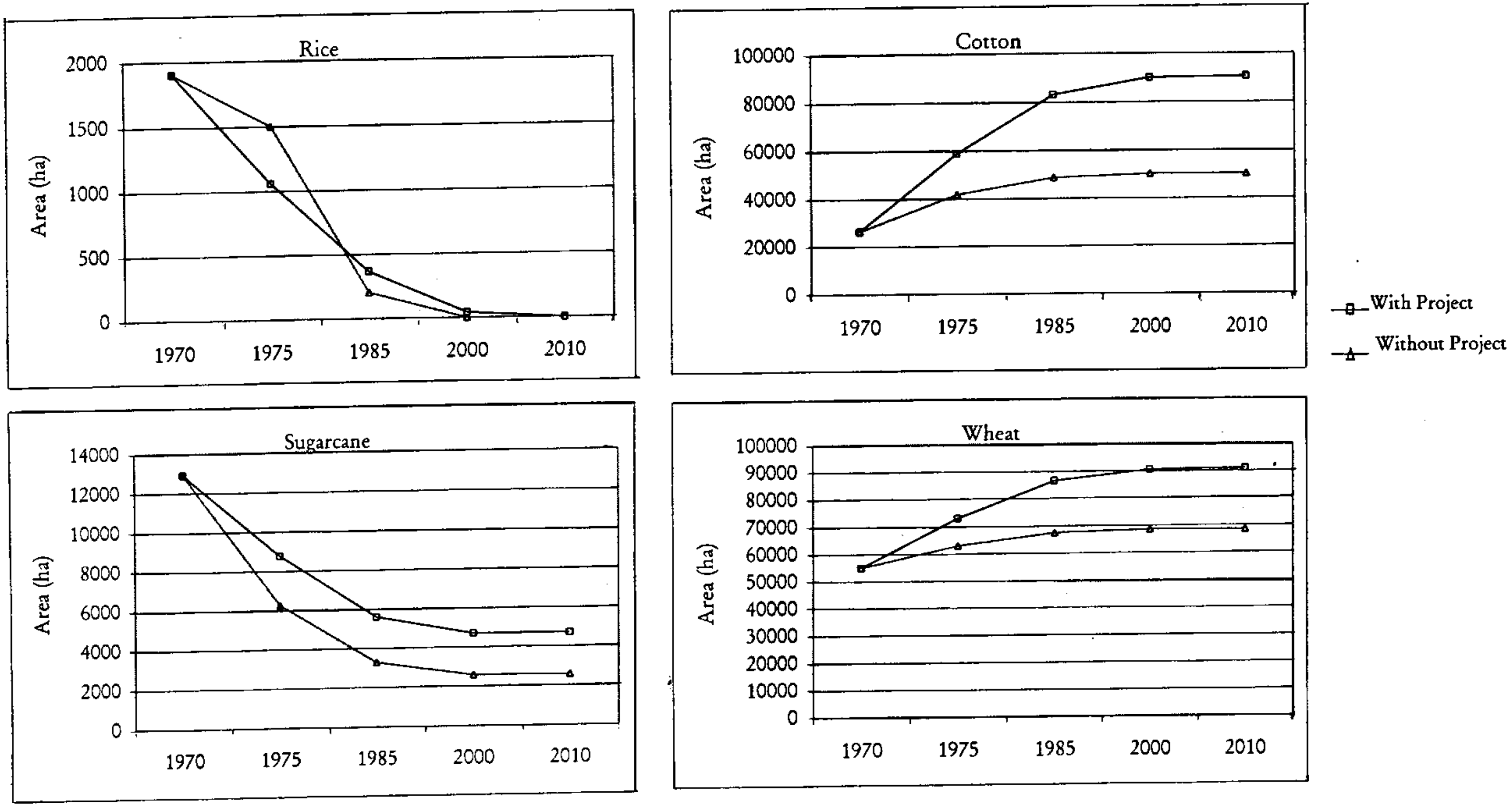


Figure 48. North Rohri Cropped Area With & Without Project Conditions.

The project has a gross area of 164,030 ha and a CCA of 144,180 ha and is irrigated entirely from the Rohri Canal (within the jurisdiction of Hala and Nasir Irrigation Divisions). The canal enters the project area about 1 km upstream of the Kumblima Regulator located 224 kms downstream of the Sukkur Barrage, and flows for about 93 kms to feed a system of 6 main branches and 54 distributaries. The land slope is .000095 from the north to the south. The topography is rough and soils are generally coarse in texture along former meander flood plains, but the soil texture is smooth and finer across the flooded cover plain. The area is covered mostly by the meander flood plains and consists of bar deposits, channel infills and channels scars. Based on the Project Planning Investigations by WAPDA (PPO South) (borehole density of 1/sq. mile) the fine-textured soils constitute 36 percent of the area and the medium soils 60 percent. Soil surface salinity occurred in small scattered patches thoughout the project area. Salinization was ascribed to under-watering the crops, low cropping intensity and leakage and seepage from canals and lateral channels. Chemical analysis of the data from the same boreholes showed that nearly 15 percent of the land was moderately to highly salinized with saline-alkali land constituting over 5.5 percent of the total.

Lithological studies indicate that there is a 200 to 400 ft thick sandy layer below the surface with inter-beds of silt and silty clay. Though the stratum is of heterogeneous composition, it forms a fairly unified, transmissive and non-artesian aquifer, and as such, is quite suitable for exploitation by installation of tubewells (Figure 49). Computer trials (by Harza) have shown the storage factor to be about 0.2 and transmissibility of 2.58 sq. cm/sec. Vertical permeabilities are low in comparison to lateral ones, but are just sufficient to ensure that there is a transmission of recharge from layer to layer.

The distribution of water quality is complex in South Rohri. In the initial project planning and implementation stage, it was thought the the location and origin of fresh water lenses was associated with old river courses. However, detailed geophysics and computer model studies have shown that the lenses are more closely linked with seepage zones. This led to the revision of tubewell siting in the later stages of implementation.

Pre-project surveys showed that about 885 tubewells were operative in the area during 1975 (126 in 1967, 994 in 1981-82, Figure 50) which pumped 19,000 Hm of water (discharge capacity of 17-34 lps) that, when combined with 170,225 Hm of surface supplies (water duty of 0.34 cumecs/1000 ha CCA), was just sufficient to meet the water requirements for 95 percent intensity of cropping. The 10 percent less than optimum cropping intensity, then, was due to inequitable distribution of canal supplies and inefficient water and land management. The intensities on some watercourses were as high as 18 percent and on others as low as 35 percent. The Kharif intensities had varied from 7 percent to 88 percent and Rabi from 12 percent to 99 percent. These historic variations in the cropping intensity are presented in Table 11.

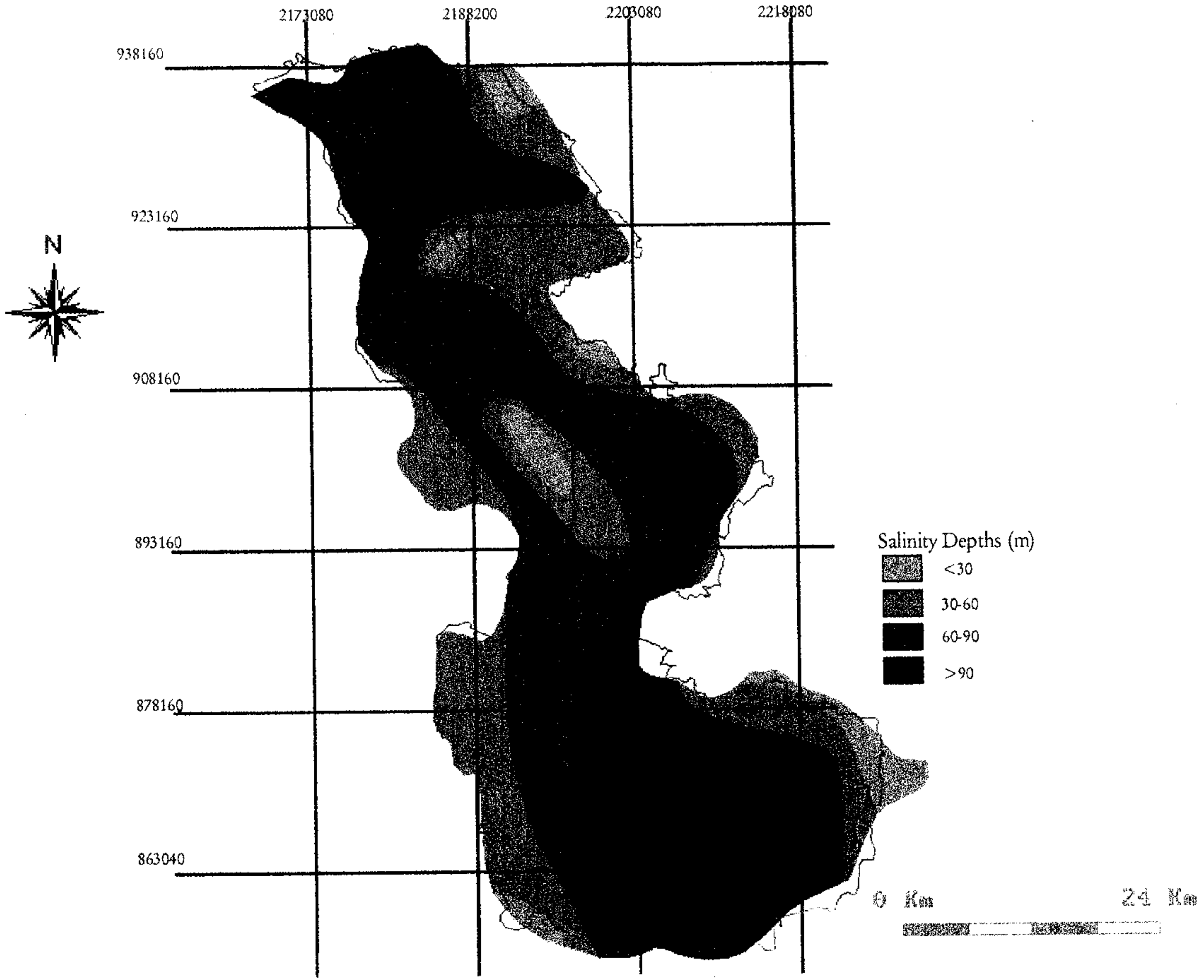


Figure 49. Groundwater Salinity Depths for TDS Concentrations <1200 ppm in South Rohri SCARP Tubewell Project.

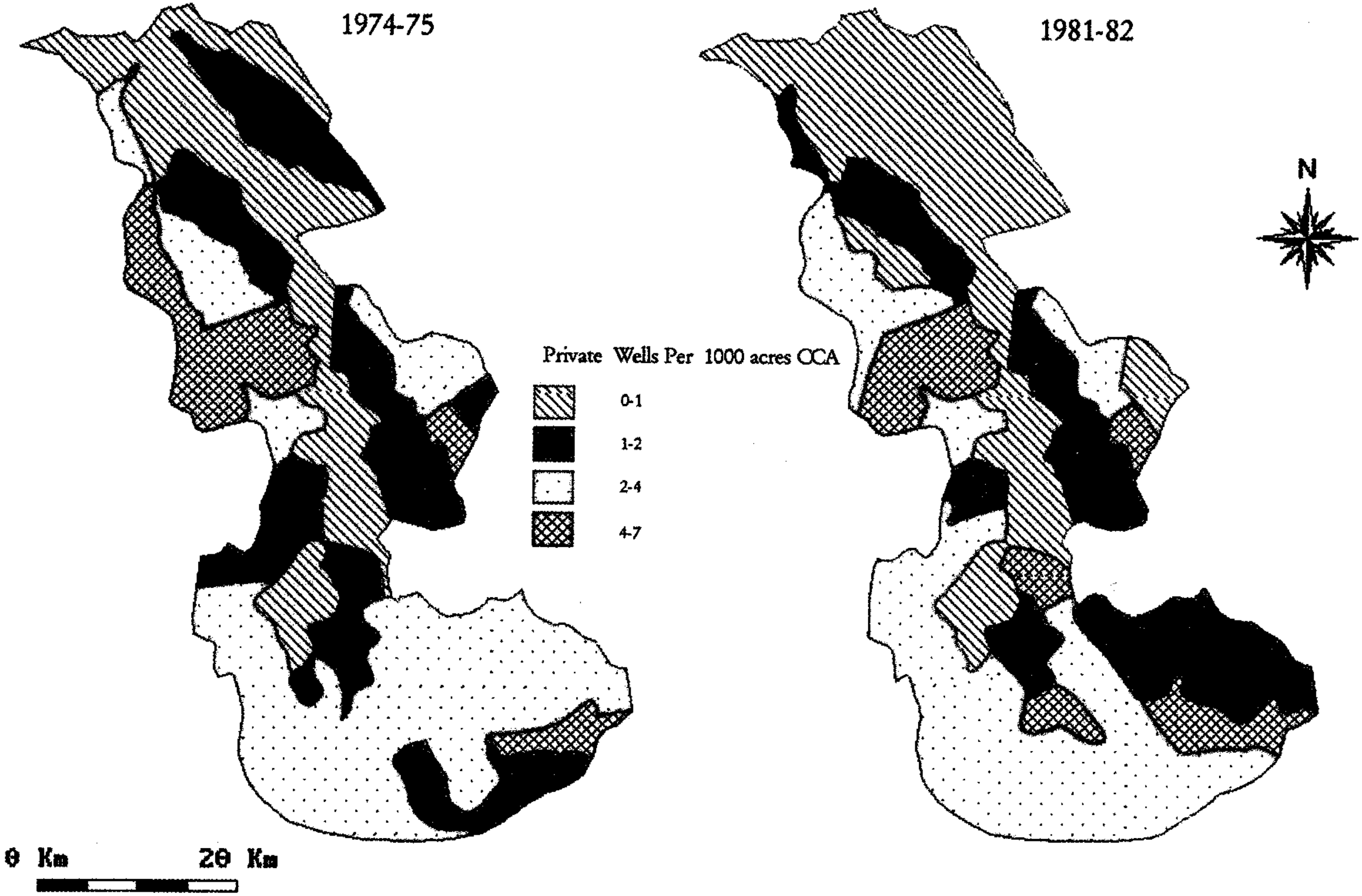


Figure 50. Private Tubewell Development in SCARP South Rohri Fresh Groundwater Project, Lower Indus Basin, Left Bank.

Table 11. · Historic Seasonal Cropping Intensities in the Command of the South Rohri Fresh Groundwater Tubewell Project.

Survey Period	Kharif	Rabi
Sukkur Barrage (Design)	27	54
1968-69	38.4	43.6
1974-75	44	42.4
Proposed	68	82

The project had proposed to increase the ultimate cropping intensities to 150 percent over a 40-year period, duly aided by an increase in the surface supplies (through Rohri Canal remodeling) from 170,225 Hm to 231,207 Hm (maximum water duty of 0.75 cumecs/1000 ha CCA) and supplemental pumpage of 101,147 Hm.

Pre-project sampling of tubewell waters (by PPO South) revealed that 79 percent of the samples were fit for direct irrigation purposes and the remainder could be used against a mixing ratio of 1:1 to 1:2 (i.e. tubewell water to canal water). Based on these initial investigations, the area was partitioned into zones of safe fresh groundwater yields and areas comprising shallow waters overlying saline zones (approx. 35% of the project area). Subsequent testing of 120 tubewells (out of 180) in 1982-83 from the Hala, Shahdadpur and Tando Adam Units showed approximately 65 percent of the wells to be of usable quality, and another 17% to be fit for marginal use. The distribution of these zones is given in Figure 51. Many of these wells, designed on the limited lifetime concept, turned saline in areas where the depth to saline groundwaters was < 75 m. It became clear that the area in which the conventional wells could be employed was somewhat less than the 84 percent of the original project area. During 1987-89 a much more representative sample of 403 wells was analyzed across all four units of the project, whereby 318 wells were found to be of usable quality and 53 were marginal; more than half of the 32 hazardous quality wells were located in the Hala Unit.

Figure 52 shows the location and the constituting units of the project area along its final boundaries. These boundaries have undergone several revisions since the original planning for this Project in which its scope and objectives have been considerably modified.

The first Project Planning Report (WAPDA, 1969) envisaged a command cultivable area of 192,230 ha in which there would be 1,692 tubewells. The first PC-I proforma (Mehran Architects and Consultants, 1975) retained broadly the same objectives as the first Project Planning Report. However, the maximum capacity of the wells was reduced from 113 lps to 71 lps, thereby reducing their total output by 10 percent. This output was further reduced in the second Project Planning Report (Mehran Architects and Consultants, 1976) by greatly increasing the proportion of 28 lps wells; the total number of wells remaining unchanged.

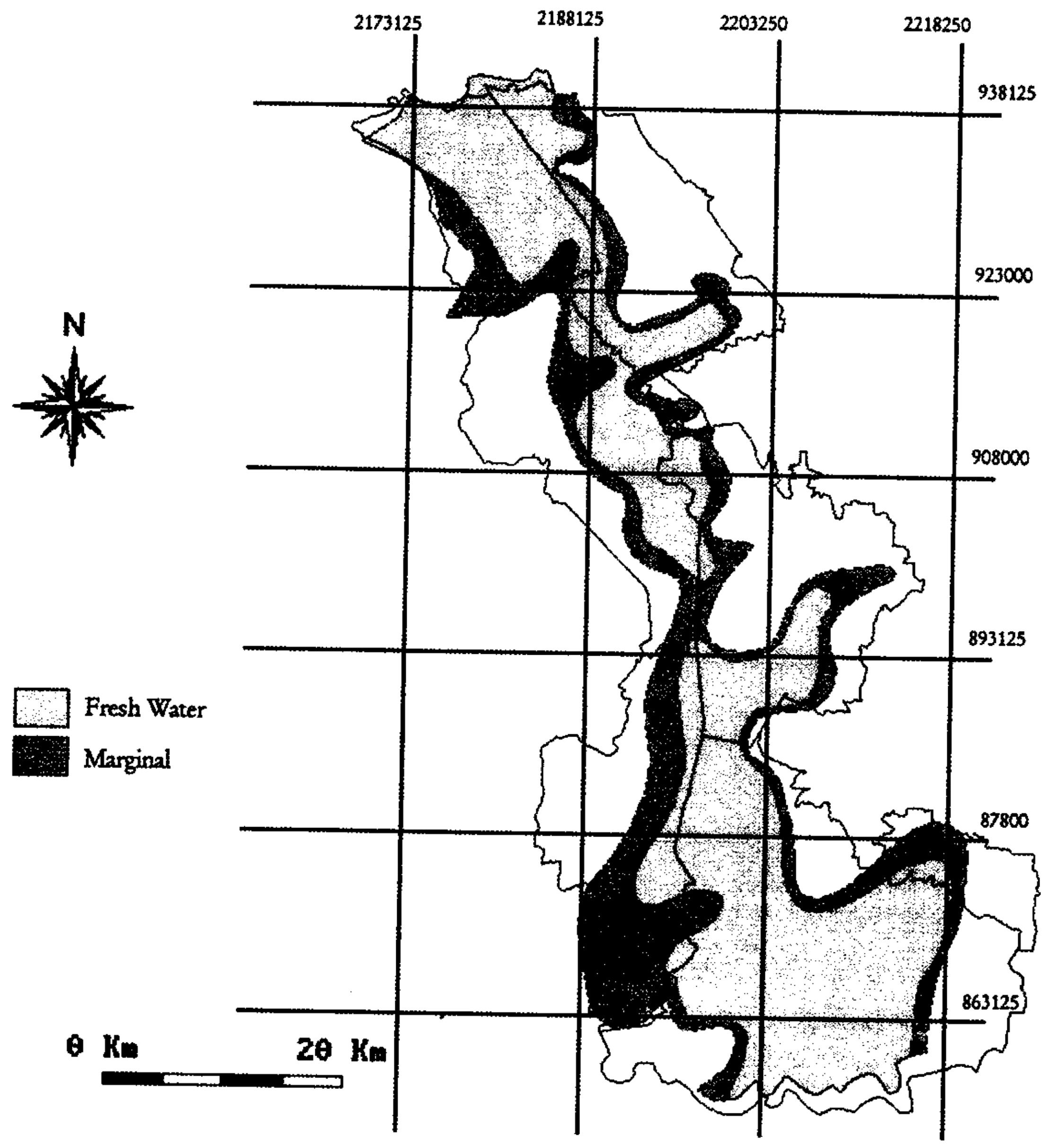


Figure 51. Groundwater Quality in SCARP South Rohri Tubewell Project, Lower Indus Basin Left Bank.

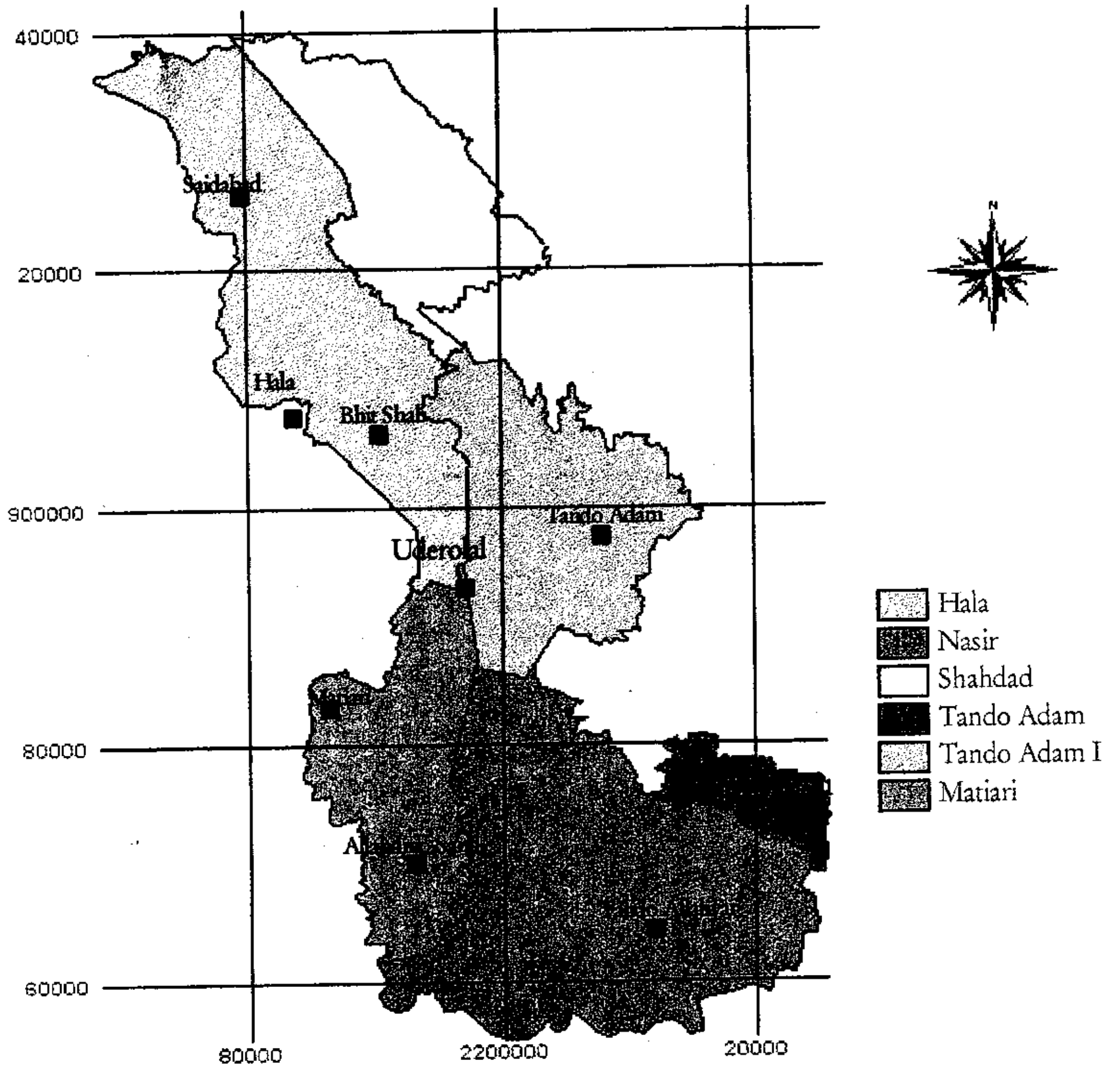


Figure 52. Location and Constitution of South Rohri SCARP Tubewell Project , Lower Indus Basin, Left Bank.

The report also noted that part of the project area, known as Area C (confined mainly to the tail areas in the western edge of the project, Figure 53), would be left for development by private wells, at least until additional water became available as a result of the first stage remodeling of the Rohri Canal. At that time, it was also apprehended that the shallow fresh groundwater zone in this area would restrict conventional pumpage and instead, scavenger wells would be required to prevent saline water upconing. Subsequent tests could not corroborate this apprehension and there was a general conclusion that the low permeability of the cemented lower aquifer unit at the fresh-saline interface retarded the upconing of the saline water. The Consultants also assumed that only 800 of the 1,350 public wells planned for the rest of the project area (areas A and B, comprising 151,760 ha of deep fresh groundwater pockets) would be constructed antecedent of this remodeling.

WAPDA began implementation of the project with the completion of 180 wells (installed capacity of 7.41 cumecs) in areas A and B (Hala, Shahdadpur and Tando Adam Units) during 1976-78. An Updated Feasibility Study (Patterson, et.al, 1979) was undertaken by a team of ADB consultants in 1979 that concluded that the existing groundwater balance was not going to be disturbed due to pumpage planned for the project areas, and that the construction of all 1,170 wells still to be installed in areas A and B could be undertaken without waiting for the remodeling of the Rohri Canal. Consequently, with financial assistance from the ADB and IFAD loans and reformulation in 1986, the much-delayed project was finally completed in June 1990. During this phase, 1,034 tubewells were installed ranging in capacity from 14-56 lps. The 42-56 lps wells were only permitted in the area where fresh water extends to at least 90 m. The total installed capacity of 1,214 wells (180 + 1034) was 44 cumecs.

Under the ADB loan, the tubewells were drilled under three contracts of 250, 299 and 485 tubewells, respectively. Construction began in September 1984 and was completed in June 1990. In addition to these tubewells, improvement of 528 watercourses was also carried out through remodeling, lining of head sections and provision of permanent turnouts and other control structures. Tubewells installed under the 250-tubewell contract became operational in 1986-87 and were handed over to the Irrigation Department in 1988. The subsequent contracts were brought into operation during 1987-90 and were handed over by 1991. Table 12 shows the progressive installation of these tubewells across the various sub-units of the project.

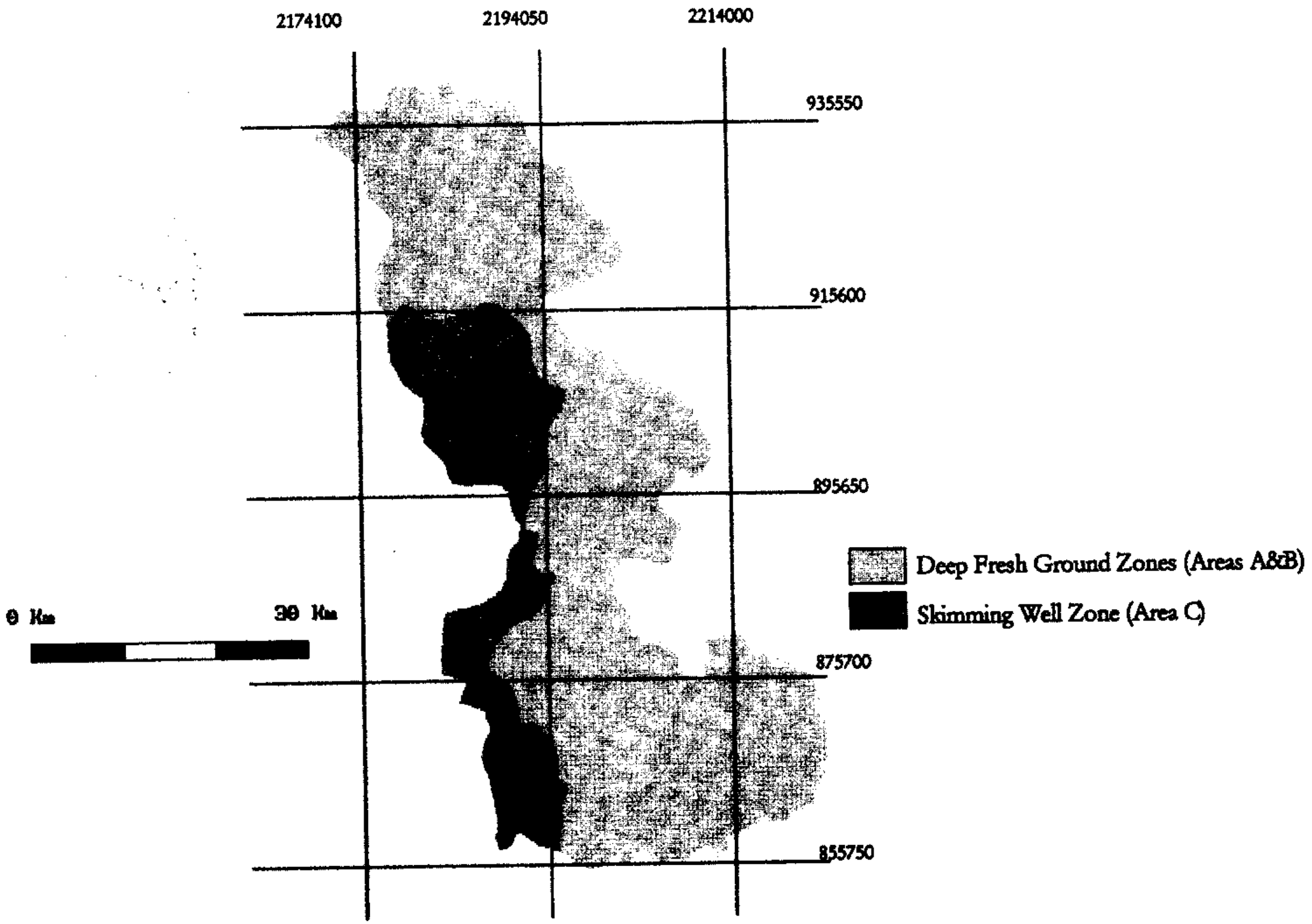


Figure 53. Location of Deep and Shallow Fresh Groundwater Zones within South Rohri Tubewell Project, Lower Indus Basin, Left Bank.

Table 12. Distribution and Number of Tubewell Installations in the Development Units of the South Rohri Fresh Groundwater Tubewell Project.

Unit	Final Installed Tubewell Numbers				
	WAPDA	1st Contract	2nd Contract	3rd Contract	Total
Hala	46	156	15	100	317
Shahdadpur	81	-	52	19	152
Tando Adam	53	-	135	44	232
Matiari	-	-	25	50	75
Nasir	-	94	72	238	404
Nasir Extension	-	-	-	34	34
Total	180	250	299	485	1214
Discharge Capacity (Cumecs).	7.41	9.22	10.61	16.79	44.04

By 1979-80, against an annual design capacity of 22,599 hm for 180 tubewells, the actual pumpage was recorded as 8,075 hm. In 1988-89 a total of 430 tubewells were monitored across the 4 units of Hala (202 wells) Shahdadpur (81 wells), Tando Adam (53 wells) and Nasir (94 wells) having an annual design capacity of 51,942 hm. The pumping capacity of the tubewells varied from 28-56 lps, depending upon the depth of the groundwater. The total design capacity of these wells was estimated to be 16.47 cumecs, against which some 17,026 Hm had been pumped corresponding to a utilization factor of 33 percent (WAPDA SCARP South Rohri, 1990).

Performance tests carried out by WAPDA SM (South) during 1988-89 showed a skewed pattern of reduction for discharges and specific capacities of the wells with respect to the acceptance values (Figure 54). Almost 65 percent of the discharge reduction values fall in the range of 10-40 percent; only 20 percent of the wells experienced more drastic reduction in their discharge. The majority of the specific capacity reductions have been under 40 percent, however, over 1/3rd of the 188 monitored wells have had a loss that exceeds this threshold. This has negative connotations towards the then prevailing efficiencies of these wells retrogressively affected by the state of the screening materials. Not surprisingly, during the year 1988-89, the minimum and maximum wire-to-water efficiency (ratio between the rate of work done by the pump and the actual power consumed during the work) was recorded as 15 and 67 percent, respectively.

Pre-project private tubewell pumpage had controlled the rise of the sub-soil water level; however, this was largely dependent on the spatial distribution of these wells. Records pertaining to the groundwater fluctuations show that in the period 1932-67, the watertables

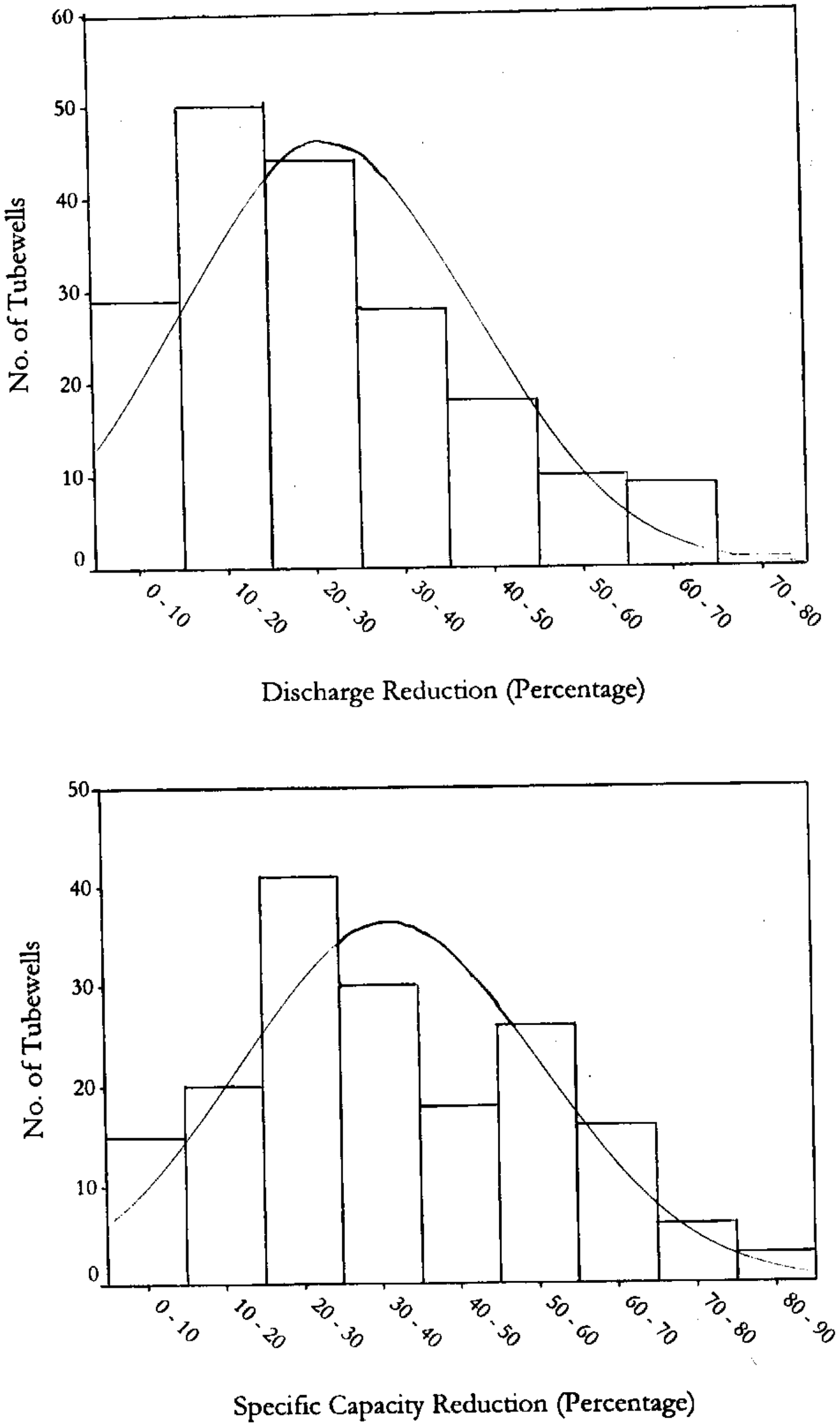


Figure 54. Comparison of Tubewell Performance for the Period between 1977 and 1988-89 in the South Rohri Fresh Groundwater Project, Lower Indus Basin, Left Bank.

had risen between 3 to 10 meters on account of the excess seepage brought on by the canal system, coupled with inadequate subsurface drainage. More specific documentation of this trend is available from 1967 onwards, wherein the average rise in watertables was found to be 11 cm/annum (Figure 55). By 1975, the watertables varied between 250-800 cm against an average of 500 cm. Figure 56 shows the comparison of the interseasonal watertable fluctuations during 1988, wherein no acute waterlogging was noticed in the project area, except in small patches near the Rohri Canal (in the reach between the Kumbdarun and Oderolal regulators).

C. Larkana-Shikarpur

This is the oldest of the surface drainage projects and covers a gross area of 283,739 ha (Figure 57). The project was completed in two stages; Stage I covered main and branch drains, while Stage II covered sub-drains for a combined length of 1,240 kms (WAPDA, 1984). Construction started in 1964 and the first phase of the project was completed in 1968 involving 212 kms of main and branch drains, and 26 kms of sub-drains. For effluent disposal from the drains, five pumping stations of 13.6 cumecs discharge capacity were installed. The second stage of construction started in December 1972, and was completed in June 1979. Another 212 kms of main and branch drains were constructed during this phase, along with 1,000 kms of sub-drains. In addition, the pumping capacity of existing stations was increased to 31.5 cumecs and three more pumping stations, with a capacity of 4.27 cumecs discharge, were added. The outfall locations of these pumping stations are given in Table 13. In the original project plan, a third stage was also envisaged involving the installation of shallow tubewells for the reclamation of some 42,000 ha.

The project works were mainly for internal drainage connected with branch and main drains to carry the effluent from rice fields. Effluent from more than 30 percent of the project area is recycled into canals (North West and Rice) or pumped over the protective *bund* and into the river. The practice does not seem detrimental for areas downstream of the pumping stations, however, the pumping stations may not be fully operational to allow for definitive assessment of the quality of water to downstream riparians. Based on detailed LIP investigations into the quality of effluent from rice areas, the salinity concentrations were found to be < 1,000 ppm, a fact confirmed by the analysis of the effluent from the Larkana-Shikarpur project itself. However, there is also the monitoring of the surface drainage effluent at Wagan pumping station of North Dadu Surface Drainage Project by SCARPs Monitoring (South), which indicates that the salinity levels may reach as high as 3,000 ppm after the rice season is over. This is the regenerated water from the depressions. During peak outflows from the area, the salinities are generally about 1500 ppm corresponding to 0.21 million tons of salts (Table 14). During 1986-90, the average annual pumpage from these 8 stations was 12,582 Mhm.

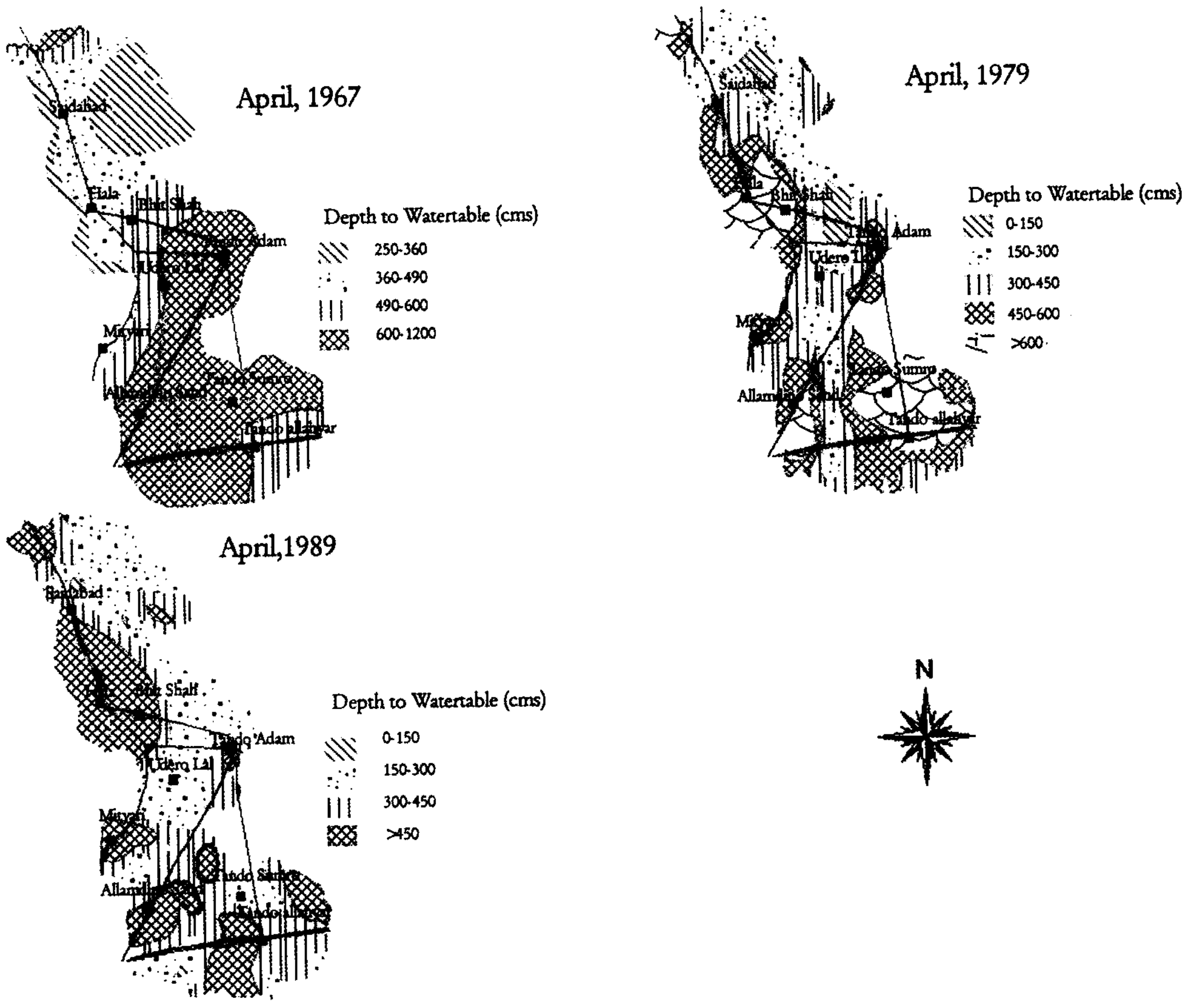


Figure 55. Temporal Comparison of Pre-Monsoonal Depths to Watertable in SCARP South Rohri Lower Indus Basin, Left Bank.

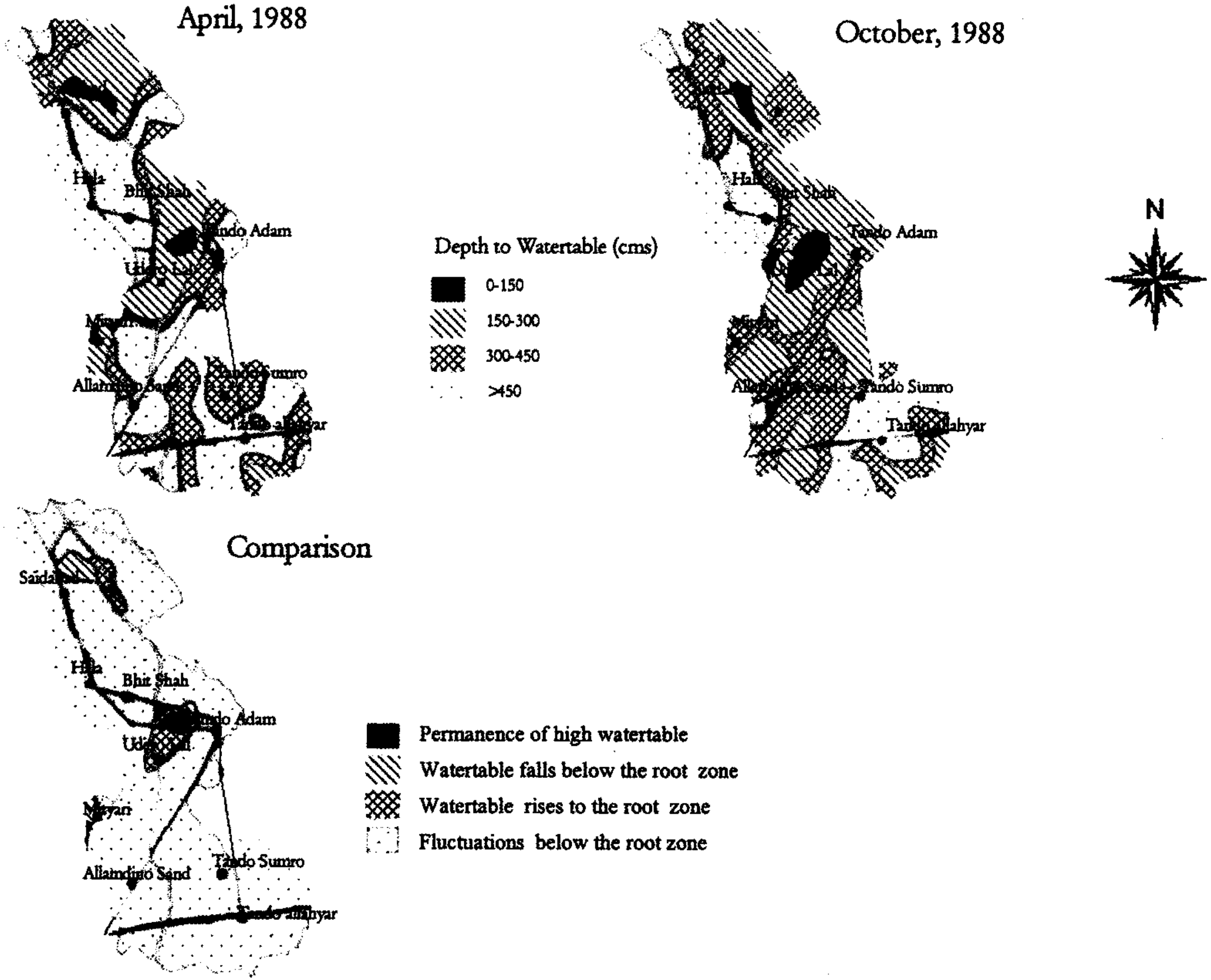


Figure 56. Seasonal Comparison of Depth to Watertable during 1988 in South Rohri Fresh Groundwater Project, Lower Indus Basin, Left Bank.

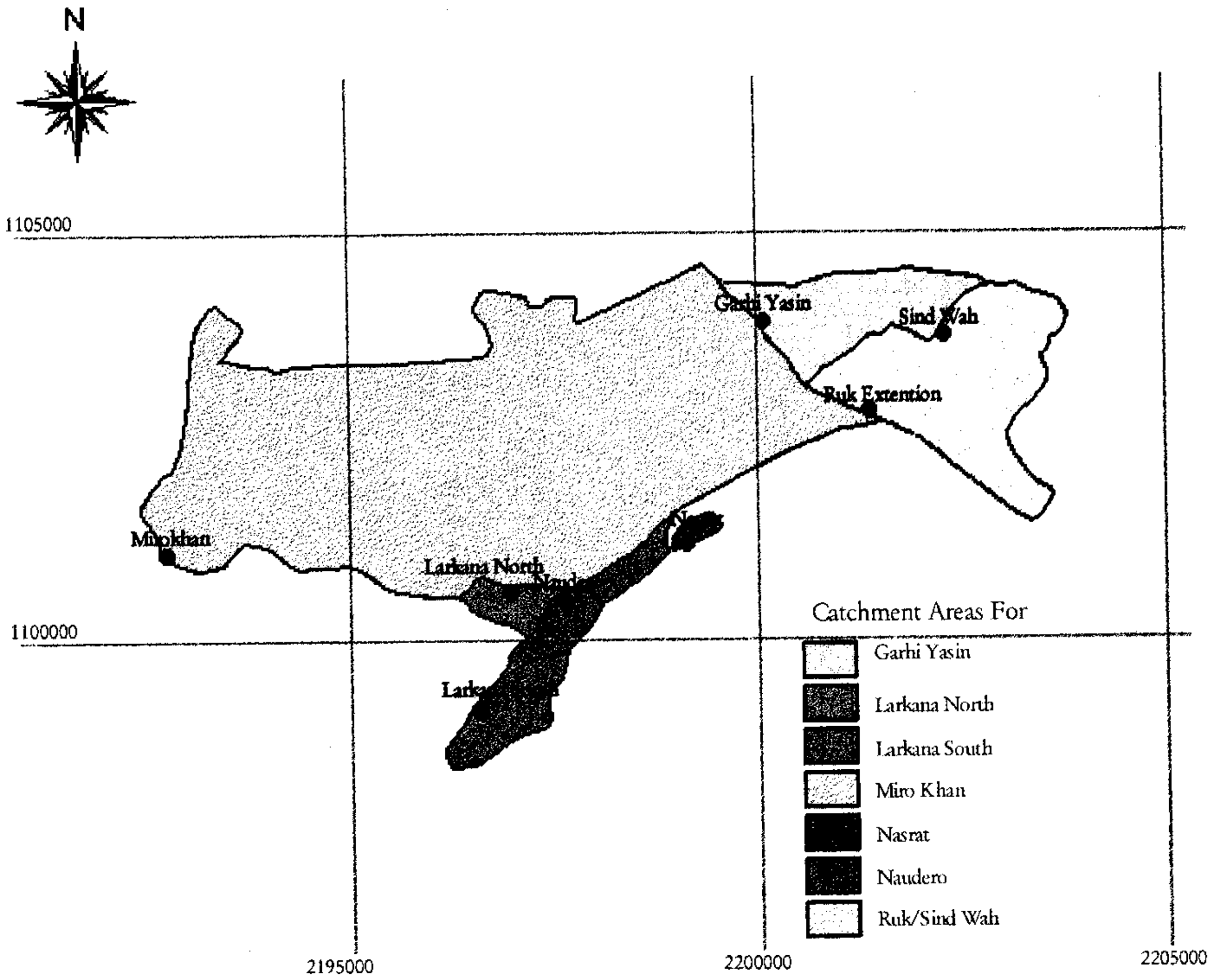


Figure 57. Location and Catchment Units of Pumping Stations in the Larkana-Shikarpur Surface Drainage Project, Lower Indus Basin, Right Bank.

Table 13. Catchment Areas of the Pumping Stations Operative in the Larkana Shikarpur Surface Drainage Project.

Catchment	Area (ha)	Discharge (cumecs)	Outfall
Miro Khan	156,177	25.6	By gravity to Hamal Lake
Shahdadkot	46,620	8.5	Miro Khan pumping station to Hamal Lake
Larkana South	11,137	2.3	Via pumping station at Rice Canal RD 290.5
Naudero	3,885	1.7	Via pumping station at Rice Canal RD 233
Shikarpur	22,792	6.0	Garhi Yassin pumping station at North West Canal RD 153
Lakhi			
a)	34,706	13.0	Ruk pumping station at North West Canal RD 91
b)	6,475	2.37	via pumping station at Sindh Wah (km 28.8)
Larkana North	5,439	1.27	Larkana North Pumping Station to Shamir Branch
Nasrat (Shamir)	907	0.62	Nasrat Pumping Station to Indus

Table 14. Annual Volume of Pumpage and Weighted Salinity of the Effluent for the Pumping Units of the Larkana-Shikarpur Surface Drainage Project.

Catchment	Pumpage (Hm)					Weighted Salinity (ppm)
	1986	1987	1988	1989	Average/yr	
Miro Khan	1938	3443	2263	2156	2450	3803
Shahdadkot	3654	4102	4863	4257	4219	845
Larkana South	871	1305	1114	1248	1135	715
Naudero	466	678	556	510	553	505
Shikarpur	1212	2032	1765	2985	1998	977
Lakhi	630	715	820	785	738	1544
Larkana North	312	407	438	452	402	1383
Nasrat	57	33	205	85	95	392
	9141	12716	12025	12479	11590	1524

D. Hairdin Surface Drainage Project

The construction of the Hairdin Surface Drainage Project commenced in 1974. Its catchment area is in the commands of the Pat Feeder and Desert Canals. Phase I of the project (covering 35,200 ha) was completed in June 1980, while Phase II (36,227 ha) is partially complete. Currently, the effluent from Hairdin is pumped into the Kirthar Branch at RD 116; however, during the project planning stage it was envisaged that the effluent would be disposed of into the RBOD. Farmers downstream of the pumping stations complain of excessive salinity in the canal affecting crop yields on their land. A variety of proposals have been developed as an alternative to this practice, including disposal into evaporation ponds to the north, and mixing with flood flows to the west of the protection bund.

E. North Dadu Surface Drainage Project

This was the second surface drainage project on the Right Bank of the Indus River (after Larkana-Shikarpur Surface Drainage scheme) (Figure 58). The area is covered by the Rice Canal command (97%) and Johi Branch (Dadu Canal). Surveys and investigations were initiated in 1975 and completed during the same year. Construction of this project commenced in 1977 to drain a gross area of 209,064 ha, much of it severely waterlogged (Figure 59). Completed in recent years, the area has shown substantial improvement to the extent that watertables now recede to levels below the root zone following the plentiful recharge period of mid- and late-Kharif (Figures 60a & b). Drainage disposal from the four catchments (Wagan, 35,000 ha; Ghar, 68,000 ha; Mehar, 47,000 ha; and Khairpur Nathan Shah, 27,000 ha) is by pumping into the MNVD. Effluent from the northern part of the catchment (area between Ghar Branch and Ganwar Branch) is collected by the Wagan Main Drain for re-use into the Ghar Branch (Rice Canal system) at Wagan Pumping station. By the early 1980s, farmers downstream of this pumping station started to complain about the adverse effects of this water on their lands, especially since the Ghar Branch Canal was non-perennial. A channel linking the Ghar Branch drain and the MNVD then became the proposed solution to dispose of the effluents from the Wagan catchment.

Overall, some 38 cumecs of additional drainage flows were planned to be put into the MNVD through 906 kms of drainage network, and supplemented with 45 pump installations of 0.85 cumecs each. The three pumping stations for the catchment areas of Ghar, Mehar and Khairpur Nathan Shah were located on the Supro Bund east of MNVD. In lieu of this discharge, the need for remodeling of the MNVD (from RD 0-343.5) was unavoidable.

Salinity was widespread in the area, largely because of the extensive rice cultivation in the absence of drainage, wherein the raised watertables brought along salts that were deposited in the top root zone (Figure 61). Approximately 15 percent of the area were either under water or was made up of swamps. In seasonal swamps, the evaporation of standing water caused the development of the extreme type of salinity. LIP investigations have shown the

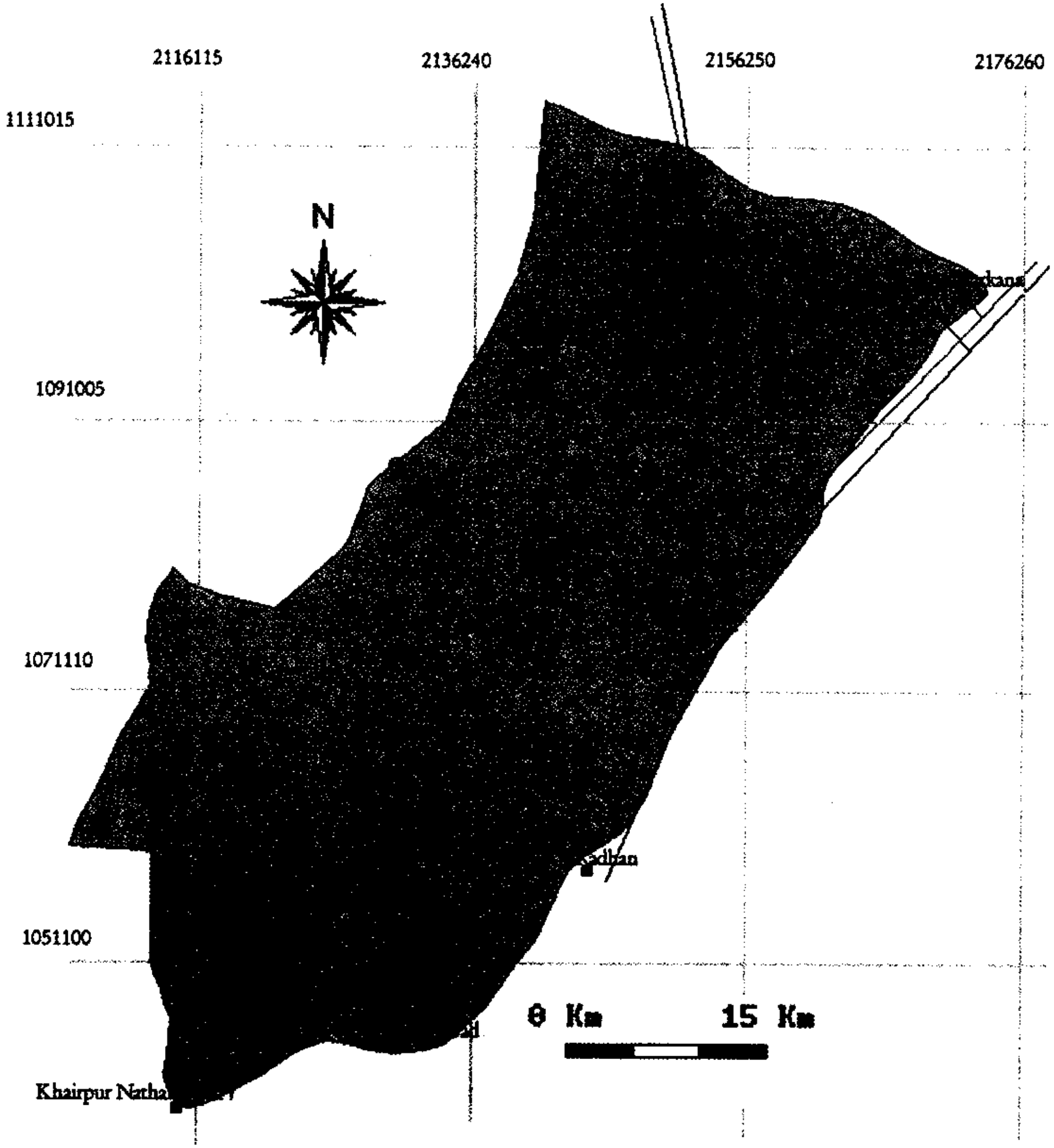


Figure 58. Location of North Dadu Surface Drainage Project, Lower Indus Basin, Right Bank.

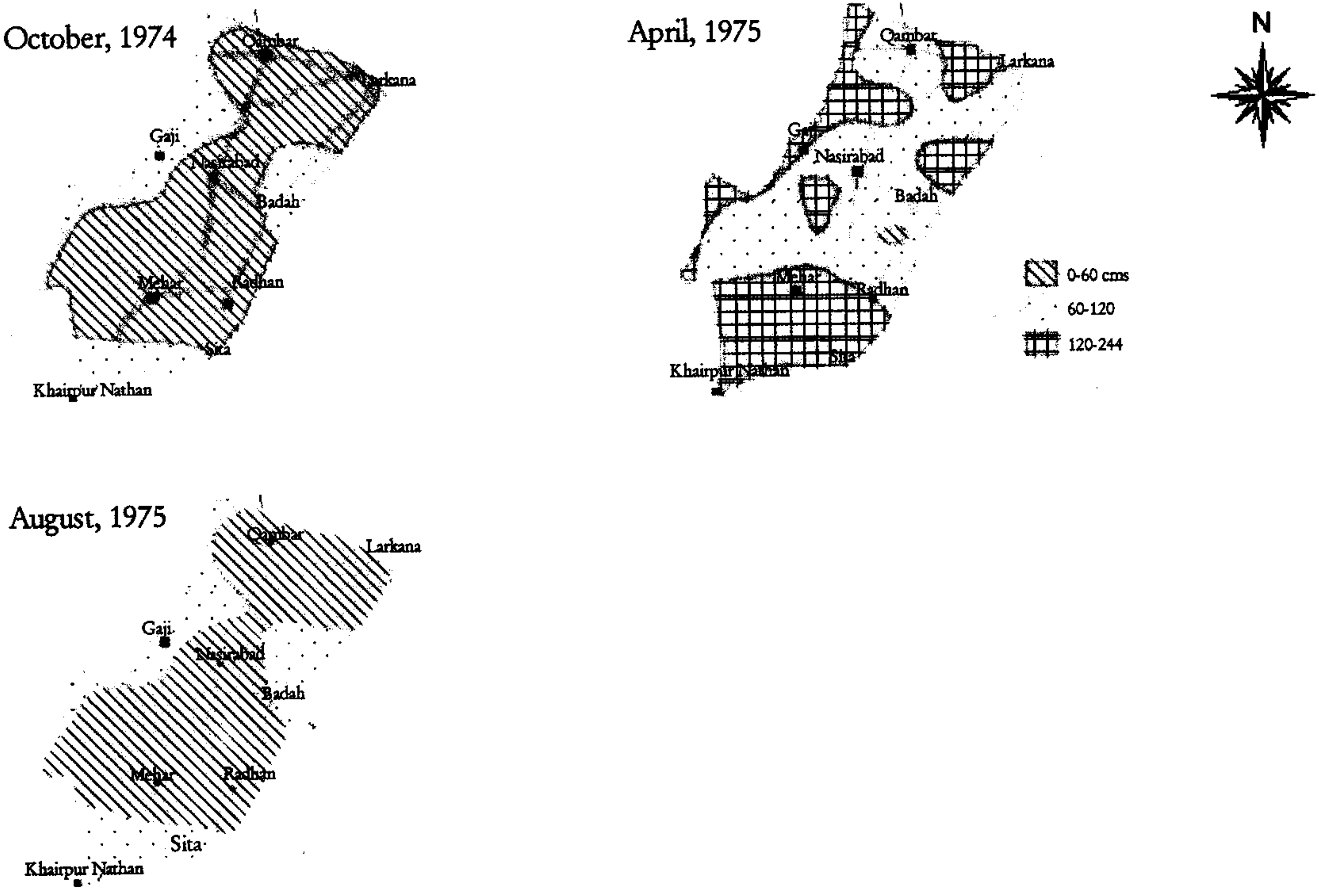


Figure 59. Temporal Changes in Depth to Watertable within North Dadu Surface Drainage Project, Lower Indus Basin, Right Bank

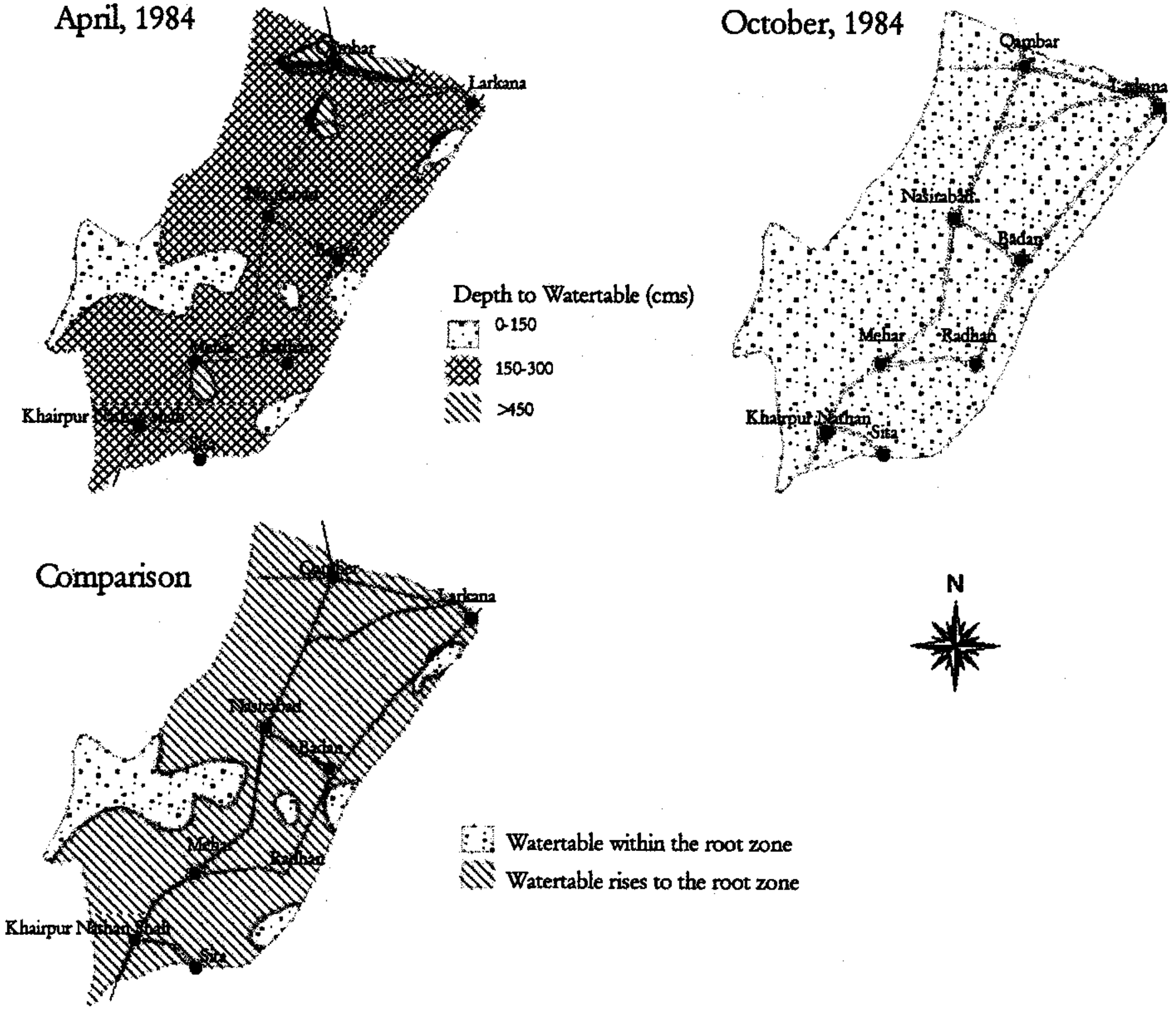


Figure 60a. Seasonal Comparison of Depth to Watertable during 1984 in the North Dadu Surface Drainage Project, Lower Indus basin, Right Bank.

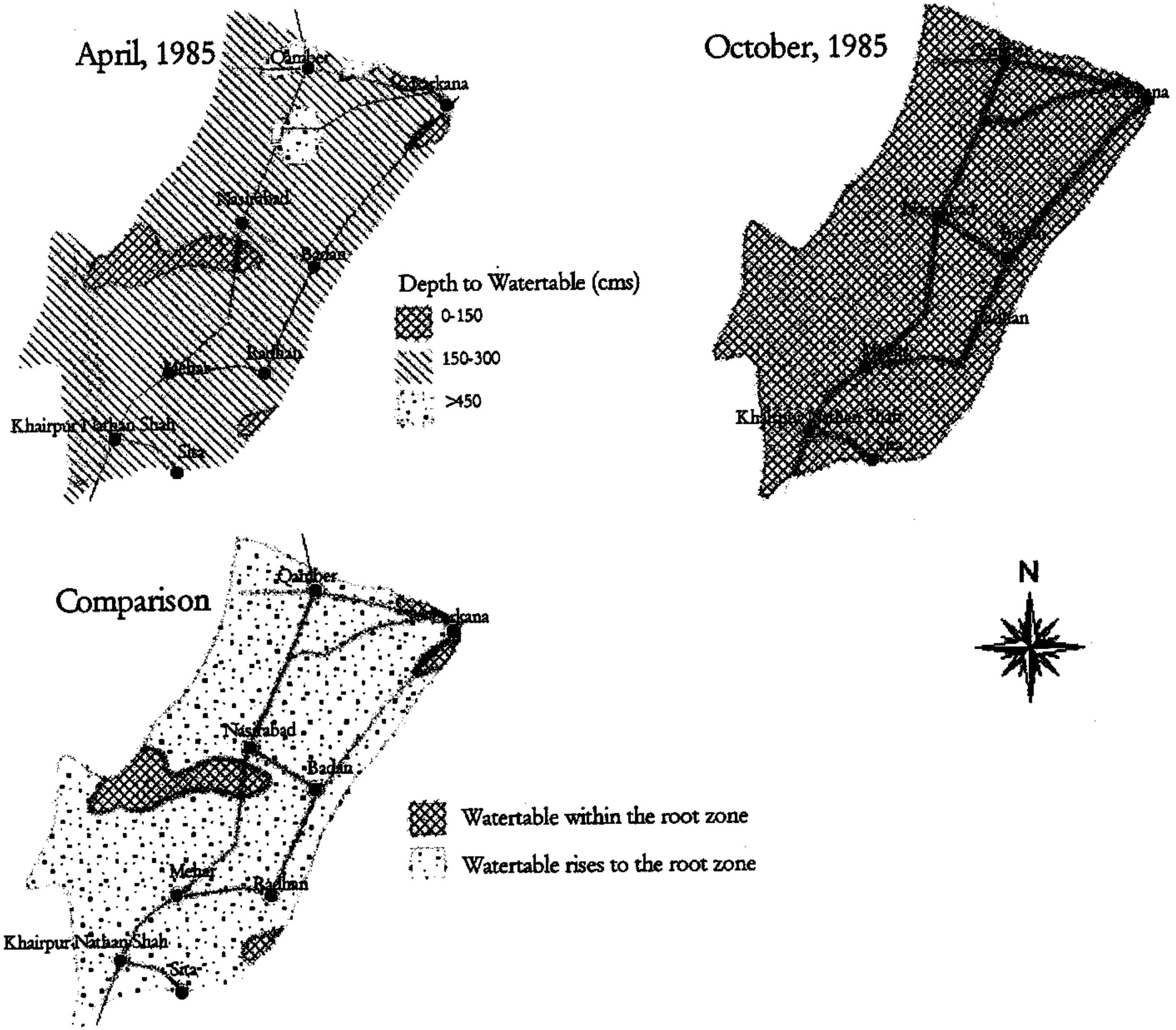


Figure 60b. Seasonal Comparison of Depth to Watertable during 1985, North Dadu Surface Drainage Project, Lower Indus Basin, Right Bank.

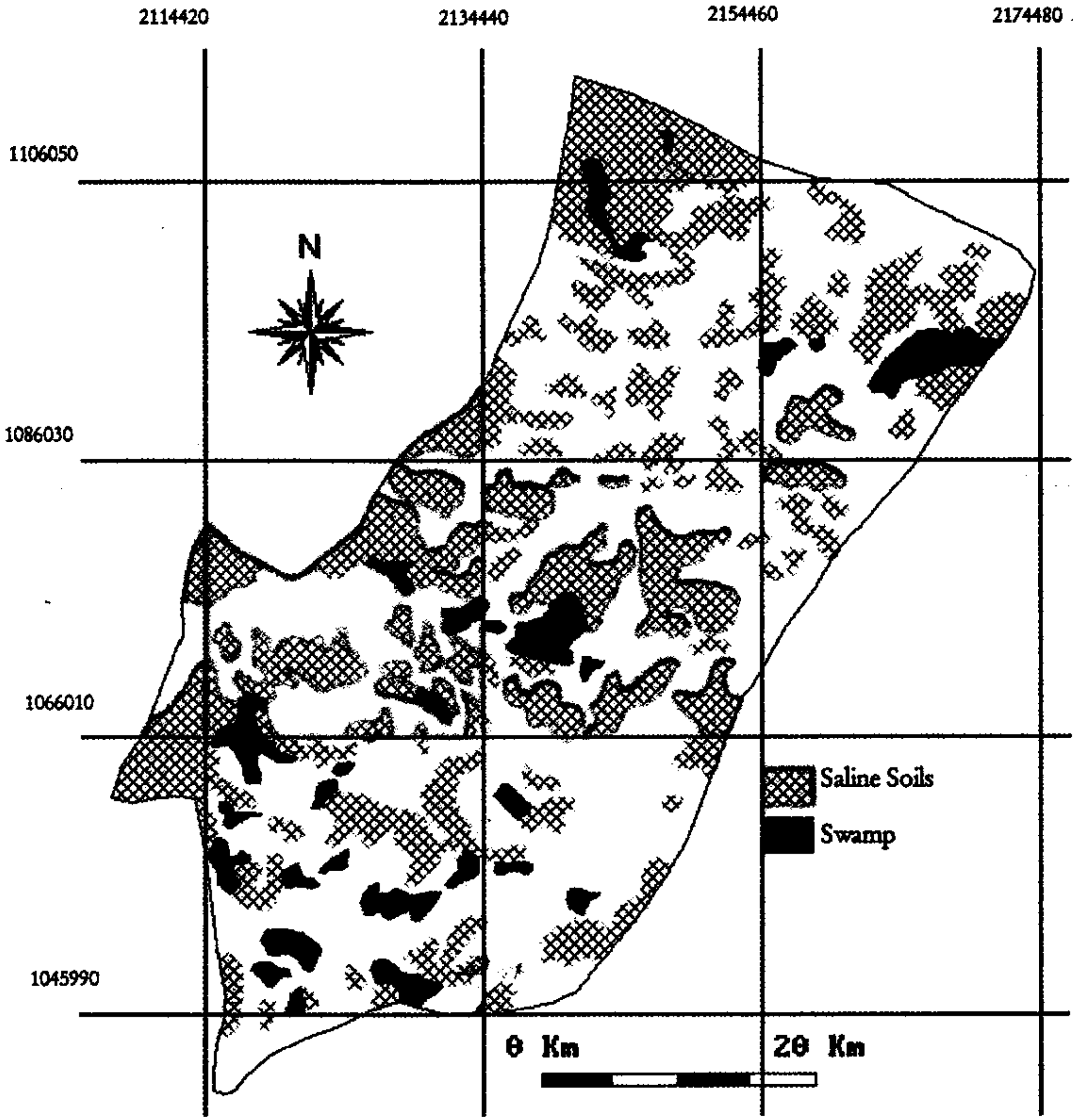


Figure 61. Topsoil Salinity within North Dadu Surface Drainage Project, Lower Indus Basin, Right Bank, 1975.

entire area to be underlain by highly saline groundwater with a distinct division of zones between shallow groundwater (15 m) and the native groundwater, the former having been modified by seepages from the canal system. The quality of water deteriorates abruptly with depth and the transition at many places is sharp.

Prior to drainage-related interventions, the annual cropping intensity in the command of the Dadu Canal was 135 percent, whereas it was 106 percent in that of the non-perennial Rice Canal. The surface drainage was expected to stimulate crop production on areas that were to be reclaimed. The expectation was that rice cultivation would be the greatest beneficiary, whereby production could be enhanced from the pre-project level of 0.142 m metric tons to 0.219 m metric tons in the year 2005, which is about 35 percent more than the expected 'without' project condition (the overall incremental production being 39% higher). The expectation was also that the total cropped area during Kharif would rise from 102.75 thousand hectares to 122.8 thousand hectares by the year 2005, while Rabi season area would increase from 73.44 thousand hectares to 104.78 thousand hectares, accordingly.

F. Ghotki Saline Zone

The irrigated regime in the Ghotki Saline Zone area, covering 222,000 ha (187,000 ha CCA) was proposed for rehabilitation under a Feasibility Report prepared by Agrar-Und Hydrotechnik GMBH (in association with NESPAK) for WAPDA in 1994. The project area comprised 55.6 percent of the gross commanded area of the Ghotki Feeder Canal off taking from the Guddu Barrage. Reconnaissance soil surveys have identified land form units in the area to be subrecent flood plain and subrecent dissected river terraces occupying 36.1 percent and 55.4 percent of the area, respectively. The remaining portion is covered by sand dunes of different dimensions.

Soils and Topography: Texturally, the soils of the project area are 47 percent silty/loamy, 43 percent clayey and 10 percent sandy. The analytical data of soil profiles indicates that there is a general preponderance of Na ions over Ca+Mg ions in the saturation extracts of the soil. Amongst the anions, there is a dominance of SO_4, followed by Cl ions. The dominant salts, therefore, are sulphates and chlorides of sodium and calcium/magnesium. These salts are easily soluble and conducive to leaching. Soil surveys revealed no major reclamation problems, while land area and labor availability appeared adequate for the modest increase in agricultural yields that can be expected with the available irrigation water supplies.

Topographically, the area falls from 75 m asl in the north to 55 m asl in the south over a distance of some 110 kms. The natural drainage pattern formed on the flood plain of the meandering Indus River has been disturbed by the construction of the irrigation system in the 1960's, the road system, the railway line and the flood protection *bunds* to the west of Ghotki Feeder Canal. Oxbows and old irrigation inundation channels form the basic drainage network, but the interconnections are poorly defined and difficult to delineate, even on satellite images.

Drainage: The only known outlet for drainage water from the Study Area is into the Nara Canal through the Karo Naro Drain (1.6 cumecs capacity). The outlet gates are regularly closed by the Irrigation Department when the Nara Canal undergoes maintenance during January. This closure policy results in extensive flooding upstream of the outlet towards Sangrar and requires a review. Also, it has become a regular practice to close the Ghotki Feeder in April and May for maintenance at a time when the supplies are most needed for the cotton plantation. Alternatively, a month between January and March would be a better time, since crop water requirements are lower then.

Groundwater: The area is part of the saline groundwater quality zone that contrasts sharply with the fresh groundwater area to the west that benefits from river recharge (Figure 62). The differentiation in these zones stems from planning for the Ghotki Fresh Groundwater Irrigation Project, wherein the limit between fresh and saline groundwater was set at 1,800 micro-siemens/cm that was not exceeded to a depth of 80 meters. This was the minimum fresh groundwater thickness required for a 28.3 lps tubewell discharge without causing upconing of the underlying salt water.

River recharge diminishes with increasing distance towards the saline zone to the east. During the dry season, the river acts as a groundwater drain and the net annual groundwater recharge becomes negligible when compared to the recharge by seepage from the irrigation system. On a regional level, groundwater inflow from the northeast approximately balances groundwater outflow to the southwest.

Based on the investigative boreholes and testwells (Figure 63)(drilled by both LIP consultants and WAPDA), the aquifer thickness has been determined to be at least 200 meters in the Ubauro area, reducing to about 60 m to the southwest in the direction of the groundwater flow (at an average gradient of 1:6,000). The investigation wells drilled during the Feasibility study period (Figure 64) have confirmed an aquifer thickness of more than 100 m over most of the area. The quality of groundwater sampled from these and other wells, along with performance data, appears in Table 15.

Irrigation: Until about 1975, the Feeder Canal was operated as a non perennial canal and was closed in Rabi. From then onwards, water has been made available throughout the year with the exception of the closure period in late April and May, when supplies are severed. The records show that an average of 2,340 Mm3 and 1,129 Mm^3 of water has been diverted from the Indus River at the Guddu Barrage in the Kharif and Rabi seasons, respectively, to the Ghotki Feeder System with an average annual diversion of 3,469 Mm^3. The Ghotki Feeder has a design full supply discharge of 240 cumecs that approximates to 0.71 l/s/ha of CCA, and discharges in excess of 280 cumecs have been safely passed down the system. The low overall water duty encouraged farmers to concentrate irrigation water on a reduced area of cultivation and this resulted in a salinity rise on the adjacent fallow areas by evaporation from the high level groundwater. Drainage, better water control and leaching-based reclamation have become the foremost requirements for sustainable agriculture.

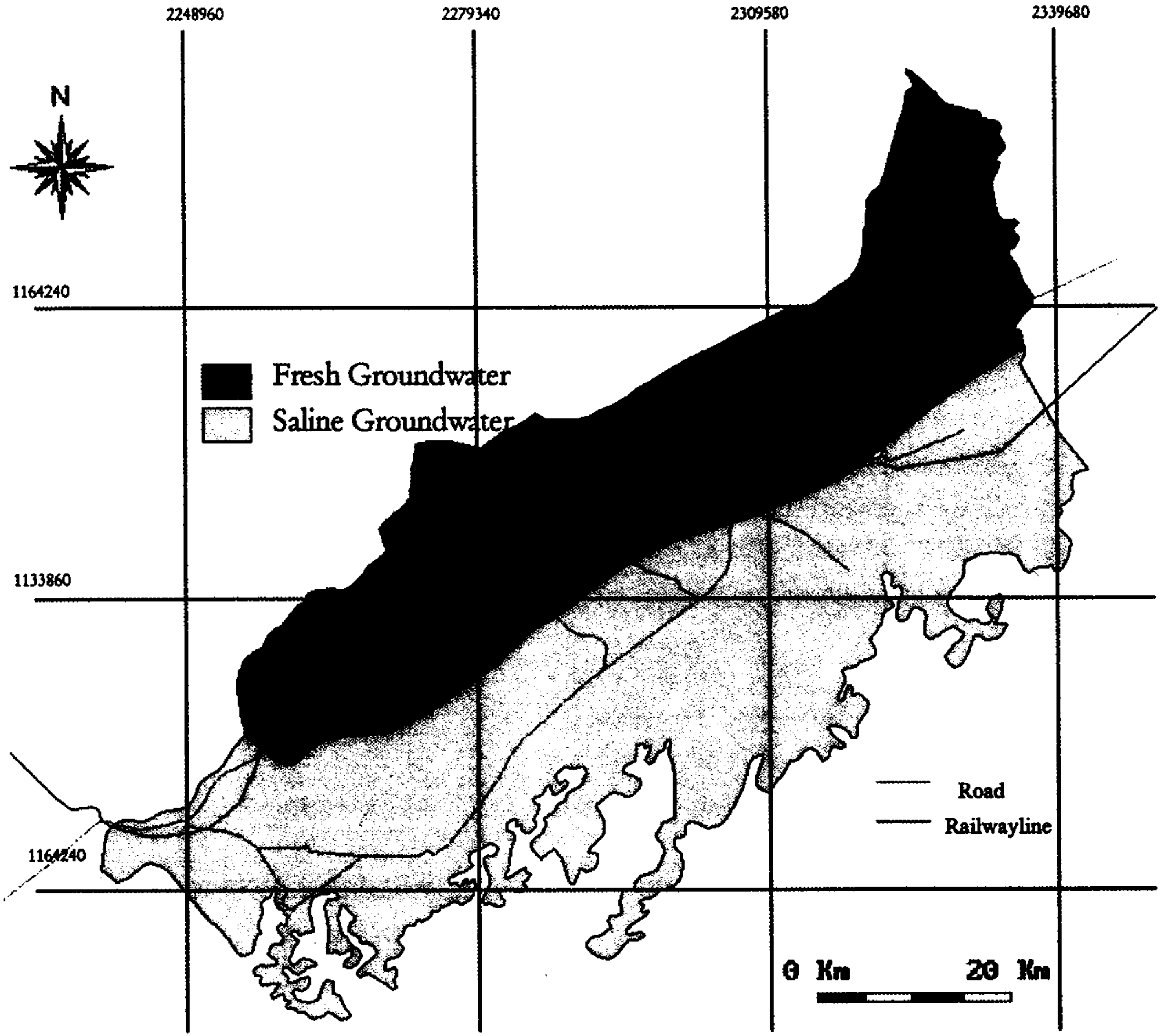


Figure 62. Location of Ghotki Fresh and Saline Groundwater Projects, Lower Indus Basin, Pakistan.

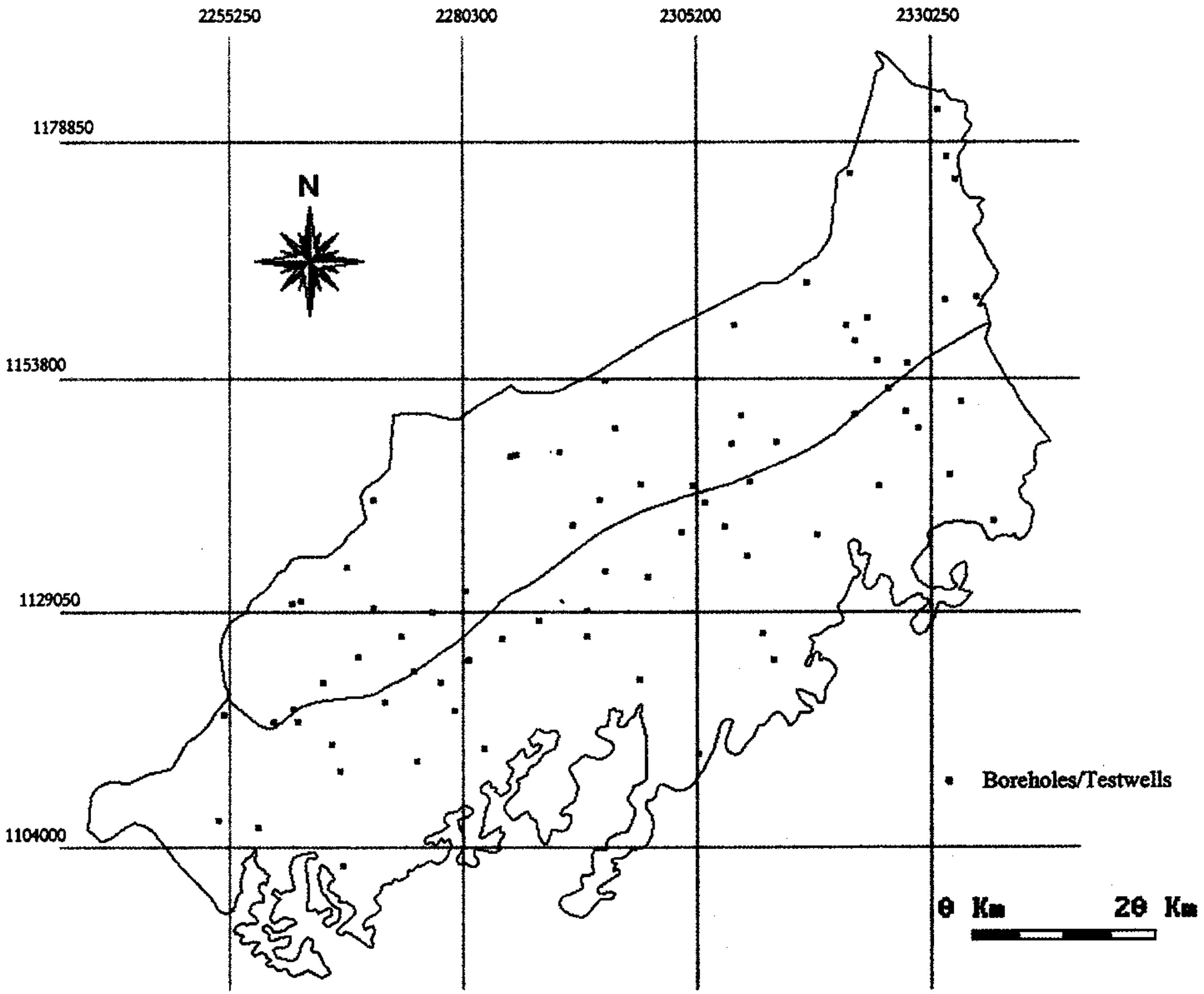


Figure 63. Location of Investigation Boreholes and Testwells in the Ghotki Fresh and Saline Groundwater Projects, Lower Indus Basin, Left Bank.

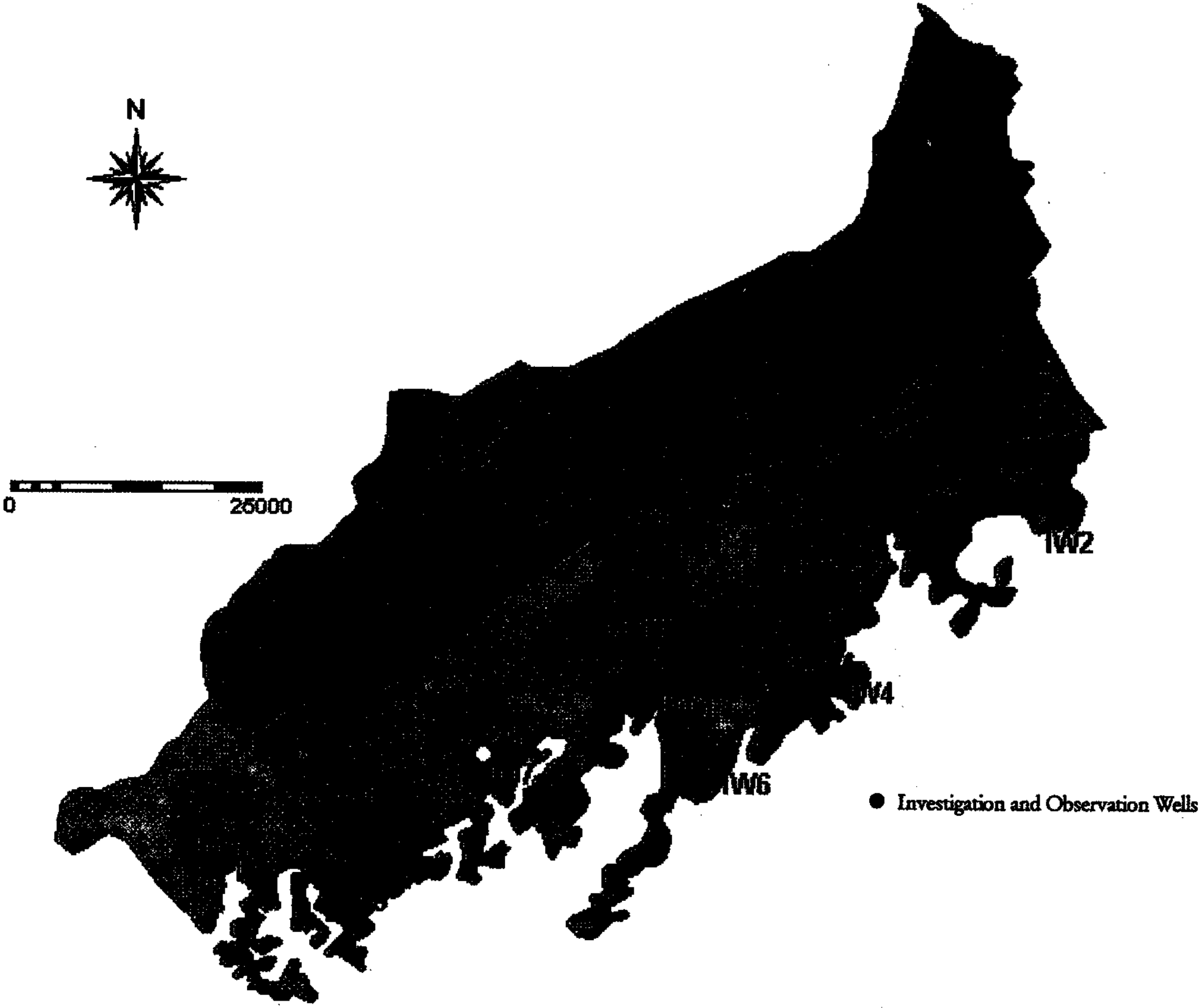


Figure 64. Investigation and Observation Wells in the Ghotki Saline Zone.

Table 15. Aquifer Water Quality (with Depth) and Performance Data of Investigation/Observation Wells in the Proposed Ghotki Saline Zone Project, Gudd

Tubewells	Groundwater Salinity Variation with Depth (in meters)																				
	3	5	10	15	20	25	30	40	45	50	55	60	65	70	75	80	85	90	95	100	105
IW-1		6950	6900	6920	6840	21400	29600	29900	29900	29900	29900	30400	30400	30400	30400	30500	30500	30600	30500	30500	
IW-2		790	795	730	710	760	5720	30400	30500	30600	30700	31100	31500	32100	32100	32200	32200	32300	32300	32300	3240
IW-4		825	785	780	1340	1370	1390	30200	30400	32500	32600	32600	32700	32700	32800	32800	32900	30000	33100	33200	
IW-5		1160	1160	1160	1330	3760	15300	27400	28600	28900	29000	29100	29200	29200	29500	29700	39900	30000	30100		
IW-6		905	840	775	745	720	910	2680	14900	25600	29500	31400	32900	34200	34600	35100	35400	35700	35800	35900	3590
IW-7		1400	1380	1380	1380	1440	2150	2810	5100	27200	27500	27500	27500	27700	28500	28600	29000	29100	29600	30500	
IW-8		1250			1170	1210	1270	1370	1270	1200	1200	1220	21000	21300	21300	21200	21300	22000	23200	24000	
IW-9		5820	5810	5810	5800	7880	12840	18500	26200	29400											
IW-10		740	720	715	710	705	705	725	895	5010											
O-1		27200	27500	27500	27800	27800	27900	28300	28500	28500	28500	28500	28500	28500	28600	28800	29100	29200	29300		
O-12	1870	2210	2240	2230	2210	2210	22900	2630	2640	2660	7450	15700	29800	30400	30600	30700	30800	31000	31300	31500	
O-13	1510	1500	1500	1500	1500	1500	2320	1750	1950	2210	2790	7020	13500	17700	22600	24900	26000				
O-24	1100	1100	1100	1310	1350	1370	1250	6010	6700	9300	17400	21500	27600	28200	28400	28400	28400	28400	28400	28400	

Barrage Command, Sindh Province.

Performance Data						
Depth		Screen Length	Discharge	WL b.GL	Draw-down	Specific Capacity
Drilled	Cased					
m	m	m	l/s	m	m	l/s/m
106.7	102.8	82.3	84.9	1.00	4.10	20.7
115.2	108.9	88.4	84.9	3.62	4.43	19.2
108.2	102.8	82.3	84.9	1.16	4.06	20.9
100.6	97.0	76.2	84.9	0.91	3.84	21.1
112.8	109.2	88.4	84.9	1.75	3.47	24.5
106.7	103.1	82.3	84.9	0.17	4.26	19.9
100.6	97.0	76.2	84.9	1.51	4.08	20.8
67.1	54.1	33.5	84.9	1.61	6.38	13.3
51.8	48.0	27.4	84.9	1.01	8.58	9.9
102.1	100.3	84.1	28.3	1.69	1.28	22.1
103.6	100.3	84.1	28.3	0.55	1.67	16.9
100.6	85.3	71.9	28.3	0.24	1.94	14.6
102.1	100.3	84.1	28.3	0.75	2.01	14.1

Next >>

There is little tubewell irrigation in the Saline Zone, being confined to localized areas usually near the canals where pockets of fresh groundwater are to be found, and where shallow tubewells are constructed by farmers and landowners. Tubewell water is pumped into an irrigation watercourse, farm channel, or directly into the main canal system.

The change from non-perennial irrigation to perennial irrigation in the mid-seventies and poor maintenance/water control have resulted in spillage from the canals and outlets over the years, expecially when the water diversions are in excess of demand. The practice removed the period of recovery between November and April when groundwater levels usually fell. The LIP investigations have shown that preceding controlled availability of irrigation supplies, the depth to watertable was > 3.6 m over about 99 percent and 86 percent of the area in April and October 1964, respectively. Subsequent investigations by WAPDA showed only 33 percent of such areas in April 1975.

Soil Salinity and Waterlogging: On the basis of the interpretations carried out by the SSoP towards characteristic soil associations, nearly 40 percent of the area was identified as saline sodic. Subsequent profile surveys by WAPDA showed this percentage to be around 28 percent. More intensive surveys conducted on behalf of the feasibility study and sustained by satellite image interpretation have shown approximately 10 percent of the area to be strongly salinized (Figure 65). The overall statistics from these surveys could be compared with the surface salinity map prepared by WAPDA in 1981 (Table 16).

Table 16. Temporal Comparison of Extent of Soil Salinization in the Ghotki Saline Zone Project.

Salinity Class	Feasibility Survey (1992-3)		WAPDA (1981)	
	Area (ha)	%age	Area (ha)	%age
Non-Saline	39740	17.9	144950	72.2
Slightly Saline	50,370	22.7	10,340	5.1
Moderately Saline	109,090	49.2	12,220	6.1
Strongly Saline	22,580	10.2	33,400	16.6
Total	221,780		200,910	

A pre- and post-monsoon comparison of fluctuations in watertable appears as Table 17 which also accounts for the pumpage initiated by in the neighboring Ghotki Fresh Groundwater Tubewell Project from 1978-79 onwards. The SCARP pumpage seems to offer maximum control during the dry April period; however, a rampant rise in watertables is clearly visible in the change in critically waterlogged area during 1990.

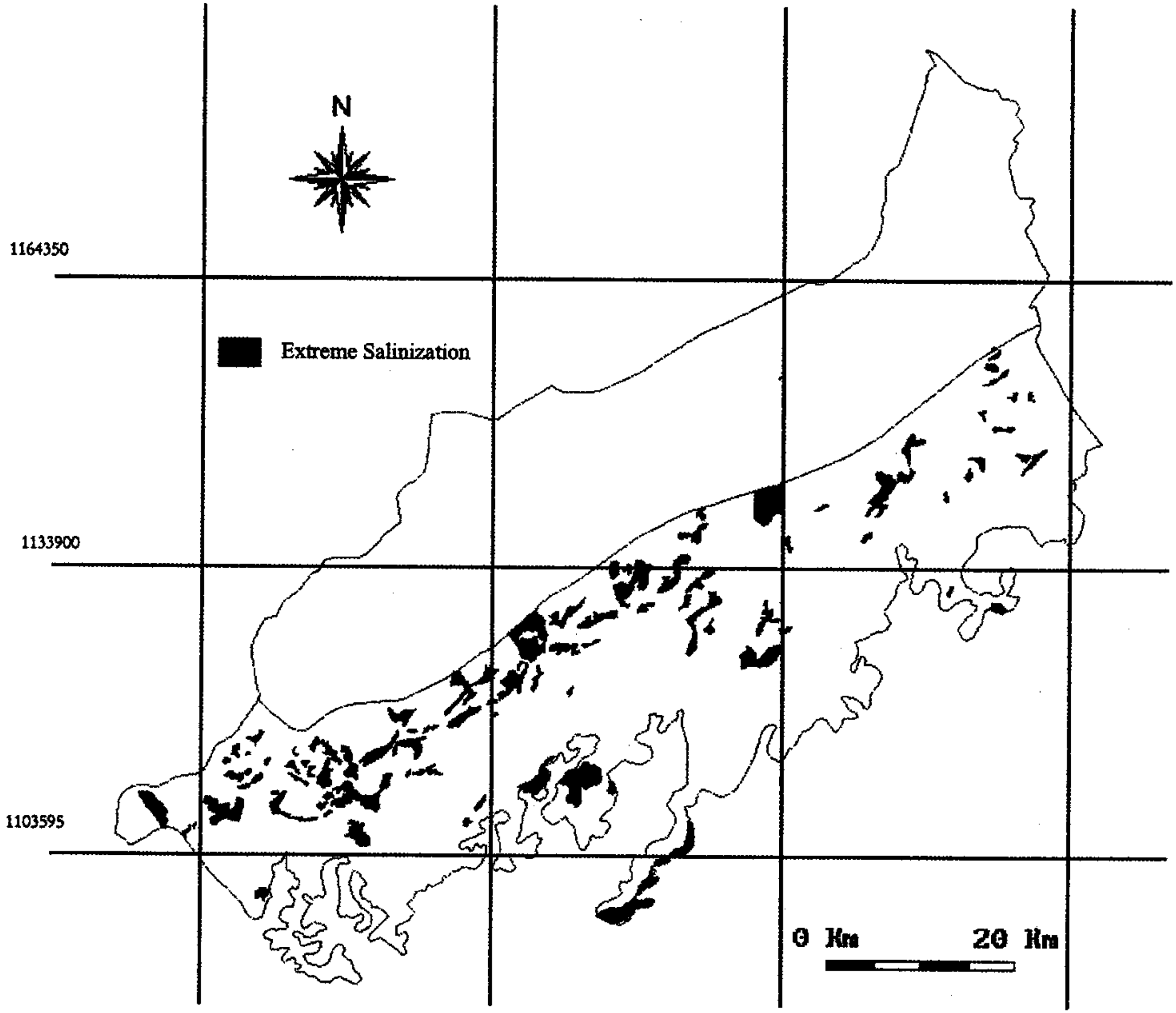


Figure 65. Extreme Salinization in the Command of the Ghokti Saline Zone Project, Lower Indus Basin, Left Bank.

Table 17. Temporal Comparison of Pre- and Post-monsoonal Watertable Fluctuations in the Ghotki Fresh and Saline Groundwater Zones.

Depth to Watertable (m)	April 1978	April 1990	June 1992	May 1993	October 1978	October 1990	October 1992	October 1993
< 1.5	9	15	18	12	44	82	84	82
1.5-3.0	45	77	80	87	26	13	15	17
> 3.0	46	8	1	0.7	30	5	0	0

Mapped representation of these interseasonal fluctuations and their related differences are given in Figures 66a-c for the years 1978, 1990 and 1993, respectively. By 1993, much of the permanently critically waterlogged area had diminished and remained confined to the eastern and southern edge of the Saline Zone.

Development Program: The Feasibility Study for the project was undertaken to determine the extent and magnitude of problems related to waterlogging, soil salinization, improper water management and the basic agricultural services. The essential components for realizsation of these aims were expected to be the:

- Control of the watertable at between 2.0-3.0 m below natural ground level;
- Construction of a combined subsurface-surface drainage system and a drainage outfall system; and
- Prevention of further salinization of land and the reclamation of saline areas for raising cropping intensity and crop yields.

The Feasibility Report divided the project area into the Affected and Most Affected areas. The Affected area was defined as the area where the water rose to < 0.9 meters from the surface during the post-monsoon period in October; the Most Affected area had the same condition prevailing during the drier months of April/May. The extent of these areas was determined to be as follows:

Affected Area	99,000 hectare CCA
Most Affected	41,000
Marginally Affected	47,000

Towards implementation of an effective drainage scheme in the area, various options pertaining to the disposal of saline effluent were considered in the study. Four possible effluent disposal alternatives were considered.

Alternative I:	Tile drainage of Most Affected areas and Affected areas over a 15-year period and construction of the complete drainage system for the entire catchment.

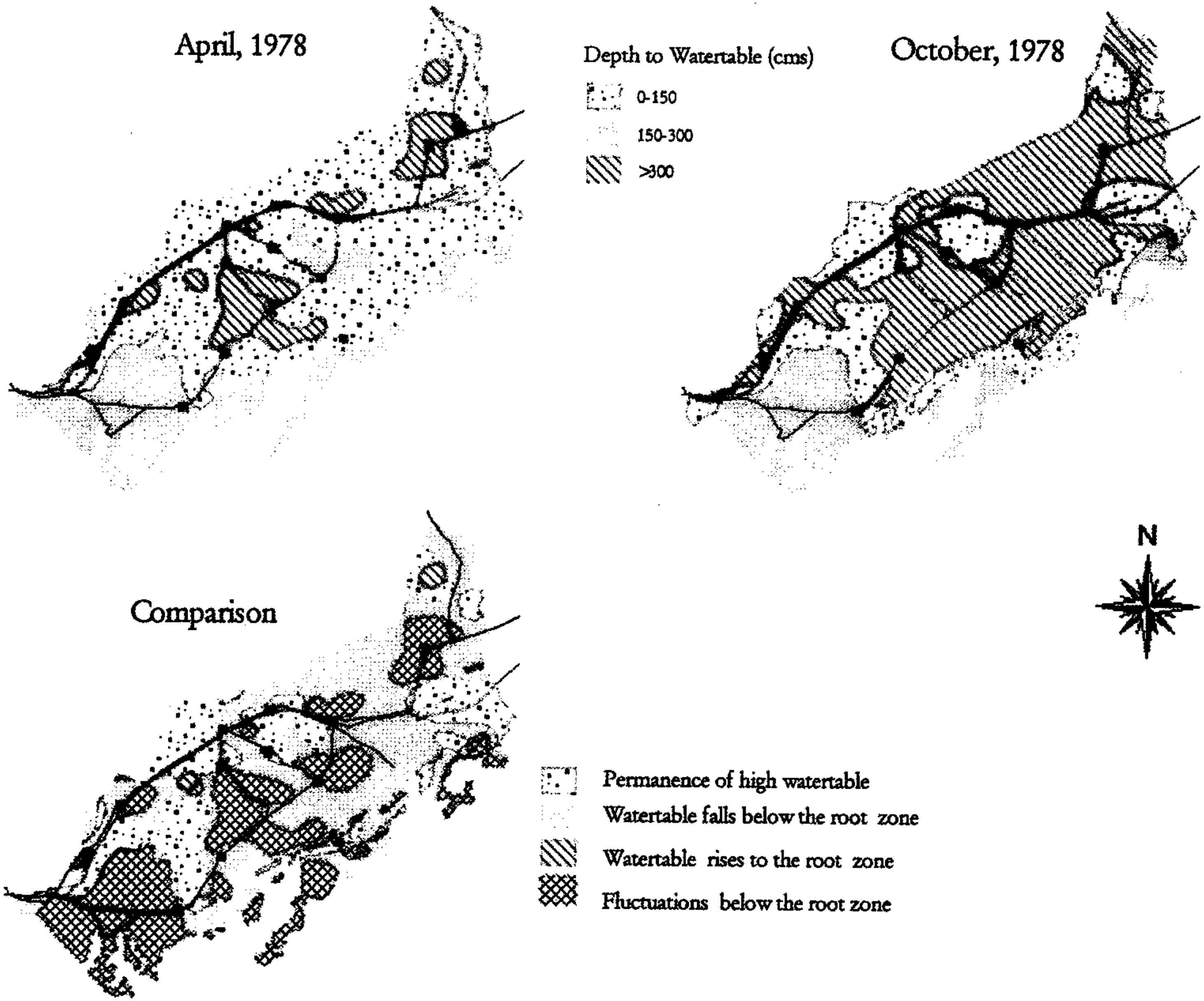


Figure 66a. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1978 in the SCARP Ghokti Fresh and Saline Projects, Lower Indus Basin, Left Bank.

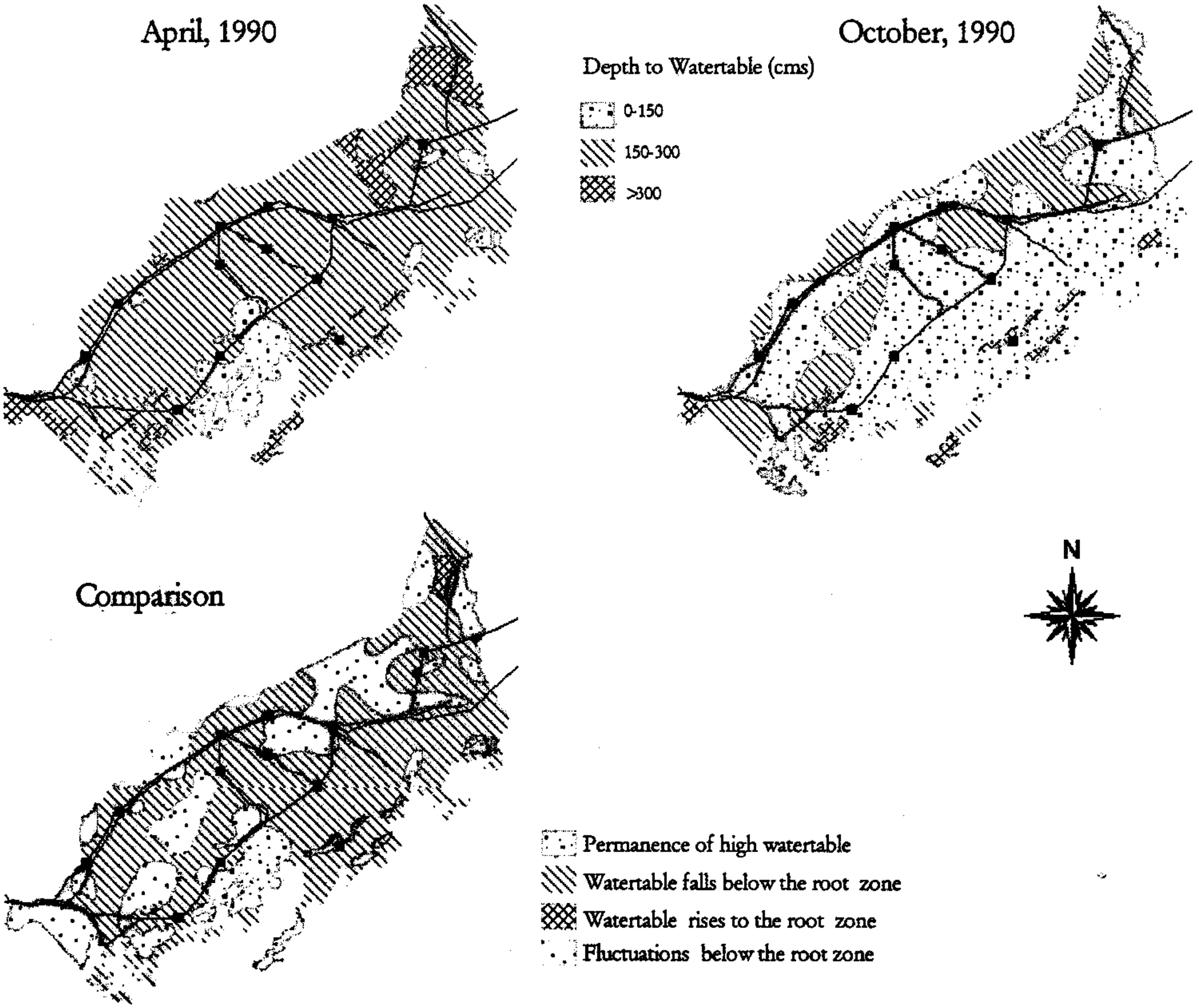


Figure 66b. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1990 in the SCARP Ghokti Fresh and Saline Project, Lower Indus Basin, Left Bank.

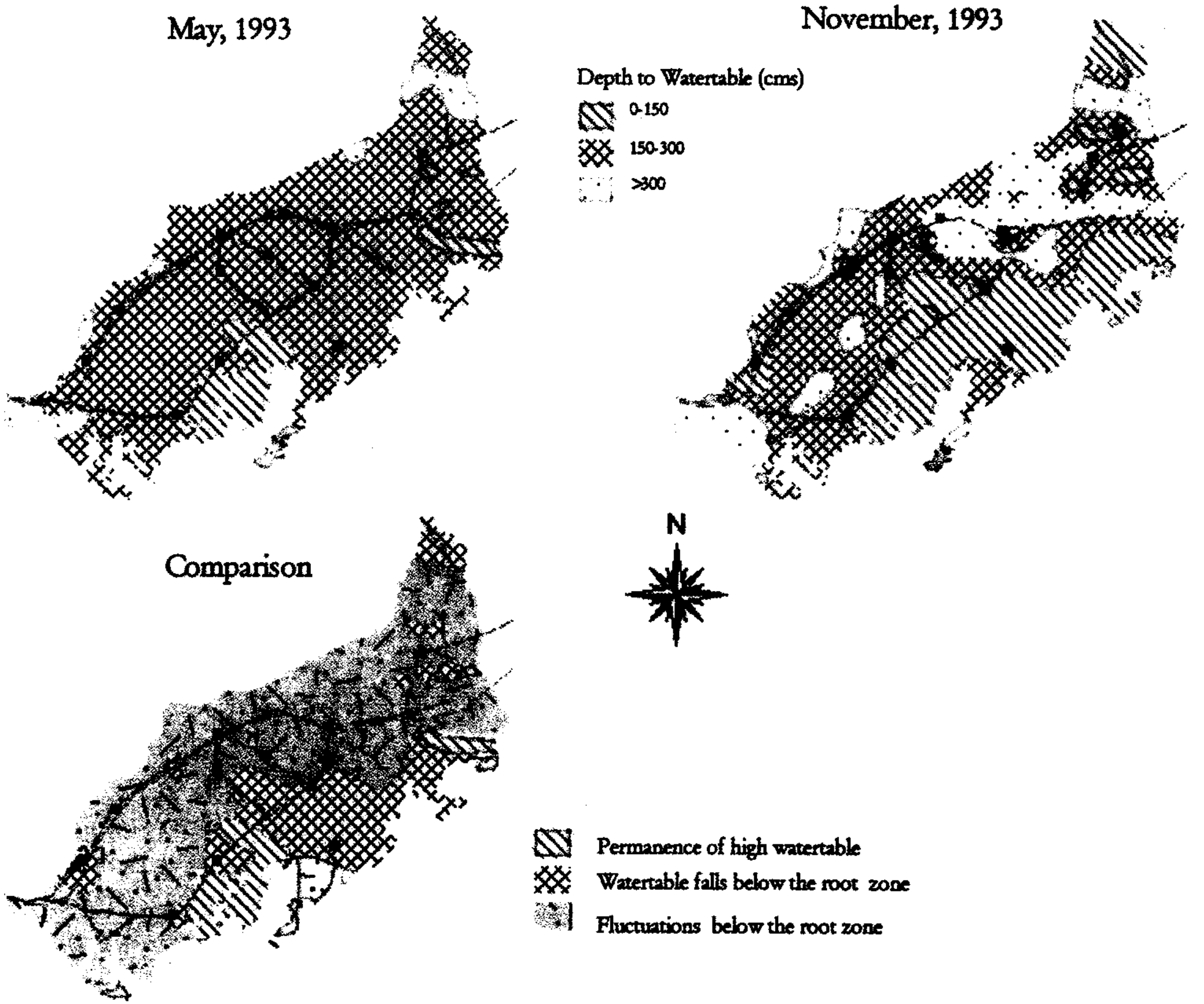


Figure 66c. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1993 in the SCARP Ghokti Saline Project, Lower Indus Basin, Left Bank.

Alternative II:	Tile drainage on 25,000 ha CCA of Most Affected area; OFWM on 30,000 ha CCA in Most Affected and Affected areas (out of 116,000 remaining in these two categories); surface drainage system to serve tile drains. This alternative has been confirmed as the preferred solution for the drainage in the Saline Zone.
Alternative III:	Close the Ghotki Feeder in the Rabi season and apply irrigaton water only in Kharif.
Alternative IV:	Provide only surface drainage to cover the entire catchment.

The drilling and pump testing program confirmed that tubewells were capable of lowering the groundwater levels, but that the salinity of the drainage water should be between 20,000-38,000 uS/cm at the wellhead. This compares to a river water quality of under 500 uS/cm and existing drainage waters at less than 2,400 uS/cm.

The project envisaged an increase in cropping intensity from 96 percent to 120 percent in tile drainage areas, or 106 percent with the implementation of an OFWM program. The OFWM program was proposed for areas exclusive to tile drainage development and was aimed at reducing the watertables slightly with concurrent savings in water for an increase in yields and cropping intensity. Without the project, the cropping intensity is expected to fall to 93.5 percent by the year 2005. The 1992-93 survey by the Consultants reported a cropping intensity of 113 percent with 13 percent for rice. A temporal comparison of the CCA-based cropping intensities, both predicted and actual, is given in Table 18.

Table 18. Major Crop Intensities corresponding to both Pre- and Post-feasibility Assessments for the Ghotki Saline Zone Project.

Crop	Cropping Intensity				
	1991-92*	Feasibility Study Assessment 1992-3	Without Project	With Project	IIMI Survey 1997-98
Wheat	28.1	28.1	27.5	28.5	65.5
Cotton	27.0	27.0	15.0	22.2	69.1
Rice	7.7	15.0	23.0	18.2	8.2
Sugarcane	0.4	0.4	2.0	2.1	1.8
Rabi	38.3	40.0	40.1	42.1	
Kharif	57.2	55.8	53.4	56.9	

*Irrigation and Power Deptt., Ghotki Canal Circle, Sukkur (1991-92).

In the LIP development plan, the entire Ghotki command was strictly considered as non-perennial and divided into two zones of fresh and saline groundwaters. In the fresh zone, 160 percent cropping intensity was envisaged (Kharif 73%, Rabi 87%) with the Rabi crop water requirements to be met from FGW development only. Only the best quality lands were to be developed in the SGW zone as part of the non-perennial system based on 100 percent rice intensity, and while Rabi was on residual soil moisture.

G. Ghotki Fresh Groundwater Irrigation Project

The project area covers some 178,500 ha under the Guddu left bank command and lies buttressed between the river Indus to the east and Ghotki Saline Zone to the west and south (Figure 67). The fresh groundwater (TDS < 1000 ppm, SAR < 7.5) harvesting envisaged under the project was the third in a series of proposals submitted by WAPDA (WASID, 1970) in the mid-1970s for the overall development of the Lower Indus Plain (the two previous being North and South Rohri FGW projects).

The project area, comprising 161,900 ha CCA, is virtually flat, sloping at 0.0001 from northwest to the south east, and is underlain by a fresh groundwater aquifer, which varies in depth from 180 m in the north to about 60 m in the south; the aquifer is limited between 30-60 m on the eastern boundary with the Ghotki Saline Zone. Despite high anisotropy, the aquifer is highly transmissive and of large areal extent, which can be economically exploited.

Assessment of soil salinity, at the time of initial Project Planning, showed nearly 10,400 ha to be affected within the Ghotki FGW area. Nearly 45 percent of this affected area was salinized and the remaining made up of saline-sodic salts. Soil surveys conducted in 1986 revealed that about 60 percent of the problem area (land underlain by saline groundwaters) was affected by salinity and sodicity of the soil and was not bearing crops. Even the cropped area had patchy salinity; the crop yields were expected to be low due to a combination of both soil salinity and high watertables. However, the characteristically high base exchange capacity of the soils is favorable to leaching of the saline-sodic soils. The salts in the soils are dominantly NaCl, Na2SO4 and sometimes NaHCO3-type.

Prior to the submission of the first Project Planning Report, 937 private tubewells (mostly fractional) had been installed in the period 1962-74 (WAPDA, 1976). These wells operated against an operational factor of 0.26 with limited use during the Kharif season. The year-wise private tubewell development and concurrent groundwater withdrawals are given in Figure 68. Until that time, the system had non-perennial service and the steady increase in the Rabi wheat acreage was attributed to this limited private tubewell development. Following the initial installation of 410 tubewells by December 1983 in the project area (300 in Ubauro Unit and 110 in Mirpur Unit), a separate PC-I was floated by WAPDA to cover for the installation of another 1,050 tubewells (342 of 43 lps capacity and 708 of 28 lps capacity). The proposed annual operating factor for these wells was 46 percent. Subsequent

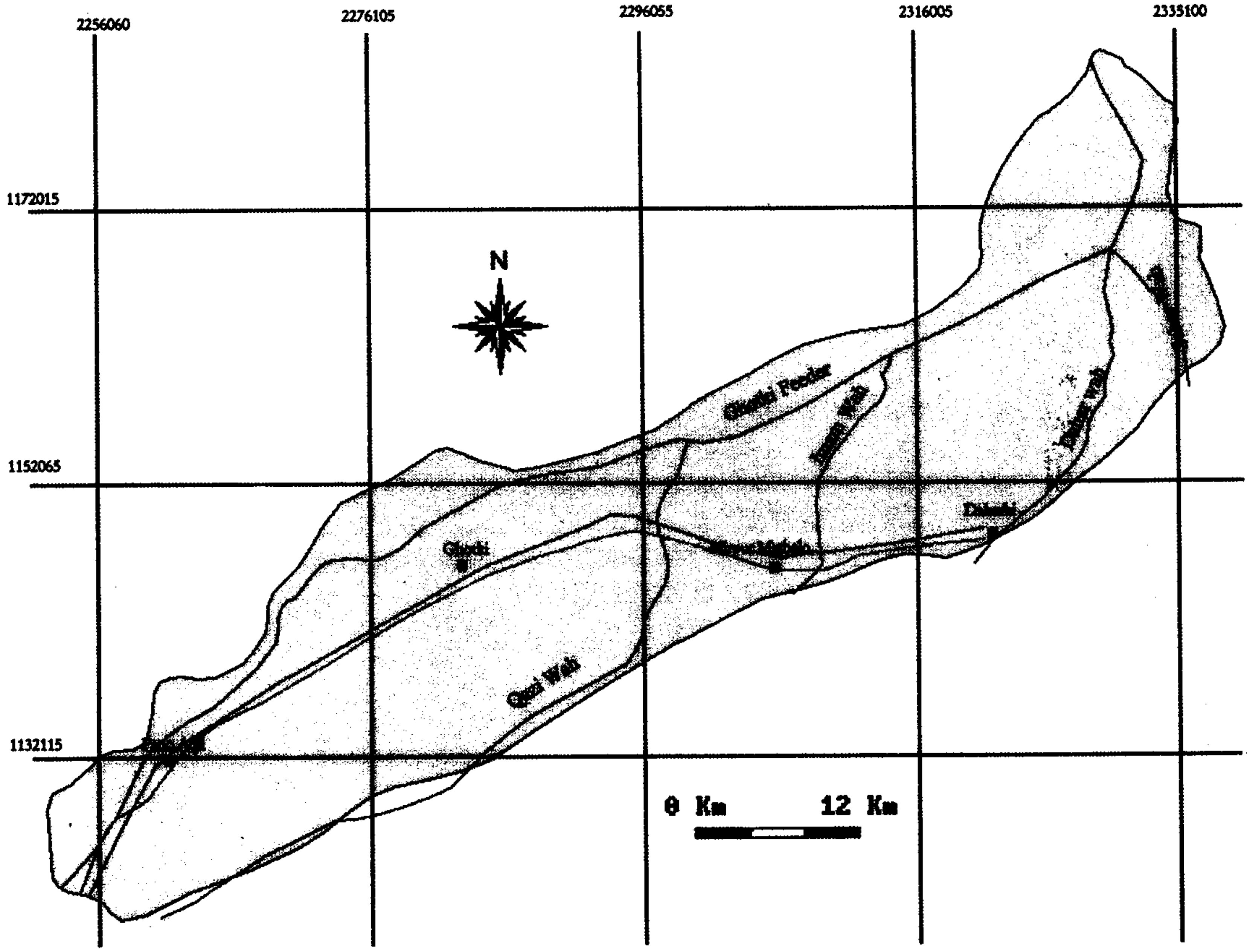
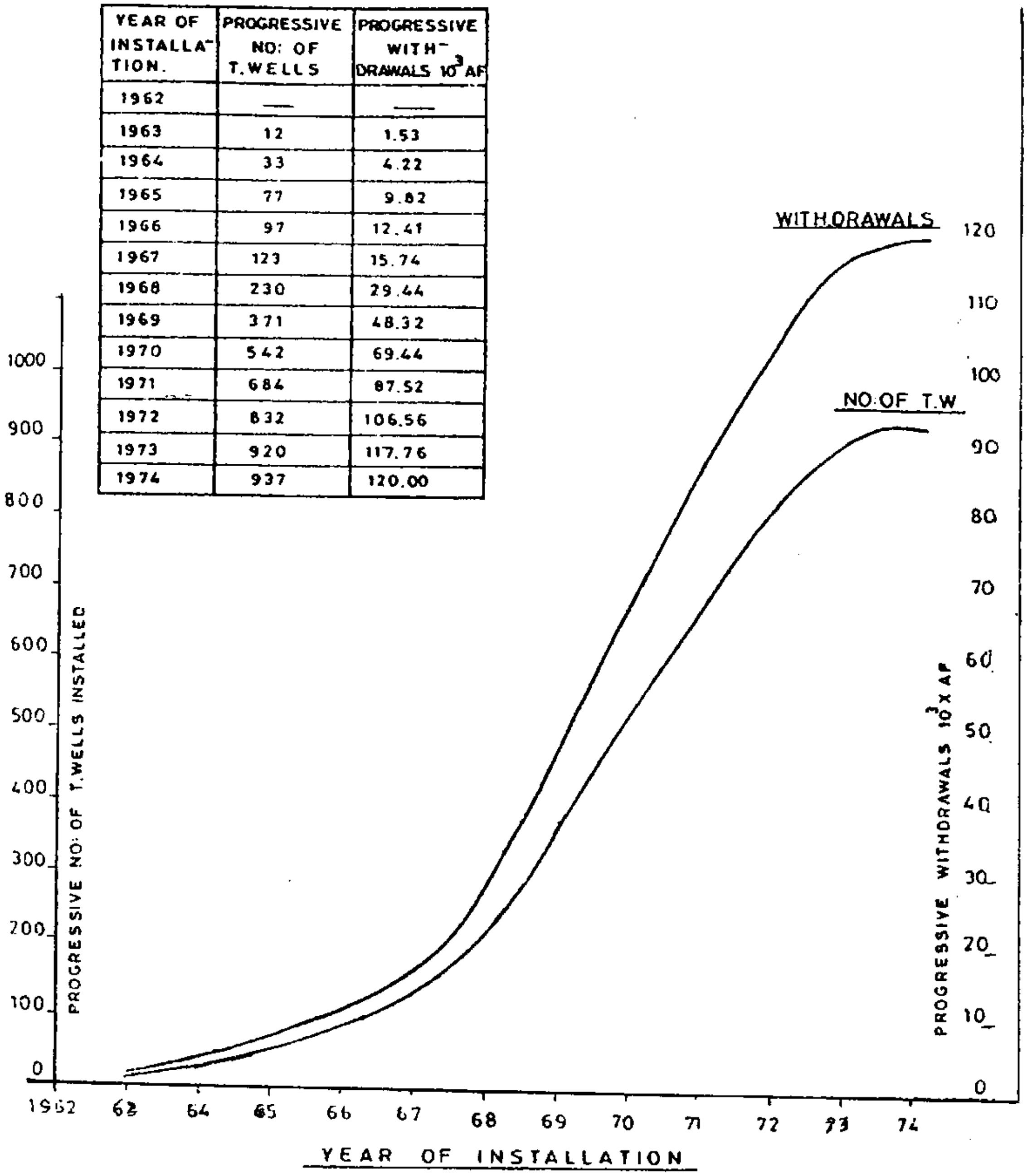


Figure 67. Location Map of Ghotki Fresh Groundwater Project, Lower Indus Basin, Sindh, Pakistan.



YEAR OF INSTALLATION.	PROGRESSIVE NO: OF T.WELLS	PROGRESSIVE WITHDRAWALS 10^3 AF
1962	—	—
1963	12	1.53
1964	33	4.22
1965	77	9.82
1966	97	12.41
1967	123	15.74
1968	230	29.44
1969	371	48.32
1970	542	69.44
1971	684	87.52
1972	832	106.56
1973	920	117.76
1974	937	120.00

Figure 68. Private Tubewell Development in the Ghotki Fresh Groundwater Tubewell Project Area.

pumping records by SM (South), WAPDA, show operation factors of 8 percent and 27 percent for the Ubauro Unit in the years 1979 and 1984, respectively.

Under a loan from KfW in 1983, the project continued with advisory assistance from the Consultants (Agrar- Und Hydrotechnik GMBH, NESPAK and Allied Engineering). The revised planning for the project accounted for the installation of an additional 669 wells (and not 1,050 wells, as suggested by WAPDA in the PC-I) of discharge capacity varying between 28-56 lps. The total installed capacity of these tubewells was 20.93 cumecs (15.69 cumecs in Ubauro and 5.24 cumecs in Mirpur) (Table 19).

Table 19. Progressive Installation of Tubewells and their Design Discharge Capacities in the Ghotki Fresh Groundwater Project.

Year	Tubewell Design Capacity (lps)			Total Number of Wells	Total Installed Capacity (cumecs)
	28.3	42.5	56.6		
1977-78	-	92	208	300	15.69
1982-83	-	70	40	110	5.24
1987-88	16	117	139	272	13.29
1988-89	219	105	73	397	14.8
Total	235	384	460	1,079	49.02

Tubewell capacity of 56.6 lps was deemed fit for areas of fresh groundwater thickness exceeding 120 m; 42.5 lps capacity for aquifer thickness ranging between 100-120 m, and 28.3 lps capacity for freshwater lenses between 80-100 m. The demarcation of the fresh groundwater aquifer thickness then became a resolute consideration that took precedence over other tubewell siting details.

Based on the 32 bore/test hole investigation results reported in the LIP Report for lateral permeability, specific capacity and groundwater quality, the project area can be delineated into three distinct zones of groundwater extraction. Table 20 shows the approximate extents of these three zones with depth of exploitable fresh groundwaters.

The salinity classification of tubewell waters, as agreed between WAPDA, KfW and the Consultants, was based on the results of the EC measurements from the Development & Testing (D&T) and Final Acceptance Test, and is summmarized in Table 21.

Table 20. Classification of Fresh Groundwater Zones in the Ghotki Fresh Groundwater Tubewell Project.

Zone	CCA (ha)	Lateral Permeability (cms/s)	Storage Coefficient	Fresh Groundwater Depth (m)
'A' Area yielding fresh groundwater indefinitely	113,300	0.00487	0.15	100-180
'B' Area of shallow aquifer, possible saline water upconing	37,200	0.00426	0.15	60-100
'C' Area of thin fresh groundwater overlying highly saline waters	11,300	0.00426	0.15	30-60

Table 21. Electrical Conductivity-based Salinity Classification of Tubewell Waters in the Ghotki Fresh Groundwater Tubewell Project.

Conductivity Range (micromhos/cm)	Description	Number of Tubewells
< 750	No restriction	768
750-1200	Good	239
1200-1800	Permissible	52
1800-2400	Permissible to problematic	15
2400-3000	Moderately problematic	4
> 3000	Hazardous	1

WAPDA's own tubewell water quality sampling, conducted by the SMO, is represented by the three distinct classifications of usable, marginal and hazardous. Analysis of the samples for the period 1982-89 indicates that SAR values are within safe limits and that 97 percent of the wells are of usable water quality. The marginal quality wells have been found to be located in the vicinity of the saline zone near the southern boundary of the project area.

The above tubewell construction was accompanied by improvement of some 216 watercourses (out of a total of 2,000) by 1990. All the project tubewells were handed over to the provincial Irrigation and Power Department by June 1991. Prior to this operational handover, finite element analysis on the long term effects of pumpage indicated that a 150 percent cropping intensity could be achieved against an operational factor of 68 percent during Rabi; the intensity would be 138 percent for an o/f of 50 percent during Rabi.

The project aimed at reversing the land deterioration caused by high watertables and simultaneously secure timely availability of irrigation waters as a supplement to the regular supplies available from the Ghotki Feeder (Figure 69). In fact, irrigation water shortages during early Kharif impeded the rather sharp increases in cropped areas to an extent wherein greater emphasis was placed on the Rabi cultivations that benefitted from the residual moisture in the soils. By 1974, the Rabi cropping intensity was four-fold over the design. The progressive changes in the cropping intensities are shown in Table 22 that captures both, pre- and post-project (1987-88) situations.

Table 22. Long Term Comparison of Changes in Major Crop Intensities within Ghotki Fresh Groundwater Tubewell Project.

Crop	Cropping Intensity			
	1967-68	1975-76	1989-90	1997-98
Wheat	41.4	20.0	30.8	77.0
Cotton	29.8	22.6	38.1	74.7
Sugarcane	1.5	1.5	18.6	3.5
Rice	15.1	6.14	na	3.19

The Final Report of the Ghotki Fresh Groundwater Irrigation Project (Agrar- Und Hydrotechnik GMBH, 1990] noted that the tubewells are not operated according to the recommendations given by the Consultants. This can be expected since the farmers do not, in general, operate their tubewells for a drainage function, as the benefits are not immediately obvious and the financial outlay in terms of power costs and maintenance can be considerable. In order to achieve a cropping intensity of 150 percent and a stabilized watertable of a minimum of 2 m bgl, a pump utilization factor of 31 percent was required during Kharif and 68 percent during Rabi. Available pumpage data shows the utilization factor varying between 15-30 percent, depending on the season (17.7 percent for the year

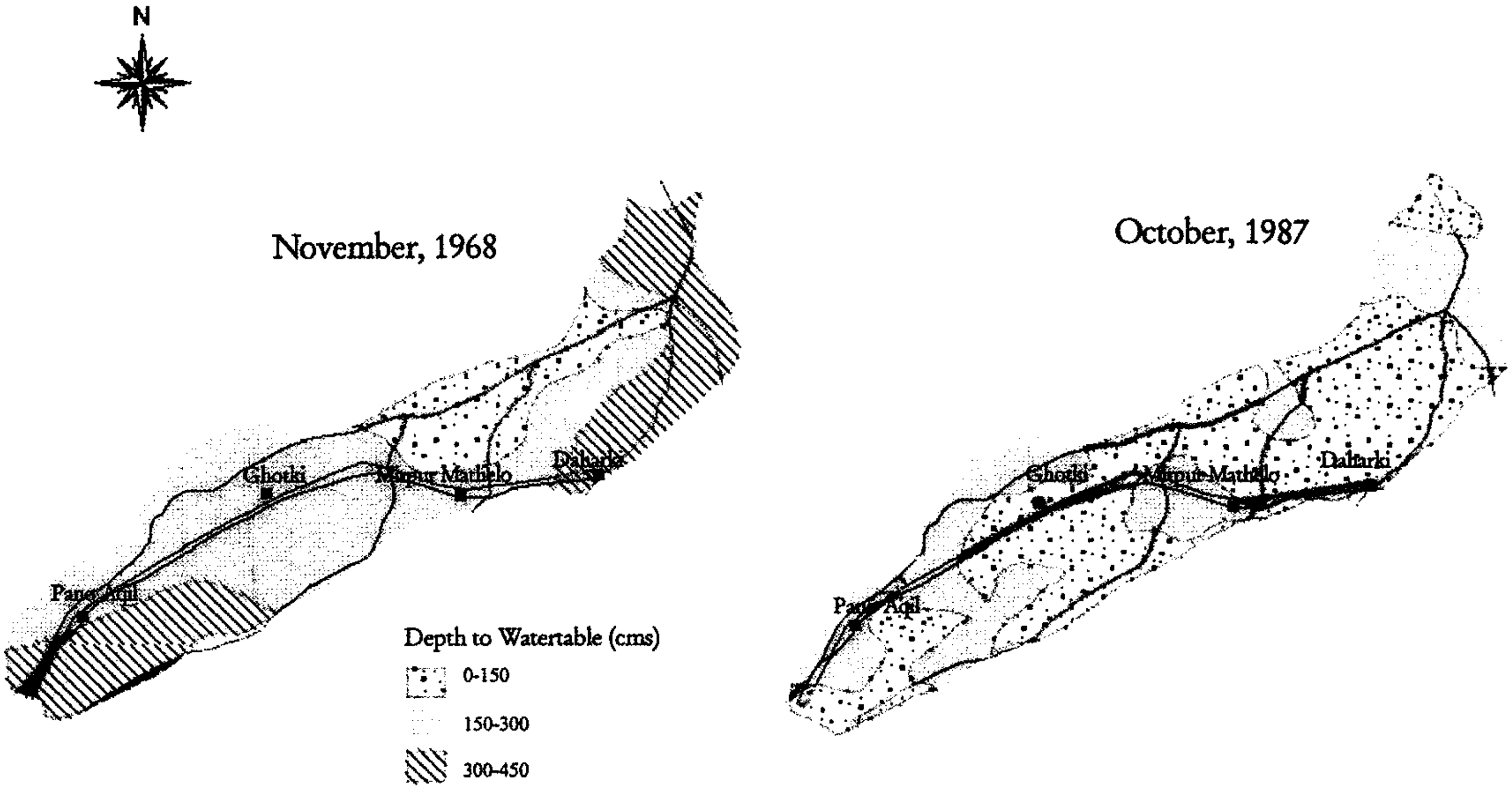


Figure 69. Temporal Comparison of Depth to Watertable within Ghotki Fresh Groundwater Project, Lower Indus Basin, Left Bank.

1991-92). Figure 70 graphs the incremental trend in the annual volume of pumpage from the project area. Resultantly, watertables have not been suppressed to the desired extent (Table 23).

Table 23. Temporal Comparison of Pre- and Post-monsoonal Watertable Fluctuations in the Ghotki Fresh Groundwater Zone.

Depth to Watertable (m)	April 1978	April 1990	June 1992	May 1993	October 1978	October 1990	October 1992	October 1993
< 1.5	16	2	4	1	60	56	68	65
1.5-3.0	76	85	96	99	39	44	32	35
> 3.0	8	13	0	0	1	0	0	0

Periodic monitoring and mapping by PPO (South), and then by SM (South), of the interseasonal changes in subsurface water levels, has allowed for more consistent comparisons to be made across space. Figures 71a-d sum up these differences for the period between 1978 to 1989. Almost all of the permanently critically waterlogged area has diminished in extent over this time.

Tubewell performance monitoring of the Ghotki FGW wells was last carried out in 1988-89. Data on discharge and specific capacity loss can be compared with FAT values determined in 1977. From Figure 72, the discharge reduction for 85 percent of the wells has been under 30 percent. However, in more practical terms, beyond the acceptable loss of 10 percent in discharge over 12 years of comparison, a solid 72 percent of the wells have experienced this deterioration that has even exceeded 60 percent in a few cases. The loss in specific capacity is slightly less skewed, which accounts for approximately 78 percent of the total reductions beyond the 10 percent mark. Maximum number of wells affected are under the 30 percent reduction range, with the median mark being 16 percent less than the value for the FATs.

H. East Khairpur Tile Drainage Project

The 1966 LIP Report recommended buried horizontal pipe drains as the most appropriate method to combat waterlogging and salinity in those areas of the Sindh Province where aquifers were not suitable for a successful operation of tubewells. In the same Report, the East Khairpur area, located adjacent to the SCARP Khairpur, was selected for the first large scale prototype project with horizontal drainage. Completed in 1986 at a cost of Rs. 271 million and covering a gross area of 18,219 ha (CCA 17,806 ha), this is the first tile drainage undertaking in the public sector (Figure 73). The project is located wholly within the command of the Khairpur East Canal and extends from Kot Diji town in the south to Rohri town in the north. At the time of project planning in 1976, some 14,985 ha were not

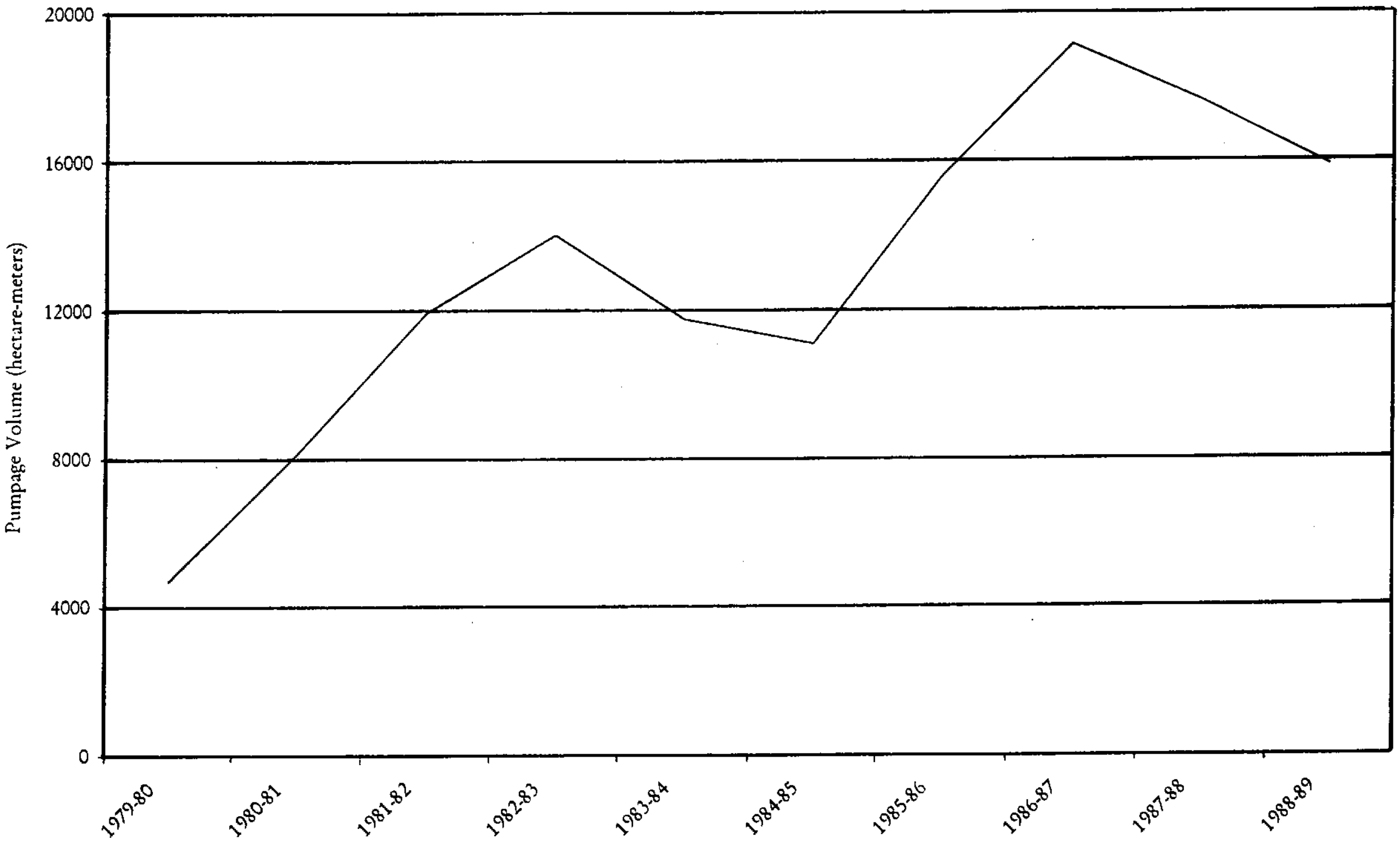


Figure 70. Year-wise Tubewell Pumpage from the Ghotki Fresh Groundwater Project for the Period 1979-89.

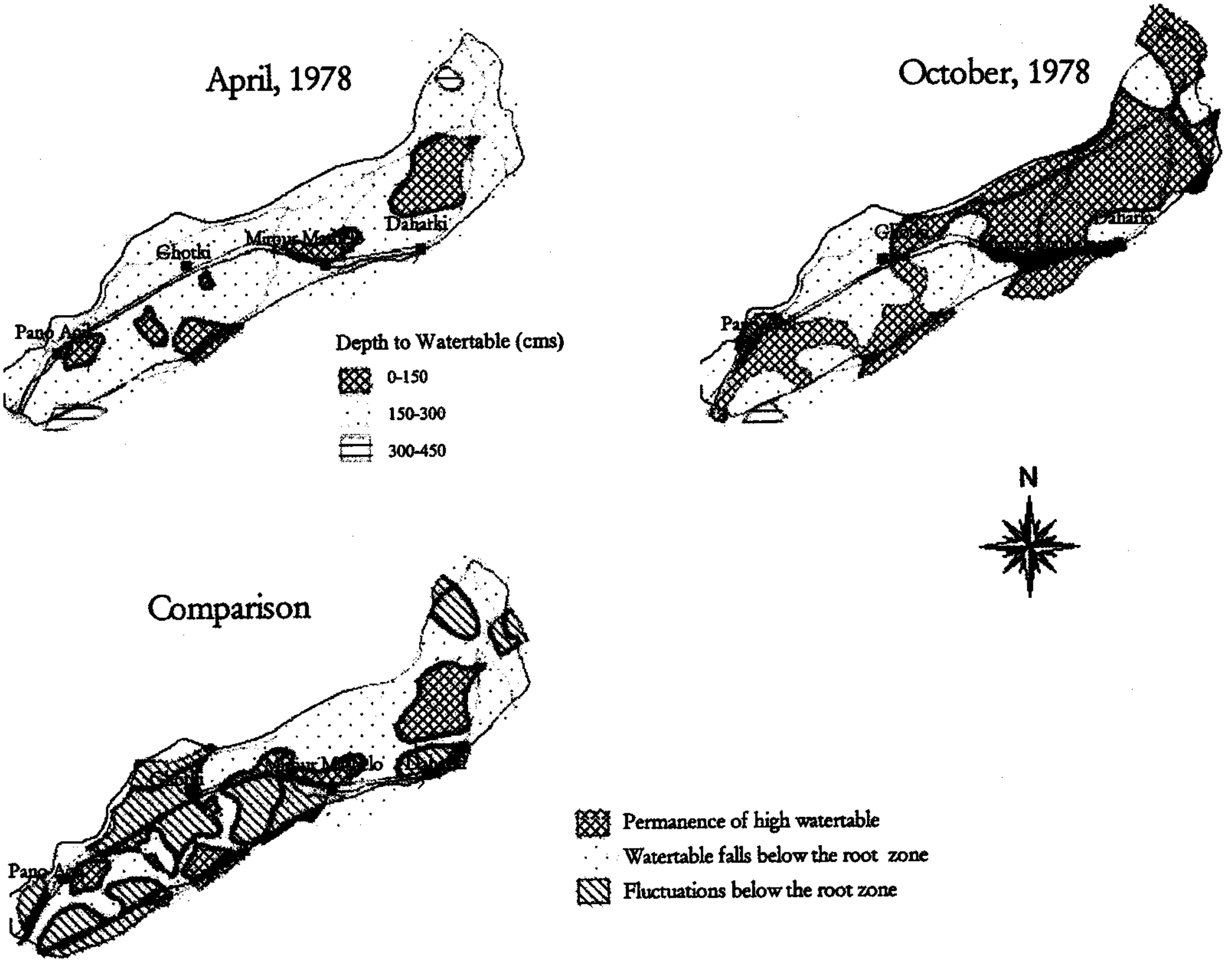


Figure 71a. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1978 in the SCARP Ghokti Fresh Groundwater Project, Lower Indus Basin, Left Bank.

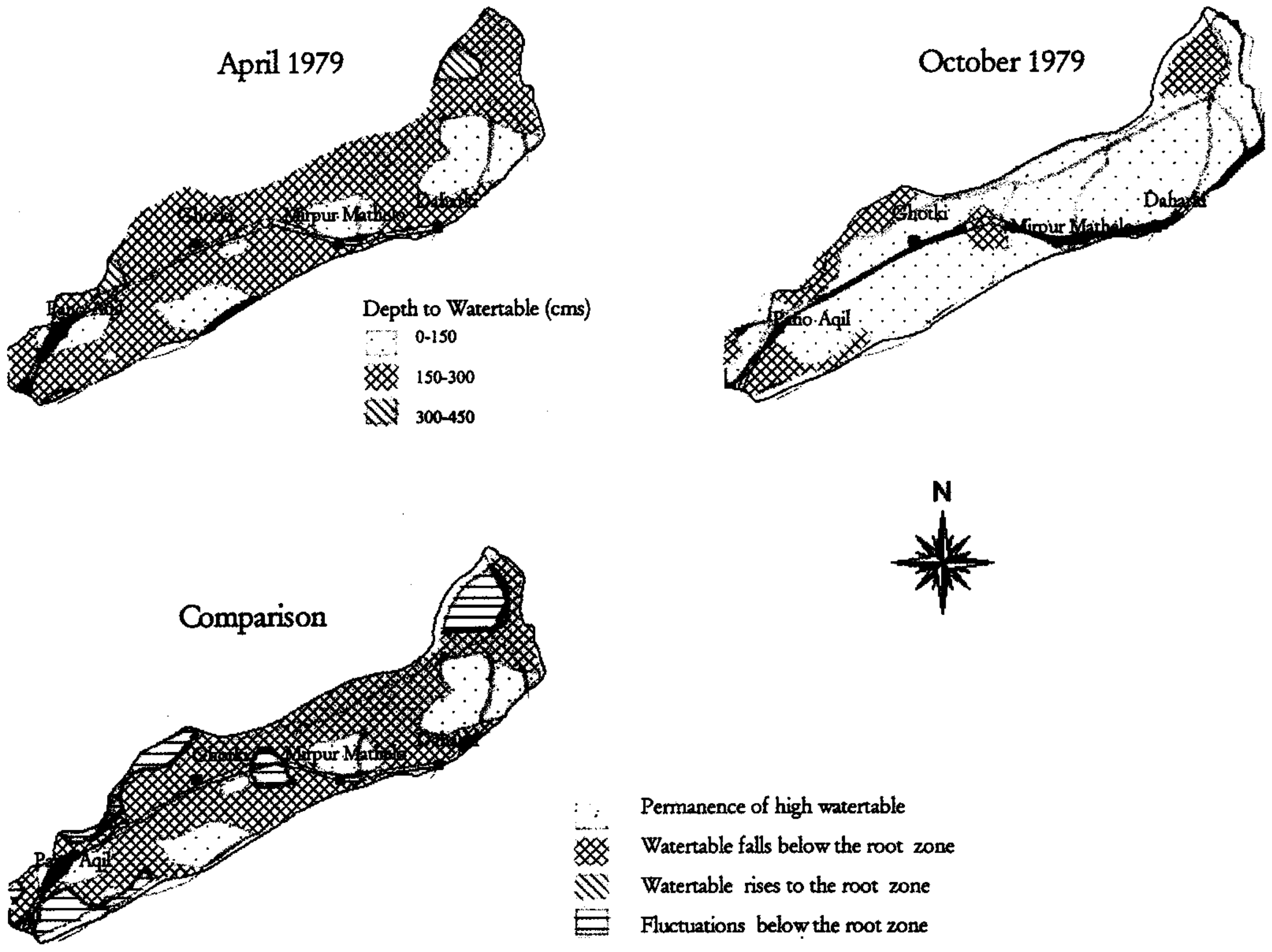


Figure 71b. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1979 in the SCARP Ghokti Fresh Groundwater Project, Lower Indus Basin, Left Bank.

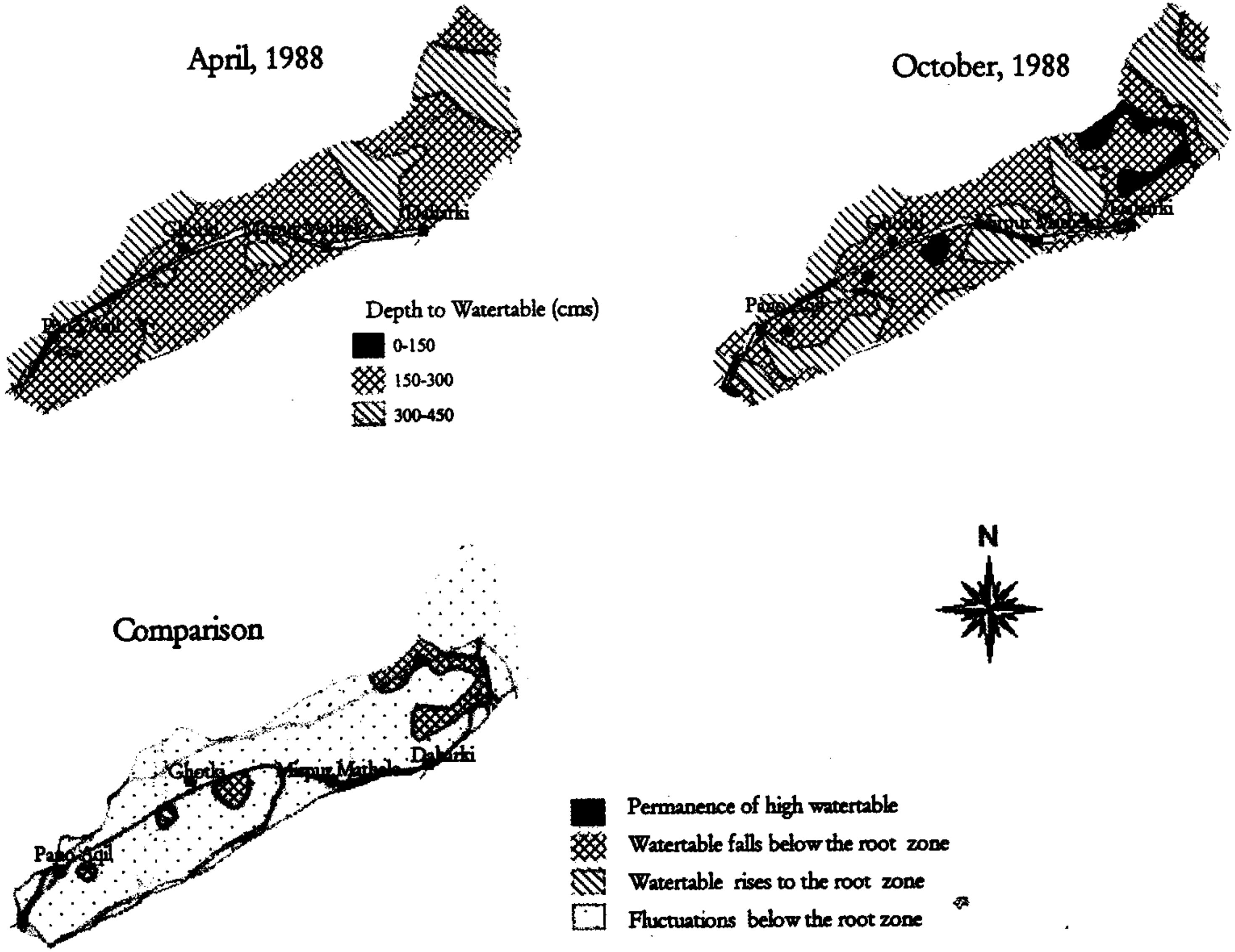


Figure 71c. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1988 in the SCARP Ghokti Fresh Groundwater Project Lower Indus Basin, Left Bank.

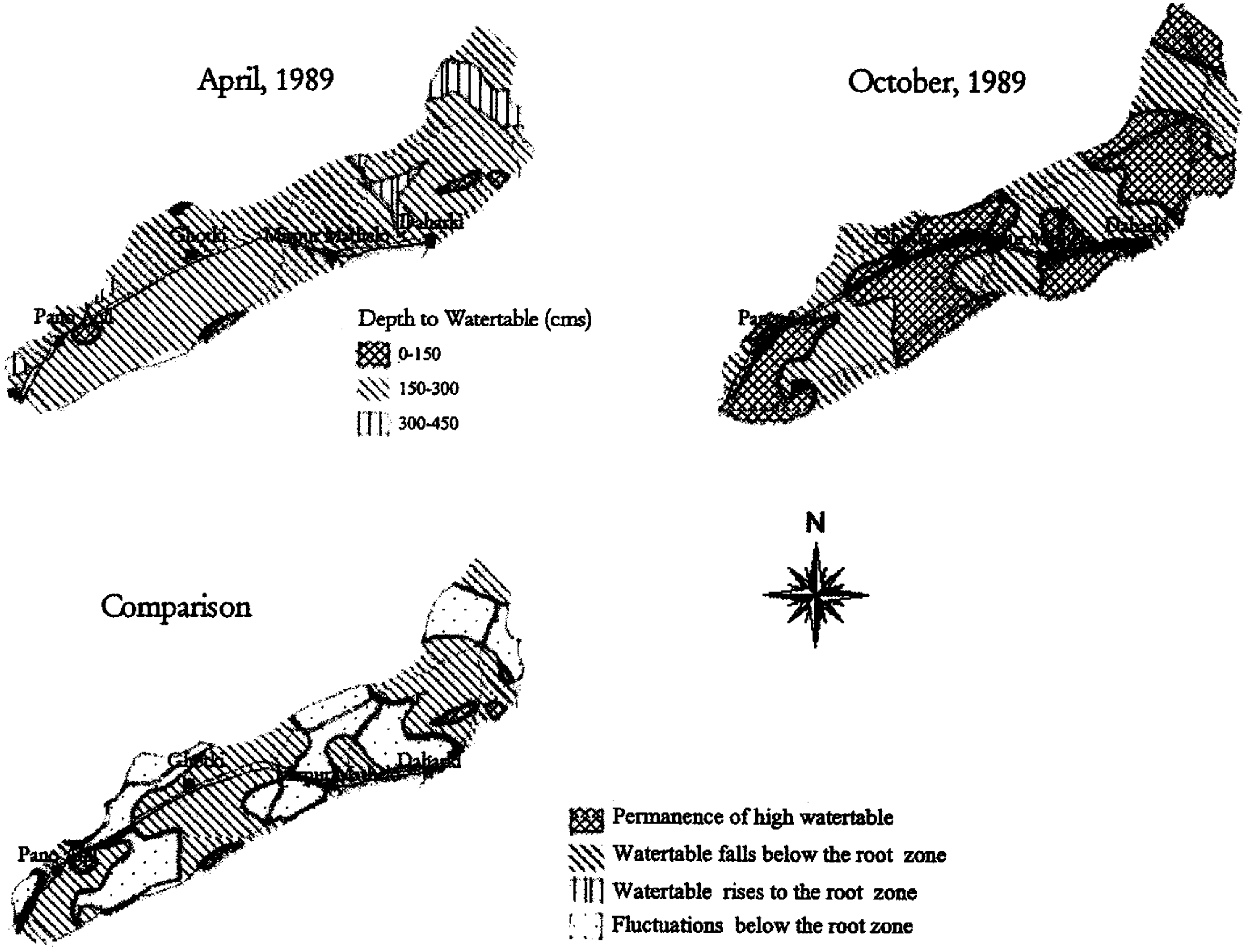
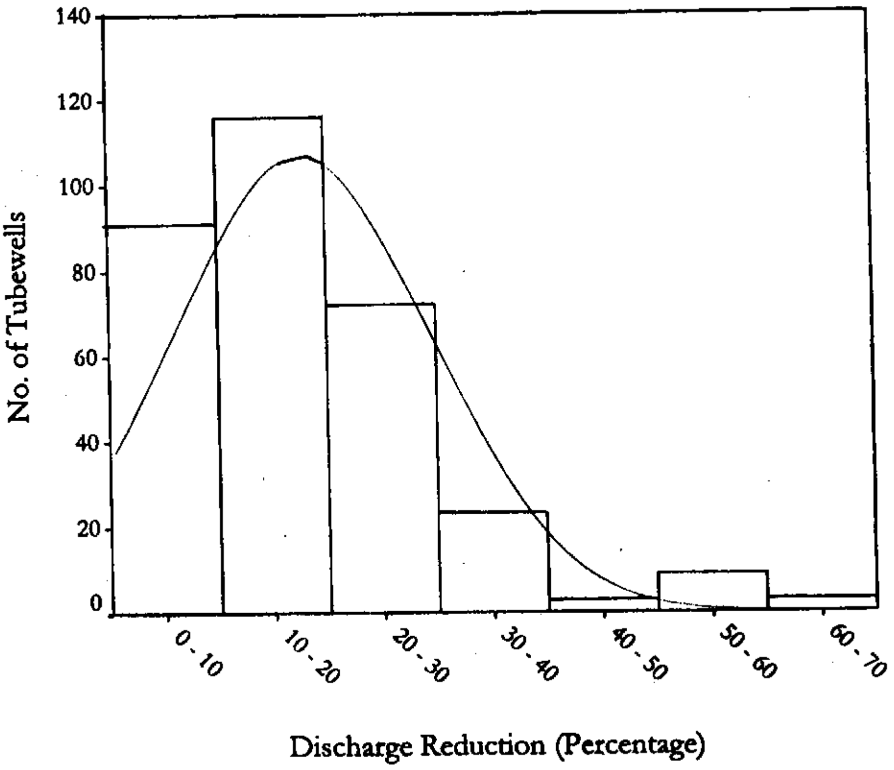


Figure 71d. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1989 in the SCARP Ghokti Fresh Groundwater Project, Lower Indus Basin, Left Bank.



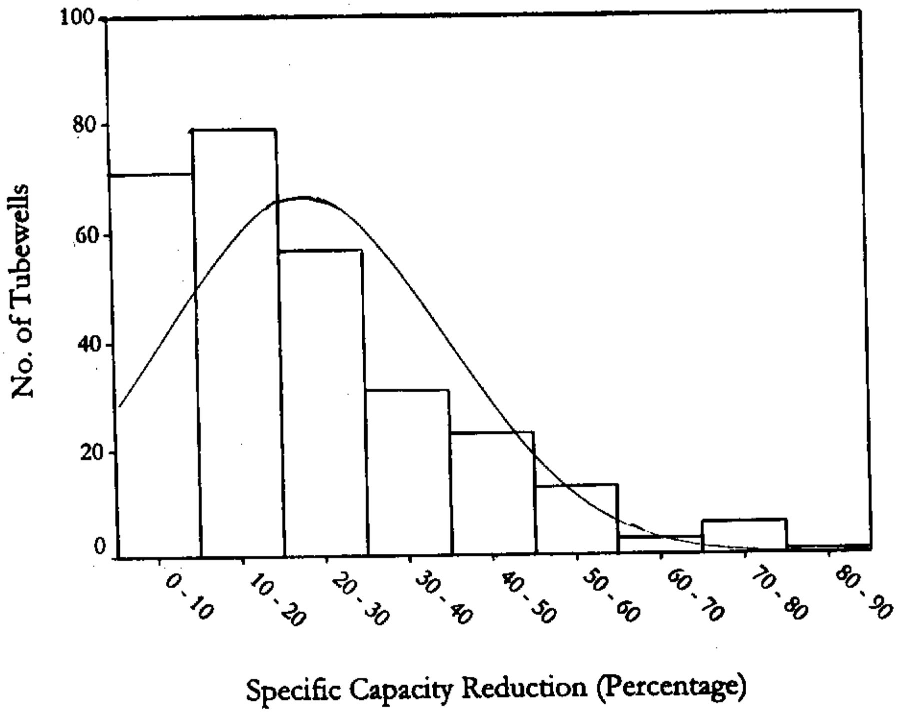


Figure 72. Comparison of Tubewell Performance for the Period between 1977 and 1989 in the Ghotki Fresh Groundwater Project, Lower Indus Basin, Left Bank.

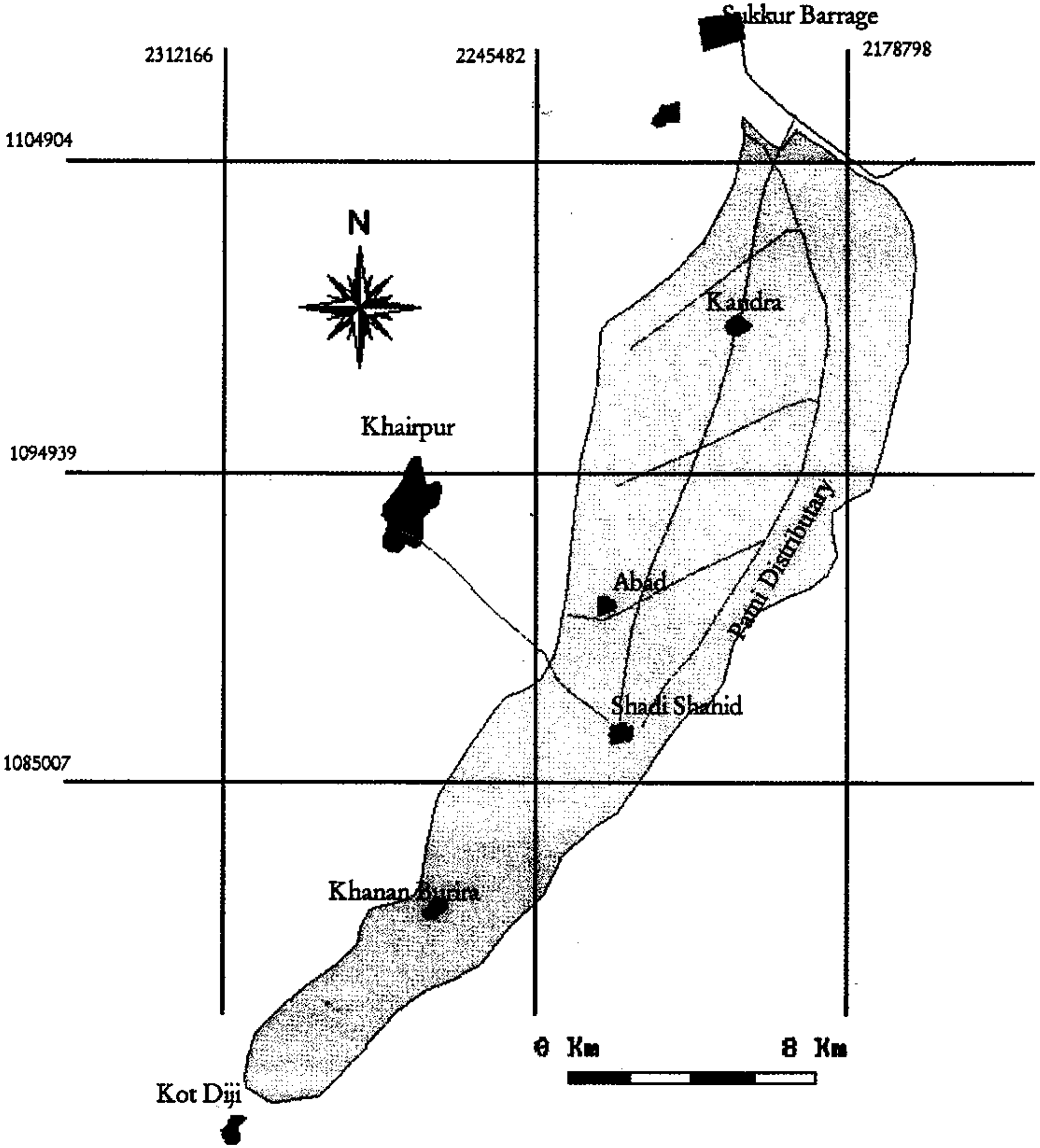


Figure 73. Location Map of East Khairpur Tile Drainge Project, Lower Indus Basin, Left Bank.

drained; the remaining area was drained by the tubewells installed under the SCARP Khairpur Tubewell Drainage Project. Much of the area is underlain by bedrock at such a shallow depth that tubwell drainage was not entirely feasible, and hence, the need for tile drainage became necessary.

The soils in this area, dominantly calcareous and slightly to moderately alkaline, are derived from river alluvium and are suitable for all kinds of crops. Infiltration and permeability rates are generally satisfactory for both irrigation and drainage. In 1976, three years before the launch of project-related activities, some 11 percent of the area was severely affected by salinity (ECe > 16 mmhos/cm). Only 60 percent of the project area was then being cropped, as the remaining area was too saline for profitable agriculture.

Pre-project investigation and analysis of 204 soil samples collected from 51 boreholes for depths varying between 1-150 cms of the soil indicated that in most of the severe and ultra saline soils, the extent of the salts decrease with increasing depth. This is corroborated by LIP investigations during the mid-sixties. Further, results showed that Ca and Mg are the dominant cations in non-saline samples, and sodium in saline samples. Chlorides and sulphates were the principal anions with a prepondrance of chlorides over sulphates. SAR values identified all the severely and ultra saline samples to be saline alkali.

The watertables in the EKTD project have been monitored by the SMO since 1979. Benchmark data indicates that in October 1968, 9 percent of the area were critically waterlogged. This increased drastically to 65 percent in just 8 years (Figure 74). Since then, there has been a steady rise in watertables. In April 1985 the area having 150 cm depth to watertable had increased to 94 percent, whereas the October figure had climbed to 89 percent (Table 24). The reasons for the then rise in watertables could be attributed to the shallow saline aquifer, and the absence of natural drainage amid perennial irrigation supplies. Borehole investigations have revealed the average groundwater salinity to be 3,200 ppm of TDS, which also includes isolated pockets of highly saline groundwaters. The realistic average value of groundwater is estimated to be around 1,800 ppm.

For the corresponding period of comparison, the cropped areas have also changed to an extent whereby an increase of 28.8 percent was recorded in the Kharif 1985 area over the base year. However, the Rabi cropped areas have decreased by as much as 16 percent. These figures, provided by the Irrigation Department, relate to project years under completion, and therefore, are not wholly representative of the potential benefits accruing from improved drainage brought about by the subsurface tiles. Table 25 provides a temporal overview of the changes in cropping intensities, in which IIMI Survey estimates have also been included.

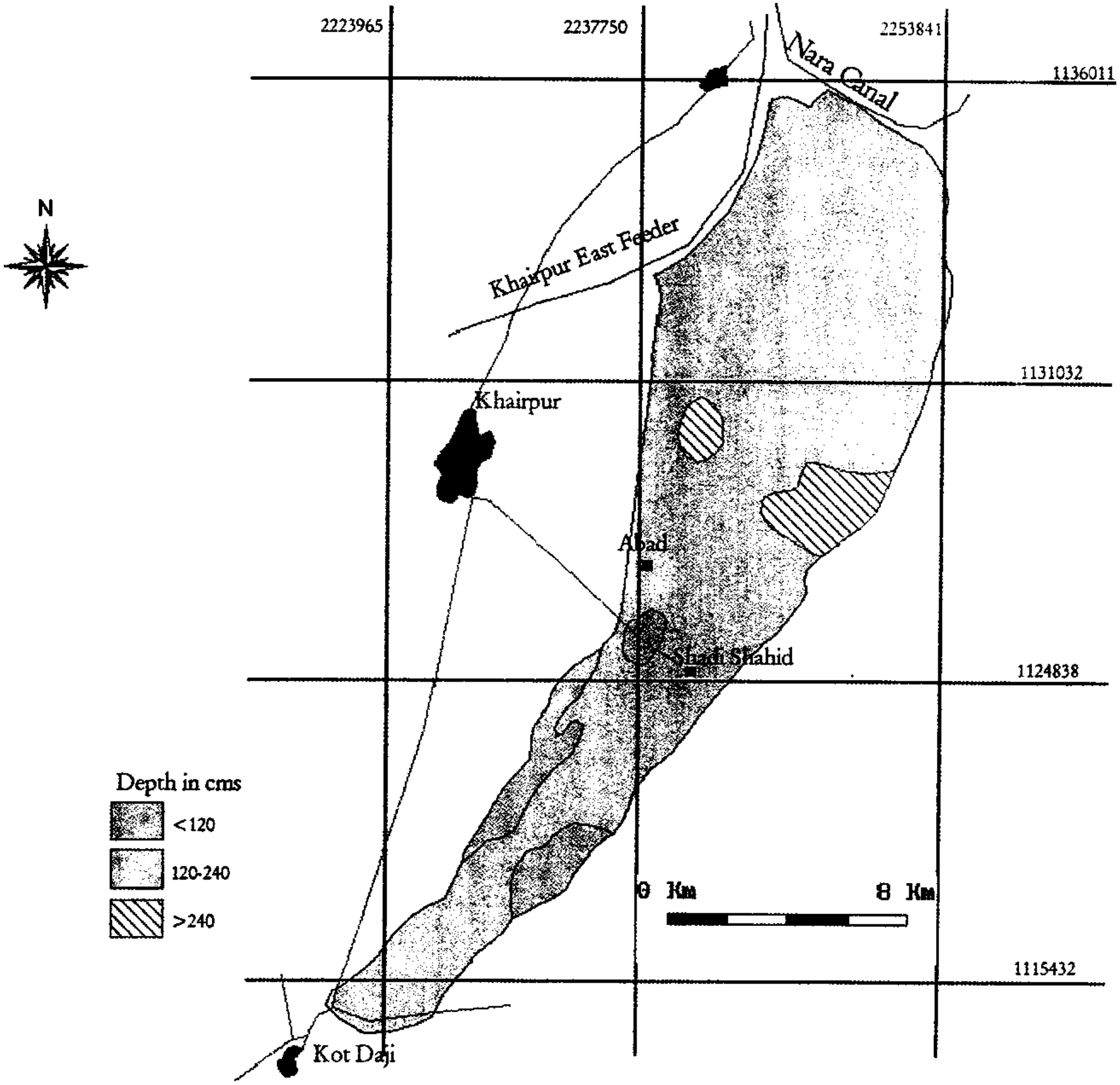


Figure 74. Watertable Depth in the East Khairpur Tile Drainage Project, October 1975.

Table 24 Area Affected by Seasonal Variations in 0-150 cm Depth to Watertable within East Khairpur Tile Drainage Project.

Year	Percentage of Area under < 150 cms Depth to Watertable	
	April	October
1968	-	9
1975	-	65
1979	39	67
1980	39	72
1981	68	83
1982	100	67
1983	44	89
1984	94	83
1985	94	89
1987	86	86
1988	46	74
1989	82	-

Source: Senior Engineer TWM, SCARP Monitoring (South) WAPDA, Hyderabad.

Table 25. Temporal Comparison of Historic and Project-related Major Crop Intensities in the East Khairpur Tile Drainage Project.

Crops	Historical 1975-76	Base Year 1978-79	1984-85			IIMI Sample Estimate
			Without Project	With Project	Ultimate Target	
Cotton	24.00	20.46	0.54	31.51	30.00	45.04
Wheat	18.00	43.60	29.95	34.32	42.00	71.60
Rice	12.00	8.60	21.19	6.67	-	23.24
Sugarcane	0.50	0.30	-	0.05	12.00	-
Rabi	39.00	64.06	49.08	54.04	85.00	86.9
Kharif	51.00	46.93	37.33	60.42	60.00	80.27

I. Khairpur Tubewell Drainage Project

The commissioning of the Sukkur Barrage system allowed perennial supplies to be diverted into the Khairpur command area, where historic reliance on inundation canal supplies had not permitted predictable cropping intensities to prevail across these otherwise fertile lands. The design cropping intensities were set at 32 percent of the CCA during Kharif and 48 percent during Rabi. The Khairpur command spans 265,500 ha and is irrigated by the Khairpur East and West Feeder Canals, which serve lands to the east and west of the Rohri Canal.

Following a spate of early investigations by WAPDA during the early sixties, a Project Plan (WASID, 1961) was prepared for works to control the watertable and to contribute fresh groundwater to the irrigation system through the implementation of a tubewell drainage scheme. The gross area of the project totaled 178,000 ha, of which 152,000 ha formed part of the culturable command (Figure 75). The cropping intensities proposed as a basis for the plan were 60 percent CCA Kharif and 75 percent CCA Rabi. This was less than the ultimate annual intensity of 154% (Kharif 74%, Rabi 80%) proposed in the LIP Report. Prior to the launch of the Project activities, the 1965 annual cropping intensity was reported to be 106 percent (Kharif 47%, Rabi 59%).

The plan document was modified on the basis of information obtained during the early contract and implementation process revealing the unsuitability of the lithology near Kot Diji to support tubewell drainage. This area was later developed under a separate scheme involving implementation of the first public sector tile drainage project. For the remaining area fit for tubewell drainage, the first batch was commissioned in April 1967 (Figure 76).

Part of the Khairpur West Canal command was found to have groundwater sufficiently fresh and widespread to be used on the land to augment irrigation supplies. In this area, open drains were not required for the pumpage effluent. The remainder of this canal command and the entire Khairpur East Canal command comprised saline groundwaters that could only be discharged into the open drains that were subsequently constructed for this purpose (see Figure 40, on location of development areas on the Left Bank). The ultimate disposal of this effluent was planned for the LBOD, whence it was extended to this area; until then, the surface drains conveyed the effluent (via five pumping stations) to the Rohri Canal for dilution and subsequent use for irrigating areas further south. These tubewells, numbering 540, cover 93,500 ha in the Khairpur West Canal command and 54,230 ha in the Khairp

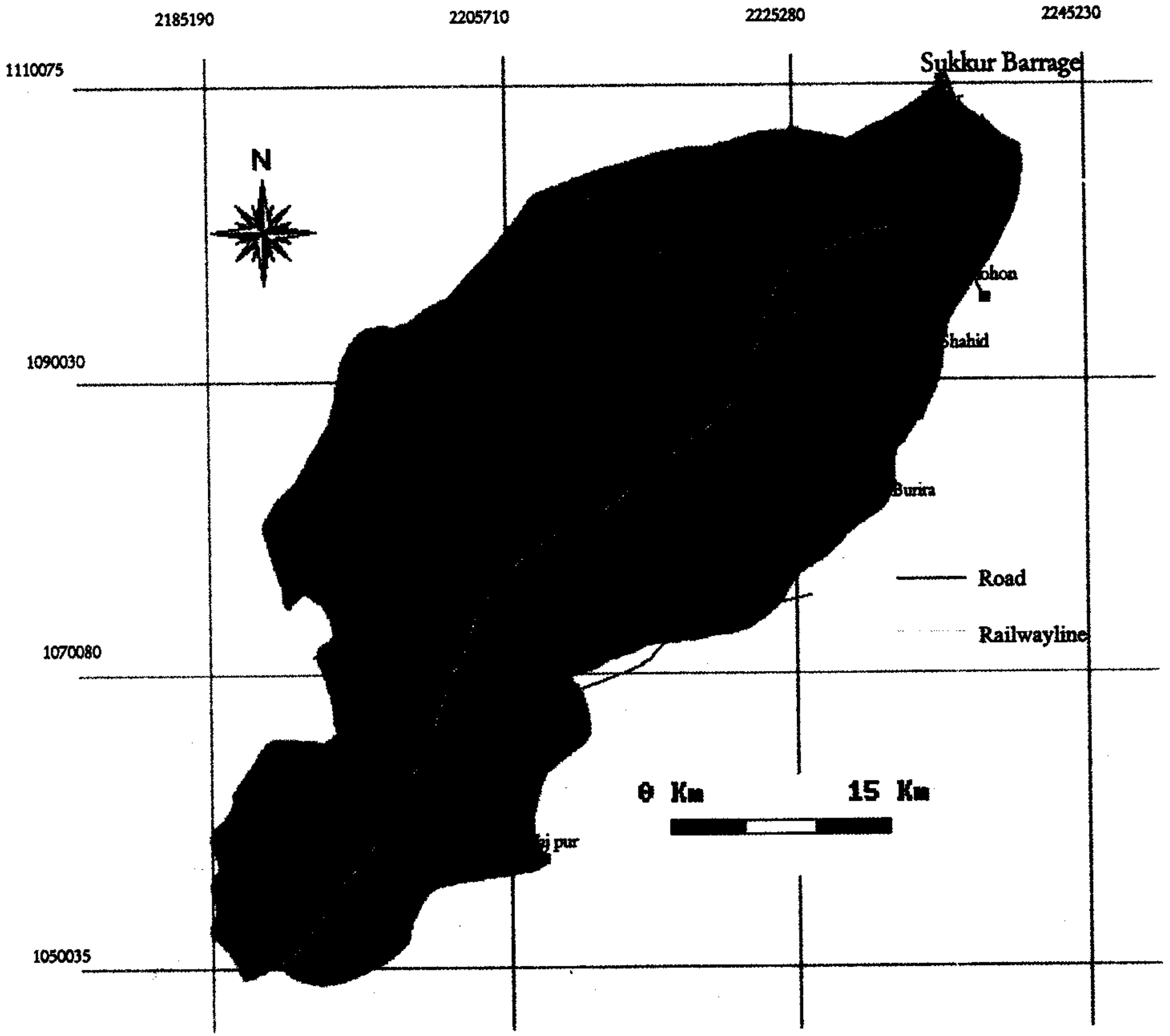
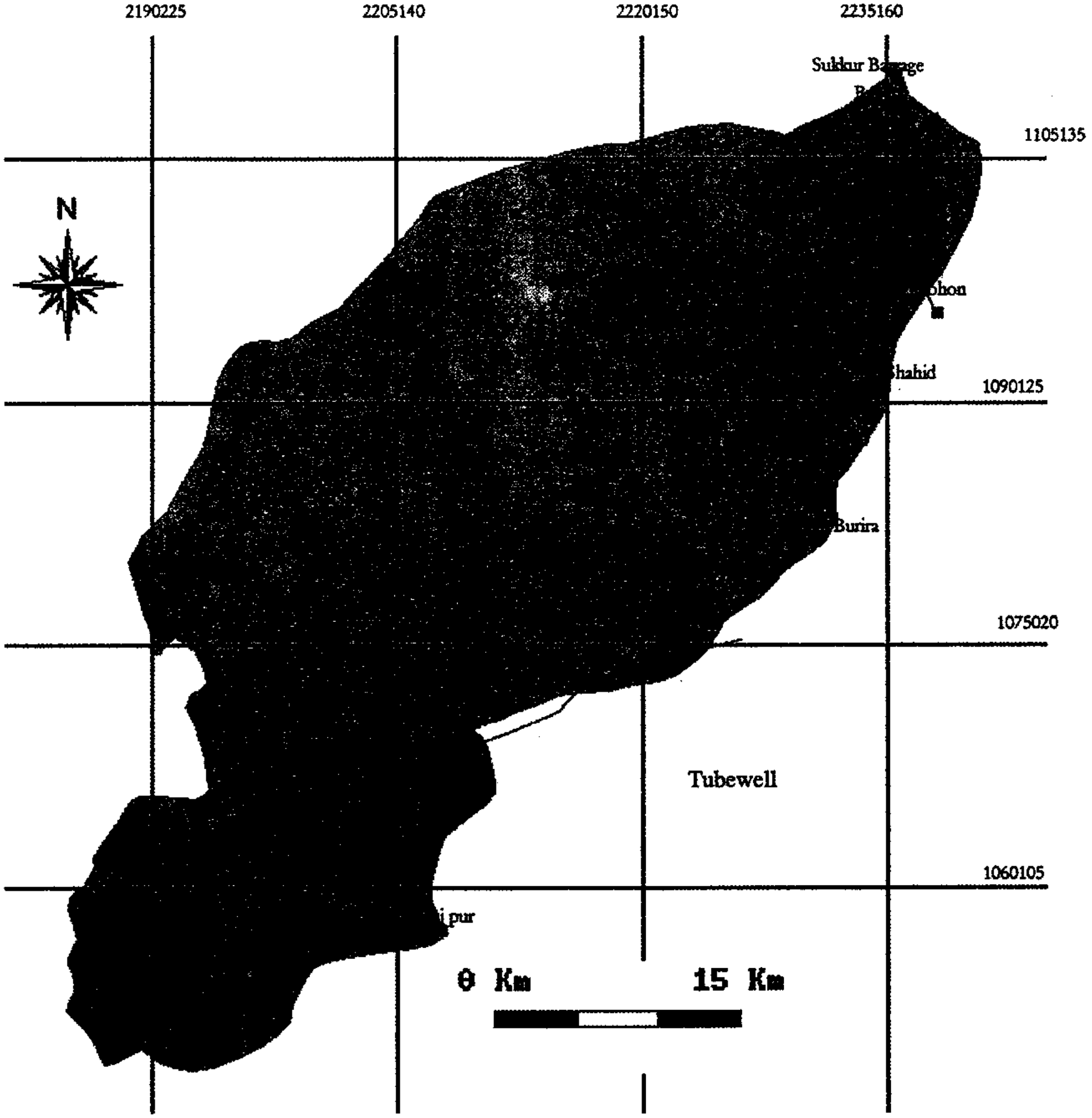


Figure 75. Location Map of SCARP Khairpur Tubewell Drainage Project, Lower Indus Basin, Left Bank.



igure 76. Location of Tubewells in SCARP Khairpur Tubewell Drainage Project, Lower Indus Basin, Left Bank.

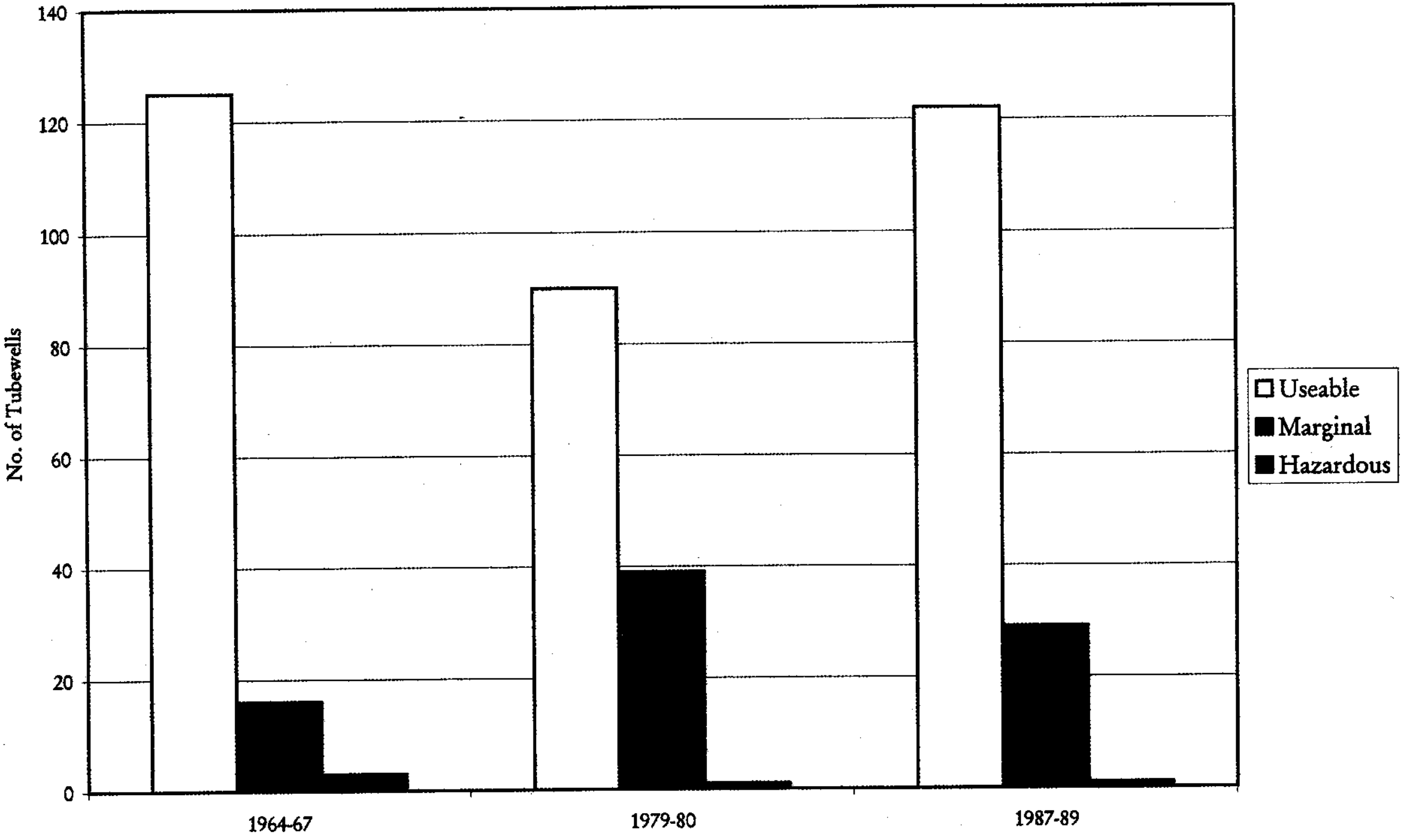


Figure 77a . Temporal Distribution of SCARP Tubewells with respect to Quality of Pumpage in the Khairpur Fresh Zone.

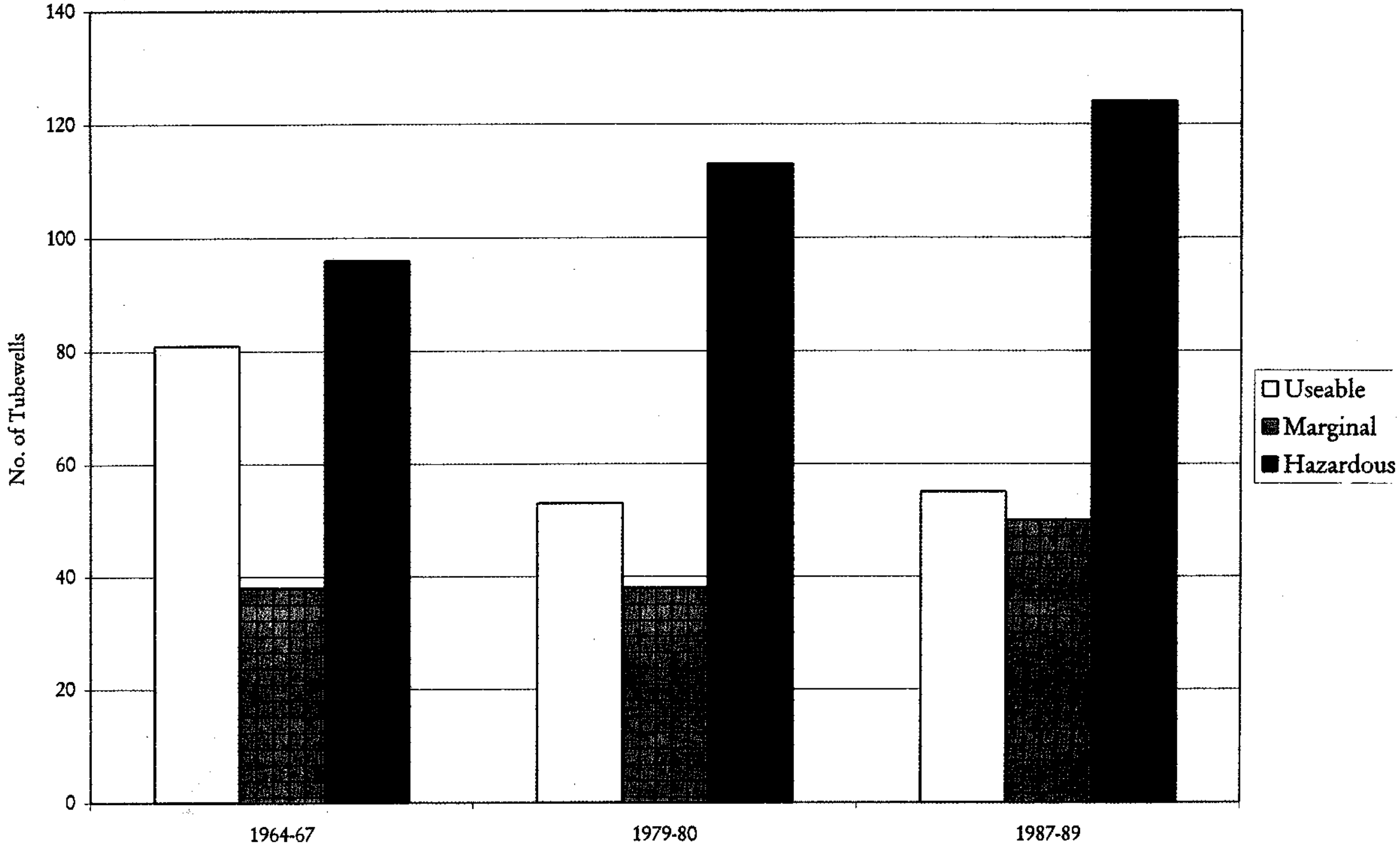


Figure 77b . Temporal Distribution of SCARP Tubewells with respect to Quality of Pumpage in the Khairpur Saline Zone.

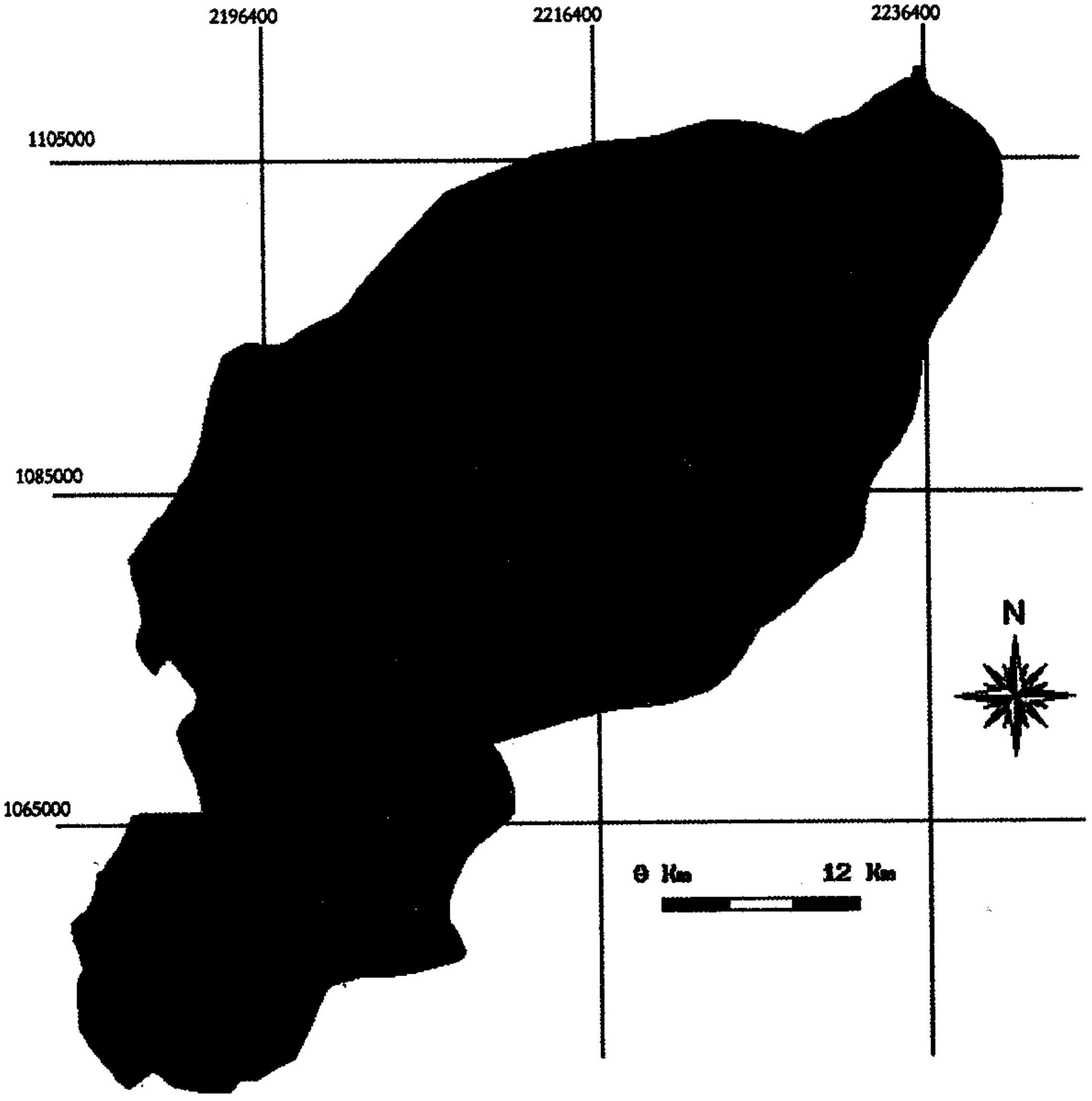


Figure 78. Saline and Fresh Groundwater Exploitation Zones and Location of Subunits for Development in the SCARP Khairpur Tubewell Drainage Project.

SCARP Khairpur, 1990). By 1989, the cumulative discharge had reduced to 100,293 Hm against a tubewell utilization factor of 0.21. The historic volume of pumpage for this SCARP, differentiated on the basis of fresh and saline zones, is given in Figure 79.

Tubewell performance monitoring of the wells in SCARP Khairpur was done separately for both Fresh and Saline groundwater zones by SM (South), WAPDA, for the period 1987-89. Comparisons were made for the reduction in discharges and specific capacities since the FATs in 1967. Figure 80 shows a near bell-shaped distribution of the reduction histogram for tubewell *discharges* within the Saline zone. This would be expected given the intervening period of over 20 years for comparison. Approximately 94 percent of the tubewells monitored suffered reduction in the range of 10-60 percent, the more acute reduction being in excess of 30% for approximately 49 percent of the saline groundwater wells. The situation for reduction in *specific capacity* is sharply skewed to reflect a near uniform decrease that extends up to 50%. Only 17 percent of the tubewells were reported to suffer beyond this threshold. Clearly, against up to 30 percent deterioration of the acceptable norm for the comparison period, nearly 48 percent of the wells were due for replacement, or rehabilitation, by 1989.

In the Fresh groundwater zone, reduction in *discharges* was most significant in the range of 20-50 percent, with the overall pattern fitting a normal curve (Figure 81). This behavior would be expected for discharge performance ratings likely to prevail within the fresh groundwater zones of the Sindh Province across an extended comparison of 20 plus years, which for this study, is uniquely available for SCARP Khairpur only. In fact, emergent trends could be expected for wells in the Sukkur Right Bank, South Rohri and Ghotki Fresh groundwater zones in the context of monitoring conducted until 1989. In the Saline zone, the loss in specific capacity was of equal magnitude across frequency intervals extending to 50 percent; tubewells with higher levels of specific capacity losses were fewer. In the Fresh groundwater zone, the majority of the related losses are clustered in the range 30-70 percent and approximately 65 percent of the wells seemingly in an advanced state of inefficient pumping, representing over 40 percent loss in specific capacity.

WAPDA SCARP monitoring of the pumpage from 392 tubewells for the period 1964-67 to 1979-80 indicated almost 70 percent of the wells that had not experienced any change in their quality (WAPDA, 1988). The water quality of 44 wells deteriorated to a marginal status and a further 46 became hazardous. Hazardous waters were more stable than usable waters, thereby indicating a trend towards deterioration. Overall, some 33 percent of the project area experienced varying degrees of deterioration in pumpage quality and only 5 percent of the area actually improved.

Figure 82 shows the distribution of groundwater quality changes across the period of comparison cited above. Some 62 percent of the project area corresponded to the no-change definition comprising 26 percent usable, 5 percent marginal and 31 percent hazardous categories. The usable part exists on the right side of the Rohri Canal adjacent to Khairpur West Canal. The constantly hazardous groundwater quality area is situated on

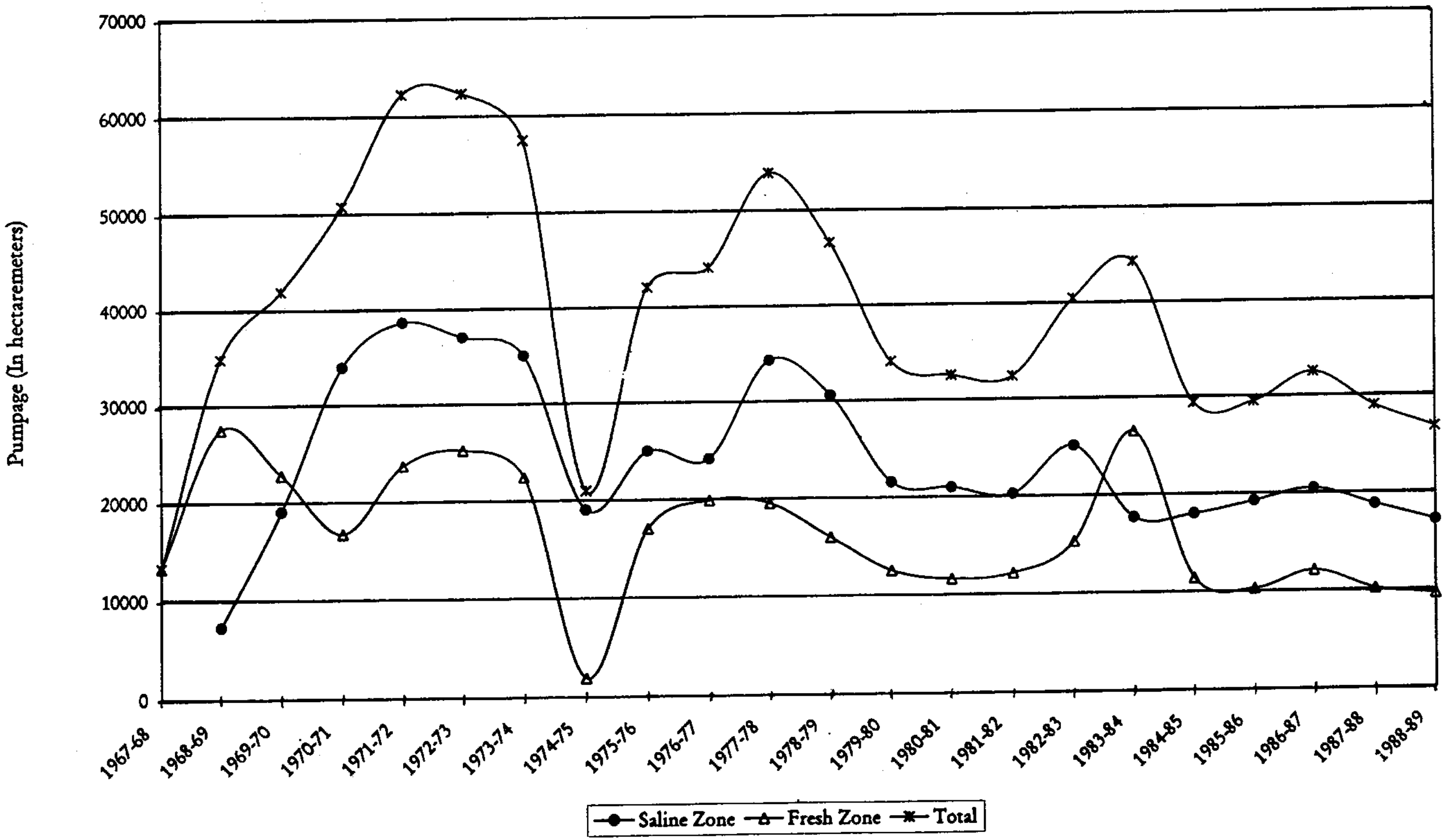


Figure 79. Pumpage for SCARP Khairpur Project for 1967-68 to 1988-89

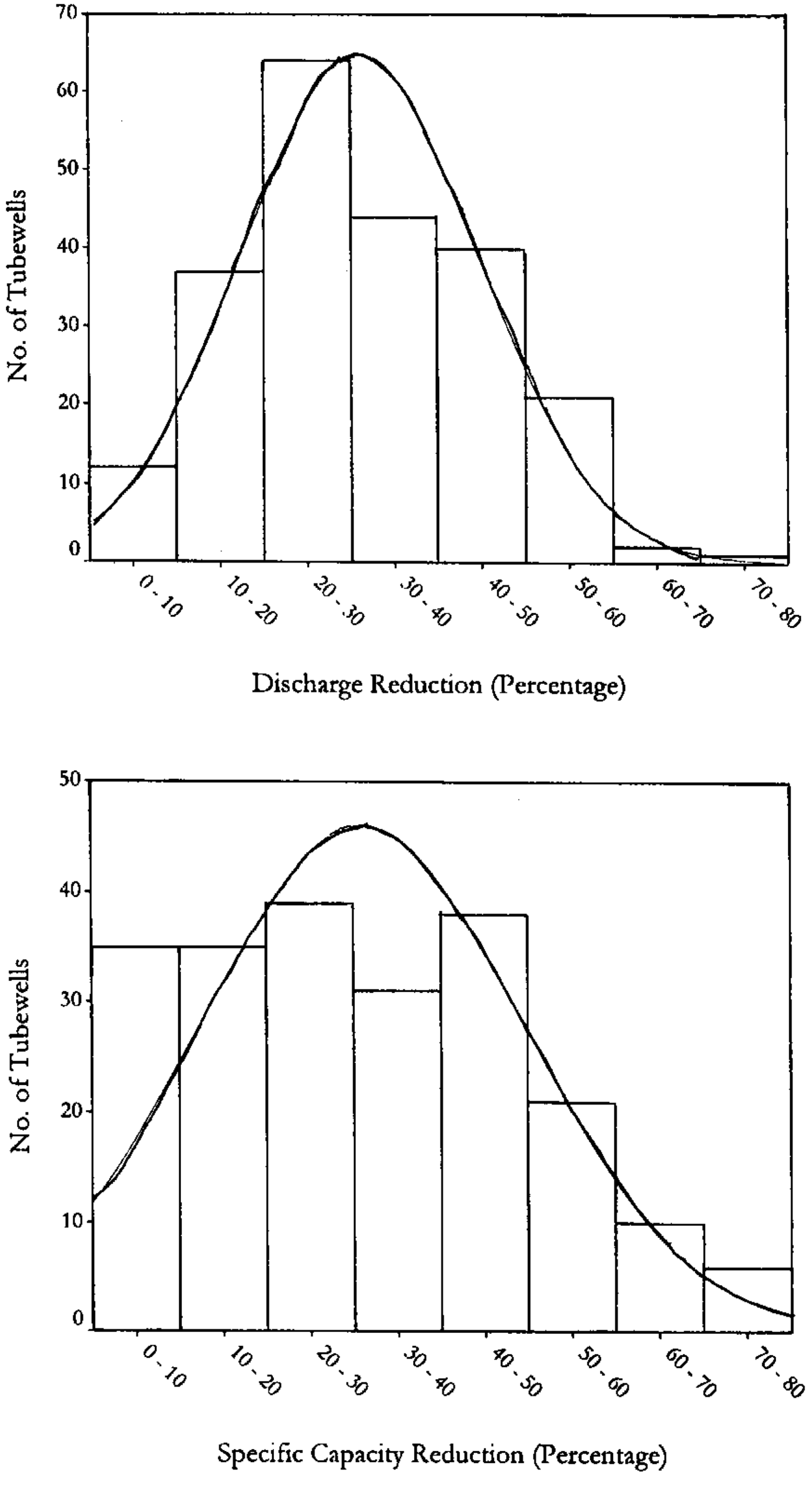


Figure 80. Comparison of Tubewell Performance for the Period between 1967-68 and 1987-89 in the SCARP Khairpur Saline Groundwater Project, Lower Indus Basin, Left Bank.

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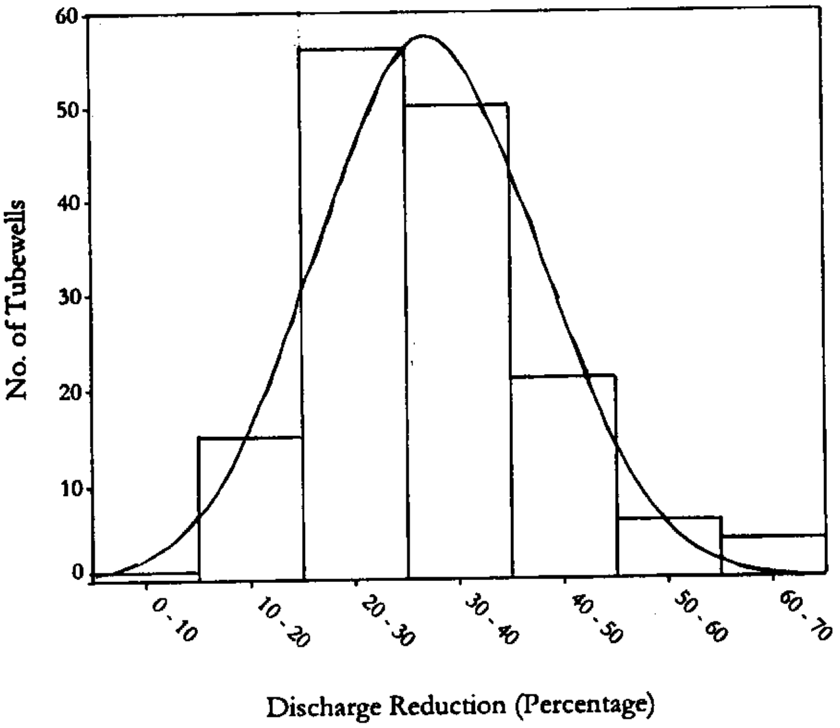


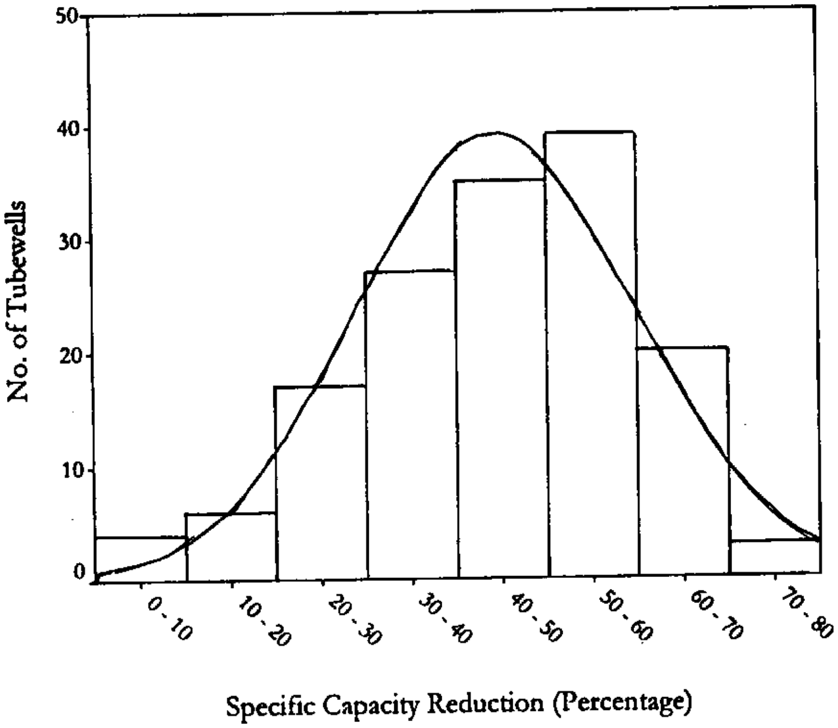


Figure 81. Comparison of Tubewell Performance for the Period between 1967-68 and 1987-89 in the SCARP Khairpur Fresh Groundwater Project, Lower Indus Basin, Left Bank.

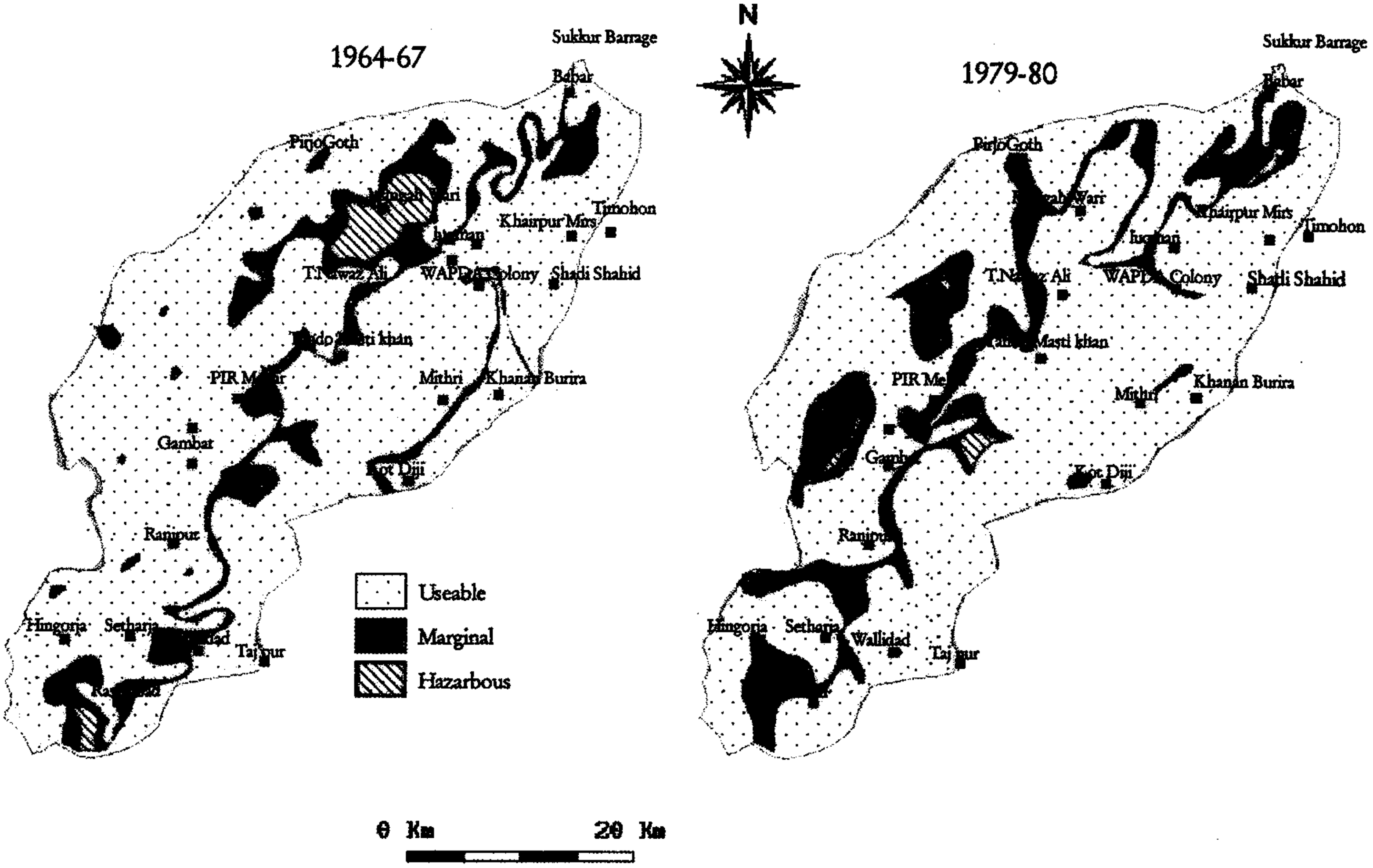


Figure 82. Distribution of Groundwater Quality in SCARP Khairpur, Lower Indus Basin, Left Bank.

the left side of the Rohri Canal adjacent to the southeast boundary line of the project area. The impervious layers of clay adjacent to the banks of the Rohri Canal may be one reason for the insufficient recharge reaching the aquifer in this area.

Subsequent data for the monitoring period 1987-89 shows that the number of tubewells in the fresh groundwater zone pumping usable water have increased from 71 percent to 79 percent since 1979-80, whereas the respective percentages of the marginal and hazardous quality wells have decreased (Figure 83; see also Figure 77a). There was no significant change in the quality of pumpage in the saline zone (Figure 77b).

Related to the tubewell pumpage, there has also been a decrease in the levels of the groundwaters since the formal commissioning of the project. Figure 84 shows a comparison of watertable depths exclusive to the dry pre-monsoon period for a time difference of over 30 years. Clearly, the critical watertable depths affecting the root zone have all but disappeared. Correspondingly, the wet post-monsoon season comparison is drawn in Figure 85, where 0-150 cm depth of watertable appears much reduced in the year 1987, although indication of a seepage-driven zone that has developed in the tail reach along the Rohri Canal also exists. An interseasonal comparison for the year 1988 shows watertables rising to the root zone over 75 percent of the project area (Figure 86).

J. Sukkur Right Bank Fresh Groundwater Project

Covering a gross area of 61,134 ha, the Sukkur Right Bank FGW project extends across the commanded regimes of Rice, Dadu and North West Canals. The project, initiated in 1978, comprises an installed base of 400 tubewells with the principal aim to facilitate drainage in the area. The rising watertables are directly related to the increased diversions of irrigation supplies into the project area to boost cultivated area under rice cultivation (Figure 87). The tubewells, ranging in capacity from 42-85 lps, are located mostly around Larkana, Ratodero, Naudero and Dakhan areas. Since these areas are also part of the the fresh groundwater belt running parallel to the river Indus, the waters from these wells are also being used to leach down the salts from the soil strata.

The project planning specified a rather unrealistic well-operating time of 22 hrs/day to enable cumulative design pumpage of up to 69,475 Hm per year. However, performance data for the period 1987-89 indicates that the total pumpage remained < 13,800 Hm per year. The utilization, thus, comes to < 20 percent of the installed capacity. The average volume of pumpage for the period 1981-82 to 1988-89 is even lower, at a little over 13,000 Hm (WAPDA, 1996).

A comparison of tubewell performance data for the period 1976 and 1990 is given in Figure 88. The comparison is drawn against discharge and specific capacity values determined for the tubewells at acceptance. The reduction in discharge has not exceeded 20 percent for almost 90 percent of the wells, with only a few reaching as high as 40 percent. Comparably,

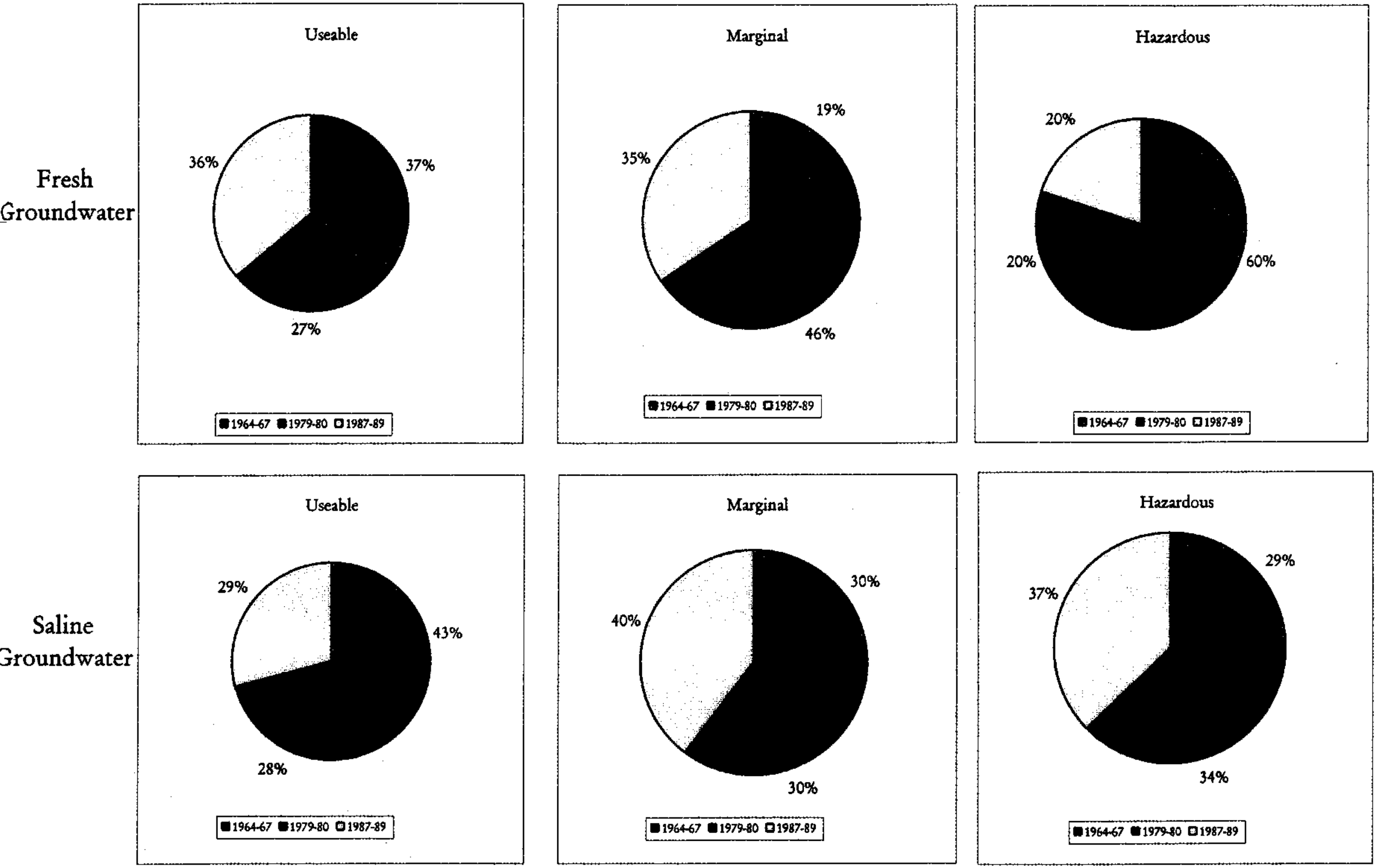


Figure 83. Percentage Constitution of Fresh and Saline Groundwater Quality Zones in SCARP Khairpur, Lower Indus Basin, Left Bank

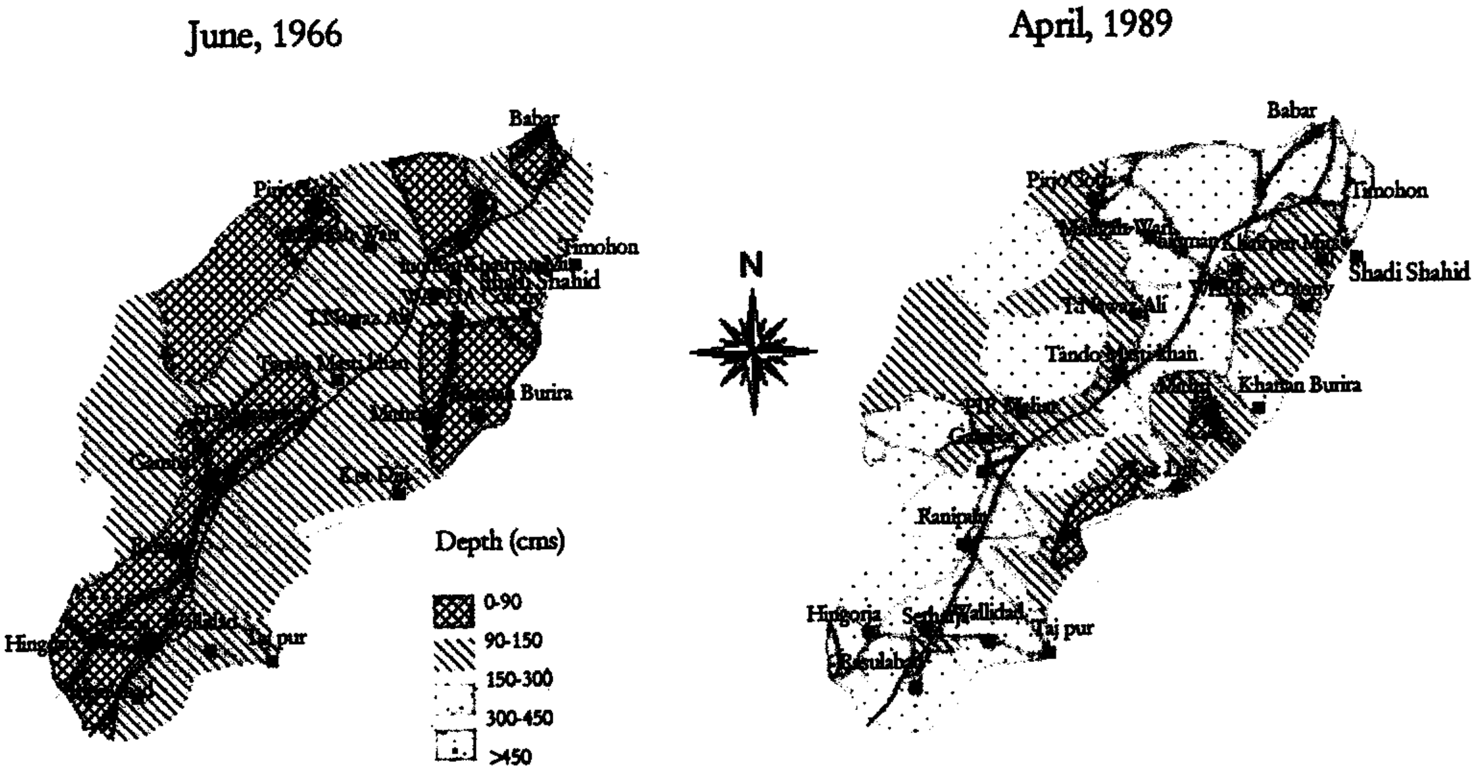


Figure 84. Comparison of Pre-Monsoon Depths to Watertable in SCARP Khairpur Project, Lower Indus Basin, Left Bank.

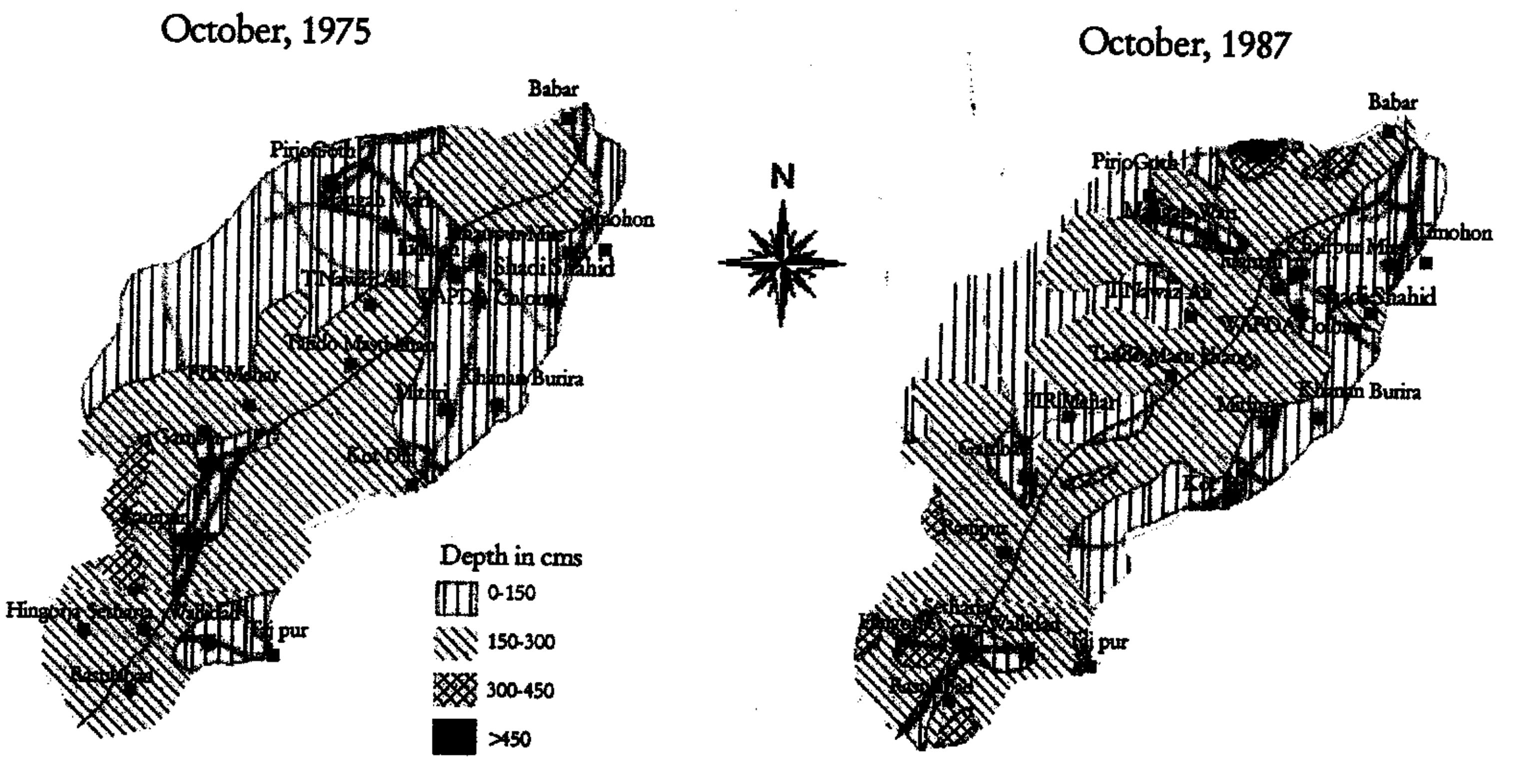


Figure 85. Comparison of Post Monsoon Depths to Watertable in SCARP Khairpur Project, Lower Indus Basin, Left Bank

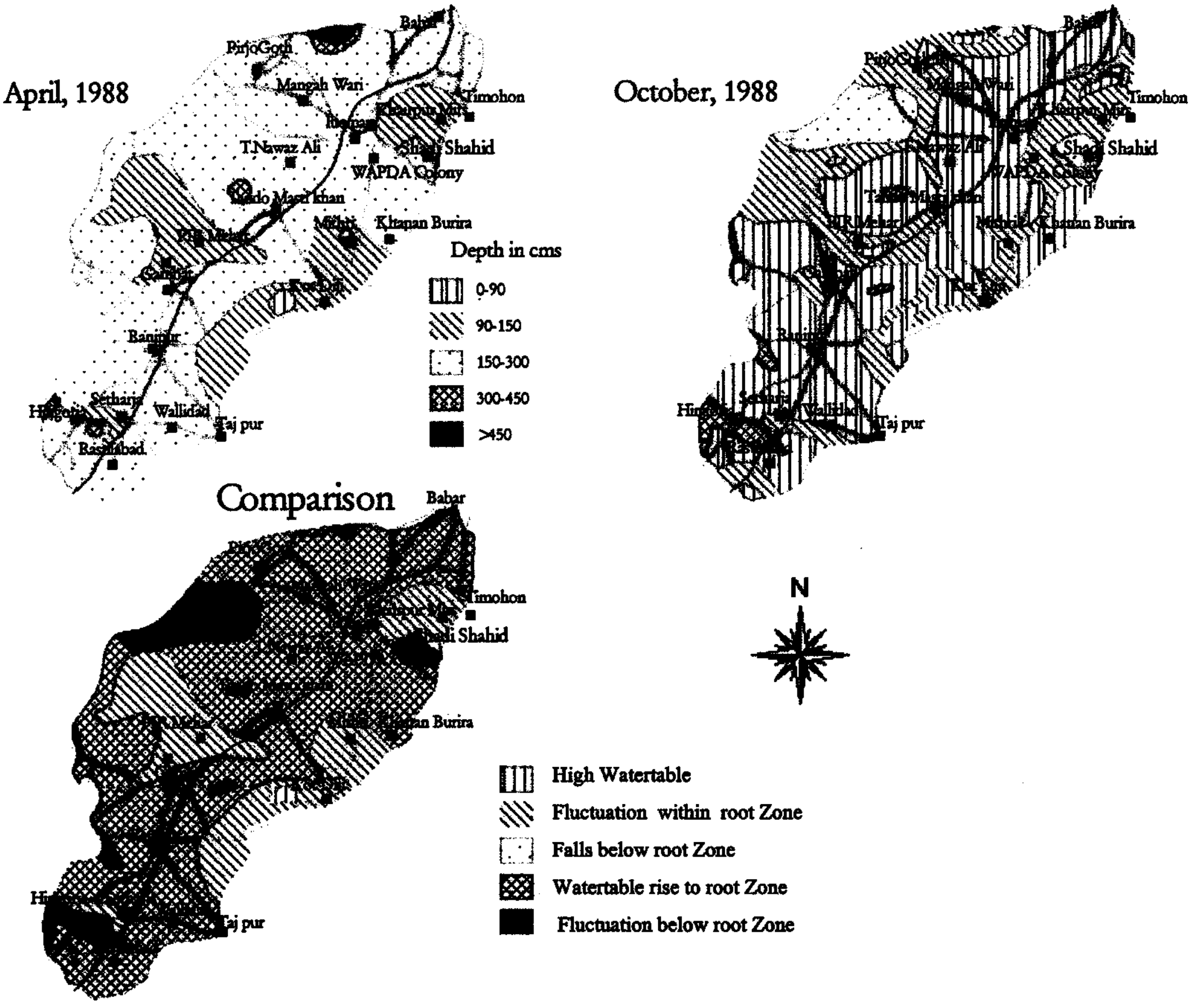


Figure 86. Seasonal Comparison of Watertable Fluctuations in the SCARP Khairpur Tubewell Project, Lower Indus Basin, Left Bank.

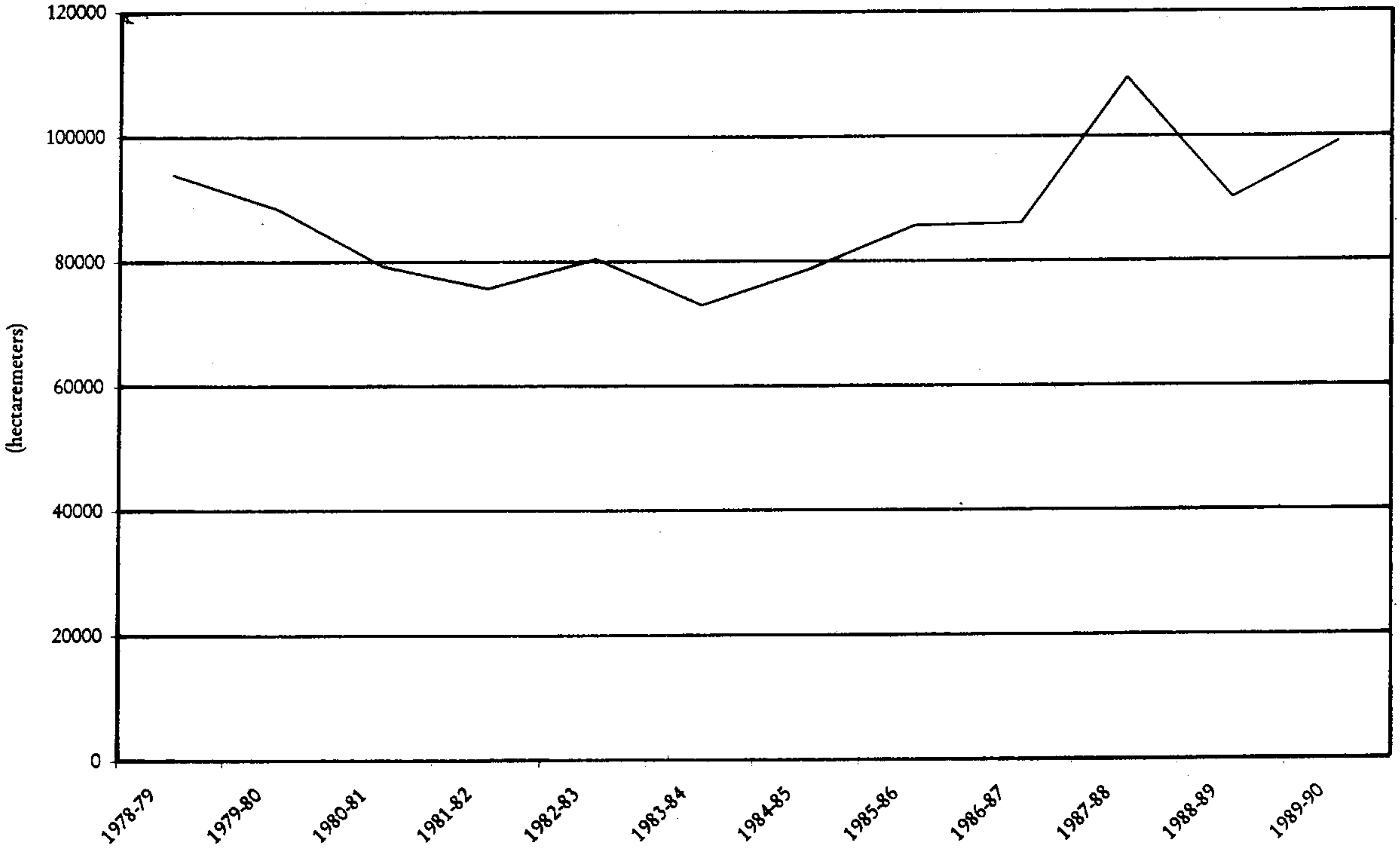
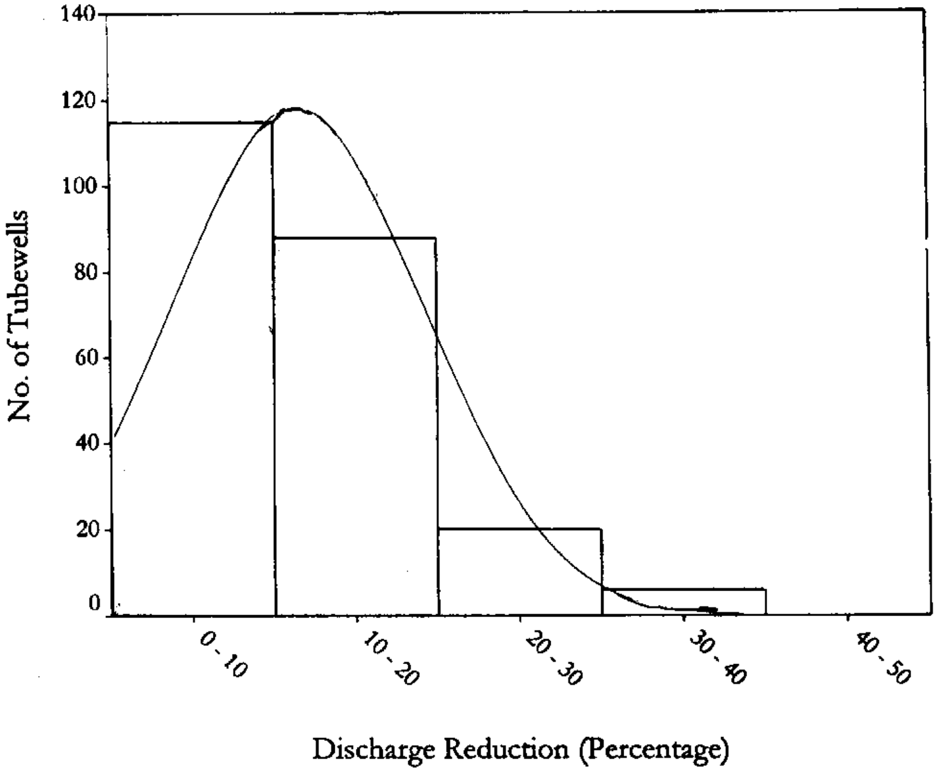


Figure 87. Year-wise Canal Supply for the Sukkur Right Bank Project Area.



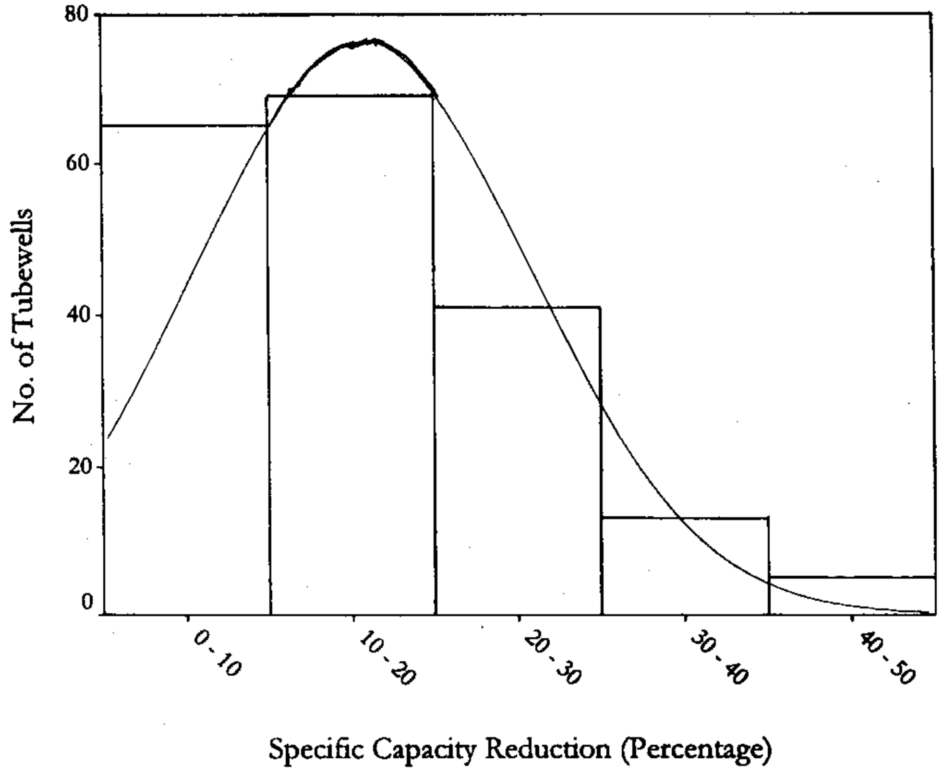


Figure 88. Comparison of Tubewell Performance for the Period between 1976 and 1990 in the Sukkur Right Bank Fresh Groundwater Project, Lower Indus Basin.

about 60 percent of the wells experienced reduction in specific capacities of up to 20 percent; more drastic loss of > 30 percent was limited to only 7 percent of the wells.

Water quality data for 360 of the 400 tubewells monitored during 1987-89 reveals that nearly 94 percent of the locations had usable waters (WAPDA, 1990, Sukkur Right Bank FGW Project). Only two tubewells were reported to be pumping hazardous waters (EC value < 3,100 micromhos/cm for both). The analysis results of 310 of these tubewells could be compared with the earliest available record of groundwater quality measurements done in 1982-83, wherein no significant differences in the quality of pumpage could be detected.

Comparisons of the interseasonal changes in watertable depths are provided for three distinct time periods in Figure 89. Raising the subsurface water levels to the root zone for the rice cropping inhibits any logical comparisons during October, however the pre-monsoon situation during April shows a total change across later years of comparison.

K. Pilot Projects

The irrigated landscape of the Sindh Province is home to several public sector land reclamation projects that were initiated against political expediencies to provide immediate relief to the localities within, or around, the urban settings from extreme hazards of waterlogging and soil salinization. Some of these pilot projects were actually complementary to larger drainage-related undertakings in that they allowed an upstart analysis of the project analysis by monitoring the performance of these much scaled-down initiatives. That all of these pilot projects are located on the Indus Right Bank where the threat of waterlogging is most severe due to extensive cultivation of rice and related seepage from the FSLs in the canals is no coincidence. The important pilot projects therein include Larkana, Shikarpur, Kandhkot and Sukkur, each characterized by exclusive reliance on tubewell drainage.

Shikarpur: This project was launched in December 1972 to provide surface and subsurface drainage facilities to the town of Shikarpur and adjoining areas where high watertables had played havoc with the environment. The project, situated on Sukkur-Quetta highway at a distance of 37 km north-west of Sukkur, covers a gross area of 7,072 ha, of which 5,822 ha are culturable. Fifty tubewells of 56 lps discharge capacity had been installed to lower the watertables; the effluent disposal was through a surface pump station located near the Larkana-Jacobabad by-pass where three centrifugal pumps of 100 lps discharged into one of the sub-drains of the larger Larkana-Shikarpur Surface Drainage Project.

Pre-project investigations on groundwater quality indicated salinities between 350-650 ppm. This was subsequently confirmed by water quality analysis done in 1979-80 that showed 47 of the 50 wells to be within a usable category. Repeat testing in 1987-89 showed no significant change in the quality of the effluent. The general direction of the groundwater movement is from north-east to south-west, against a very flat gradient.

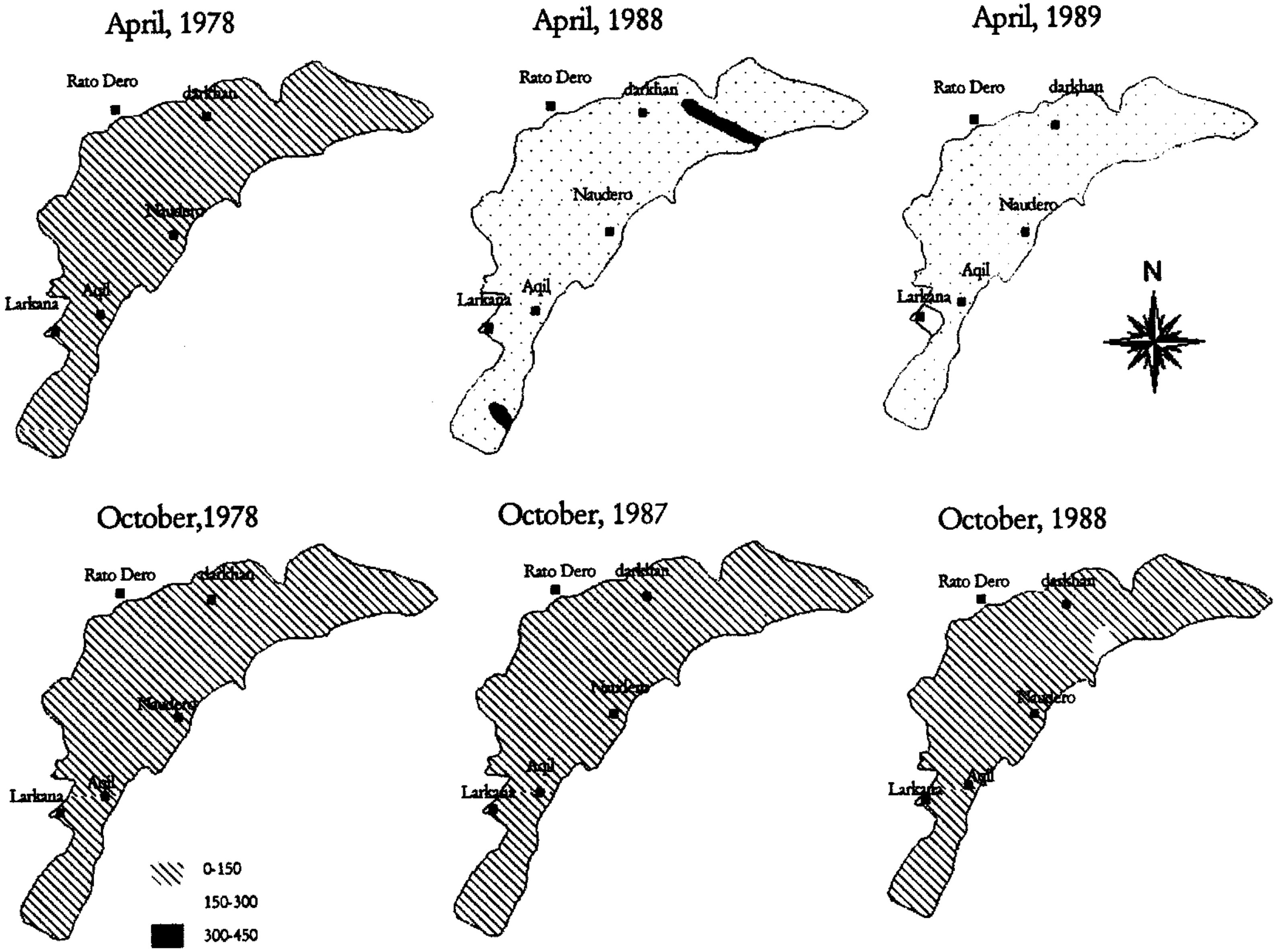


Figure 89. Temporal Comparison of Pre- and Post Monsoonal Fluctuations in Groundwater Levels within Sukkur Right Bank Tubewell Project, Lower Indus Basin.

The project tubewells were constructed in two stages; in the first stage, a small scheme consisting of 16 tubewells around the town and the surface pump station was framed on an emergency basis to provide immediate relief to Shikarpur town. These wells had dual disposals, i.e. into irrigation canals and watercourses. The construction of this stage was completed within one month of the start in June 1973, and the tubewells were energized by January next.

In August 1973, a more comprehensive pilot tubewell scheme consisting of 34 tubewells was proposed, and construction was started by May 1974. These tubewells were commissioned by December 1974. The total designed pumping capacity of the project tubewells was 8,193 Hm, which was exceeded by the FAT value of 11,993 Hm. By 1989, the discharge data collected by the SM (South) showed the pumping capacity to have reduced to 10,360 Hm against a utilization factor of 0.31. The year-wise details on actual pumpage for the period 1973-74 to 1988-89 appear in Figure 90, wherein a cumulative volume of 43,380 Hm had been pumped by then (WAPDA, 1990, Shikarpur Pilot Project). During this time, watertables receded to a point rendering much of the root zone secure, especially around the city of Shikarpur (Figure 91). A more recent interseasonal comparison for 1988 shows that for much of this rice growing area, water levels rise to the root zone during Kharif. However, eastwards from the town of Shikarpur, the root zone is not affected much (Figure 92).

Performance data on *discharges* for the comparison period 1974 and 1989 indicates a trend similar to the ones observed for the SCARP Khairpur FGW zone (Figure 93). There has not been much of a decline since the original FAT observations, and more than 2/3rds of the wells are under the 15 percent discharge reduction range. Relatedly, almost all the tubewells have had a specific capacity loss of under 25 percent, this pattern being similar to the one seen in SCARP Khairpur Saline zone and Sukkur Right Bank FGW Project.

Kandhkot Tubewell Pilot Project: This project, located 32 km southwest of the Guddu Barrage, is part of the the larger Guddu Fresh Groundwater Development Area designated in the LIP Report (Figure 94). The weir-controlled supplies from the newly constructed Guddu Barrage were primarily responsible for raising the watertables in an environment devoid of any drainage infrastructure. This degradaton not only affected the productivity of the agricultural lands in this rural backyard, but also threatened the urban property in the town of Kandhkot (Figure 95).

The Project Plan envisaged boosting the cropping intensities from the mid-1970s figure of 81 percent to an ultimate figure of 120 percent (rice ultimate 40%, wheat ultimate 24%). The coarse and medium soils, covering more than 80 percent of the project area, could support the targeted increase in cropping intensity with no serious problem of internal drainage. The project planning for the pilot scheme was done by WAPDA and investigations were completed by October 1975 to cover a GCA of about 5,260 ha.

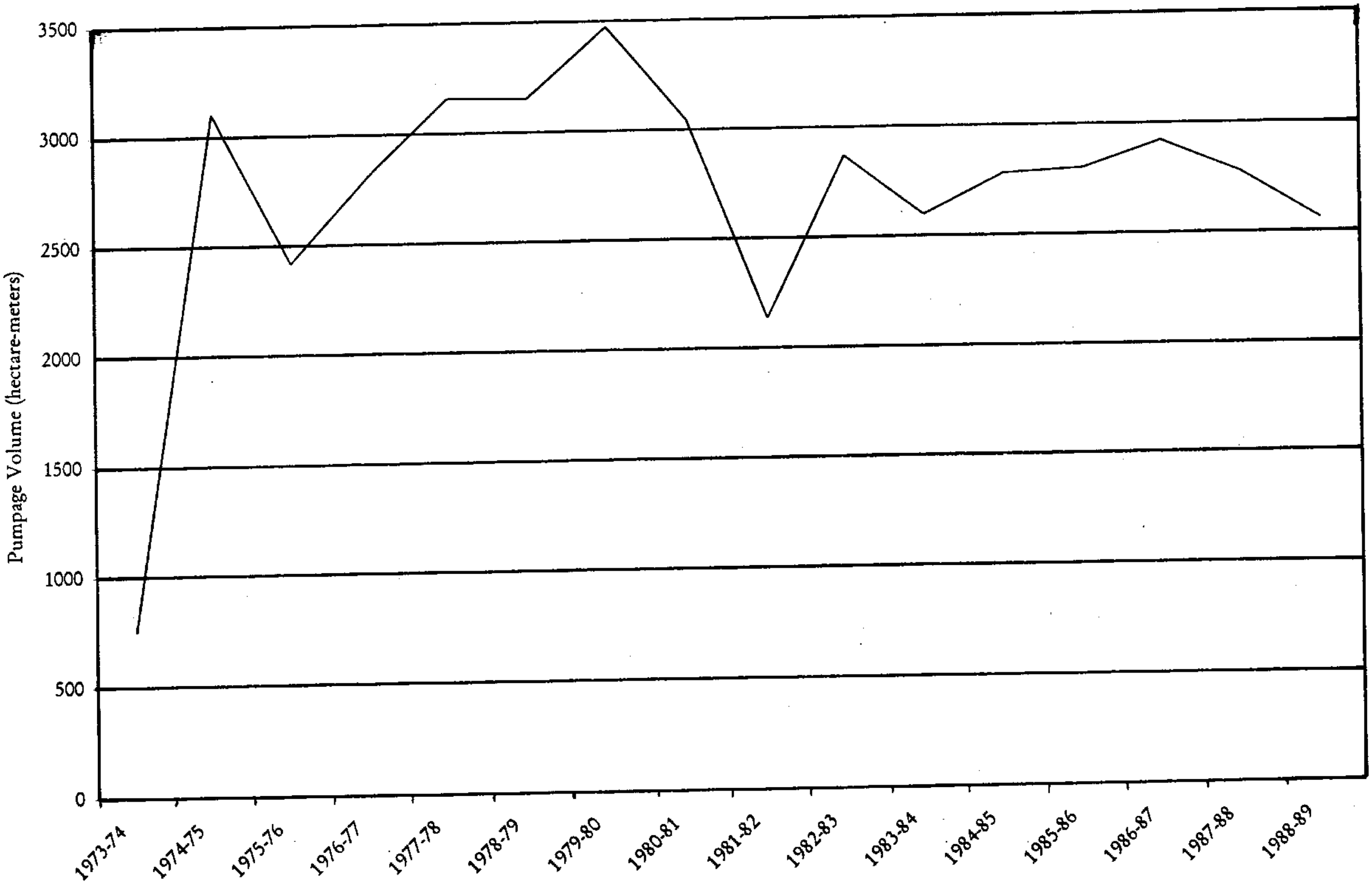
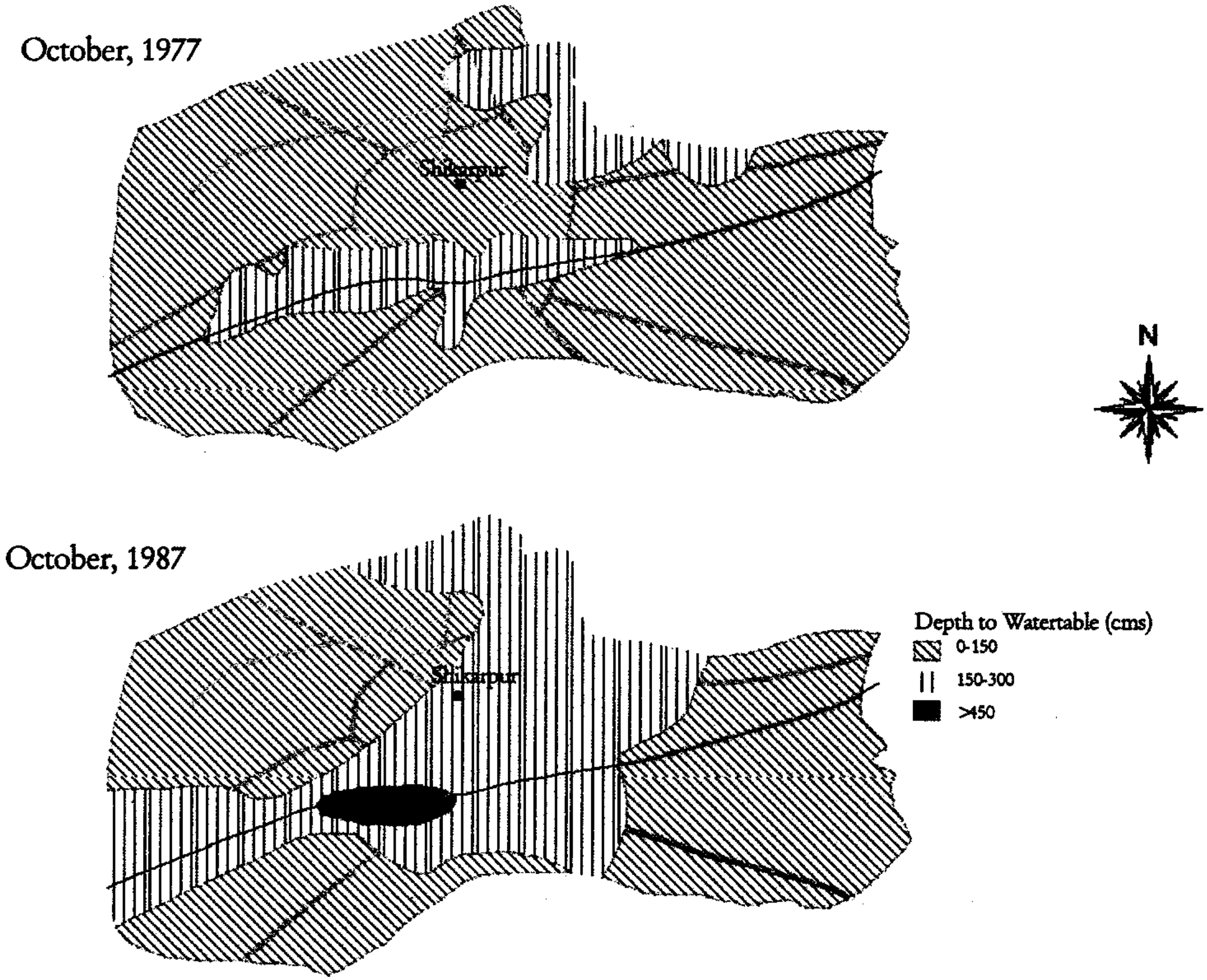


Figure 90. Year-wise Tubewell Pumpage from the Shikarpur Tubewell Pilot Project for the Period 1973-89.


October, 1977

October, 1987

Figure 91. Temporal Comparison of Post Monsoonal Depths to Watertable, Shikarpur PilotProject, Lower Indus Basin, Right Bank.

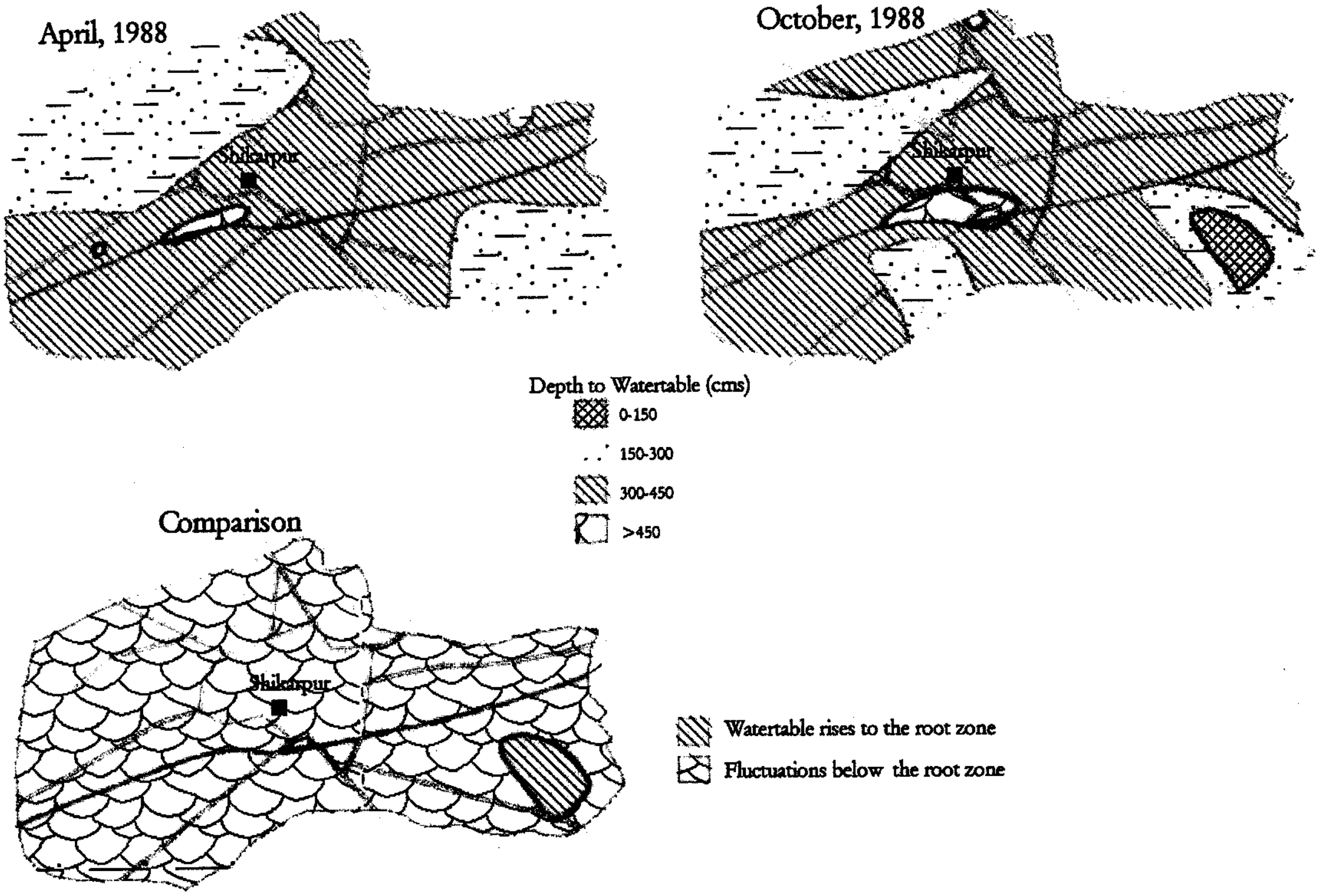
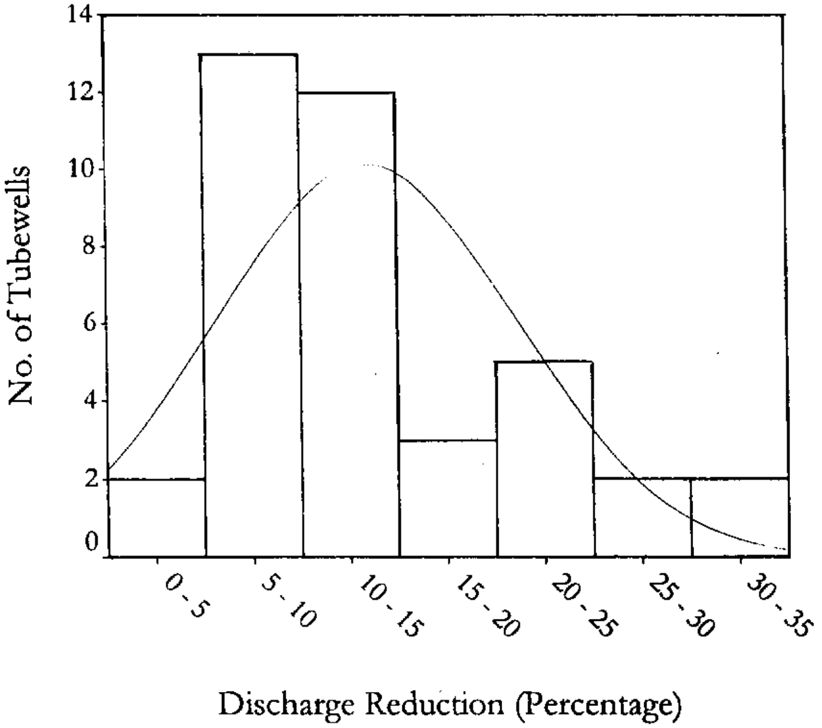


Figure 92. Seasonal Comparison of Depth to Watertable during 1988 in the Shikarpur Pilot Project, Lower Indus Basin, Right Bank.



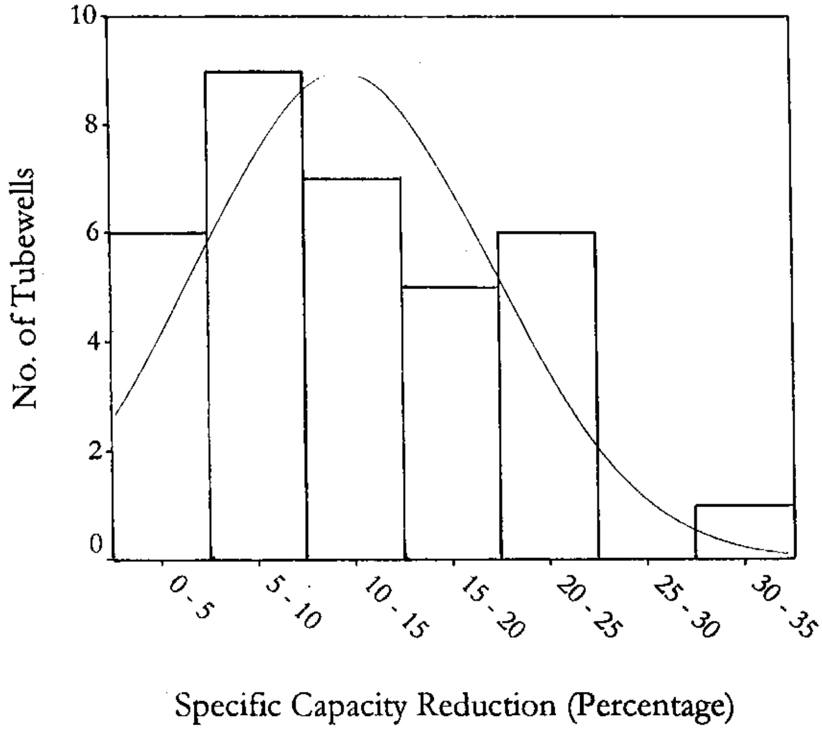


Figure 93. Comparison of Tubewell Performance for the Period between 1974 and 1989 in the Shikarpur Pilot Project, Lower Indus Basin Plain.

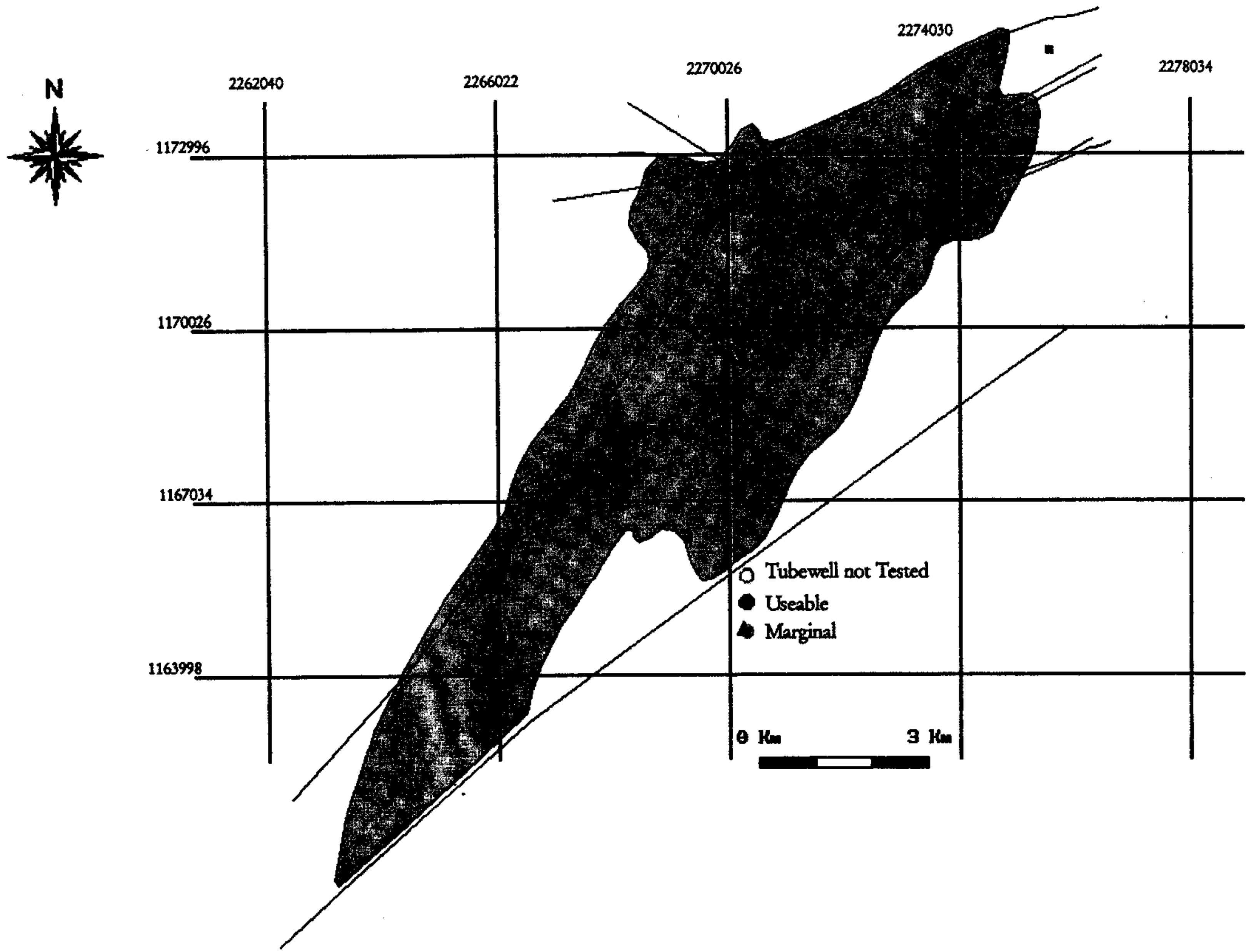


Figure 94. Location Map and Quality of Groundwater in the Command of KandhKot Pilot Project, Lower Indus Basin, Right Bank.

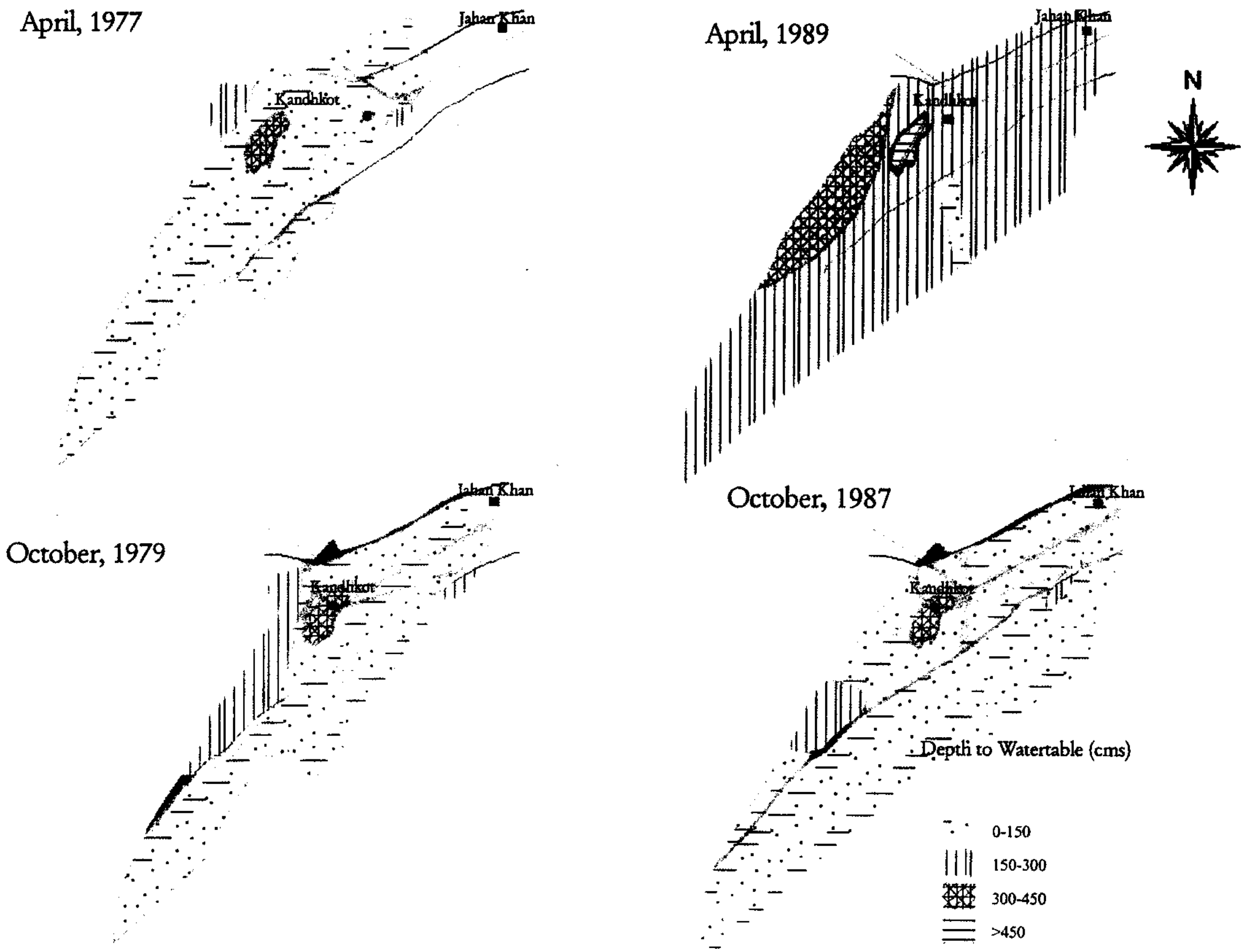


Figure 95. Groundwater Fluctuations in Kandhkot Pilot Project, Lower Indus Basin, Right Bank.

The project benefits were invariably tied into lowering the water levels and reclaiming about 800 ha of salt-affected lands in an area of extensive rice cultivation. This was to be achieved through vertical drainage from 36 tubewells of 56 lps capacity each. Later, this number was curtailed to 26 tubewells covering a gross area of 3,480 ha, of which 2,960 ha were culturable. Eight of these wells discharge directly into watercourses and the remaining, irrigation-cum-drainage. The planned pumpage sought to convert the non-perennial status of the irrigation supplies to a perennial one by utilizing the groundwaters for the Rabi season also. The standing water in the *dhoros* and other depressions was to be removed through a separate surface drainage scheme covering the areas of Thul, Kandhkot and Shahdadkot.

Construction work on the project was started in January 1977 and the tubewells were energized by July 1978. Prior to the installation of the public wells, there were already a few private tubewells operative in the area. The project wells had a total design capacity to recover 4,256 Hm of water annually, against a crop water deficiency of 2,334 Hm expected during the Rabi and early Kharif periods. At the time of acceptance, the pumpage capacity was reported to be 6,889 Hm. Figure 96 shows the year-wise pumpage of the project tubewells for the period 1978-79 to 1988-89. The total pumpage recorded by that time was 14,112 Hm.

The water quality was deemed to be non-deleterious for irrigation purposes, as it was generally acceptable, and in most cases < 1,200 ppm (recommneded by the LIP Consultants as the upper safe limit). Water quality sampling between 1979-80 showed 14 of the 24 wells sampled had usable groundwaters and 8 were of marginal quality. Subsequent sampling of 20 wells in 1987-89 indicated 15 to be of usable quality and only 2 were marginal. The number of wells pumping hazardous waters had increased to 3 from the 2 in 1979-80.

Peformance monitoring of 17 wells for discharge and specific capacity during 1987-88 showed a majority decline in the former of about 20 percent, in comparison to acceptance tests in 1977 (WAPDA, 1990, Kandhkot Pilot Project). The frequency histogram in Figure 97 indicates 4 of the wells to have experienced still higher discharge reductions. The reduction in specific capacity for the same period is much more significant, exceeding 35 percent in almost half the number of wells monitored.

Interseasonal changes in watertable depths during 1988 indicate that, for much of the project area, the watertables rise to the root zone during October; the town of Kandhkot, together with large strips of land along the eastern and western boundaries of the project area are an exception to this post-monsoonal rise (Figure 98).

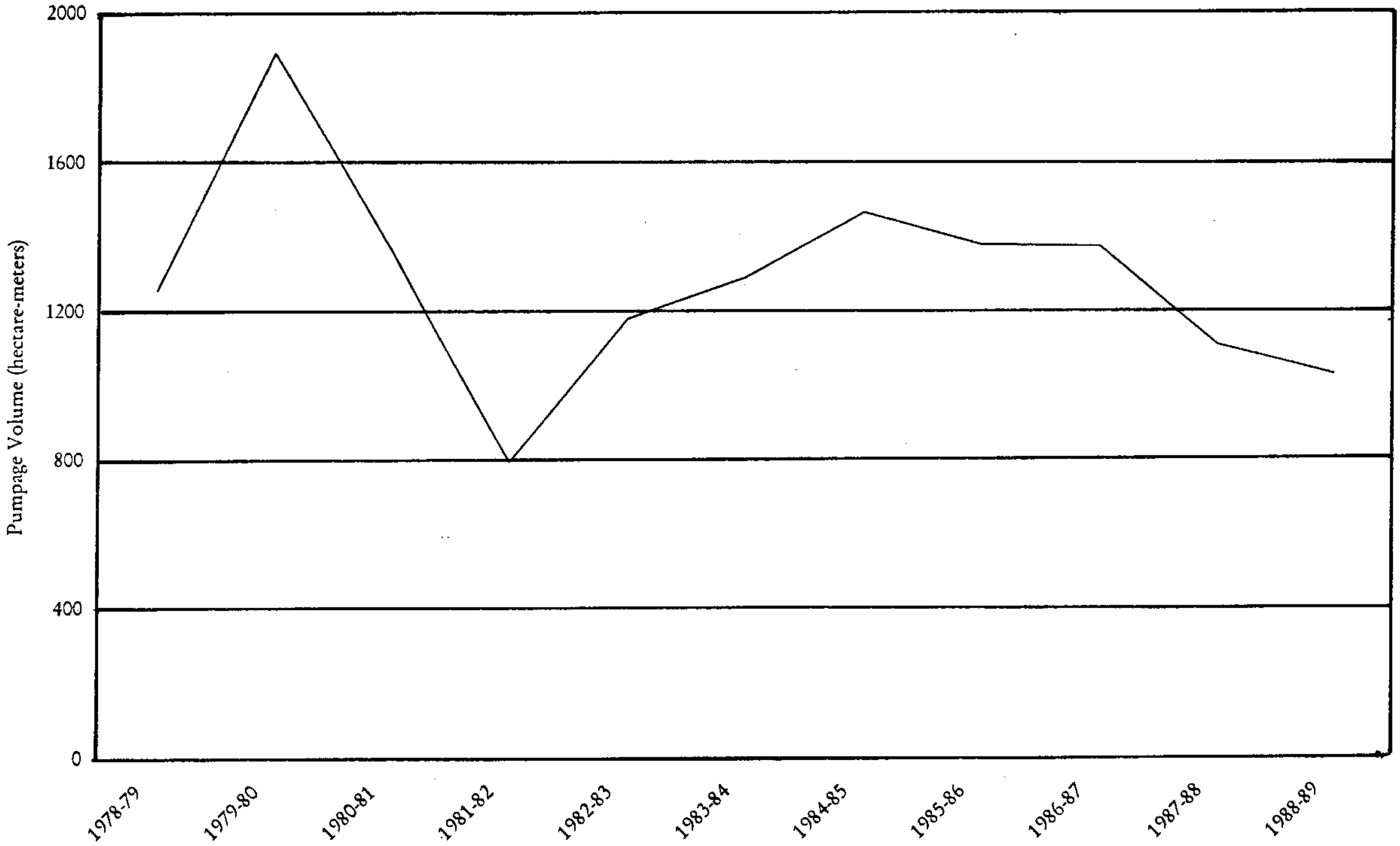
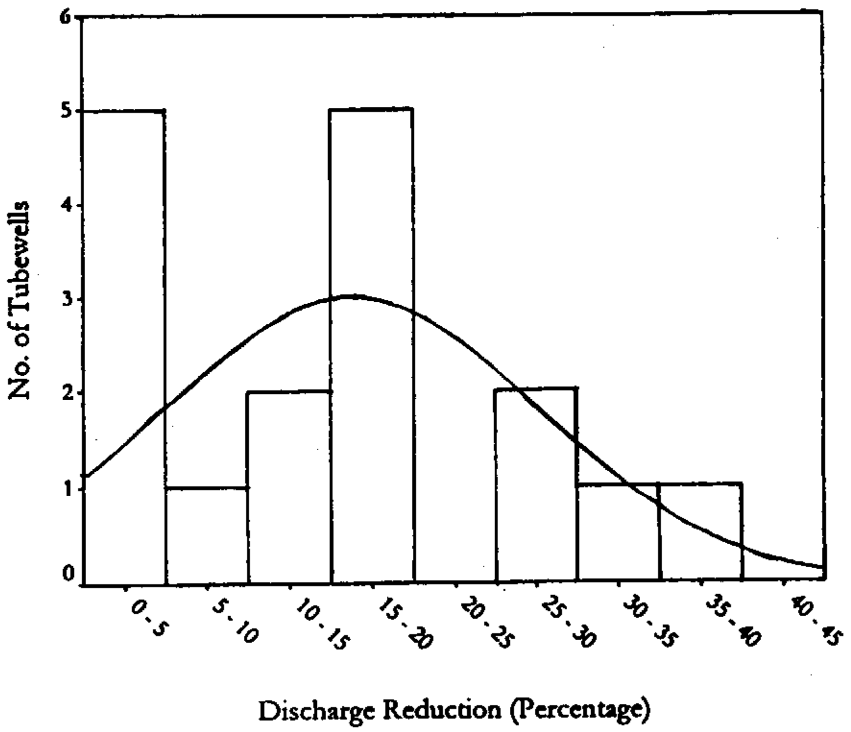


Figure 96. Year-wise Tubewell Pumpage from the Kandhkot Tubewell Pilot Project for the Period 1978-89, Lower Indus Basin, Right Bank.



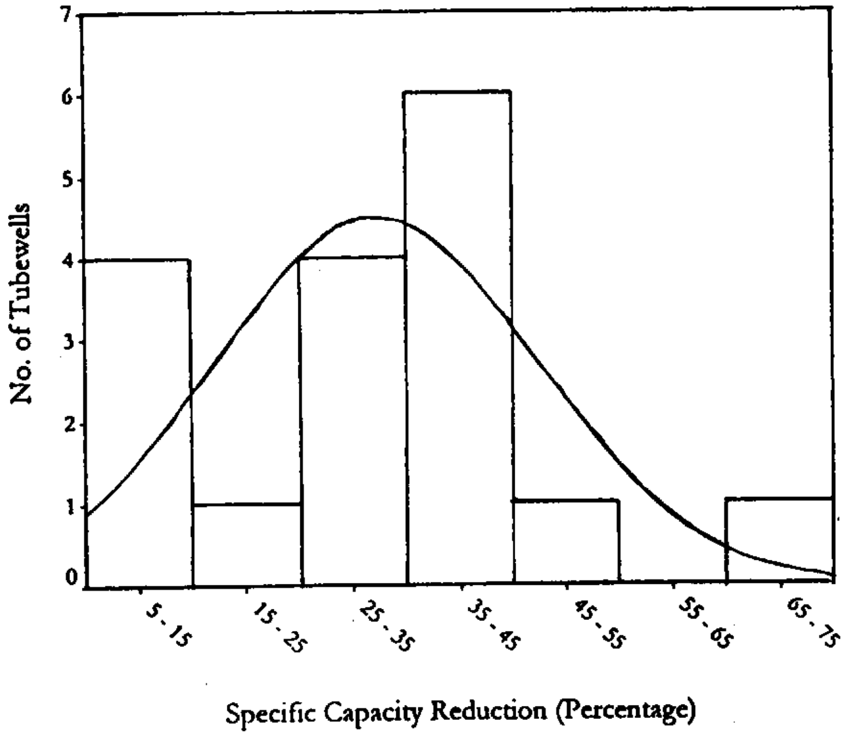


Figure 97. Comparison of Tubewell Performance for the Period between 1977 and 1988-89 in the Kandhkot Pilot Project, Lower Indus Basin, Right Bank.

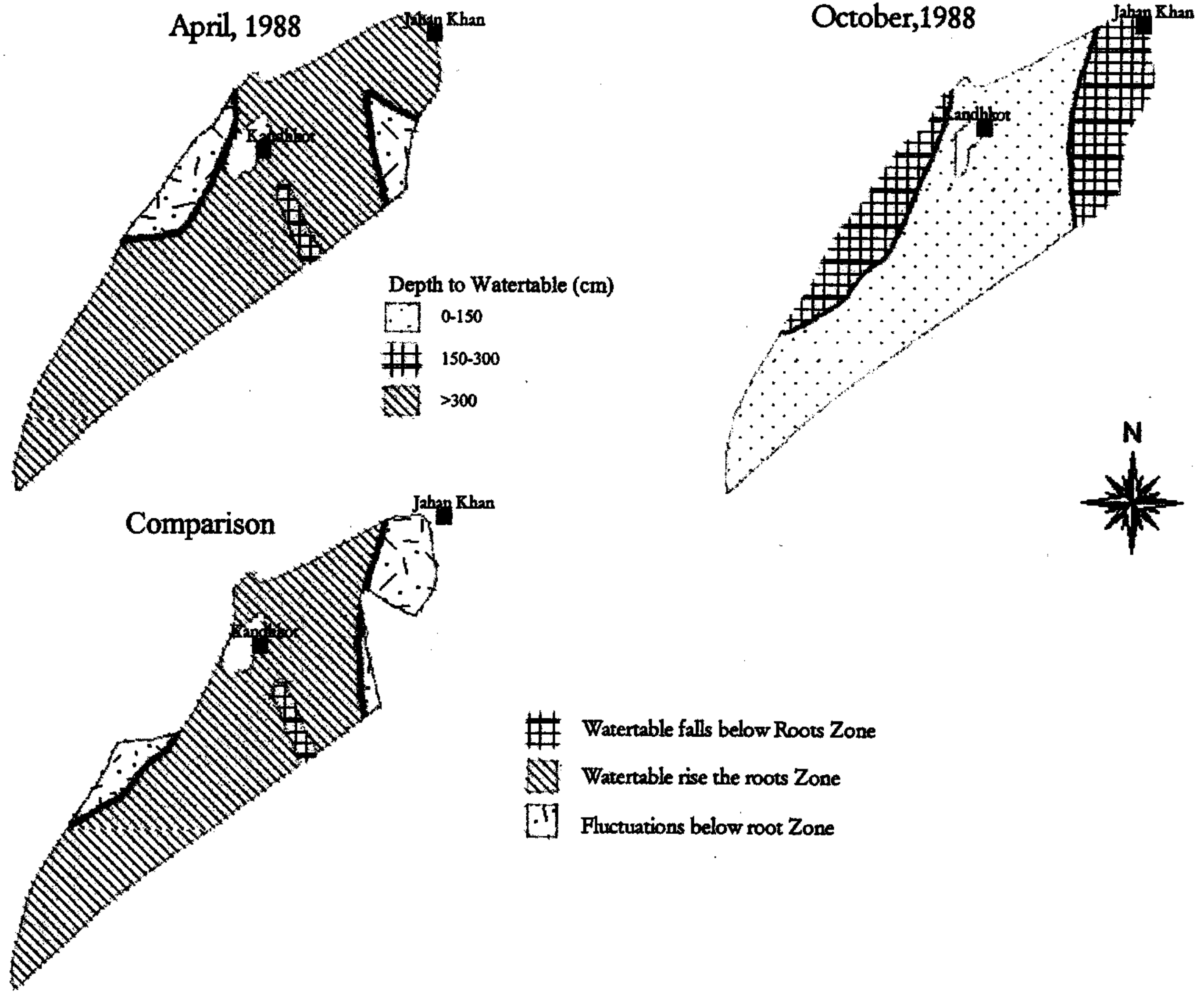


Figure 98. Seasonal Comparison of Depth to Watertable during 1988 in the Kandhkot Pilot Project, Lower Indus Basin, Right Bank.

Larkana Tubewell Pilot Project: This project was executed by specific instructions from the Federal Government to alleviate the extreme lack of drainage around the town of Larkana, and concurrently make supplemental irrigation supplies in an area with traditional rice cultivation available. Located at the southern-most tip of the Sukkur Right Bank fresh groundwater zone, the Pilot Project covers a gross area of 3,158 ha and culturable commanded area of 2,032 ha (Figure 99). Construction work for the installation of 35 tubewells of 56 lps capacity each was started in April 1974, and by September that year all the tubewells were energized. The total designed pumping capacity, established on the basis of 22 operational hours/day, was determined to be 6,255 Hm. The FATs reported the capacity at 8,400 Hm. By 1988-89, the performance monitoring of these wells yielded a pumping capacity of 7,770 Hm against which 690 Hm had been pumped during that year, which equates to a utilization factor of only 11%. Figure 100 shows the yearly variations in pumpage since the beginning of the project, wherein some 18,365 Hm had been pumped out by June 1989.

Of the 14 wells tested, none showed a decrease in discharge over the *design* (not acceptance) values, however, 10 of these wells showed a reduction in their respective specific capacities by as much as 20% (WAPDA, 1990, Larkana Tubewell Pilot Project). With respect to acceptance test figures, 12 out of the 14 wells monitored experienced varying degrees of reduction in discharges and specific capacities. The *discharge* reduction in half the wells was between 10-20%, others being lower than this range (Figure 101). Meanwhile, 10 of the 12 tubewells had experienced a reduction in *specific capacity* not exceeding 25% (more than half of these wells being under 10% range of reduction).

Water quality sampling of 34 tubewells between 1979-80 showed that 30 wells were pumping usable groundwaters and the rest were of marginal quality. Repeat sampling of 21 wells in 1987-89 showed 19 to be of usable quality. Overall, there is no indication of any worsening trend.

Data on watertable depths indicates that there has been a significant decrease in the water levels for both pre- and post-monsoon seasons (Figure 102). More recent comparisons for the year 1988 indicate that, season-wise, fluctuations tend to remain below the root zone (Figure 103).

Sukkur Pilot Project: Located on the Right Bank of Indus about 6 kms north west of Sukkur, the project area covers a gross area of 2,023 ha (1,434 ha of GCA and 1,288 ha of CCA) (Figure 104). The area is under the command of Lakha Wah and Garang Wah, which are inundation channels offtaking from the river at 6 and 10 kms from the Sukkur Begari Bund.

During 1974, the discharge in the River Indus above Sukkur was abnormally low. The inundation canals can satisfactorily only run when the river discharge exceeds 9,900 cumecs, which is possible for just a limited period of time. As a result, the command areas of these

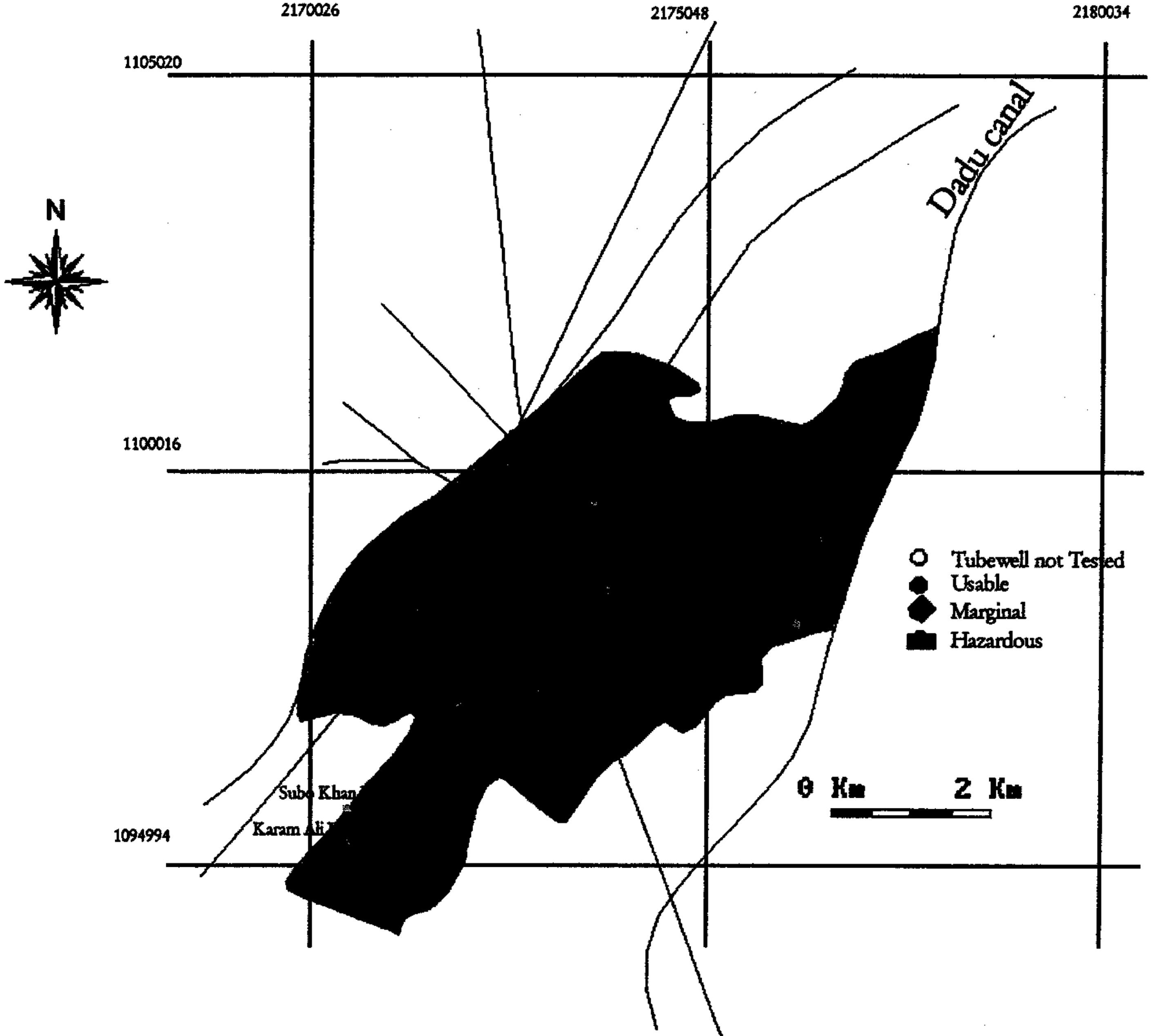


Figure 99 . Location Map and Groundwater Quality of Tubewells during 1987-89 in Larkana Pilot Project, Lower Indus Basin, Right Bank.

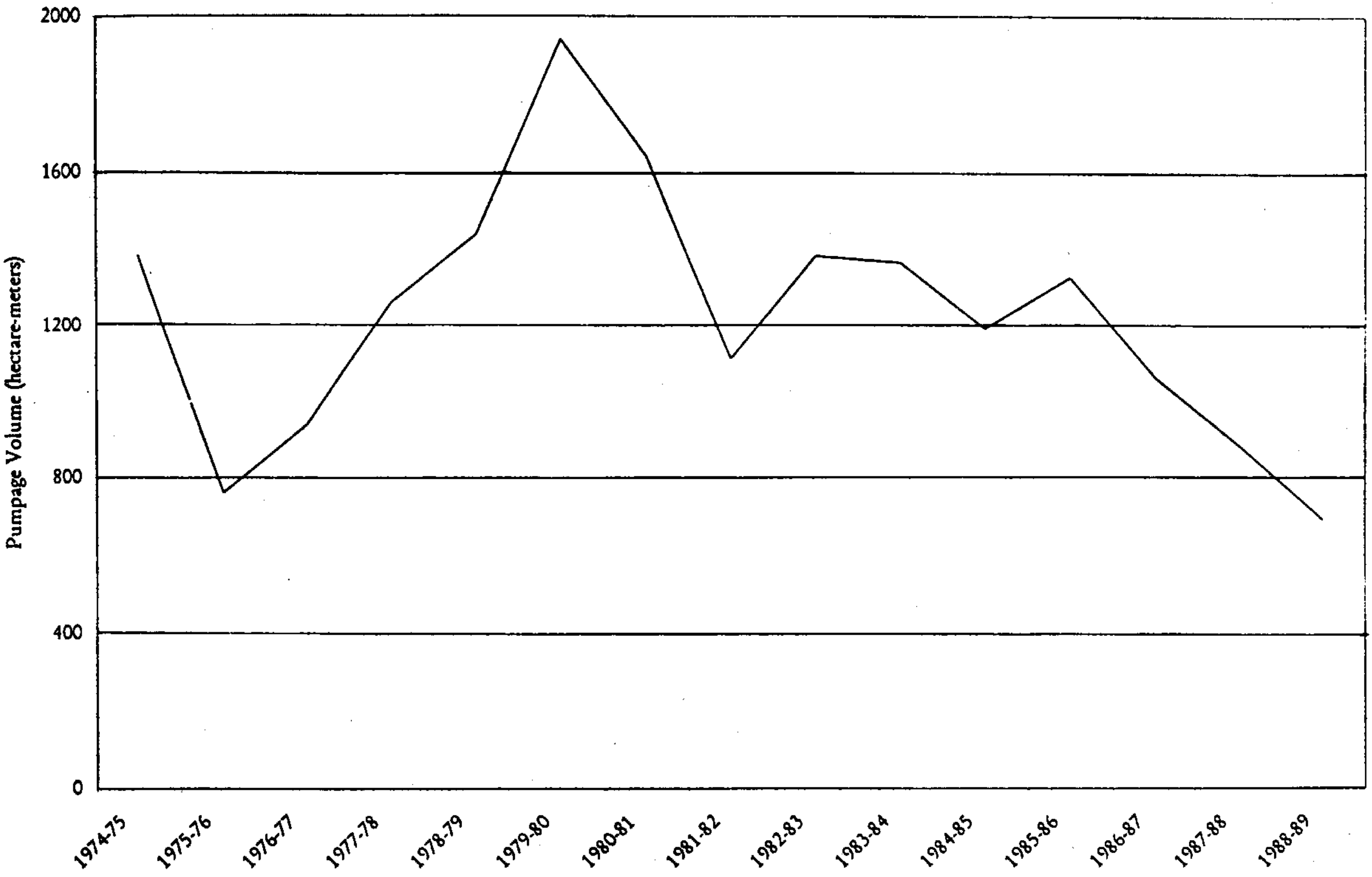


Figure 100. Year-wise Tubewell Pumpage from the Larkana Tubewell Pilot Project for the Period 1974-1989.

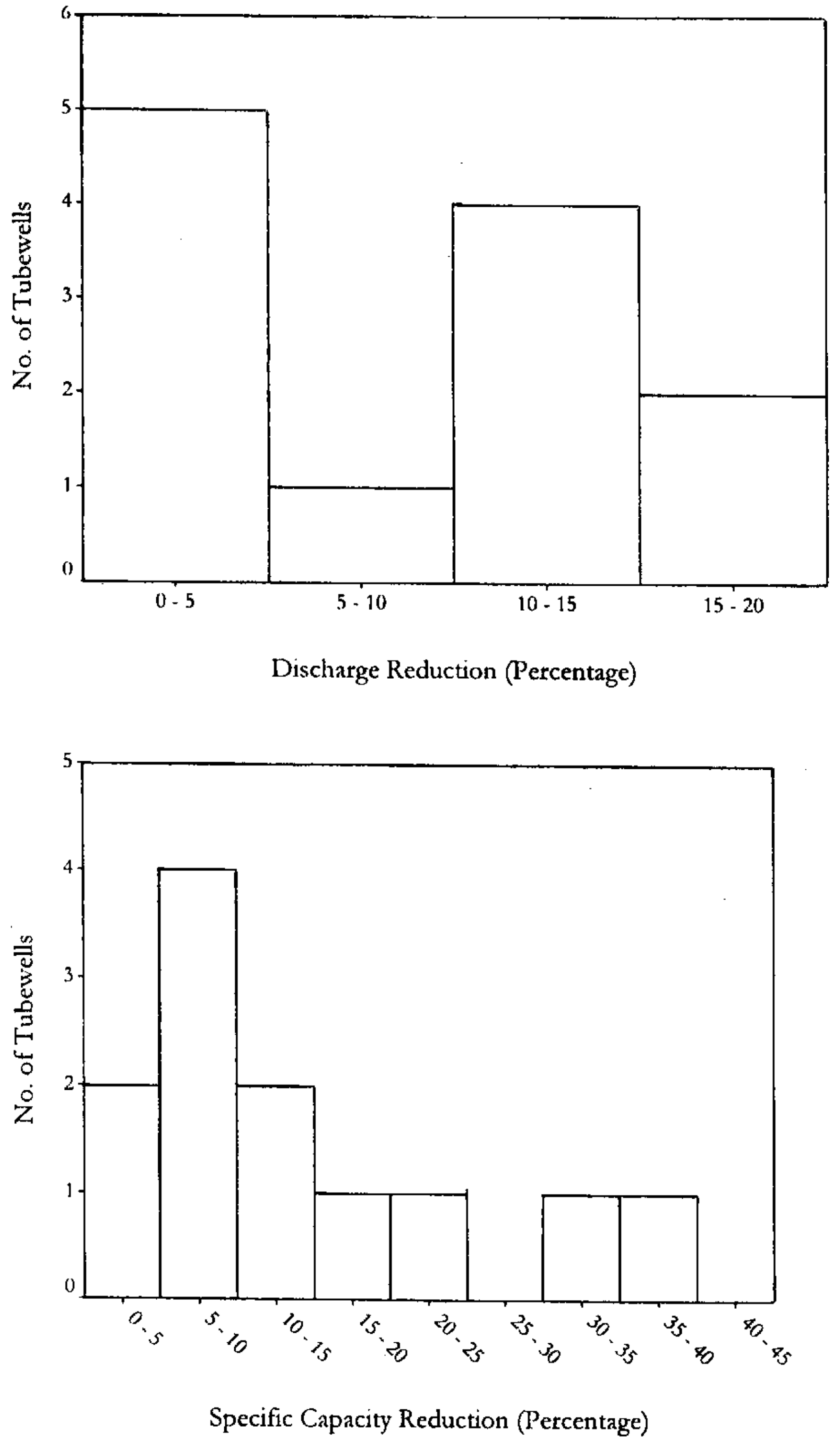


Figure 101. Comparison of Tubewell Performance for the Period between 1974 and 1989 in the Larkana Pilot Project, Lower Indus Basin, Right Bank.

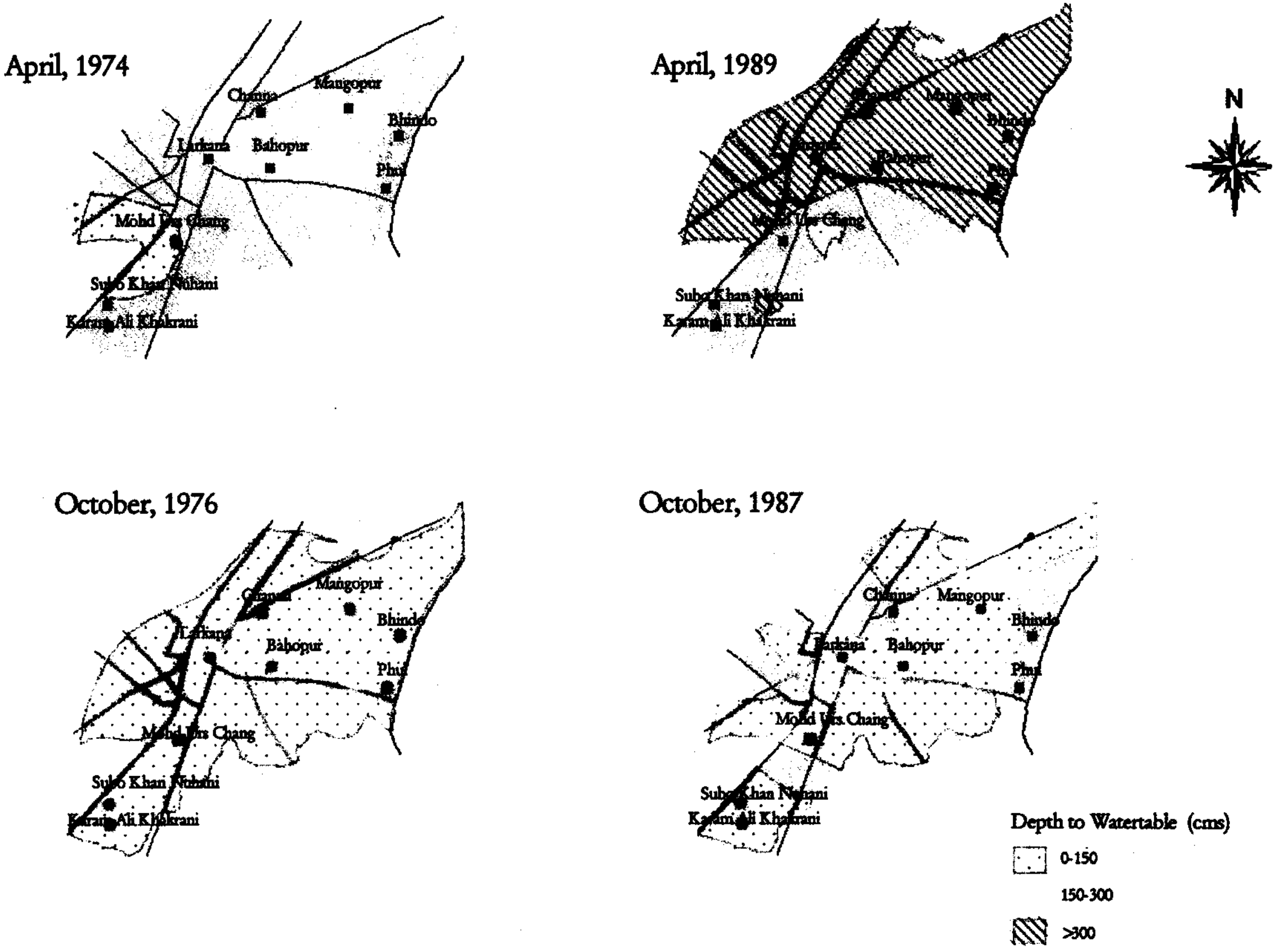


Figure 102. Interseasonal Comparison of Depth to Watertable for Larkana Pilot Project, Lower Indus Basin, Right Bank.

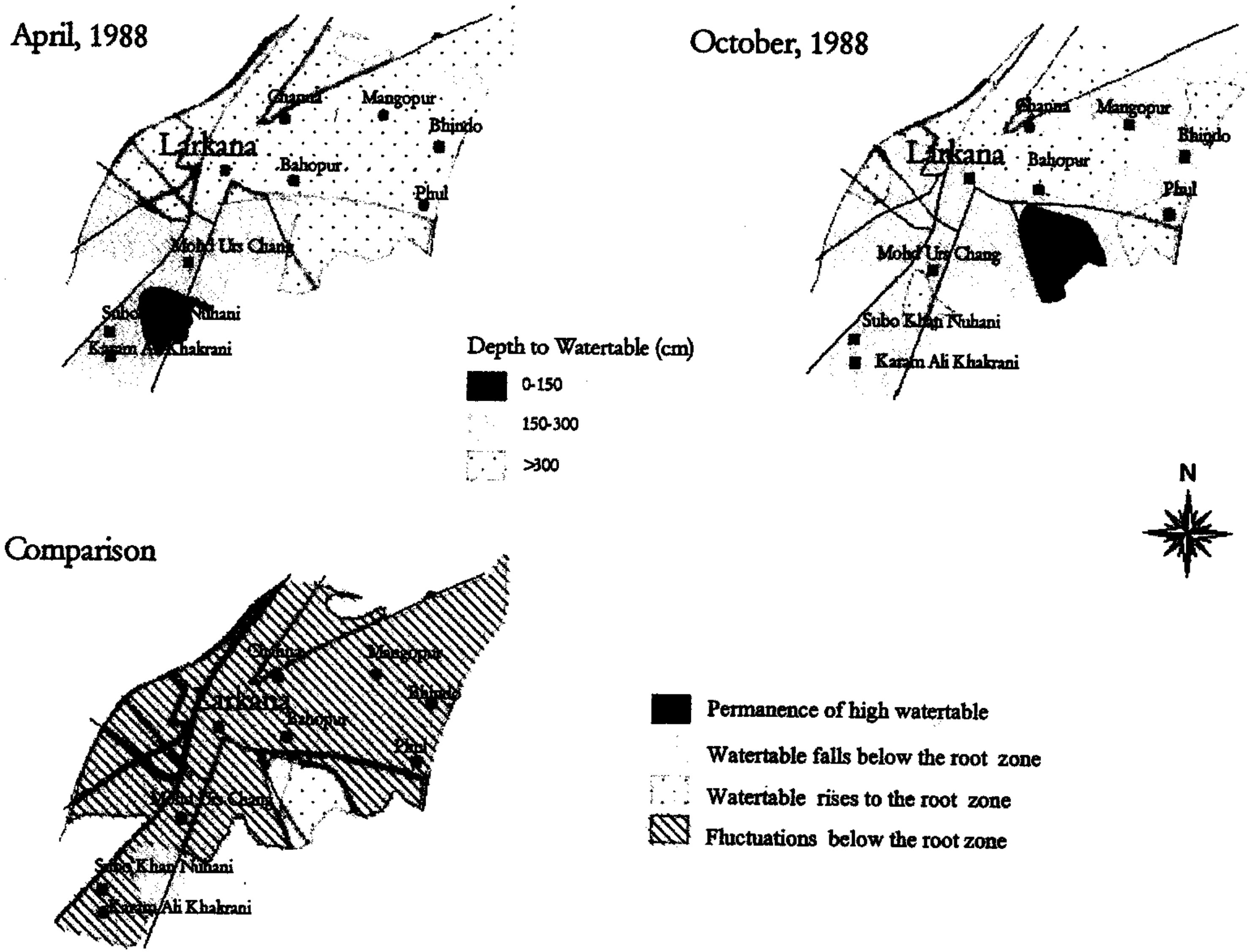


Figure 103. Comparison of Pre- and Post Monsoonal Watertable Fluctuations during 1988 in the Larkana Pilot Project, Lower Indus Basin, Right Bank.

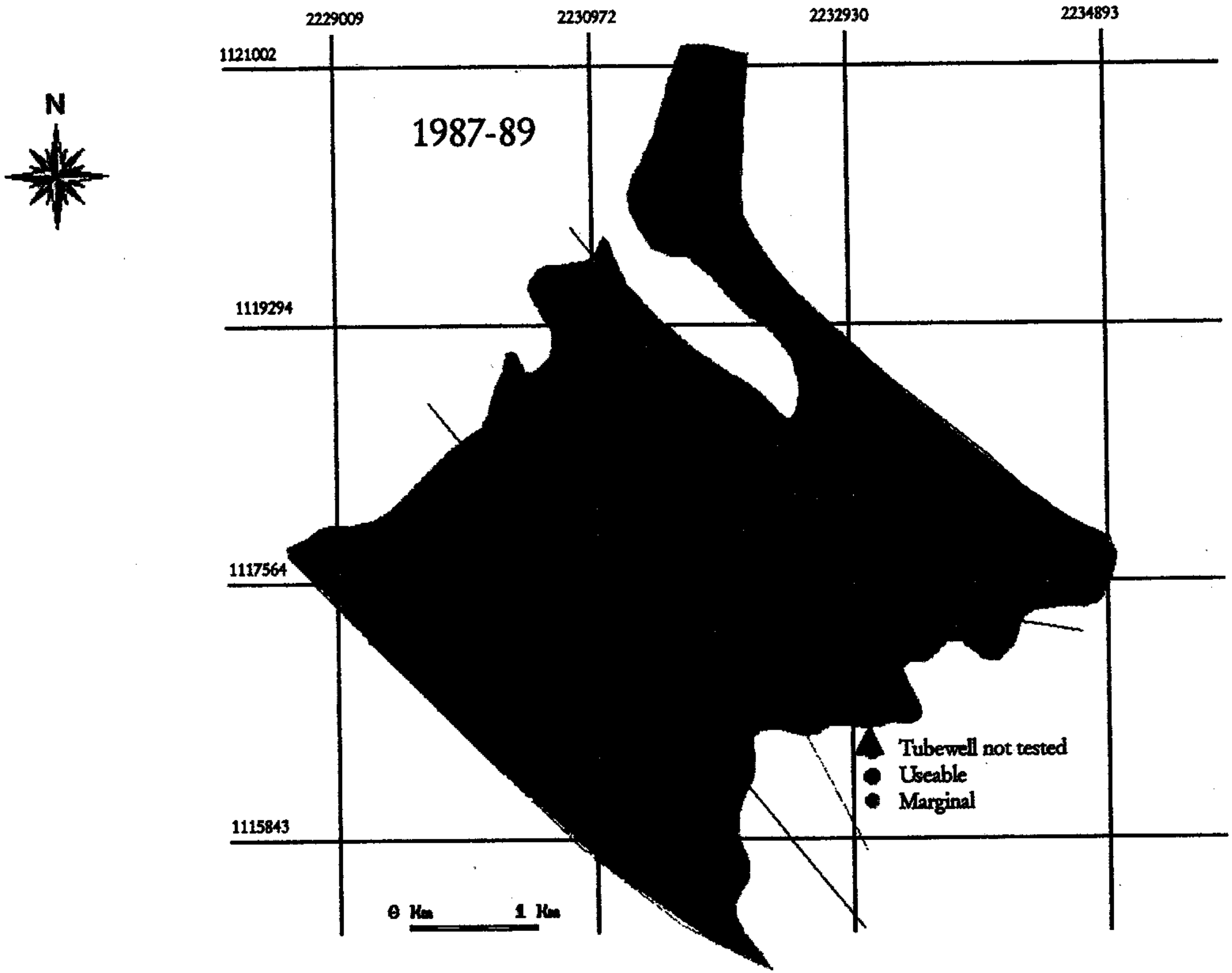


Figure 104. Location Map and Groundwater Quality of Tubewells within Sukkur Pilot Project,Lower Indus Basin, Right Bank.

two canals remained dry during the important Kharif season. Given this omnipresent threat of interruptions to the run-of-the-river irrigation supplies, the GoP decided to implement the Sukkur Tubewell Pilot Project to supplement irrigation supplies through harvest of the fresh groundwater zone, especially during the early and late Kharif seasons.

Originally, the plan was to install 15 tubewells of 42-56 lps capacity to discharge a total of 0.73 cumecs into Garang Wah. However, owing to the limited depth of the aquifer, 15 shallow tubewells of 28-56 lps capacity having a total discharge of 0.58 cumecs could be drilled. An additional 3 tubewells, having a total discharge of 113 lps, were later installed on Lakha Wah.

The construction work on this project started in November 1974 and the 15 tubewells on Garang Wah were completed by January 1975. Work on Lakha Wah tubewells started in May 1975 and were completed the same year in July. The total design pumping capacity of these wells was estimated to be 2,005 Hm. During 1988-89, the reported pumpage capacity was 2,322 Hm, against which only 481 Hm had been pumped and corresponds to a utilization factor of 24 percent. Figure 105 shows the yearly variations in pumpage since the beginning of the project, wherein some 11,294 Hm had been pumped out by June 1989 (WAPDA, 1990, Sukkur Pilot Project). Of the 11 tubewells tested for performance during 1988-89, only 2 showed a reduction in discharge compared to design; the reduction in specific capacity was below the 30 percent mark (Figure 106).

Water quality sampling between 1979-80 showed that 14 wells were discharging water of usable quality and the remaining were marginal. Subsequent testing in 1987-89 showed this differentiation to be quite stable with no significant change.

Groundwater levels have steadily declined for the pre-monsoon period, especially in the northern part of the project area; however, intensification of the rice cultivation has seen the entire area subjected to raised water levels to the root zone during Kharif (Figure 107). Data for 1988 indicates rather low subsurface levels even during the Kharif season; waterlogged root zone is maintained only in the north, whereas elsewhere, the seasonal rise has been restricted to > 150 cm depth of soil (Figure 108).

L. Proposed Right Bank Master Plan

The irrigation systems on the Right Bank were originally constructed without any provision for drainage. The need for drainge was recognized at an early stage and, following the recommendations of the LIP Report in the 1960s, various drainage projects were implemented that together account for over 30 percent of the alluvial area (Table 8 above). The LIP report proposed subsurface drainage for dry foot crops in perennial commands, and surface drainage for rice in seasonal areas. The recommendations were not implemented in full, and are no longer considered appropriate, since rice is now the main crop over most of the area, and the distinction between seasonal and perennial canals has become rather

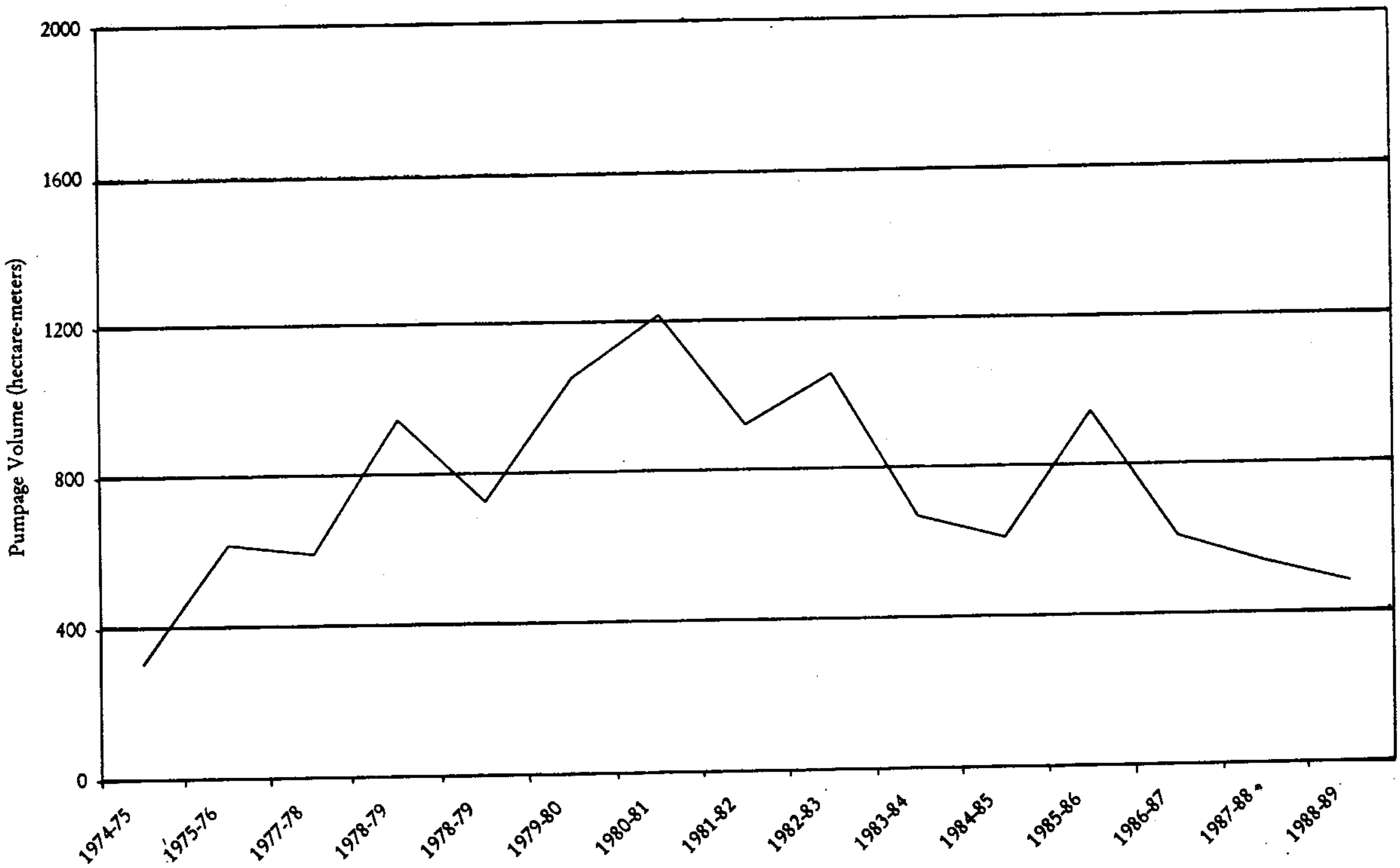


Figure 105. Year-wise Tubewell Pumpage from the Sukkur Pilot Project for the Period 1974-89, Lower Indus Basin, Right Bank.

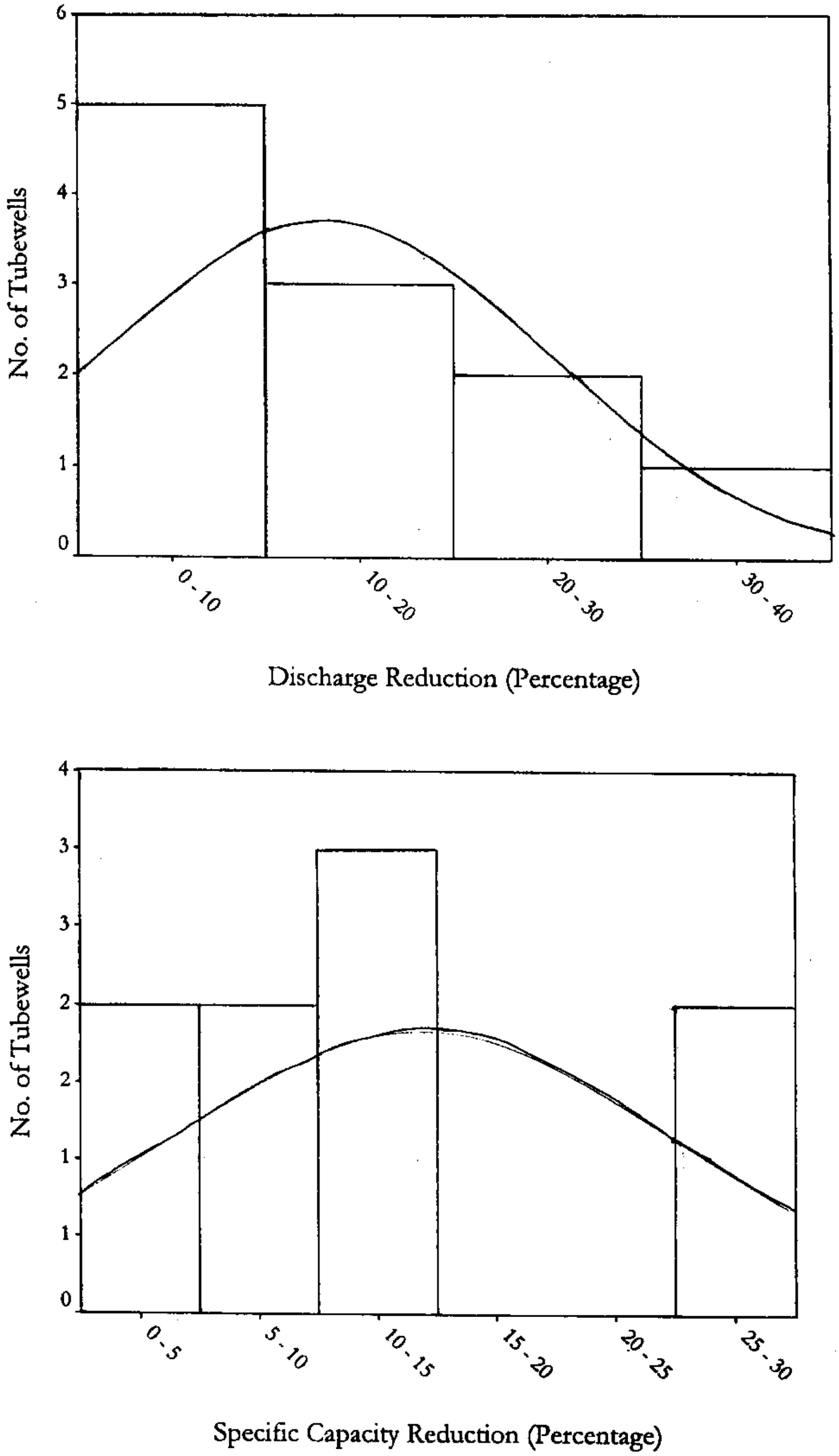
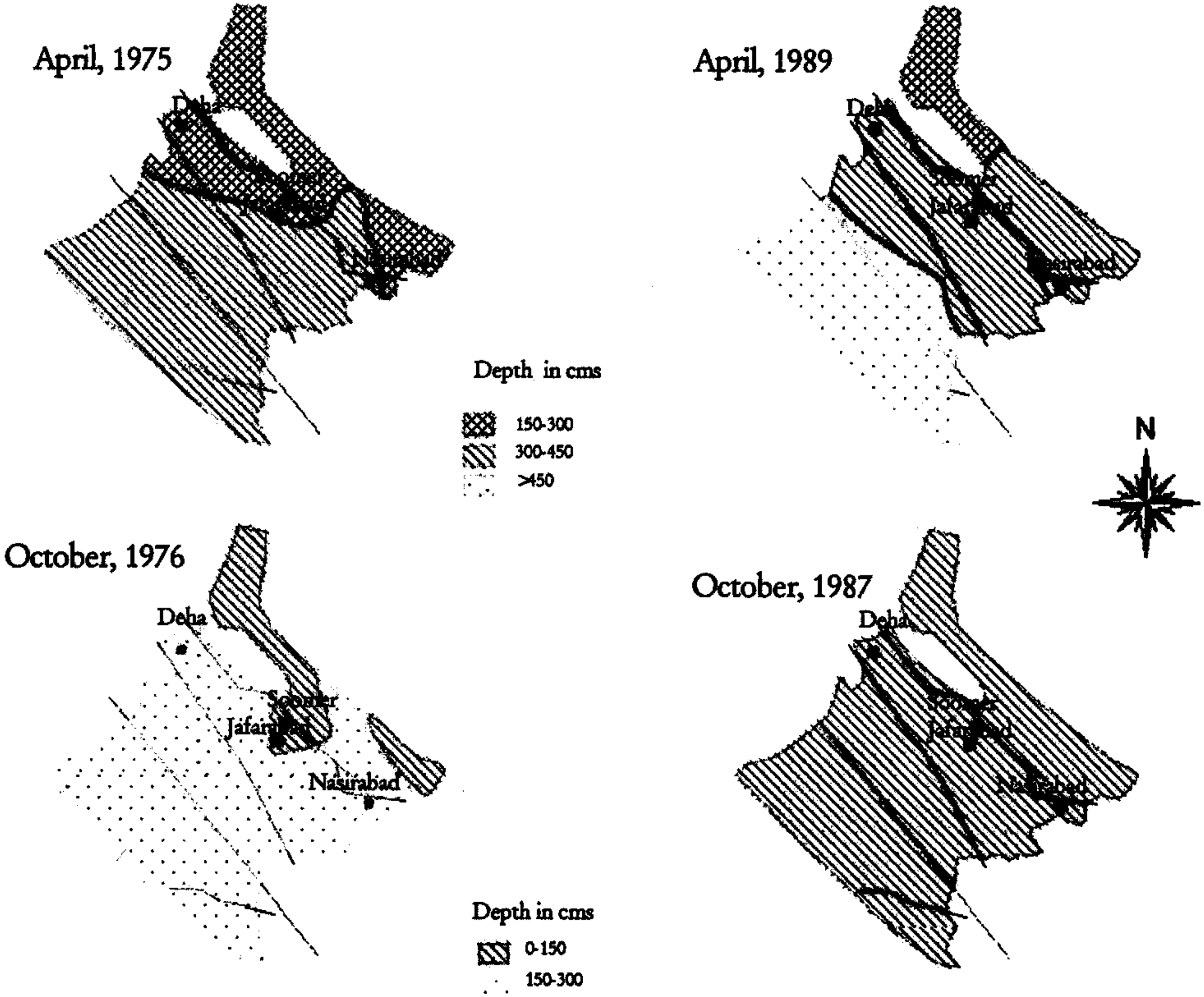


Figure 106. Comparison of Tubewell Performance for the Period between 1975 and 1989 in the Sukkur Pilot Project, Lower Indus Basin, Right Bank.


April, 1975

April, 1989

October, 1976

October, 1987

Figure 107. Temporal Comparison of Pre- and Post Monsoonal Fluctuations in Groundwater Levels within Sukkur Pilot Project, Lower Indus Basin, Left Bank.

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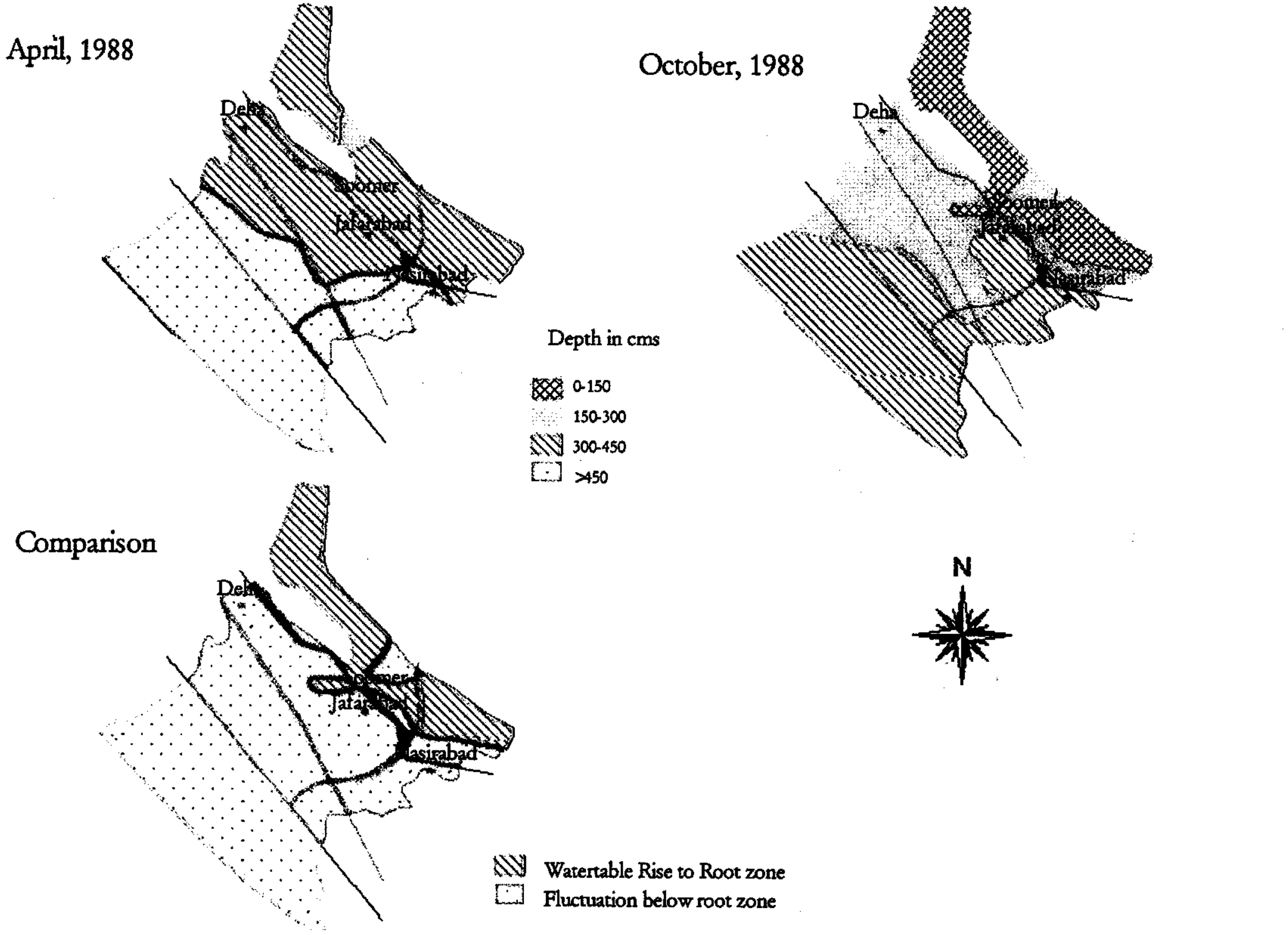


Figure 108. Seasonal Fluctuation in Watertables within Sukkur Pilot Project during 1988, Lower Indus Basin, Right Bank.

vague. Moreover, the installation of subsurface drainage is an act to control the watertables, whereas the situation across the Indus alluvials is exactly the converse in that the water levels are intentionally raised for rice plantations. It would only be relevant in areas of less consumptive use crops, such as in the command of the Dadu Canal.

In addition to the manifest requirements for improved drainage necessitated by the cropping system, the canal network itself has interfered with natural drainage lines and has resulted in the formation of extensive internal drainage basins. The areas between Shikarpur and Kandhkot and in the vicinity of Mehar have been particularly affected in this way. Also, the performance of the drainage infrastructure has been questionable in lieu of poor design, construction and maintainance. The calculations for drainable surplus have had to be revised over the initial constructions, e.g. the Larkana Shikarpur surface drainage has been remodeled to accommodate a four-fold increase in design capacity. Such examples stem from the fact that there has been little or no consultation between farmers and the agency vested with drainage works on the typical requirements for drainge. This appears odd given the responsibility of the farmers for field drain construction and maintenance. In practice, field drains are rarely constructed due to the prevailing practice of sequential passover of irrigation flows across contiguous fields.

Management of completed drainage projects and disposal of saline effluent is an issue dealt with separately from the operational aspects of the irrigation network. Often, the distinction between the two is blurred when the effluent is recycled back to the irrigation system. This is typical of the Larkana Shikarpur Surface Drainage Project, where up to 30 percent of the effluent is mostly recycled into the North West Canal, while the remainder is disposed of through the flood protection bund at Miro Khan into the Hamal Lake. Less acceptable, is the practice of pumping saline effluent from the Hairdin drainage scheme into the Kirther Branch (off taking from North West Canal). Water users downstream often complain of the poor canal water quality. Issues such as these result in poor coordination between the irrigation and drainage divisions, especially when excess canal flows are being passed over to the drains. The conventional O&M emphasis is on the operation of the pumping stations; surface drains are difficult to maintain due to lack of regulating structures. In fact, under the circumstances, such a control would be undesirable since it would add to the complexity of operation in the wake of minimal allocations for O&M (typically < 1% of capital cost). This is compounded by the poor initial standard of construction, so that even the optimal maintenance budgets (estimated to be 2% of the capital cost) are insufficient to keep the infrastructure in an acceptable condition.

WAPDA has already prepared a regional development plan, called the Right Bank Master Plan (RBMP), for the development of agriculture, comprising the Lower Indus areas within the Sindh and Baluchistan provinces. The plan is based on studies carried out over a 24-month period between 1989 and 1991 under consultancy services provided by the British Government. This plan is supplemental to the surface and subsurface drainage schemes introduced by the GoP under the recommendations of the LIP, which had been implemented across only 30 percent of the Guddu-Sukkur Right Bank commands.

The coverage area of 1.8 Mha is in the commands of the Guddu and Sukkur barrages and the central feature of the plan is the enlargement and extension of the existing Main Nara Valley Drain (MNVD) (constructed in 1932) to become the Right Bank Outfall Drain (RBOD), mainly for the disposal of excess surface waters from the rice growing areas. Originally, the MNVD was only designed to carry flood flows from the hill torrents via Hamal Lake (then called Mirza Khan Reservoir) to the Manchar Lake (100 km) in the south, but it has now been remodeled to carry agricultural effluents that are discharged from the North Dadu Surface Drainage Project. The RBOD will also provide for the disposal of storm runoff from the hills surrounding the Kachhi Plain and the northern end of Kirthar Range, which collects outside the flood protection *bund* in Hamal Lake, and sub-surface drainage in the saline groundwater areas. For the fresh groundwater areas, lying close to the river, the plan identifies improvements to the operation of the existing tubewell projects and the much-needed encouragement for private sector participation in groundwater exploitation.

The location of RBOD in the context of the existing surface drainage network and related tubewell drainage schemes, is shown in Figure 109. It starts from a point about 13 kms northeast of Jacobabad town and runs west up to the Sindh-Baluchistan border, then along the border up to Kirthar Branch. Southwestwards, it will cross Saifullah Magsi Branch west of Garhi Khairo, and then run south to join the existing MNVD for onward disposal into Manchar Lake. The total length of the drain is about 256 km.

The planning for the drainage component was based on the identification of the 'Drainage Units' shown in Figure 110, which were similar in scope to the Watertable Units cited above in Figure 31. Each of the drainage units represented the planned interventions given the preliminary surface drain layouts prepared for the area. Land use, agriculture, soils, water supply, disposal alternatives and other relevant data formed the basis for all incipient planning at the level of each drainage unit to estimate the drainage benefits from alternative development options. In this respect, the Ratodero Surface Drainage Improvement Project, which is part of the existing Larkana Shikarpur Project, has been selected as the first priority. Ratodero is to be used as a pilot project to evaluate the benefits of drainage and the criteria for drainage development.

Disposal arrangements are a major constraint to further drainage development as there is no suitable natural outfall. Three options are available: recycling in canals, disposal in lakes, and construction of an outfall drain to the river. Recycling has relatively low capital costs, but does entail pumping and is only possible where there is sufficient irrigation water to dilute the effluent (Figure 111). The two lakes have a limited capacity and comprise a sensitive ecosystem. The outfall drain would be very long and high on capital costs. Improved drainage in the head reaches of the North West and Rice canals would shift the priority to the Desert, Begari and Dadu canal commands. Some parts of these commands can be drained by recycling, or pumping directly into the river; the remainder would require construction of the RBOD to as far as Jacobabad. Outfall costs vary greatly, and are highest

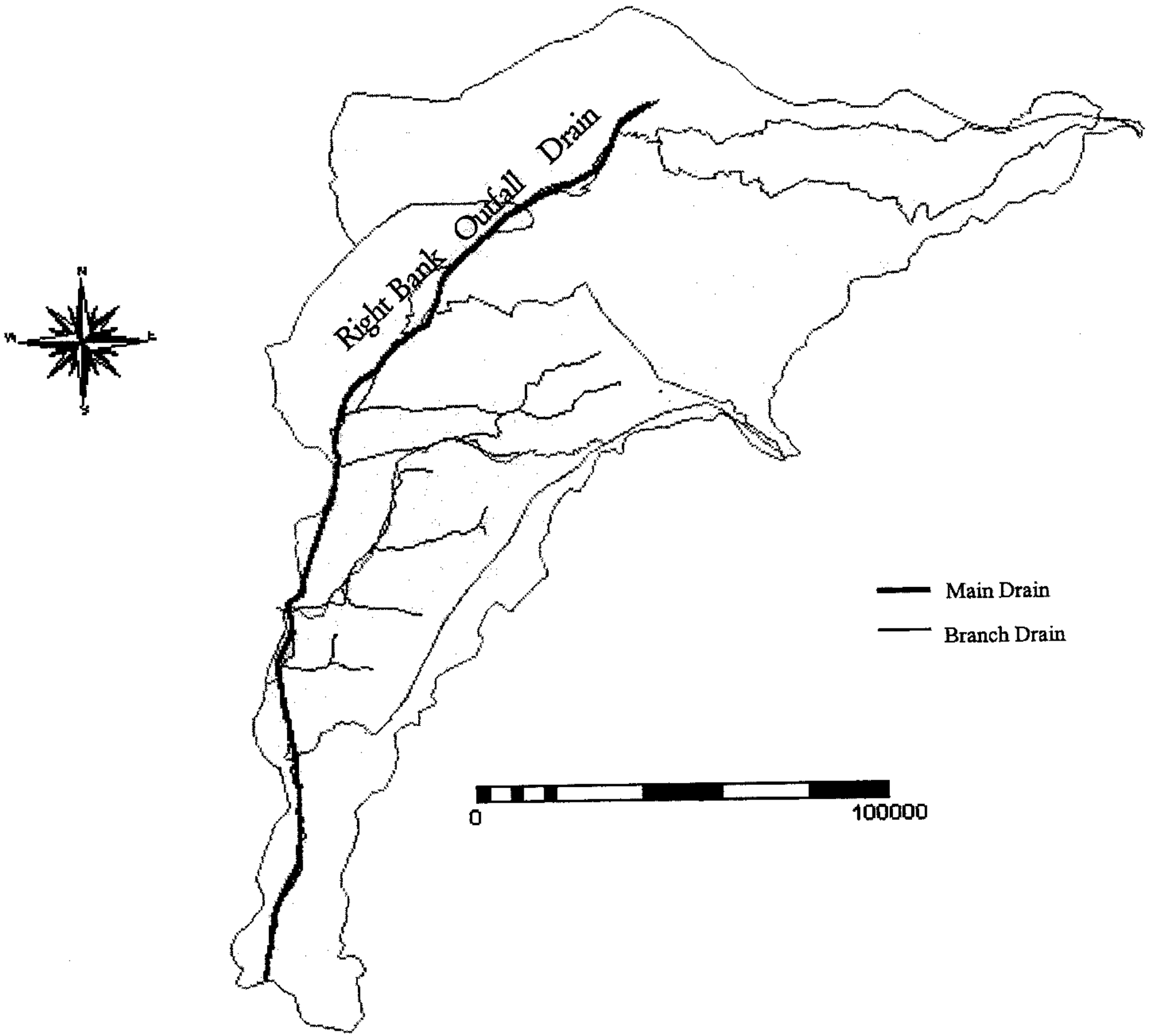


Figure 109 Location of the Right Bank Outfall Drain in the Lower Indus Basin.

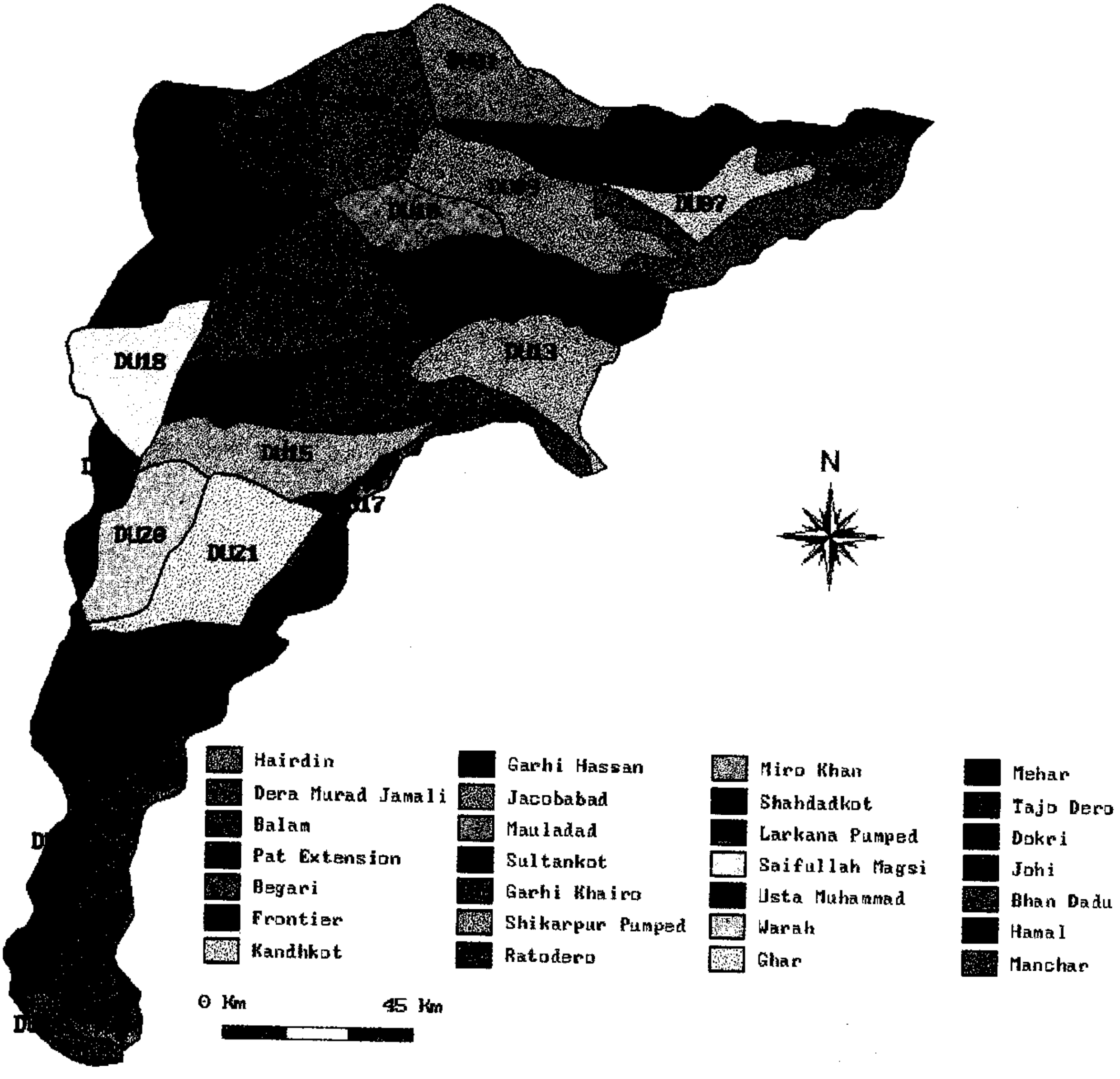
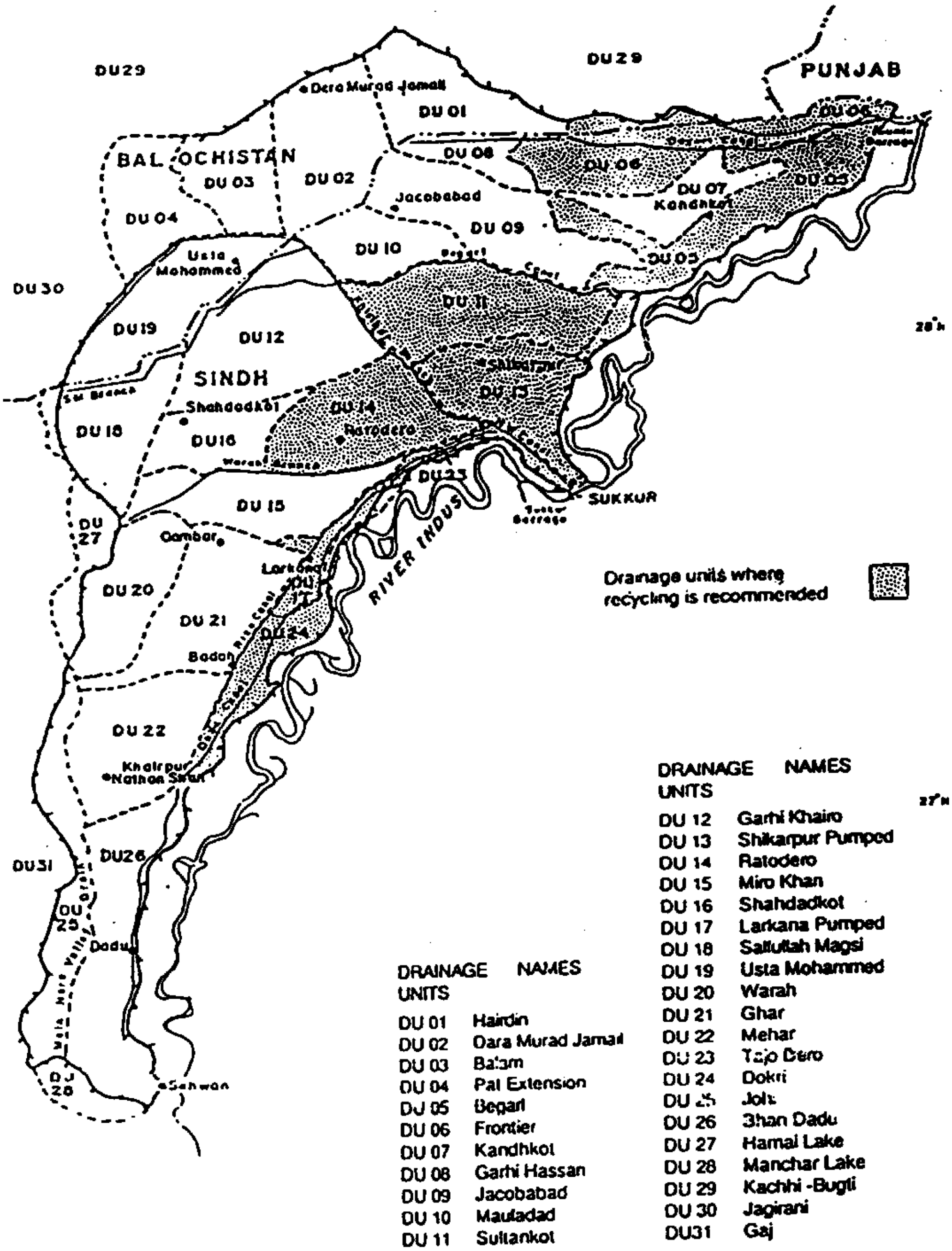


Figure 110. Drainage Units Proposed in the Right Bank Master Plan, Lower Indus Basin.



DRAINAGE UNITS	NAMES
DU 01	Hairdin
DU 02	Oara Murad Jamali
DU 03	Balam
DU 04	Pal Extension
DU 05	Begari
DU 06	Frontier
DU 07	Kandhkot
DU 08	Garhi Hassan
DU 09	Jacobabad
DU 10	Mauladad
DU 11	Sultankot

DRAINAGE UNITS	NAMES
DU 12	Garhi Khairo
DU 13	Shikarpur Pumped
DU 14	Ratodero
DU 15	Miro Khan
DU 16	Shahdadkot
DU 17	Larkana Pumped
DU 18	Saifullah Magsi
DU 19	Usta Mohammed
DU 20	Warah
DU 21	Ghar
DU 22	Mehar
DU 23	Tajo Dero
DU 24	Dokri
DU 25	Johi
DU 26	3han Dadu
DU 27	Hamal Lake
DU 28	Manchar Lake
DU 29	Kachhi -Bugti
DU 30	Jagirani
DU31	Gaj

Figure 111. Drainage Units in the Right Bank Master Plan Study for which Disposal by Recycling in Recommended.

in some of the areas where drainage is most needed. In these cases, the outfall may cost more than twice the local drainage system.

Study Conclusions

The salient conclusions from the RBMP study are:

- Salinity is not a major problem across the alluvials; the area of abandoned land resulting from excessive salinity has not increased over the past 25 years;
- The rise in average watertables has reached an equilibrium since the early 1980s;
- Agricultural output rose significantly between the 1960s and the 1980s. The production of rice increased 4.9 times (80% of the total cropped area), wheat 3.8 times (50% of the total cropped area) and pulses 5 times. Cotton and sugarcane expanded rapidly, but remain minor crops;
- The rice-wheat annual rotation accounts for 30 percent of the farm land. Large volumes of water supplied in Kharif for rice are stored in the aquifer and utilized for Rabi cropping. Use of this stored water by Rabi crops results in a water use efficiency of about 70 percent, with water being lost principally as evapotranspiration from uncultivated lands;
- The rice-wheat cropping pattern is financially attractive and is efficient in terms of water use;
- There is no evidence to suggest a detrimental impact of the rice-wheat cropping in the long term;
- There are substantial inequities in water distribution at every level of the system;
- Existing drainage schemes have been poorly maintained and have not improved drainage significantly;
- There is little scope for expanding the area of cropped land;
- Future interventions should target production increases from small land holders;
- In the absence of planned interventions, an increase in water supplies will result in additional area under rice cultivation;
- There is a tremendous need to improve the awareness of crop water management at the field level in order to achieve a fairer distribution of water;

- Monitoring the land use is essential to offset any long term environmental degradation; and

- Livestock, fisheries and forestry have not developed to the same extent as field crop production since the 1960s, and together account for only 5 percent of the gross value of agricultural output.

The study also identified three key environmental features: land use; water quality in the Indus River; and the wetlands. These were not deemed to constrain development significantly. However, caution needed to be exercized towards the maintainability of predictions over an extended period of time in lieu of recurrent monitoring.

Sustainable Recoveries

The plan has substantial implications for subsequent commitments to recurrent budget expenditures, which could only be met if there are significant changes in the collection of fees for irrigation and drainage services and, possibly, in agricultural taxation. This is rather ambitious in lieu of the past trends in revenue collection (abiana assessments) that are about 50 percent of the yardsticks established by the IPD in terms of the type and number of structures and lengths of canals. This collection reduces to a pitiful 20 percent of what would constitute a reasonable level of O&M expenditure. At present, there is about 50 percent leakage in revenue collection, which is covered by the IPD through under-reporting of the cropped area, and leads to an incorrect apparent high rate of revenue collection. The following is a summary of RBMP estimates on *abiana* (revenue) loss and shortfalls in O&M.
Farmer Payments (1989-90 estimates, million Rupees)

Revenue	
• Actual Abiana Collection	71
• Legitimate Abiana	135
Leakage/extra farmer payments	
• Abiana-related	32
• Unofficial Charges for Extra Water	60
Total payment by farmers	163

Proposed Recurrent Budget

Establishment	137
Irrigation Works	234
Total	371

Budget Shortfall	208

The Plan recommended a 25 percent increase in water charges to cover such deficiencies since the present rates of *abiana* are already low and account for between 2-3 percent of net farm income. Farmers could pay against the recommended increase since their unofficial payments (for augmenting inadequate water supplies) are already much higher than is officially recognized. However, even with this intervention, the gap in revenues and O&M expenses would have remained unrealistically dismal. This would be particularly important in the wake of additional drainage works that would, in the long run, constitute an additional burden on the already low allowances towards O&M.

The yardstick for recoveries through drainage cess is less than for irrigation, and in the present circumstances would only cover 75 percent of the requirements. Effective recoveries are only 30 percent of the target, meaning serious implications for the expansion and improvement of drainage in the area. Typically, the O&M costs for drainage are high because unlike the canals, that could maintain their regime, the drains are not self-maintaining and were originally constructed to poor standards. Moreover, drainage cess, like *abiana*, is based on the cropping rather than the coverage afforded to the CCA.

Benefits

The targeted benefits through the plan, to be realized over 25 years, included an increase in the annual average cultivation intensity from 135 percent to 152 percent; a 58 percent increase in rice production; a 79 percent increase in wheat production, besides major increases in the outputs of oilseeds and sugarcane (Figure 112). The planning for the Project envisaged GoP approval by mid-1992, detailed design by the end of 1993 and contract awards by 1994. Throughout, the priority being to complete or improve the existing schemes, and then to evaluate and quantify the benefits. Construction of existing schemes generally gives a much better return than construction of new projects. Additionally, there is a gestation period involved in the maturity of the O&M recoveries to match targeted benefits for new projects.

VI. CHARTING THE STUDY COURSE--THE INTEGRATED APPROACH

Historically, since 1959, the Water Wing of WAPDA has been the premier government agency vested with the responsibility to conduct country-wide surveys and investigations for the development of land and water resources within the agricultural sector. The planning and investigation studies had an adjunct relationship with the determination and alleviation of the long-term threats to the sustainability of irrigated agriculture through recurrent waterlogginng and salinization. The organization's track record and achievements in irrigation, drainage and investigation of land and water resources (including groundwater)

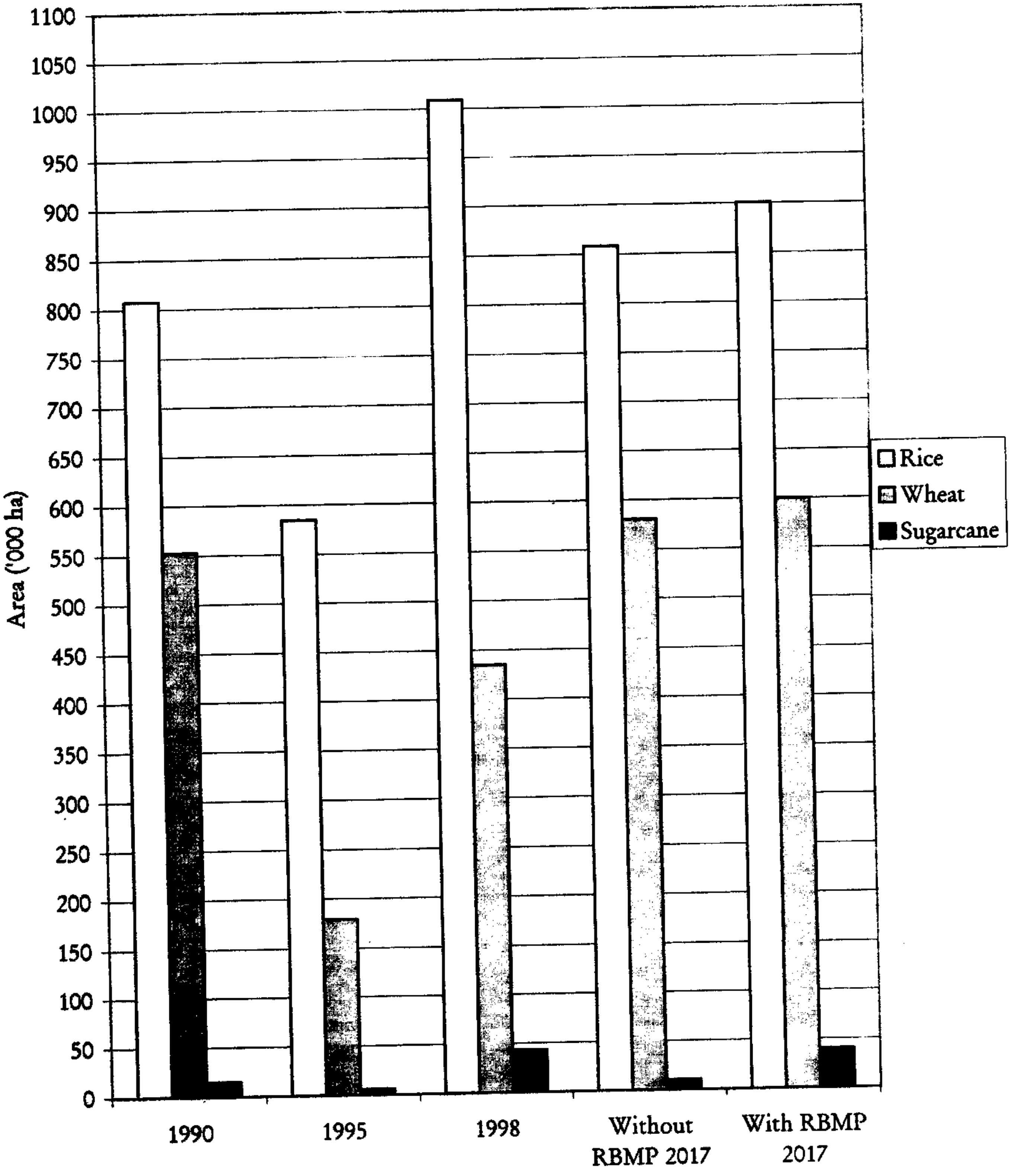


Figure 112. Impact of RBMP on the Expansion of Major Cropped Area.

are enviable. Its Water & Soils Investigation Division(WASID) mainly catered to investigations of land and water resources relating to drainage, whereas the Planning & Investigation (P&I) organization dealt mainly with surface water including basin planning, planning of small dams and irrigation projects, and related investigations. Hydrologic investigations were initiated and hydro-met networks were established in areas of interest.

The most significant activity of the Water Wing had been the implementation of Salinity Control and Reclamation Projects (SCARPs), which is continuing despite a drastic curtailment of GoP fund allocations for new developments. In the process, routine monitoring activities pertaining to measurement of tubewell performance, quality of pumpage, watertable fluctuations and surface drainage flows have also received a setback.

With the disbanding of the WASID and P&I organizations, the survey and investigation facilities in WAPDA have been dispersed and the capabilities that were acquired have largely dissipated. For the foreseeable future, the responsibility has largely shifted to consulting firms that rely on their own limited data collection campaigns that are exclusive to projects. There is a need to take stock of the situation and find ways and means to implement such service units that are capable of supplanting basin-scale studies.

For basin-wide studies, reconnaissance level surveys are an absolute necessity. The continuing increase in population pressures only promote land fragmentation (more than 38% under 5 ha of holding) that directly stress farm level productivity. Thus, it is important that these stock-taking surveys are conducted at frequent intervals as an aid to improved and automated handling of data on the quality of land and water resources for strategic and concurrent policy making. Analysis of the extent of debilitation caused by waterlogging and salinity would then constitute a rational cornerstone to much of the story on impact assessment.

There is considerable controversy over the actual extent and modern trend of waterlogging and salinity. Two factors are responsible for the controversy: first, the relevant information is inadequate, inconsistent, and subject to different interpretations; and second, large capital and O&M costs have politicized the issue. In the late 1970s, some authorities claimed as much as 50 percent of the canal irrigated areas of the country had a watertable of less than 3 m and, thus, was waterlogged, or potentially waterlogged, and as much as a third of the country's irrigated land was strongly saline or sodic (Malik, 1978; Lowdermilk et al. 1978). According to data published by Hussain (1970) and Rafiq (1975), never more than 0.6 percent of the CCA was severely waterlogged in Pakistan. There are very small areas, not more than 0.4 Mha in the Indus Plains, where crop yields are affected by a perched watertable. Of this, only a small proportion is severely affected.

Public sector undertakings at the national level to assess the magnitude of both surface and profile salinity have been conducted far apart, and, depending upon the agency involved, difficult to correlate. The Indus Basin salinity survey by WAPDA during 1976-79 provides comparative figures with the earlier investigations dating back to the mid-fifties. Apart from the intervening changes in the qualitative extent of salinity across more than two decades of reference and adequacy of sampling, the indications are that soil salinity is dissipating across all levels of soil classification. Since no integrated assessments on soil salinization have been made beyond the 1977-79 Revised Action Program (RAP) survey by WAPDA, it is possible that these figures are no longer a potent reference of changes to soil salinization. In fact, in the period since, there has been an increase in groundwater pumpage (courtesy commissioning of several public sector tubewell SCARPs with concommitant stimuli for private sector tubewell installations) in areas where groundwater TDS < 1500 ppm was classified as usable. In actual practice, the lack of recurrent monitoring of groundwater quality may not have been able to substantiate the degradation over time. While the estimates on the quantum of salts retained in the root zone may most likely be conjecture, the broader reliance on soil chemistry would dictate a situation that would threaten the gains made through soil reclamation in the past.

In addition to salinity, the root zone suffocation caused by high watertables across the irrigated landscape has been a persistent problem, though not as acute as in the past. In fact, the past reclamation schemes had the removal of high watertables as their primary objective. The GoP continues to reckon that watertables < 1 meter in irrigated regimes are disaster areas requiring concentrated efforts. However, in the absence of a strong support for O&M, the indications are that the operational life of many of the vertical and surface drainage projects may be much less than planned.

Much of the focus on management and capital intensive projects in recent years has been anchored to the recommendations brought forth by the RAP, the prioritized enunciations of the succesive Five Year Plans since 1983, and the selective appraisal of public projects by the WSIP. The targeted redemptions in agricultural growth rates put forward by the NCA, cognizant of the bulging population, have been the catharsis for prioritized ranking of many public sector projects at the federal and provincial levels. However, at best, these investments would secure the ***mechanisms*** needed to enhance productivity, but would stop short of the ***optimizations*** coincident with variable growth rates and selective resource mobilizations that are invariably scale-specific.

The geographical size of the Lower Indus Basin does not favor piecemeal approaches to resource optimization. The initial returns from SCARPs were encouraging in that not only did they reverse land degradation, but also augmented available irrigation supplies. Without ambient O&M relief, their performance has staggered to a point where the past project-wise distinctions of returns to scale have blurred to represent a new balance in irrigated agriculture. And since water is the primary input and constraint to any furthering of the gains thereof, consideration of the strategic options must take into account the current ranking of the land use and the most likely scenario for its sustained growth.

It was against this backdrop of past reclamation and investment strategies that IIMI undertook the impartial, but arduous, appraisal of the irrigated landscape across the Sindh canal commands to establish the new benchmark in resourcefulness and productive realizations, based on a combination of physical and farm level surveys. The integrated assessment aimed to:

- develop a strategy to maintain favorable surface and groundwater balances with concurrent recommendations on changes to the existing pattern of cropping and the rate of intensification of agriculture;
- model the returns to scale and production enhancements amidst the threat of land degradation; and
- predict the likely impact on cropping patterns in lieu of the augmentation of surface and groundwater supplies.

The above assemblage derives much of the inference from the past investigations into the physical and qualitative details within the Lower Indus Basin. All spatial information for this database was conceived within a geographic information system where terminal referencing for all aggregations and comparisons was at the level of the canal command. In fact, this spatial enunciation lends itself to be the fundamental building block of the assignment undertaken by IIMI. Subsequent to this stratification in space, the procedural steps for information processing were defined for each of the components of the study, as explained below.

A. Spatial Component

Across the overwhelming expanse of the irrigated regime within the Sindh Province, the collection of primary data on the physical and farming peculiarities necessitated a sampling strategy that would optimize on time and scope of coverage. From the very outset, it was felt that this task would be unrealistic to acomplish in the absence of precise maps for geographical reference of the sample areas. An updated coverage of the communications network and assessment of the physical condition of the land (to satisfy sampling criteria) was not available from any source. Accordingly, satellite image coverage, corresponding to a very high degree of spatial resolution of 6 meters, was purchased from the Indian Remote Center at Hyderabad. The footprint of this coverage, corresponding to the Rabi seasons for 1996-97 and 1997-98, is shown superimposed on the canal command delimitation in Figure 113. A total of 18 IRS-1C satellite panchromatic scenes and subscenes were utilized for delimitation of sample areas (of size 1-2 sq. km) across productive farming regimes. For each enclosed sample area, access was clearly identified to a village nearby. The base map, prepared from onscreen digitizing, consisted of the communication network (for accessibility), hydrological network, extent of wastelands (Figure 114), distinction of the cultivated areas and location of population settlements. The map registration and coordinate referencing for the datum was based on the metric grid referencing of the Survey of Pakistan using the Lambert Conformal Conic Projection. All other sources of secondary mapped inputs were also registered to this referencing feature. The boundaries of the main

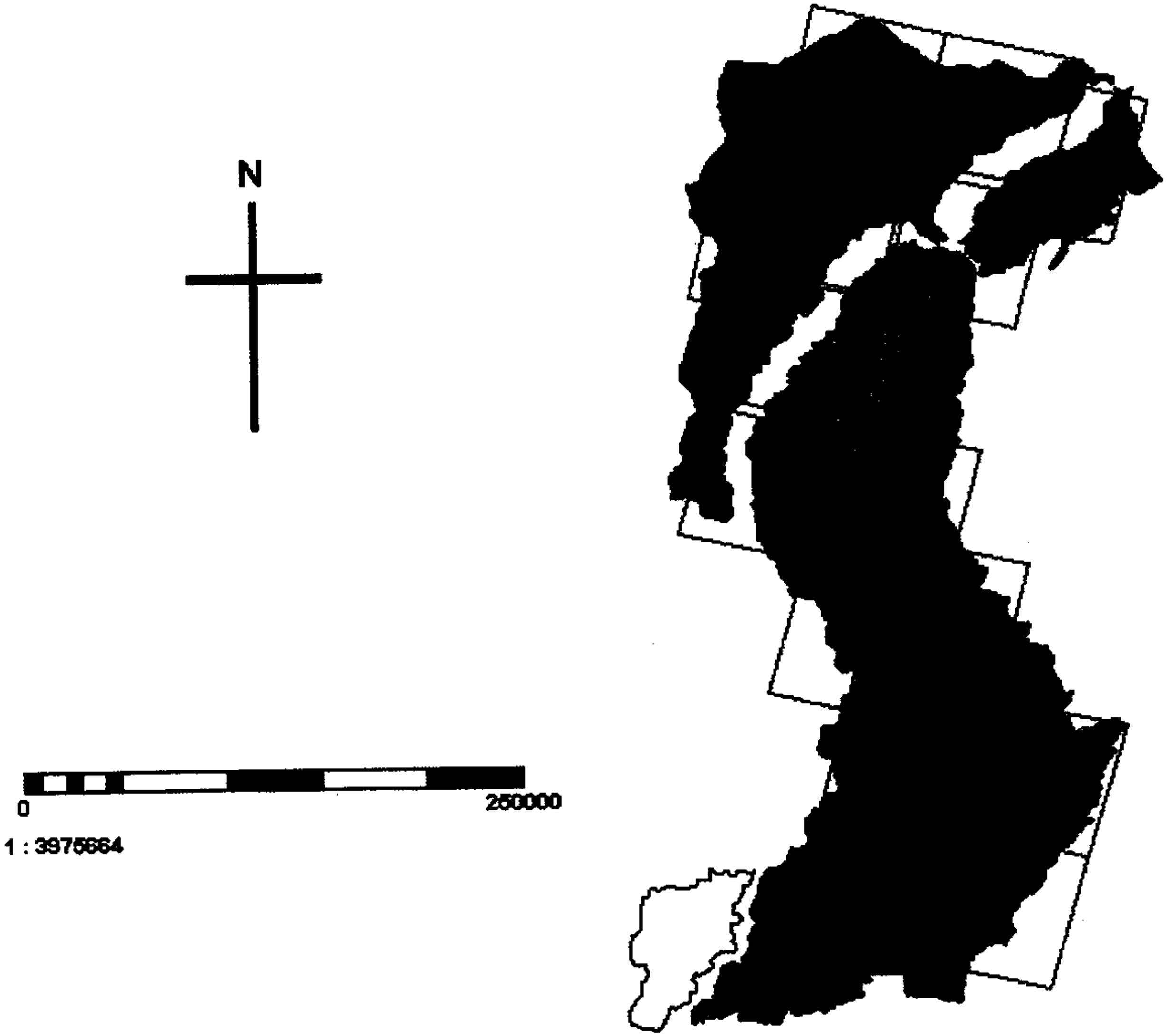


Figure 113. Satellite Image Coverage of IRS-1C Data for the Lower Indus Basin.

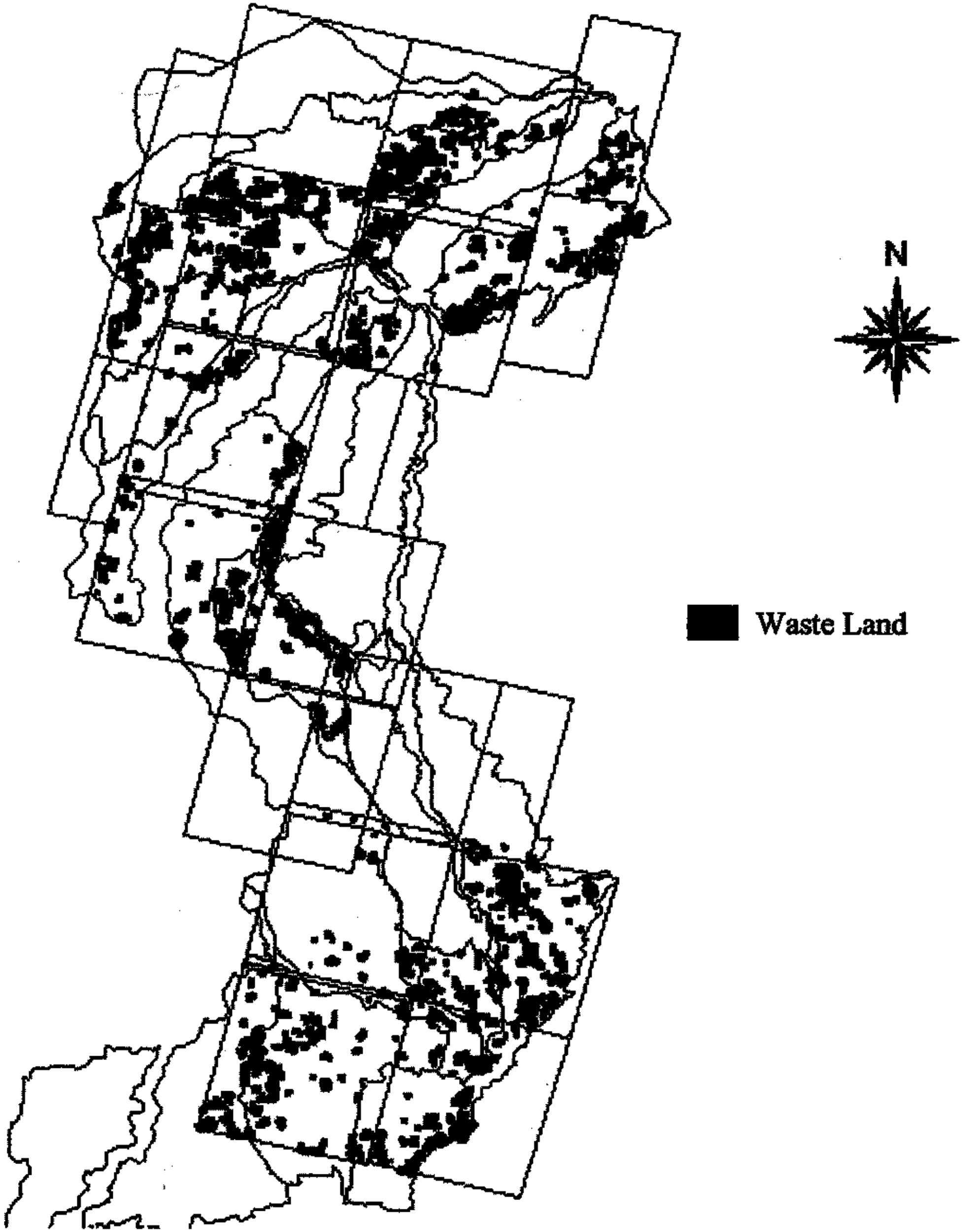


Figure 114. Distribution of Wasteland Interpretations for the IRS-1C Panchromatic Satellite Image Data for the Lower Indus Basin, 1997-98.

canal commands were used to resample all information, including the incidence of wastelands, soils, groundwater quality, watertable depths and land suitability assessments. The individual canal commands, thus, served as the primary unit of reference for all statistics pertaining to the physical and agroeconomic characterization of the land.

The importance of this common stratification in space is not lost in the context of the area-specific application of the functional forms to ascertain production and profit from sample farmholdings. Similarly, for the Indus Basin Model Revised (IBMR), simulation of surface flows corresponded with the principal canals based on a select criteria for water allocation and concommitant changes in cropping patterns.

B. Economics Component

Based on the sample area delimitations specified above, hired enumerators were provided with reference maps to gain access to the respective villages with an even geographic distribution. Each sample area was coded with reference to its occurrence within the respective canal command. The farm level interviews commenced in early December of 1997 and were completed by the end of May the following year. For the same sample areas, concurrent assessment of the soil textures, salinity/sodicity assessment, and augured depth to watertable were also separately performed as the physical counterpart of the pooled information on agroeconomic evaluation of the land. Upon completion of these surveys, historic data on the physical characteristics of each canal command was tallied to the sample information *vis-a-vis* the major crop/land use intensities, incidence of culturable waste, and the quantum of investments and returns.

For each hydrological divide, subsampling of the farmer population was conducted for geographical overlap with prevailing land suitability rankings to facilitate the generation of production functions. When multiplied with the respective area under each suitability ranking, an aggregate assessment was obtained for the current production potential of the land for major crops. Macro-economic assessments, provided in Volume II of this report, include:

- proportion of the farming classes affected by the resource deficiencies and the resultant shortfalls in resource capitalization;
- specific interventions for the farm based on land suitability categorizations;
- crop-specific production potentials with the accompaniments of net profitability; and
- recommendations for extensions to irrigated agriculture to overcome inefficiencies in low cropping intensities and culturable waste areas.

In order to simulate the dynamics of the changes brought about in the conventional cropping patterns and the concurrent impact on the farm level investments and returns, a visual simulation model was prepared in Visual Basic programming. This dynamic model, comprising the basic physical and economic characteristics of a canal command, simulated in real time the economic viability of such changes to the existing cropping pattern that encourage equitable distribution of surface supplies and maximize on-farm returns. The dynamic linkages in cropped and fallow areas, prices of outputs, costs of inputs and extents of commanded regimes were meant to facilitate the concurrent impact assessment of the implied use of multiples of production functions specific to a canal command. Initially, this model, capable of being generated as an executable file, was tested for one of the major canals on the Left Bank.

C. Surface Water Management Component

The existing surface water management practices for a major cropping system on the Right Bank of the Indus River have been the focal point of this component. The rice-wheat cropping system was chosen because of its homogeneously implied coverage across 1.56 Mha of the commanded area falling under the Sukkur and Guddu barrages. Except for the North West and Dadu canals, the remainder of the canal commands within the system show Kharif water surpluses; this situation is reversed during the dry Rabi season. It is during the plentiful season of Kharif that much of the mismanagement occurs in the distribution and timely availability of surface irrigation supplies. This component adopts a two-pronged strategy in arriving at plausible management interventions. The first of these, described as a situationer under Supplement I.A, identifies improved water management practices from published literature, both from within and outside the country. The aim was to suggest potential strategies to minimize drainage in high consumptive use environments. It takes cognizance of the prevailing environmental constraints of soil salinity/sodicity, waterlogging, irrigation supplies and inadequate drainage to obtain optimum yields of rice and wheat on a sustained basis.

The improved irrigation and drainage practices identified for the Sindh Province at the system level include irrigation water delivery accountability, management decision support system, irrigation management information system, performance indicators, farmer participation, reuse of drainage effluent and physical rehabilitation. The farm level water management interventions are geared towards a non-degrading environment borne out of water-saving procedures, irrigation scheduling, on-farm drainage, rice transplantation methods, discontinuation of the *pancho* system, land leveling, improved layout of irrigation ditches and fields, and farmers' awareness of land reclamation.

In the second study, the scope of these findings was extended by field investigations involving on-site observation of irrigation practices and farmer interviews across the Warah Branch system, the southern-most offtake from the North West Canal (Figure 115). For this system, located in the heart of the Sindh Province rice-wheat zone, the farm area sampling was biased towards irrigation and drainage concerns. Figure 116 shows the locations of over 160 sample sites within the Warah Branch command that were marked from the IRS-1C panchromatic satellite image coverage for the period 1996-97. An exhaustive questionnaire was developed that addressed issues pertaining to the efficacy of existing drainage, adequacy

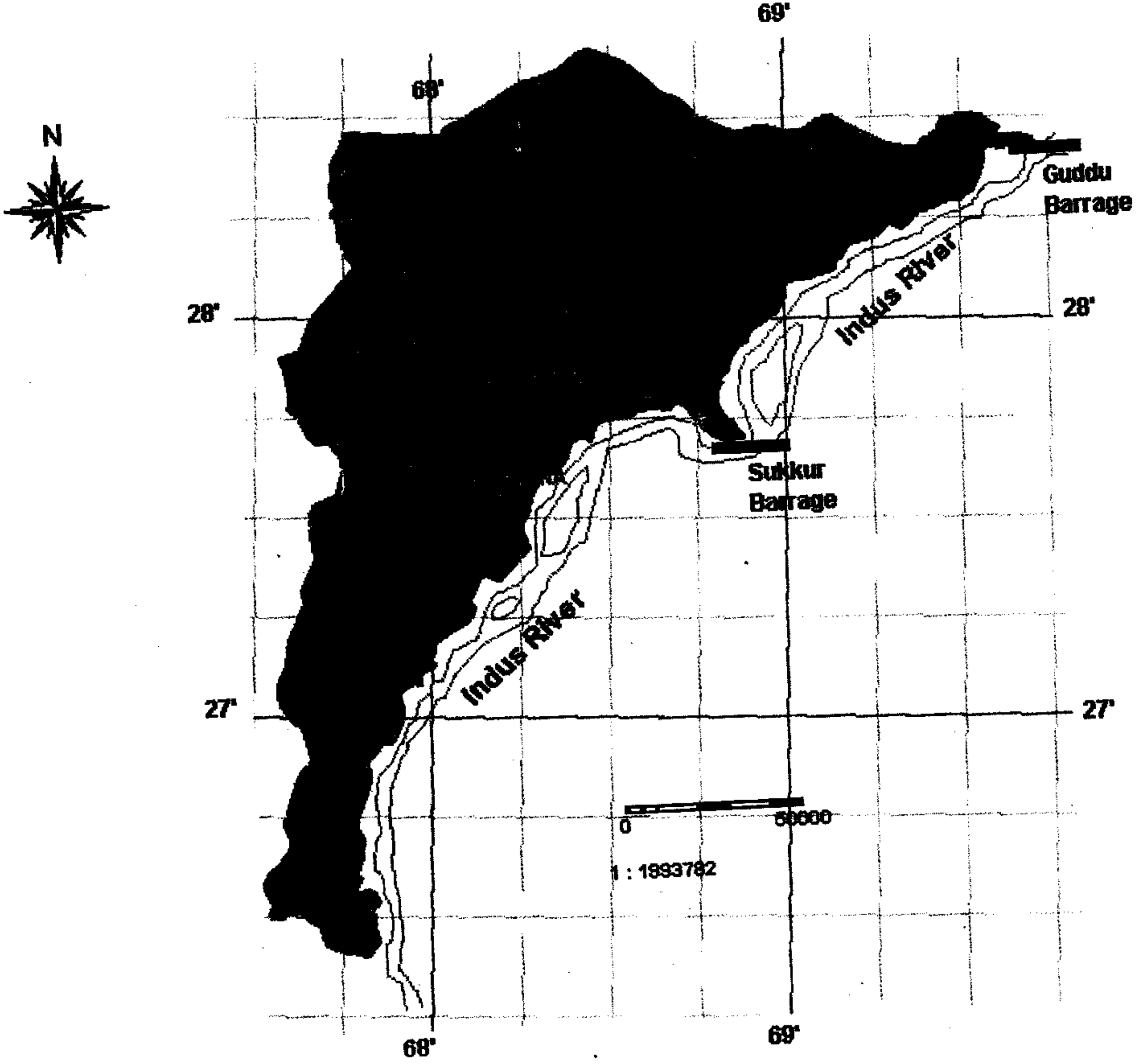


Figure 115. Location of Warah Branch Canal Command, Right Bank, Lower Indus Basin.

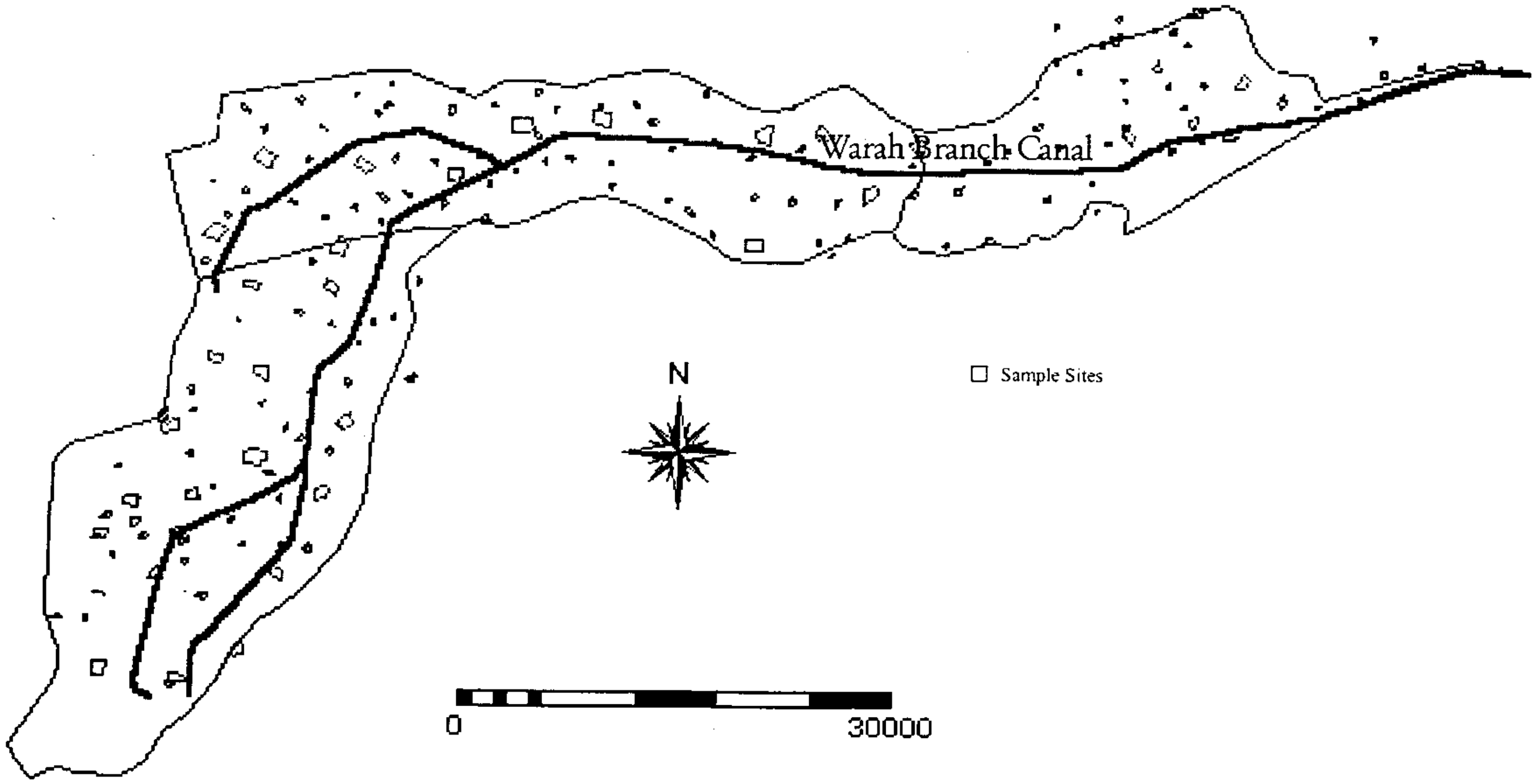


Figure 116. Location of Sample Sites within Warah Branch Canal Command

and timely availability of irrigation supplies, returns on investments, and long term changes in the productivity status of the land. The sampling coincided with the land preparation and transplanting period of the rice crop and was completed over a period of 45 days ending in late June, 1998. A complete discourse on the operational and maintenance situation that prevails within the system, together with the recommended scope of management interventions, appears under Supplement I.B of this report.

D. Groundwater Hydrology Component

Details in the preceding section on Public Sector Projects has already shown that the major thrust of the past land reclamation schemes has been directed towards attenuation of the groundwater recharge imbalance brought about by the increase in area devoted to high delta crops. In areas where FGW zones could be exploited, part of the recharge has been recycled back into irrigation use. Elsewhere, selected areas have benefited from an installed network of surface drains to remove drainage waters, some of it pumped directly into drains. Almost the entire Lower Indus Right Bank is being drained in this manner, whereas areas in the command of the LBOD have started to benefit fairly recently.

Subsequent to the extensive physical investigations carried out for this project, there is also published archives on operational aspects to include tubewell-related discharge rates, seasonally monitored watertable hydrographs, quality of groundwater with depth and other aquifer characteristics that were deemed sufficient towards an applied use of a groundwater balance model. The Nawabshah component of the LBOD Project was chosen for simulated assessment of the groundwater balance to the year 2010 using the MODFLOW software model. This software allowed the generation of hydrographs of watertable depths corresponding to pre-determined rates of pumpage local to each 4 sq. km cell of a gridded reference covering the entire component. Simulation results, described under Supplement I.C, target selected scenarios for watertable control in terms of variations in discharge rates that are heterogeneously distributed across the Nawabshah area. The geographical distribution of these variations is the key to the determination of what constitutes the minimum drainage requirements in lieu of reduced subsurface water levels and the resultant quality of this drainage into the system of surface drains.

E. Impact Assessment Component

This component, realized as part of a Masters' level academic research by three students, drew upon comparative physical evaluation of the irrigated regime within the command of the Left Bank Outfall Drain Project in the Lower Indus Basin Plain (Figure 117). Nearly completed, this project represents one of the most ambitious public sector drainage-related investments in the world. Coincident with the construction-, operation- and maintenance-related activities of the project, a significant mass of data was collected on the physical monitoring of the system that could facilitate progressive evaluation of the tangible, and for

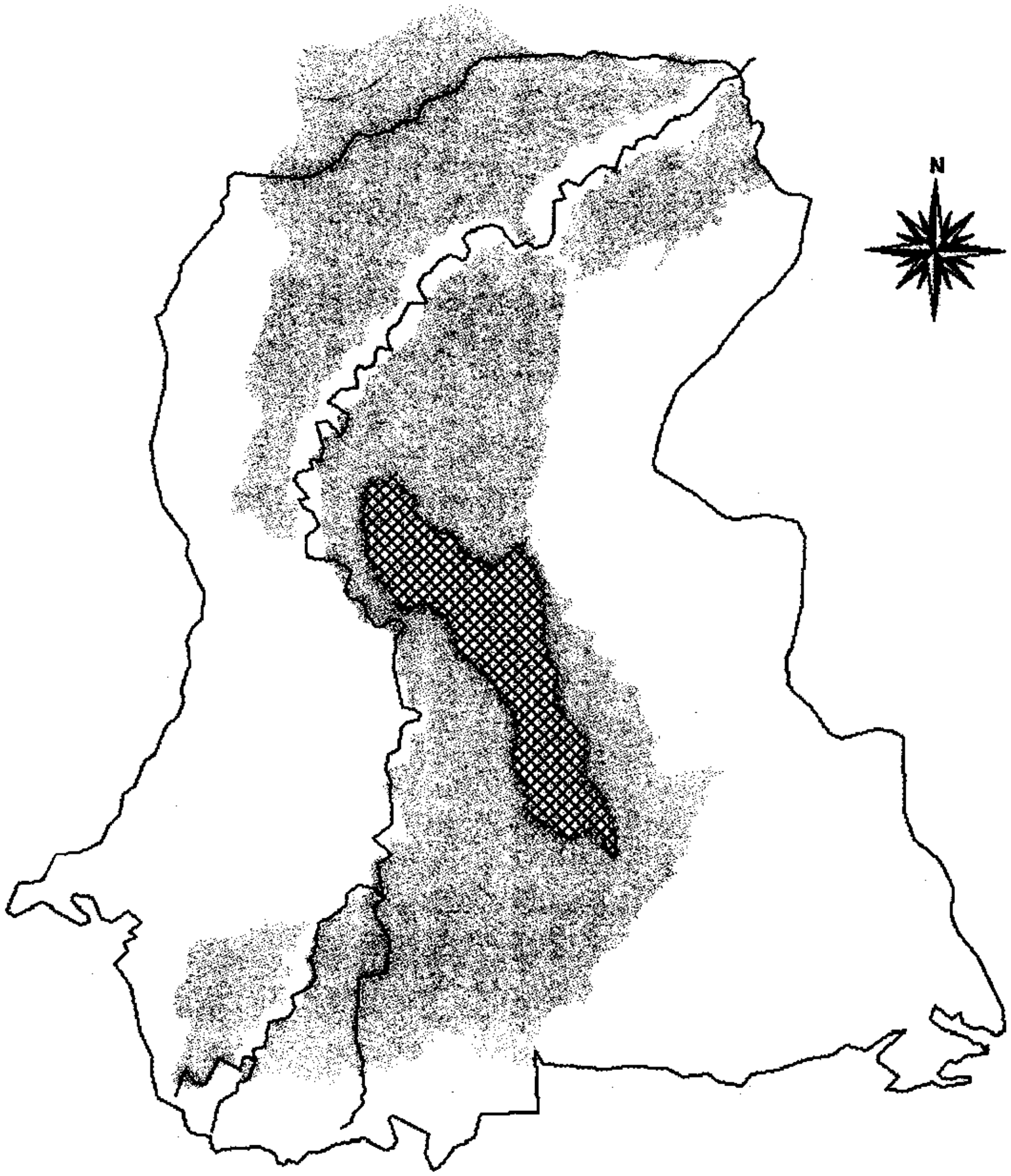


Figure 117. Location of the Left Bank Outfall Drain Project in the Sindh Province, Pakistan.

the purpose of this study, visible benefits accruing from the project. The premise is that additions to cultivated areas and suppression of stressed land margins are major indicators of incipient stimuli for progressive improvement being brought about by the drainageworks. These physical changes bear direct relevance to the overall production potential of the land for which public sector data sets on soil salinization, watertable fluctuations, groundwater quality and topographic relief were identified to allow for a spatial comparison with the emergent situation. The assessment dwells separately on each of the three districts of Nawabshah, Sanghar and Mirpurkhas, for which integrated spatial analyses have been made through the use of a geographical information system (GIS). Most recent updates to the physical condition of the land were facilitated through interpretation of the IRS-1C images of 1997 and were benchmarked against respective surveys by both WAPDA and the Soil Survey of Pakistan. The results are described in Supplement I.D of this report.

F. Water Balance Component

The current demands on water availability imposed by the high consumptive use cropping in the Sindh Province has acutely stressed the carrying capacity of the canal system. Available data in Annexes-I & II has shown that peak Kharif season flows are almost always at or above full supply levels. This operational stress is matched with equal vigor in the retrogressive gap between periods of imminent demand and supply. IIMI's past research in this inequity of distribution of irrigation supplies is well documented across all levels of the system divide; now, the concurrent emphasis should be on practical and realistic management level interventions that account for ensuring both production-oriented gains and long term sustainability of the system. In this respect, most critical is the issue of reallocation of surface supplies and whether it would be feasible given the current physical constraints in the system. The decisions in this respect largely pertain to the anticipated water stress in different parts of the irrigated regime vis-a-vis the cropping pattern. Changes in the cropping pattern may be needed to offset the timings of the root zone water requirements.

Towards an implementation strategy that invokes changes to the cropping pattern to best suit crop water requirements and simultaneously maintain favorable surface and groundwater balances, the Indus Basin Model Revised, developed by the World Bank for WAPDA, has been used in this study. The model was originally used as part of the planning for the Water Sector Investment Plan (WSIP) report around the end of the last decade; for the purpose of this study it has been adapted to the canal commands of the Sindh Province using the latest figures on crop production and surface water allocations for the period 1995-96. The simulation plan targets the year 2010 for implied rates of growth in cropped area and yields that closely match the ones observed during the IIMI farm level surveys of the productive tracts during 1997-98. In other words, the currently productive status of farming has been set as the target for the entire irrigated area of the Sindh Province leading to the year 2010. The iterative nature of the solutions on both surface and groundwater balances was achieved through adjustments to the crop area growth rates, especially for the high delta crops. The stress remains on the alternative cropping patterns, or perhaps the most judicious distribution of the same in lieu of the physical constraints specific to a canal command.

The results, produced under Volume III of this report, have been compared, for the same targeted growth rates, against two other options that emphasize canal lining in SGW areas and the more sumptuous water availability promised by the Water Apportionment Accord. The interpretations have to be seen in the context of overall production gains, expansion of the cropped area, water surplus at the root zone and, most importantly, the groundwater balance. Follow-ups to this study could include the estimation of the optimum potential for crop production specific to each canal command in the context of available fallow and culturable wastes that could benefit from the redistribution of irrigation supplies.

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