INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE - PAKISTAN

TENTH PROGRESS REPORT

ON

MANAGING IRRIGATION SYSTEMS

TO

MINIMIZE WATERLOGGING AND SALINITY PROBLEMS

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TENTH AND FINAL PROGRESS REPORT

1. INTRODUCTION

This report summarizes progress at IIMI Pakistan on the research project Managing Irrigation Systems to Minimize Waterlogging and Salinity Problems for the last and final half yearly period, July 1, 1993 - December 31, 1993. In addition, the report contains a summation of key project findings and results that have been achieved.

Throughout the half year period covered by this report, primary emphasis was given to (1) management interventions intended to improve canal system operations, *(2)* the continuing analysis and interpretation of data sets obtained through primary field-based and secondary data co lection activities earlier in the project, and (3) the write-up and reporting of research results.

IIMI's work with managemerit interventions to improve canal system operations continued in collaboration with the Punjab Irrigation Department at established research locales in the command areas of the Upper and Lower Gugera Branch Canal of the Lower Chenab Canal (LCC) system in central Punjab and of the Fordwah - Eastern Sadiqia Canal (FES) system in southeastern Punjab. The bulk of this work was closed at the end of the Project in December, 1993. A significant exception to that closure, however, is the continuation of the Irrigation Management Information System decision support activity in Chishtian Sub-division, FES, through modest core research support from IIMI's Research Division.

Field research activities were continued in these same locales until the closure of IIMI's field station in Farooqabad and field offices in Mananwala and Kamalia on November 1, 1993. Notable among those activities was the completion of the 1993 *kharif* season survey of ***warabandi*** operations in selected watercourse commands 6 distributaries in the LCC and FES systems. Otherwise, primary data collection was concerned with monitoring irrigated agriculture and salinity conditions at established research sites.

Throughout the second half of 1993, analysis and interpretation of research data was actively supported by geographic information system (GIS) applications using ILWIS. Collaborating national research institutions also were increasingly

frequent requestors of assistance from IIMI's GIS facility. Several GIS products completed during the reporting period are included in this progress report.

Several special studies complementing or directly related to the objectives of the overall project were completed during the period under review. They and other research findings were the subjects of several research and discussion papers authored by IIMI's professional research staff. Abstracts of these papers have been annexed to the body of this progress report.

The analysis and interpretation of salinity-related agro-hydrologic data was also assisted by two consultancies to IIMI Pakistan undertaken by specialists from ILRI and Wageningen Agricultural University. Their recommendations have been especially helpful in planning for the next phase of irrigation and salinity management research; a summary of those recommendations has been included in the full report.

The draft Five Year Plan for IIMI Pakistan, noted in the Ninth Progress Report, was completed and widely circulated to national agencies and collaborating research institutions for review and comment. The draft Plan also was discussed extensively at the national IIMI Consultative Committee meeting held in Islamabad in October, 1993. Subsequently a revised and modified Five Year Plan for IIMI Pakistan has been completed.

2. RESEARCH PROGRESS: FINDINGS AND RESULTS

2.1 Management Interventions

Over the final two years of the Project, IIMI has given primary emphasis to the joint implementation with the Punjab Irrigation Department of agreed management interventions intended to improve canal system performance, thereby enhancing both agency and farmer capacity to manage irrigation resources in ways that will reduce or minimize the risk of further salinity. The management interventions that have been underway--in some cases for a year or more--have focused substantially upon reducing or eliminating information constraints on making more timely and effective irrigation management decisions. Progress has been slow but promising.

The willingness of many PID field operations staff in different locales to participate actively in these intervention activities and to assist IIMI research and monitoring components designed to support the interventions without monetary or other incentives is strong evidence of a more widespread recognition that system management must be improved if operational objectives are to be achieved. The absence of consensus about the kinds of institutional changes that are necessary is perhaps more indicative of the PID's position at a still early stage in the change process than it is a negation of the necessity of improving system operations and management. That adoption and internalization of these management interventions is not faster also reflects the negative impact of shorter field tenures and more rapid turnover of staff in operational positions. This and similar institutional constraints are likely to be the focus of further "action" research by IIMI in the next phase of the salinity project.

Progress with the IIMI-PID management interventions underway during the present reporting period is described in greater detail under separate sub-headings below.

2.1.1 Irriaation Manaaement Information Svstem (IMIS)

The pilot intervention initiated by IIMI in collaboration with the Punjab ID in Chishtian sub-division of the Fordwah canal system to improve the quality and quantity of information for irrigation system management was strengthened during the reporting period. The installation *of* an Irrigation Management Information System (IMIS), begun in April, 1993, has been successfully completed. The process consisted of the following components: (1) the development of a reliable field data collection network operated by ID personnel, (2) the establishment of an effective

communication system to ensure timely flows of management data and information between the field and the system manager, (3) the collecting, processing, and display of field data showing current system status.

Installation of the IMIS was implemented through a participatory approach which promises greater likelihood that the innovation will be sustained for the long term, although the rapidity of implementation is slower. The implementation process is documented in the report by Mr. Nicolas Riviere, an IIMI MSc Research Scholar from France, "Introduction of a Management Information System at the Main Canal Level - A Study in the Chishtian Sub-Division, Fordwah/Eastern Sadiqia Area, Punjab, Pakistan." A summary of this report is attached as Annex 1.

Previous IIMI studies during the diagnostic phase in Chishtian sub-division confirmed that the existing pattern of canal water distribution was unsatisfactory. In the next 'action' phase of this intervention, the information provided to and processed by the irrigation agency at the sub-division level will be used by the system manager to support water delivery decisions and actions. The expected result is an improvement in canal water distribution performance which can be readily assessed by comparing the difference between specified operational targets, and measured deliveries. Improving canal system performance to better match stated operational objectives, of course, is central to this project insofar as better overall farmer access to high quality irrigation water enhances opportunities to minimize the impacts of salinity on irrigated agriculture.

The pilot IMIS intervention described here is based upon a more generic model conceptualizing the transfer and adoption of management information systems (MIS) by irrigation agencies. This model postulates an initial or pilot testing of a MIS intervention following a thorough diagnostic phase. Subsequently, if the pilot testing phase is successful, the MIS, typically one of several components of a more comprehensive decision support system (DSS), will become internalized by the agency and more widely used. An agency capacity to carry out both diagnosis and pilot interventions elsewhere is an important element in this last phase.

This generic model is currently being tested by IIMI in both Sri Lanka and Pakistan. In Sri Lanka where the work began in the late 1980s, the pilot intervention stage has been successfully completed in the Kirindi Oya system. The Sri Lanka Irrigation Department now has decided to install IMIS in five other irrigation systems, marking the first step in implementing the management information system internalization phase. In Pakistan, IIMI's effort remains focused upon the pilot intervention stage which has only just gotten underway.

During the reporting period, a comparative analysis of the experience and results thus far achieved in Sri Lanka and Pakistan in establishing a MIS at the irrigation system field operations level was completed. The results of this study were reported in a research paper jointly authored by Jacques Rey, Marcel Kuper and Manju Hemakumara, '*Setting-Up an Information System at the Main Canal Level: Participatory Approach in Sri Lanka and Pakistan," presented at IIMI's annual Internal Program Review held in late 1993. An abstract of this paper is given in Annex 2.

An exchange of information management system experiences took place in a IMIS Network Meeting on "Information Techniques for Improving the Water Management in Irrigation Schemes," held December 6-10, 1993 in Colombo, Sri Lanka. IIMI researchers and irrigation system managers from Sri Lanka, Pakistan and Mexico participated in this first network meeting. The pilot IMIS activity underway in Chishtian sub-division was described and reviewed during the meeting. The potential of decision support systems for improving system management at the main canal level was demonstrated in a field visit organized for the network meeting to the Kirindi Oya system where IMIS has been pilot tested. Unfortunately, invited Pakistani system managers from the Fordwah/Eastern Sadiqia area were ultimately unable to participate in this initial Network Meeting as a consequence of administrative reasons internal to the Punjab Provincial Government. Substantive issues discussed in organized sessions are reported in the IMIS Network Meeting proceedings.

2.1.2 Improving Irrigation System Delivery Accountability

The collaboration between the Punjab Irrigation Department and IIMI in Lower Gugera and Burala divisions of East Circle, LCC, on the management intervention to improve irrigation system delivery accountability was completed during the last half of 1993. A parallel program also had been implemented in Chishtian sub-division, FES, and this work, described more fully above under 2.1.1, is continuing.

At the heart of this management intervention activity was the systematic calibration of control structures in the main and secondary canals and the preparation of up-dated rating tables for these locations for use by canal staff in their regulation duties. Agency field staff were trained to carry out the necessary discharge measurements and subsequently these personnel implemented the measurement program with modest IIMI supervisory inputs. This approach was consistent with the objective of facilitating the mobilization of agency resources to improve irrigation system management rather than providing substitute resources.

The results of the activity have been documented and summarized in a report presented at IIMI's 1993 Internal Program Review, "Improving Canal System

Management: An Intervention to Calibrate Control Structures in Punjab, Pakistan," prepared by Bagh Ali Shahid, Marcel Kuper and Edward J. Vander Velde. An abstract of the paper is included in this repcrt as Annex 3. The following key conclusions and recommendations have emerged from the work on this management intervention:

- Existing PID rating tables for control structures along main and secondary canals are outdated or simply not present for most if not all Punjab systems. If water delivery objectives are to be met, a program for developing discharge tables or rating curves is needed where they are missing, as well as for regular, systematic review and up-dating wherever they are present.
- Only control structures at the head of secondary canals are regularly monitored by the PID. There is a genuine need to monitor conditions at selected points within distributaries if canal operations are to be made more efficient and effective. Assessment and feedback processes also need to be established so that collected monitoring data are used in operations and management.

- Structure dimensions are often different from official records. Dimensions "as built" should be determined and recorded. The best time for systematically checking structure dimensions is the annual closure period. Also the present location of many gauges impedes reliable discharge estimates. This can be corrected by locating up-stream gauges at a minimum distance of 4 times the maximum head on crest.

The results of the jointly irrplemented calibration program revealed that the gaps in water delivery information essential to meeting system performance objectives were much more serious than heretofore recognized. Indeed, the now widely acknowledged problem of water shortages in the tail reaches of secondary canals is undoubtedly at least partly related to the non-availability of such information at key control points in the system and to the fact that where available, the information often is unreliable.

The intervention program also has demonstrated that an agency water measurement capacity can be created and mobilized at the sub-division level from existing PID personnel resources. These water measurement "teams" could be effectively used to calibrate structures and then from the data obtained develop up-to-date rating curves and tables for use by gauge observers/gate keepers to support accurate delivery information flows and feedback. With a little continuing effort the PID also could sustain a program of regular review and necessary up-dating of structure calibrations. The costs are modest and well within even current levels of PID O & M budget resources.

2.1.3 Irrigation Management Decision Support

The report of the GON Review Mission for the Project completed earlier in 1993 reiterated the need for additional economic analyses of principal IIMI irrigation and salinity management recommendations in order to provide sector policy makers and agency managers further information essential in the decision making process. The special study of irrigation water markets in canal commands that has been initiated in the past six months (described in more detail below in section 2.4.2) is intended, in part, to directly address that recommendation. An additional research activity completed during this last reporting period also has responded to the Review Mission's recommendation.

Earlier IIMI Pakistan research results have highlighted the importance of secondary channel maintenance in sustaining water delivery performance consistent with operational targets and objectives. The run-of-river gravity flow alluvial channel systems of the Indus Basin with their traditional low densities of control structures have long been recognized as rnaintenance-sensitive. Despite the addition of considerable reservoir storage capacity to the system, *kharif* season system discharges continue to deliver secliment laden water to the secondary and tertiary systems. The complex interaction of sedimentation and either deferred or poorly implemented annual maintenance has been confirmed by previous IIMI research as an important factor contributing to persistent water distribution inequity in the secondary canal system.

An early IIMI management iritervention to prioritize annual maintenance inputs at the distributary level using current maintenance budget resources demonstrated quite conclusively that improved planning and implementation of maintenance activities would significantly reduce head to tail water distribution inequity. The resulting improvement in the supply of higher quality surface water would enhance the irrigation resources available to tail-end farmers to better manage the problem of irrigation-induced soil salinity.

With increasing frequency in Punjab and elsewhere in Pakistan, distributary canal lining also is being advocatecl as a "solution" to both the maintenance issue as well as the significant problem of seepage and other distribution losses of scarce high quality surface water to the irrigaied agriculture system. Indeed, it is argued that performance gains relative to operational objectives will be considerable in terms of improved flow conditions and overall water distribution efficiencies; maintenance requirements even may be reducecl, it is suggested, because a greater proportion of sediments will pass into the tertiary system to be disposed of at the watercourse level and farmers fields.

IIMI now has completed Field-based research comparing the changes in secondary canal system water distribution performance achieved by three physical intervention strategies--improved annual maintenance, major periodic channel desilting, and canal lining--and the financial costs and implications of each intervention. The research was carried out over several years at research sites in the LCC system and was done primarily upon three secondary channels, Lagar distributary (improved annual maintenance), Pir Mahal distributary (major channel desilting) and Khikhi distributary (canal lining), and could not have been effectively done without a sustained long-term field presence. The results of this work were documented and reported in a research paper jointly authored by Hammond Murray-Rust and Edward J. Vander Velde, "Hydraulic Changes and Economic Impact of Lining of Secondary Canals in Punjab, Pakistan," which was presented at the international Workshop on Canal Lining in Pakistan, organized by IWASRI and HR Wallingford in Lahore in October, 1993.

The canal lining activity was monitored and assessed in Khikhi distributary throughout an extended period beg nning with pre-lining conditions and ending several years after lining was completed. The study concluded that canal lining appeared to have had significant positive effects on the hydraulic performance of the canal. However, there is no evidence of mproved water supply conditions at the tail end, either in terms of total volume delivered or delivery reliability. The only immediately tangible benefit is that more water can be delivered into the lined canal as a result of improvements in the canal's banks that reversed the previous dangerously low freeboard condition.

The performance in hydraulic terms resulting from alternative maintenance interventions, involving either minor annual (Lagar distributary) or major periodic (Pir Mahal distributary) canal desilting, was significantly better than lining. The head to tail delivery performance ratios in both channels showed strongly positive improvement after the maintenance' intervention, changing from 4.2 to **1.3** in the case of Lagar and from **6.1** to 2.6 in the case of Pir Mahal. By contrast, the head to tail delivery performance ratio in Khikhi actually was worse after lining, changing from 0.8 to **1.6.**

Both maintenance options also appear to represent more feasible strategies under most circumstances in the present financial environment of Pakistan where capital is increasingly scarce. If the annual maintenance desilting at Lagar needs to be repeated every year, then it is possible to justify major or heavy desilting with a recurrence interval of approximately five years. However, if the effects of selective annual maintenance last even two years, it will always be more beneficial than major desilting at current costs.

Lining proved to be expensive, even though the lining type adopted for Khikhi distributary was relatively less costly than other approaches. Evaluated under the most favorable assumptions on life length (at least 10 years) and water saved (more than **15%** of design discharge), lining manages to be viable. provided the value of water is close to the price currently paid by farmers for pumped groundwater. This means that there will have to be very large increases in cropping intensity to generate sufficient ***abiana*** (water tax) to justify the capital cost of such an investment. It is difficult to imagine a set of circumstances where these most favorable assumptions will be valid.

From the perspective of comparative financial and performance analyses 'in the context of Punjab circumstances arid experience, it is clearly much more cost efficient to pursue ways of maintaining the original hydraulic function of canals through improved maintenance than through canal lining. Thus it is possible to conclude that good annual maintenance continues to be highly cost effective, and effectively implemented programs of periodic major desilting may be equally financially viable, too. From the perspective of improving water delivery performance to ensure a fairer distribution of surface water resources for salinity management among farmers, improved maintenance strategies are financially justified.

2.2 Analysis of Data

2.2.1 Farmer Irriaation Practices and Salinitv

Farmer irrigation practices have been an important research focus in the overall effort to meet the project objective to "identify possible improvements in irrigation management that may lead to prevention of further land degradation and could mitigate the effects of waterlogging and salinity on crop production." As reported in the Ninth Progress Report, analyses of data on field-level irrigation practices and sample soil data collected over several agricultural seasons in the study areas of the LCC and FES systems was well underway. The immediate objective of this work was to identify the range of relationships existing under real field conditions between farmer irrigation practices and conditions of incipient soil salinity. The analyses were completed during the final 6 month period of the project and the results were summarized and reported in the pacer prepared by Marcel Kuper and Erik van Waijjen, "Farmer Irrigation Practices and their Impact on Soil Salinity in the Punjab, Pakistan: Is Salinity here to Stay?" presented at IIMI's Internal Programme Review in December, 1993. The abstract of this paper is included in the Progress Report as Annex 5.

This research has built upon earlier work by Kijne and VanderVelde (1992) and it especially seeks to characterize and quantify the impact of farmer irrigation practices on soil salinity. Among the findings to have emerged, there is encouraging, if not yet conclusive, evidence of farmer capacity to successfully manage field-level salinity conditions. This clearly is being accomplished, however, within a given set of constraints, partly environmentally determined (*e.g.* rainfall, the quality of the groundwater aquifer) and partly generated at higher levels in the irrigation system by operational and management patterns (*e.g.* inequity and unreliability in canal water distribution).

Data from several different watercourse commands of distributaries in the LCC and FES systems indicate that farmers manipulate their total irrigation water supplies to mitigate the effects of salinity on crop production. These data are summarized in the following table.

FARMER IRRIGATION PRACTICES AND WATER QUALITY FOR SAMPLE FIELDS IN SAMPLE WATERCOURSES

	IA+Rf/CWR			EC_{iw} (dS/m)		
Season	**Kharif 91**	**Rabi 91/92**	**Kharif 92**	**Kharif 91**	**Rabi 91/92**	**Kharif 92**
Mananwala 24R	**2.26**	0.96	2.73	0.81	0.83	0.72
Mananwala 71R			3.12			0.74
Mananwala 141R	**1.84**	0.83	1.72	2.52	2.26	2.03
Mananwala 143R				**2.05**		
Junejwala 8L		0.98	0.94		0.60	0.72
Junejwala 29R		1.04	1.05		0.62	0.72
Junejwala 46L	**1.38**	1.30	1.03	1.52	1.32	1.49
Azirn 63L	0.75	1.27	0.96	0.63	0.84	0.65
Azirn 111L	11.11	1.11	11.13	10.99	11.01	10.99
Fordwah 62R	**0.77**	0.98	0.86	0.62	0.55	***0.58***
Fateh 184R	0.85	1.34	1.13	1.46	1.49	0.73

In this table, values under the heading IA + Rf/CWR refer to depth of application plus rainfall over crop water requirement which is used as a proxy for the quantity of irrigation'. Where *kharif* season relative water supply (RWS) values are comparatively high, rice is also a dominant crop; in most watercourse commands, however, RWS is quite near to or somewhat less than 1. The second parameter identified in the table is water quality. Here the electrical conductivity of all irrigation water, EC_{iw} in dS/m, is derived by multiplying the different ratios of irrigation water farmers use from different sources (canal, public tubewell, private tubewell, purchased, *etc.*) with their respective **EC** values. It can be seen that in the majority of sample watercourses, farmers are able to keep EC_{iw} (a mix of canal and tubewell water) at relatively low levels. In particular, private tubewells, the one source of irrigation water farmers directly control, are used in this process. Only in watercourse commands where canal supplies are scarce and groundwater is of relatively poor quality (*e.g.* Mananwala **141**R) do EC, levels exceed a safr? limit.

Using such irrigation practices and other agricultural management techniques, some farmers have demonstrated a capability to lower soil EC, values as high as ***8*** dS/m in their fields to acceptable levels in the course of one or two seasons. These findings confirm that through efficient farm-level resource management, especially sources of irrigation water, many farmers are able to effectively mitigate salinity impacts on irrigated agriculture, even in situations where salinity levels are relatively high.

Less easily managed and possibly a more significant impediment to the long-term sustainability of irrigated agriculture than previously recognized in IIMI's research locales is the problem of sodification. This research also sought to evaluate the sodicity hazard of farmers' irrigation water in the sample watercourse commands. Reduction in soil permeability was taken as the more important component of the sodicity hazard and, in this context, decreasing levels of electrical conductivity of irrigation water actually increase the permeability hazard. On average nearly **40%** of the irrigation waters were found to be posing sodicity hazards, falling in the category of "likely permeability hazard." Irrigation water judged to be unfit **by** this standard was found widely present in nearly all sample watercourses of the FES and LCC systems.

Overall, this latest research again has highlighted the temporal and spatial variability of, especially, emerging or incipient salinity under actual field conditions of irrigated agriculture in Punjab. Here farmer irrigation and agricultural practices significantly mask water-salinity-yield-drainage relationships that have been

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1. This parameter resembles the Relative Water Supply (RWS), proposed by Levine in 1982.

established by researchers under more controlled conditions. This ought not be surprising given the complexity and durability of the processes of salinization and sodification in a heterogenous irrigation environment.

That finding, however, emphasizes the urgent need to strengthen national research programs by incorporating more field level studies into on-going and planned research on these deeply inter-related problems of improving irrigation and salinity management. Otherwise it remains unlikely that the actual patterns of temporal and spatial development of soil and groundwater salinity induced by irrigation in the Punjab and elsewhere in the Indus Basin will be accurately defined and sufficiently understood to develop appropriate policies and programs that reinforce and strengthen the localized efforts of farmers to manage salinity.

What is the cost to farmers of current salinity and sodicity conditions? The answer to that question, as in the case of so may other economic questions concerning the sustainability of irrigated agriculture in Pakistan remains uncertain, However, some results from research carried out under the project by an IIMI pre-doctoral research fellow in 1992 on the impact of salinity on wheat production now provide a useful starting point for such a financial assessment. Under current conditions, average loss in wheat yields *to* farmers in Mananwala distributary command have been estimated at over 500 kg/ha; wheat production loss in Pir Mahal command, near the tail of the LCC system, are rather less, but still amount to an estimated 200 kg/ha. If these findings can be extrapolated to wheat production throughout the Indus Basin, salinity-induced reductions in wheat yield may amount to 1.3 million metric tons, a financial loss to Basin farmers of more than **Rs 4** billion.

2.2.2 Tubewell Ooerations and Management

As noted in the Ninth Progress Report, the analysis and interpretation of tubewell operations and management data for Mananwala distributary command have been completed. The findings arid conclusions of this research now have been published as IIMI Working Paper No. 27, Management **of** Private Tubewells in a Conjunctive **Use** Environment: A Case Study in the Mananwala Command Area, Punjab, Pakistan, jointly authored by Saleem Malik and Pierre Strosser.

Over the past six months, a arge amount of time and effort has been given to 'cleaning' tubewell operational data and organizing it for incorporation into the IIMI Pakistan master database. The objective of this work was to ensure before the closure of the present project that these primary tubewell data sets will be both readily usable and accessible for further use by IIMI and other researchers in Pakistan. This activity was completed by the end of December, 1993, and an overview of

tubewell data in IIMI Pakistan data archives is provided elsewhere in this progress report.

At this juncture, it also has appeared to be timely and important to synthesize the current state of knowledge about tubewell operations and management accumulated by IIMI-Pakistan during the past 5 years of field work in monitoring private and public tubewell operations and conjunctive irrigation management activities in several locations of the Punjab The results of such an effort would assist the definition of remaining priority issues concerning groundwater irrigation management to be incorporated into the research agenda for Phase II of the Waterlogging and Salinity Project. This retrospective analysis is now underway and is expected to continue as an initial activity in the expected second phase of the Project.

As the previous progress report highlighted, problems related to the use of ground water . . . not only concern tubewell owners, but nearly every farmer through (his) purchase of tubewell water. Although the importance of markets for groundwater is now recognized in Pakistan, very little is known about the factors influencing the operations of these markets, or their impact on agricultural production and significance for the sustainability of irrigated agriculture.

To address some of these issues, secondary data have been analyzed as a complement to and cross-check of IIMI research findings to date. The results of this study subsequently were reviewed by and discussed with research scientists of the International Food Policy Research Institute (IFPRI), Washington, who have been involved in an independent analysis of groundwater markets in Pakistan. Two key findings with potentially significant implications for irrigated agriculture in Pakistan have emerged so far from this collaboration. They are (1) in general, the operations of groundwater markets improve the quality of irrigation services available to and the agricultural productivity of farmers participating in them; however (2) farmers owning tubewells exert more control over their groundwater supplies and, thus, on average, they achieve higher levels of agricultural productivity than do farmers who are water purchasers in groundwater markets. The long-term equity consequences of this latter finding remain uncertain.

A research paper summarizirig the results of this work, Ground Water Markets in Pakistan: **An** Analysis of Selected Issues, jointly authored by Pierre Strosser and Ruth Meinzen-Dick (IFPRI Research Fellow), was presented at the Workshop on Water Management: India's Ground Water Challenge, held at Ahmedabad, Gujerat, India in December, 1993. A summary of that paper is appended to this report as Annex 6.

2.2.3 Warabandi Operations

As reported in the Ninth Progress Report, a *warabandi* operations study was initiated in 22 watercourse commands of 6 distributaries in the LCC and FES systems during *Kharif* 1993. Field observation and data collection activities were begun in mid-June and completed by mid-October. Data collection included compilation of official *warabandi* lists and schedules, actual schedules implemented by the farmers, records of daily irrigation practice:;, measurement of length of sample *sarkari khal* (official watercourse), identificatiori of irrigation turn diversion points (in/out *nakkas*), location of farms along the watercourse, assessment of surface salinity on the farms, and other special information related to *warabandi* operations.

The objectives of the *warabandi* operations research include an assessment of the potential of farmer-managed water distribution at the watercourse level to identify ways in which farmers can be more effectively involved in managing salinity-related problems. **A** second important objective is to assess the operation of the equity criterion embodied in the *warabandi* system, insofar as inequitable water distribution may significantly exacerbate salinity problems in the tail-end or other disadvantaged watercourse command areas.

Initial analysis of data has produced the following findings:

>> The actual operations of *warabandi* differ substantially from formal or official schedules; farmers make adjustments according to need and opportunity, demonstrating considerable cooperative behavior in doing *so.* Total length of turn is changed less frequertly than is the sequence of water turns viz-a-viz sanctioned turn time. Exchange of irrigation turns (lending and borrowing) is a regular practice at the watercourse level.

>> In about 10% of the sample watercourse commands, kachcha or unofficial *warabandi* was practiced. In these cases larger, more influential farmers more often have advantageous turn allocations than do smaller landholders. Water-related disputes occur and they are usually arbitrated by the influential farmers themselves.

>> The official or *pucca warabandi* exists in about 90% of the surveyed watercourse command area:;. Generally farmers do not rigidly adhere to the schedule of irrigation turns; instead they implement flexible water distribution procedures to better meet seasonal crop water needs.

>> Present *warabandi* schedules do not allow sufficient irrigation time per unit area for the crop grown and average cropping intensity. At times of significant canal supply variability, *warabandi* operations can not effectively proportionate water quantity in relation to cultivable landholding.

>> Water distribution inequity most strongly impacts upon watercourse command tail reaches, leading to sub-optimum water applications and increasing the incidence of surface salinity.

Before finalizing the conclusions from this study of *warabandi* operations, some of the above findings will be further evaluated in an additional sample of watercourse commands during the second phase of the waterlogging and salinity project.

2.2.4 Farmer organizations

In the late 1970s in Pakistan, the development of watercourse level farmer organizations was being strongly advocated by irrigation researchers, policy makers and donor agencies. Such institutions were viewed as a more effective means for increasing irrigation efficiencies at a system level where water losses were high and irrigation operations were outside the traditional area of responsibility of existing agencies. Farmers organized into water user associations would be able to both better maintain the watercourse level physical infrastructure and sustain water allocation and distribution improvements. Consequently, the On-Farm Water Management (OFWM) Programme was initiated by the Government of Pakistan with the objectives of improving irrigation water management through formal Water Users Associations (WUA) at the watercourse command level and linked to reduction of irrigation water losses through an extensive programme of watercourse improvements, including lining, designed to increase water delivery and on-farm application efficiencies.

Recent research indicates that informal farmer organizations, a prevalent institutional mode for water management at the watercourse level even before the establishment of formal WUA's, remain functionally important for organizing irrigation in many watercourse commands. IIMI initiated a study to assess both the types and operations of formal and informal farmer organizations in a number of watercourse commands in Junejwala minor distributary in the LCC system. Farmer interviews as well as direct field observations begun in 1992 were completed during the review period, and a first analysis of the collected data has been done. The formal write-up of the results of this study is now underway.

In all six watercourse commands that were surveyed, informal organizations are instrumental in facilitating a range of irrigation management activities, including water allocation, watercourse maintenance and water trading. They provide the institutional framework through which farmers undertake occasional desilting and maintenance of reaches of distributary and minor channels. Although the sample was small, there is some evidence that even where a watercourse was lined through the OFWM programme and a formal WUA established for that purpose, the preexisting informal

organization has replaced the now dormant WUA as the functional watercourse level institution.

The effectivity of such informal organizations appears to vary widely and is dependent upon a range of factors, including land tenure patterns and landholding size, the distribution of influence among farmers, and the number of castes in the locality. Water allocation disputes are often mediated at the village level through a *panchayat,* a traditional institutional form long used to resolve local conflicts. In five of six cases where a *panchayat* was identified, it was informally organized and varied in size; representatives, however, were drawn from castes and families locally held in high regard.

The enduring nature of these informal institutions is an important finding. It is unlikely that they would persist if farmers did not find them useful. With the growing recognition that institutional development efforts focused upon the WUA in the OFWM Programme have not achieved the intended objectives or level of durability initially expected, the successes of informal farmer organizations may offer important insights for structuring more effective local level irrigation management institutions. Surely stronger farmer organizations are needed to facilitate the delivery of improved services to support watercourse and farm level salinity management activities.

2.3 Geographic Information System (GIS) Applications:

During the previous two reporting periods, outputs from the GIS program in IIMI Pakistan were strongly focused upon map preparation which directly supported two activities. As previously reported, GIS products had become especially important for the collection of primary data at several field sites, such as in the rapid surface salinity appraisal survey and tubewell census carried out in Mananwala distributary command in January-February, 1993. For the past year, GIS-produced maps also have significantly enhanced IIMI's capacity for the spatial analysis of data for both surface and groundwater irrigation and irrigated agriculture within sample watercourse commands of secondary canals.

The Ninth Progress Report noted the need to expand GIS analysis and interpretation of more sample data variables over larger, spatially contiguous extents of irrigated area, thereby accessing the overlay analysis potential inherent in a GIS. Data extrapolation over an entire distributary command area was achieved in sufficient detail by using a 25 ac (10 ha) block as the minimum mapping unit. This was initially completed for the Mananwala distributary service area rapid appraisal survey and subsequently it has been used for interpolating sample data about private tubewell operations there.

A similar exercise also has been completed covering the command area of Fordwah distributary (Figure 1). In fact, the preparation of command layouts in Fordwah Division, FEC, has proven to be relatively easier compared to those for Upper Gugera Division, LCC. In the latter case, historic anomalies in the gridding of land parcels in the Rechna Doab have required much tighter controls to ensure the topological accuracy of map output.

The uniformly gridded land parcels in the Fordwah distributary command served as a pilot case for even larger mapping efforts, such as the entire irrigation sub-division of Chishtian (part of Fordwah Branch command) at a level of detail (blocks of 25 acres) that was common across both watercourse and distributary commands. The map of Chishtian Sub-division covered a total area of 75,286 ha and included 19 distributaries and minors (Figure 2). The purpose of such extensive coverage is to realize the potential of GIS for decision support applications in support of the continuing IMIS activity. In this case, regular reporting of canal discharge measurements at the secondary level will be able to be linked to both tubewell operations data and cropping pattern/cropping intensity information at the outlet or tertiary level to provide information critical to improving canal system operations management.

The tubewell census carried out earlier in 1993 in conjunction with the rapid appraisal surface salinity survey in Mananwala distributary provided sufficient data to permit a reasonable estimation of the proportion of pumped groundwater contributed seasonally by different private tubewell types at the watercourse level. A comparison of these estimates with those of watercourse tubewell densities provides a seasonal approximation of tubewell utilization (Figure 3). The use of tractor-driven tubewells is markedly greater during the *kharif* season as compared to rabi, confirming the low cost "insurance policy" nature of this type of well for farmers in the lower half of the system during periods of high water stress and when canal supplies are more unreliable. Contrastingly electric arid diesel powered tubewells are generally used as intensively or somewhat more so curing the rabi season, a reflection of their overall lower operational costs and the larger cropped irrigated area at this time. Confirming earlier findings, private electric tubewells also show a much higher utilization rate as compared to other tubewell types.

Three years of detailed cropping data from the Hasilpur field site have permitted the development of seasonal cropping and predominant crop cover maps for nine sample watercourses of the Fordwah, Azim, and Fateh distributaries (Figure 4). Such maps facilitate a rapid inter-seasonal spatial comparison of changes in cropping patterns covering the period from kharif 1990 thru rabi 1992. The dominance of cotton and wheat is immediately evident in this watercourse command located in Pakistan's cotton-wheat agro-ecological zone, with nearly 50% of the fields producing

cotton in 3 consecutive *kharif* seasons. Cotton production followed by wheat or by fallowing is about equally common in the watercourse command, each covering roughly 20% of the command area; the latter sequence, however, may exacerbate soil salinity conditions. The utility of such output in, for example, more carefully targeting subsequent salinity research and data collection activities is clearly obvious. A similar, but less comprehensive temporal comparison of cropping patterns has been completed for four watercourses in the Pir Mahal distributary command, LCC.[2]

Although there is an extensive set of data for physical and chemical parameters of private and public tubewells compiled through IIMI's field work in the LCC system, these data cover conditions in only those watercourses selected for tubewell operations studies. Consequently, this constraint restricts spatial extrapolations across the distributary command. However, within the sample watercourses, useful interpolations have been made for primary indicators of water quality and potential pumpage, permitting location specific inferences with respect to within watercourse tubewell distribution (Figure 5). In general, seepage from the distributary appears to improve groundwater quality near the outlet, however a strong trend of decline in groundwater quality towards the tail reaches of the watercourse can not be discerned.

The ILWIS GIS also has been used to carry out a temporal analysis of groundwater quality change in the SCARP-I area in the central Rechna Doab of Punjab. Data for this analysis were taken from one of the large public sector tubewell data sets maintained by WAPDA's SCARPs Monitoring Organization (SMO) which have recently become more accessible to researchers following the completion of SMO's database component in the Irrigation System Management (Research) Project. Tabulated data for groundwater electrical conductivity (EC) for nearly two thousand public tubewells were analyzed for two periods, 1960 and 1985. The data were interpolated as maps to provide a reasonable estimate of the spatial extent of changes in water quality conditions (Figure 6).

The results indicate that public tubewell water quality generally has slightly worsened throughout much of SCARP I, with the bulk of changes having occurred in areas where public wells initially pumped water with EC values < 2000

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2. For crop-based irrigation systems operations, such cropping pattern information is particularly important in order to proportionate the allocation of canal supplies with reasonable accuracy. The ILWIS GIS also has been used in such an application in support of IIMI's research underway in the Chashma Right Bank Canal system Stage I area. A spatial comparison across two successive rabiseasons for one watercourse clearly indicated the utility of the GIS to accurately identify the spatial distribution of farmers' cropping pattern changes following increased water supplies to the system.

micromhos/cm (2dS/m). Depending upon localized soil conditions, such changes may have resulted in an increased sodicity hazard of tubewell irrigation water over quite large areas of SCARP-I. Recent IIMI research discussed elsewhere in this progress report has revealed that sodicity hazard conditions are more widespread in the commands of LCC study distributaries than was heretofore recognized. This map also locates significant areas within the Shahkot and Shadman schemes of SCARP-I where initial (1960) EC values of tubewell water in the 1000-3000 micromhos/cm ranges had increased between 25% to 100% by 1985, clearly placing these waters either outside the broadest parameters currently used in Pakistan to define irrigation suitability or into a very marginal category.

Throughout 1993, the modest operational GIS facility at IIMI Pakistan also has attracted increased attention and interest from national water sector research agencies. Following IIMI's work with spatial processing of the large public data sets for SCARP-I described above, Chief Engineer, SMO, expressed a strong desire to have SMO staff trained on ILWIS as a prelude to establishing a SMO in-house GIS capability. It is anticipated that IIMI will subsequently collaborate with WAPDA's Central Planning Wing to assist the SMO to digitally archive their existing data sets on groundwater quality.

In the past six months, WAPDA's Watercourse Monitoring and Evaluation Directorate (WMED) also has requested technical assistance from IIMI Pakistan in support of the planned adoption and application of GIS technology in the World Bank-assisted Fordwah/Eastern Sadiqia (South) Irrigation and Drainage Project. The objective of that Project is to remove severe water supply constraints in the system command area through technical and managerial interventions designed to improve water delivery efficiency and a lowering of the water table. The objective of the WMED TA component, spread over 5 year period, is to enhance WM&E's monitoring and planning capabilities by facilitating operational use of a GIS through, for example:

* accessing IIMI's experience with GIs-based monitoring and planning;
* training and assistance in the use of GIS;
* selection of suitable types of data sets;
* developing feedback mechanisms for irrigation scheduling and drainage control;
* overlay model preparation for assessment of soil salinity in relation to other factors such as depth of groundwater, irrigation practices, soil characteristics, drainage layout, etc.

As a prelude to the preparation of detailed watercourse maps to be used by the WMED staff in the field, a command area map of Sirajwah distributary (GCA 20490 ha), Eastern Sadiqia Canal system, was prepared to support selection of sample watercourses in the area.

Beginning in early June, a science postgraduate joined IIMI Pakistan as the first GIS intern. This three month internship emphasized the development of basic map making skills using the ILWIS GIS, and the intern's contributions were particularly helpful in generating increased useable output from the GIS facility. The results of this first GIS internship were judged to be mutually favorable and successful in furthering both human resource development and GIS output without significantly encumbering existing staff time. Additional GIS internships are contemplated to the extent that suitable candidates can be identified.

2.4 Special Studies

A number of special studies were continued by IIMI Pakistan research staff through the latter half of 1993. Some of these studies (*e.g.* Land Reclamation Operations) were focused upon issues or problems specific to the waterlogging and salinity project and were directly supported by it. Other special studies (*e.g.* Irrigation Water Markets), usually supported by other resources, frequently address problems or issues that transcend the specific objectives of the waterlogging and salinity project. Nevertheless, research on those topics often contributes important complementary information and findings that represent a significant "value added" dimension to the project. Recent progress in both types of special studies has been summarized for this progress report.

2.4.1 Land Reclamation Operations

The special study of institutional aspects of land reclamation operations focusing on the functioning of the Punjab Irrigation Department's Directorate of Land Reclamation (DLR) was concluded in 1993. The overall objective of the study was to document the organizational and operational issues and constraints related to reclamation activities conducted by the DLR, and to identify whether or not there was potential for realizing further benefit from the additional irrigation supplies sanctioned for the reclamation of saline soils in canal command areas of Punjab.

Field investigations conducted in 1992 in 20 selected watercourses in seven distributary commands of the LCC East Circle focused on existing agency practices of identifying salinity-affected land for reclamation, and then sanctioning, installing

and operating additional pipe outlets, known as reclamation "shoots" (chutes), to supply more water for leaching purposes. The study examined whether or not authorized reclamation "shoots" matched adequate water supplies in the canals and watercourses chosen for these operations, and attempted to assess the effect of additional water supplies for reclamation on the farmers' irrigation and farming practices, including the existing *warabandi* and cropping patterns.

The results of this research will be reported in a forthcoming IIMI Working Paper, Institutional Perspectives of Land Reclamation Operations in **Punjab.** Principal findings are as follows:

>> Although the present method of selecting land for reclamation operations using a visual salinity survey appears to be cost effective, the selection process is subjective and its reliability is questionable. Classification of salinity-affected soil is not used effectively to discriminate site selection. Reliability could be improved by actively using in-house laboratory facilities available with the **DLR.**

>> Measurement and monitoring of flow conditions in the seven distributaries provided no evidence that extra water actually was made available during the period of operation of reclamation outlets as prescribed in the rules. Outlet measurements also indicated that discharges through reclamation "shoots" varied from 400% to 64% over their sanctioned amounts. These extra supplies impacted negatively upon distributary water distribution equity, primarily affecting tail-end outlets.

>> Of the 20 reclamation outlets monitored, 12 were located in distributaries' head reach, 8 were located in the middle and none were in the tail reach. The absence of even a single reclamation outlet in the tail portions of the 7 distributaries is notable in the context of other IIMI research findings that these tail areas often have a greater incidence of soil salinity.

It was generally concluded that DLR's operational and enforcement procedures required extensive review. In order for the agency to again be effective in the important land reclamation functions that have been assigned to it, significant changes in its present institutional status would be necessary.

Two inter-related institutional issues highlighted by the research have attracted the attention of senior officials in the DLR. These issues are (1) that the process of selecting land for reclamation operations is subjective and not strictly related to the salinity status of the soils, and (2) that, under present practices, irrigation supplies meant for reclamation are not being used for that purpose; rather the process has

become a means by which influential farmers cheaply obtain extra canal water supplies for their own agricultural purposes.

Consequently, in a joint collaboration, the DLR and IIMI Pakistan have prepared a formal proposal ("Improved Land Reclamation for Irrigation: Reducing Threats to Sustainability") which seeks external financial assistance in support of a proposed set of activities designed to improve the DLR's reclamation operations capability. The planned activities, including a comprehensive reclamation monitoring system, would substantially complement work on improving irrigation management to minimize salinity thus far conducted by IIMI under its current project. The DLR also plans on IIMI's continued collaboration in the proposed activities, especially for the development of a set of policy recommendations and implementation guidelines to increase effectivity of reclamation operations in the Punjab.

2.4.2 Irrigation Water markets

Work on this special study has continued throughout the current reporting period. Using the results of previous water market research (already reported) and current research pertaining to the management of the warabandi system by farmers, the primary concern has been the definition of the research methodology to be used to analyze the allocation of irrigation water within the watercourse command area and the role of water markets in the process. The methodology now developed has been reviewed by research scientists at both IIMI and the Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts (CEMAGREF). It is formally described in a paper titled "A Research Methodology to Analyze the Impact of Water Markets on the Quality of Irrigation Services and Agricultural Production," jointly authored by Pierre Strosser and Thierry Rieu (Economist, CEMAGREF) and presented at the 1993 IIMI Internal Program Review. *A summary of* the paper is appended to this progress report as Annex 8 .

Canal water allocation and tubewell operations data have been collected for 8 watercourse command areas of the Fordwah Branch irrigation system. These data represent a large variety of irrigation water supply conditions. A hydraulic model for the distribution of water within the watercourse command area has been developed. However, further refinement is required before the model can be used with confidence for an acceptable estimate of the quantity of irrigation water received by farmers at different locations along sample watercourses, and to assess the impact of water markets on the quality of their irrigation services.

2.4.3 Potential economic consequences of manaaement chanaes

The analysis of farming systems in the Fordwah Branch command area was begun late in the *kharif*, 1993 season. A formal farm survey to obtain additional data on farming systems and farming practices for all 280 farmers in *8* sample watercourses of the Fordwah and Azim distributaries had been completed in September, 1993. The data that were collected pertain to: (i) the basic characteristics of farm households; (ii) agricultural production; (iii) farming practices and costs of agricultural production; (iv) irrigation environment and water management (including water markets and water trading activities). Data have been entered into a suitable database and their analysis is well underway. The major focus of this research is on the relationship between the characteristics of the irrigation water supply at different levels of the irrigation system (main, secondary and tertiary canals), farming systems, and farmers' decision making processes.

As in the case of the water markets special study, further research on this subject will continue following the completion of the present Waterlogging and Salinity project because it is also a part of the overall research collaboration between IIMI and CEMAGREF. It is worth recalling that the primary objective of this component is to test a methodology to estimate the economic impact of changes in the operation of the irrigation system that are expected to be used in Phase II of the Waterlogging and Salinity Project.

2.4.4 Irriaation Goals and Objectives in Pakistan

Research begun earlier in 1993 to critically examine the hierarchy of goals and objectives that presently govern rrigation operations and investments in Pakistan, undertaken jointly with the International Food Policy Research Institute (IFPRI), was completed. Study methodology and research results have been summarized in a paper jointly authored by Edward J. Vander Velde and Mark Svendsen, "Goals and Objectives of Irrigation in Pakistan: A Prelude to Assessing Irrigation Performance," which was presented last December in IIMI's Internal Program Review. An abstract of the paper is included in this report as Annex 9.

One purpose of this special case study was to document irrigation-related goals in Pakistan and to analyze them for both internal consistency and consistency with objectively-measured irrigation and agriculture system output performance. After extracting goal statements from various official sources and organizing them to facilitate analysis and comparison, irrigation goals were examined for consistency across goal and organizational levels. Then selected goals were briefly examined in

the context of selected agricultural trends or compared with measured performance in sample distributary canals in Punjab.

A second, equally important objective of the study was to develop and demonstrate a practical research methodology which could be used in undertaking analyses of existing goals related to irrigation and irrigated agriculture system performance. Emphasis was given to practicality, especially ease of use and replicability. The conceptual underpinning for this study was the earlier work by Small and Svendsen (1992) in developing a framework for assessing irrigation performance.

Nine documents were used as the sources for current irrigation goals. They ranged from the recent *Water Seclor Investment Planning Study (WSIPS)* and *National Agricultural Policy (NAP),* to the older *Revised Action Programme for Irrigated Agriculture* and the irrigation agency's *Manual of Irrigation Practice;* the chapters covering water resources and agriculture of Pakistan's most recent five-year plans also were included. Because both irrigation and agriculture in Pakistan are provincial subjects, individual and joint interviews were conducted with a sample of 20 officials and staff of the Punjab Irrigation (PID) and Punjab Agriculture (PAD) Departments with operational responsibilities at various levels in the field to identify the present operational goals of irrigation mariagement.

One irrigation goal in particular was prominent in the documents reviewed, transcending nearly all organization levels; that was controlling waterlogging and salinity, "the twin menace" in Pakistan. It was specified as a national level goal in both the *6TH* and ***7TH*** five year plans as well as the *National Commission of Agriculture* report. Protecting lands from waterlogging and salinity is a stated goal in the *WSIPS* at national and provincial levels as was reducing the yield constraints of waterlogging and salinity, recognized as an irrigation system level goal. Generally, at the irrigation system level, the goal focus shifted to more specific drainage objectives, *e.g.* improving drainage systems O & M standards, or reducing system water losses, *e.g.* conserve irrigation water by lining channels and watercourses in saline zones. At the watercourse level, tubewell-related objectives were often stated (*e.g.* restrict public tubewell development to saline groundwater zones or link tubewell policies with regional groundwater regimes *(NAP).*

With respect to actual irrigation field performance and stated goals, notable gaps in achievement were identified in this study. Among PID personnel interviewed, one-half defined the equitable distiibution of irrigation supplies to farmers as a system operations objective. By contrast, in the recent *WSIPS* report, water distribution equity is almost lost among the more than 20 different system level goals and objectives identified; there it is expressed as a secondary objective and is sought to be achieved thru farmer-ID joint system management.

The relative loss of national focus on water distribution equity as a primary system operational objective reflects both the extent to which much more is now expected from Pakistan's irrigation systems and the degree to which irrigation goal-setting in Pakistan also includes responses to the developments and pressures of external experience and institutions. That change conflicts with design criteria incorporated into virtually all of Pakistan's canal systems, however, and may be contributing to the serious difficulties irrigation agency managers currently are experiencing in matching system operations and specified objectives.

The study concluded that there is a genuine basis for concern about the compatibility of the goals and objectives that have been articulated in major reports and policy statements for irrigation and (irrigated) agriculture over the past decade in Pakistan and the actual capacity on the ground, at the operational level to achieve them. Little evidence could be deduced of any real concern with practical matters of how irrigation goals and objective!; are to be accomplished or whether or not there is even system management and physical infrastructure capacity to do so. Documents which might assist this process in Pakistan, particularly the *Manual of Irrigation Practice* and the *Revenue Manual,* have never been completely revised and up-dated; in fact the former has yet to be completed in the first instance! Up-dated manuals and guidelines, however, are likely to offer scant assistance to operational staff in meeting specific objectives where essential data, management and physical capacity is mis-matched or absent. At least in the case of Pakistan, it does appear that articulating clear, specific goals and objectives, that can usefully guide irrigation management and investment in irrigation in the country has not received the sort of attention that is warranted.

2.4.5 Irriaation Policy Analysis

In the last Progress Report, the completion of an irrigation policy analysis study by IIMI Pakistan's Senior Management Specialist associated with the project was noted. The results of that study have now been published as IIMI Country Paper - Pakistan No. 6, The **Role** of **Research-Supported** Irrigation Policy in Sustainable Irrigated Agriculture: An Interpretive Precis of the Case of Pakistan.

2.5 Data Collection, Processing and Database Management at IIMI Pakistan

Primary and secondary data collection, processing, management and storage have been significant activities at IIMI Pakistan throughout the period of the waterlogging and salinity project. Indeed, this work has been the essential underpinning for salinity project research findings and results that have been extensively reported in a large number of published research and discussion papers as well as in the half yearly project progress reports.

The work of data processing and management at IIMI Pakistan progressed through three distinct phases.

Phase I, the period from '1987-1989, marked the beginning of IIMI's field research and related data collection activities in Pakistan. International and national senior professional staff associated with one or another research project developed different ***pro forma*** to facilitate the recording of field data and its subsequent entry into permanent spreadsheet or database computer files. Some ***pro forma*** were computer generated, but many others were hand drafted and less standardized.

Reflecting the early prominence and core nature of research on these subjects in IIMI Pakistan's program, data for canal and tubewell operations were quickly processed into standardized computer files from the very beginning. Watercourse and farm-level field data were less frequently entered into both computer-based and hard copy, but often non-standard, files; data judged less urgently needed were set aside for later processing.

During Phase II, 1989-1993, IIMI Pakistan shifted to using standard computer-generated ***pro forma*** for all of its regular data collection activities at all field locations. Appropriate research protocols and methodologies were adopted to govern and guide primary data collection. Data were promptly and regularly entered into standardized spreadsheet or database computer files, and the backlog of un-entered data that had accumulated in earlier years was gradually diminished. Text-based interview data, especially that derived from socio-economic surveys, also began to be entered into database files. Selected primary data from other sources also began to be added to IIMI Pakistan's irrigation and irrigated agriculture data holdings.

By the end of 1993, very nearly all primary field data collected during 1987-1993 had been entered into computer files and most data in these files have been thoroughly error-checked and cleaned. The back-up of hard copy raw data in computer files also was regularized and file compression adopted to minimize the required disk storage space.

In Phase III, 1993-1994, an interactive Database Management System that permits the more effective management of the data entry, storage and archiving processes has been developed and implemented. Running on a stand-alone desktop 386 computer, the DBMS system provides research staff at IIMI Pakistan both easy and rapid data access as well as essential background information about the data. The DBMS system also facilitates more general access to IIMI's primary data holdings, especially materials related to irrigation-induced salinity, by national research scientists at collaborating institutions.

Data Manaaement at IIMI Pakistan:

Key persons in the success of the data management process have been international research staff and IIMI Pakistan's Systems Analyst who has been assigned primary data management responsibility. Virtually all research staff have contributed to the process, however, at one or more steps. The result has been the acquisition and maintenance of many sets of primary, locationally-keyed field data, much of it basic for any analysis of irrigation-induced salinity problems, and all organized around basic surface irrigation hydraulic units (*e.g.* the distributary canal or the watercourse command). These holdings are quite likely unrivaled anywhere in Pakistan today and they represent an important national resource which IIMI is pleased to make available for legitimate research purposes.

The process of primary data acquisition and management at IIMI Pakistan has been divided into the following sets *of* activities:

(1) Data Collection:

(i) preparation of *pro forma* by senior international and/or national research staff;
(ii) field testing and refinement of *pro forma* with field staff;
(iii) data collection and initial entry into field books by field staff;
(iv) data entry into standard *pro forma* in field offices by field staff and initial error checking by field team leaders;
(v) transmission of data to research supervisor and/or data management specialist at IIMI's Lahore office.

(2) Data Entry and Backup:

(i) computer entry of raw data into spreadsheet or database files;
(ii) data checking and computation of some quantities to quickly assess consistency and accuracy;
(iii) data file compression and backup.

(3) Data Cleaning, Processing and Backup:

(i) data cleaning--a thorough checking for acquisition problems and entry error;
(ii) processing--basic tabulations and statistics;
(ii) final archiving of clean and processed data.

(4) Entry into **the** Data Base Management System:

(i) data archive in compressed files;
(ii) descriptors and other information added to the master status file of data so far collected and available;
(iii) file extraction from the main archive facility at user's discretion on to user-provided disks.

Introduction to Database Managernent System:

The primary objectives of the Database Management System are to organize IIMI Pakistan's field data into a wel structured computer database, provide quick data reference and retrieval for research users, and to secure the safety of primary data through an efficient storage and retrieval system. The DBMS helps research professionals to easily check on tte status of data entry and availability and then to discriminately select data required for a particular research purpose.

Once all IIMI field data have been cleaned and stored, backed-up and cataloged, and a similar operation completed for primary and secondary data acquired from other sources, the DBMS system will be iurther expanded to include data analysis and result files prepared by different IIMI research scientists. One result of such an activity would be the facilitation of comparable data files from different IIMI field stations and offices.

Storage of field data in computer files is now up-to-date. A menu-driven data reference and file retrieval system has been developed, using the FOXPRO2 database software and a batch file handling utility, AUTOMENU. The program treats the information or data category as the primary key, the study area as the secondary key, and the year or cropping season as the tertiary key. Users can move through a data category and/or sub-category to identify the type and time span for which information is available for different study locations.

For data retrieval, the DBMS program provides a user-friendly set of screen selections to identify the user's requirements. The program then generates file names based on that information and the user is allowed to browse through data files or to immediately back them up on a diskette. The backup process first unzips compressed files and then copies them to the user's floppy diskette.

The components of the DBMS include:

(i) data archive
(ii) information module
(iii) output module

(i) Data archive:

It is essential to use a suitable nomenclature for file names before archiving, otherwise, the DBMS program would be unable to identify the files of user interest. File names in the IIMI Pakistan DBMS are defined according to the following format:

(data type)(channel name or location)(year)(optional).ext

Data type codes, consisting of one to three letters, have been established for all data and saved in a special file; two letter abbreviations for canal and location names also are fixed and displayed on the screen for users, two letters are reserved and used for year identification. The 4th segment of the file name is optional; in some cases, particular units or crop season are identified by this segment. Three file extensions (*i.e.* 'ext') are available in the databank; 'dbf' for database files, 'WQ1' for QuattroPro spreedsheet files and 'WK1' for Lotus spreedsheet files. All properly 'named' files are compressed or "zipped" using the software compression package, PKZIP. The files are then storecl in a structured directory, a sample of which is attached to this progress report as Appendix I.

(ii) Information Module:

This information module has been developed in FOXPRO2, and it provides general information about the categories of data, duration or time period for which data are available and the nature of the data collected for a particular canal command or a location. For each data category, the module provides a list of identifier names from which the user may select, and then displays the relevant information on the screen. Menu driven screens guide the user through the selection of categories of interest and permit viewing of available data. An example of sample menus is provided in Appendix I.

(iii) Output module (data extraction):

This module is a combination of DOS-based BAT(ch) files and a small utility, AUTOMENU. The menu-driven set-up guides the user through identifying the required data from the data bank on the hard-disk and the extraction of data files to a diskette. The program also provides a screen display that permits the user to move between options that generate other file names, identify the target drive for copying data onto diskette and to unzip marked files on user's diskette. A sample of this screen is also given in Appendix I.

3. CONSULTANCIES, FELLOWSHIPS, and VISITS

To assist IIMI Pakistan research staff with specific components of the analysis of salinization processes, the services of two consultants were engaged during the reporting period.

Mr. Jelle Beekma, soil scientist with the International Institute for Land Reclamation and Improvement (ILRI) worked with IIMI Pakistan from July 31, 1993 until August 6, 1993. The main objective of his consultancy, reflected in his terms of reference, was to assist in a review of water and salinity data collection at the field level and to help identify the role of soil properties and characteristics in salinization/sodication processes identified in the study areas. The main conclusions of Mr. Beekma's consultancy are documented in a mission completion report titled Soil Salinization and Sodication in Tubewell Irrigated Fields. The main conclusions are summarized in Appendix II.

Ir. Jos C. van Dam, agro-hydrologist in the Department of Water Resources of the Wageningen Agricultural University, work with IIMI Pakistan staff from October 30, 1993 until November 12, 1993. The main objective of his consultancy was to test and assess the utility of simulating water and solute transport using an agro-hydrological model for the further analysis of irrigation-induced salinization processes. Such a simulation approach may be adopted to assist the future evaluation and selection of various management intervention scenarios intended to minimize irrigation-induced salinity in the next phase of the project.

Recommendations to IIMI Pakistan concerning data requirements, research organization and other matters regarding salinity simulations using an agro-hydrologic model were presented by Ir. van Dam in his mission report, Simulation of Water and Solute Transport to investigate Irrigation Management in Punjab, Pakistan , They have been included in this progress report as Appendix III.

During the period under review Mr. Nicolas Rivière, MSc student from the Ecole Nationale du Génie Rural des Eaux et Fôrets (ENGREF, Montpellier, France), completed his fellowship assignment as a junior research associate with IIMI-Pakistan in December 1993. Before his departure, Mr. Rivière completed a report, "Introduction of a Management Information System at the Main Canal Level - A Study in the Chishtian Sub-Division, Fordwah/Eastern Sadiqia Area, Punjab, Pakistan," which is briefly described elsewhere in this document.

In August, 1993, Mr. Sarath Wijesekera, Resident Engineer, Right Bank Main Canal, Kirindi Oya, Sri Lanka Irrigation Department, visited Pakistan for a two week period. During his visit, Mr. Wijesekera interacted closely with Punjab ID officials in

the Fordwah/Eastern Sadiqia system and with IIMI Pakistan researchers. The main purpose of his visit was to facilitate a manager-to-manager transfer of knowledge of the practical utility and applications of computer-based decision support programs in irrigation management. Mr. Wijesekera has documented his experiences in a trip report, Regulation Management of Fordwah Branch Canal Irrigation System, Punjab, Pakistan,

During the same period of Mr. Wijesekera's visit, Mr. Manju Hemakumara, Research Officer, IIMI-Sri Lanka, also visited Pakistan to support the research efforts of the IIMI Pakistan - PID IMIS team. Mr. Hemakumara is one of the principal researchers involved in the IMIS activity in Sri Lanka. He worked with both IIMI Pakistan researchers and PID officials on the computer software that is used in the IMIS intervention underway in Chishtian sub-division. He summarized his experiences and findings in a trip report, Irrigation Management Information System in the Fordwah Branch, Punjab, Pakistan.

4. SUMMARY OF KEY PROJECT RESULTS AND CONCLUSIONS

It is appropriate at this juncture, the final progress report of the five year project, "Managing Irrigation Systems to Minimize Waterlogging and Salinity Problems," to summarize and emphasize significant research findings, conclusions and recommendations that have emerged from the project. IIMI's findings and research results are, by and large, limited to Punjab; work originally planned for Sindh Province could not be initiated during the project for reasons specified in earlier project progress reports. It is expected that in a second phase irrigation management and salinity-focused project, new research activities would be planned for and implemented in Sindh as well as elsewhere in the Indus Basin. Research proposed to be undertaken in Punjab would build upon results thus far achieved under the present project.

Foremost among IIMI Pakislan's research findings in this project was strong evidence linkina the present pattern of irrigation system ooerations with persistent & incipient salinity problems, especially at the secondary canal level. The general failure of the irrigation department to meet water distribution performance objectives in surface irrigation system operations severely restricts irrigation supplies available to farmers in large areas of a canal command, notably those served by tail reach outlets. The relationship is often a complex one, involving a number of interpenetrating variables, such as soil type, groundwater quality and its irrigation use, season, cropping pattern, farmer irrigation techniques, etc.

Even within current budaet limitations, it is possible for the Puniab Irrigation Deoartment to significantly improve canal system ooerations. A policy of carefully planning and consistently targeting annual maintenance and periodic heavy maintenance inputs at the secondary system level is cost-effective and could be substantially accomplished within current levels of O & M resources. Modern computer-based decision support systems are available that can be tailored to assist an ID operations staff in improving main and secondary canal system O & M with respect to meeting objectives and targets.

Given the diversity of irrigation environments in Punjab, let alone throughout the Indus Basin, it is very likely that many site and system specific solutions will be required to effectively manage and minimize salinity impacts upon irriaated agriculture in the province. The key variables involved in irrigation-induced salinity are essentially known, but how they interact--which is more important, which is less--to contribute to salinity conditions, emergent or persistent, in different Punjab canal systems (a macro-level) and distributary commands (a mezo-scale) is not clear nor can it be readily deduced from data currently available.

IIMI field research has revealed that many farmers have a heretofore largely unrecognized or unacknowledged capacity to manage their irrigated agriculture operations in ways that reduce, if not minimize, the impact of salinity on crop production. Many other farmers do not have such a capacity. Central to farmer capacity to successfully manage salinity at the field level is access to sufficient and flexible supplies of irriaation water--both high quality surface water and groundwater (often of lesser quality). Generally. Puniab farmers are not wasteful in managing irriaation water. What most farmers need is fairer access to the irrigation resources that will provide them the opportunity (and challenge) to manage salinity at the farm level.

Private aroundwater development and use for irrigation in Punjab has been more rapid and extensive than previous estimates have suaaested. with large numbers of farmers now using additional water of marainal to Door quality to meet their irrigation requirements. Although such groundwater development provides greater flexibility in irrigation supplies and adds to the overall quantum of water available, concomitant changes in irrigated cropping patterns frequently result in farmers continuing to have serious difficulties in maintaining appropriate salt/water balances at the field level, increasing the risk of more widespread salinity. This phenomena presents a formidable challenge to organized efforts to minimize the impact of irrigation-induced salinity, especially in terms of agricultural extension service requirements.

If present and future salinity trends are going to be accurately determined and monitored, then there must be reliable data from field sites that fairly reflect the agro-environmental diversity of the Puniab (and of Pakistan) over extended periods of time for such variables as soil type and salinity conditions, groundwater quality and aquifer changes, canal system deliveries, cropping patterns and farmer irrigation operations. It can not now be determined with confidence, for example, whether or not the very serious problem of sodification is iricreasing, decreasing or remaining more or less the same, primarily because insufficient time series data are available for a sufficient number of canal command areas for the variables that need to be monitored. Project research findings represent a clear warning of the need to widely monitor for changes in the salt/water balance at secondary canal command and watercourse levels, supplemented by suitable sample field level data measurements.

Some useful data are available, but they are commonly scattered among several operational and research agencies and often limited in temporal and/or areal extent as 'well as in quality; seldom is the range of data required either complete or locationally consistent. Just as importantly, there needs to be a national capacity established and sustained that can consistently manaae and quickly analyze such data, develop and recommendoractical, cost-effective salinity management solutions, and feedback such useful results to agencies and farmers for that purpose.

5. PUBLICATIONS AND REPORTS

During the project reporting period under review, the following pub'.:ations and reports were prepared in connection with the Project.

BANDARAGODA D.J *1993_* Institutional Framework for Irrigation: Some salient features of the South Asian situation, Chiang Mai, Thailand.

SHAHID, BAGH ALI, KUPER MARCEL AND EDWARD J. VANDER VELDE. ***7993*** Improving Canal System Management: An Intervention to Calibrate Control Structures in Punjab, Pakistan

D. HAMMOND MURRAY-RUST AND EDWARD J. VANDER VELDE. ***7993*** Hydraulic Changes and Economic Impact of Lining of Secondary Canals in Punjab, Pakistan.

KUPER MARCEL AND ERIK G. VAN WAIJJEN. ***7993*** Farmer Irrigation Practices and their Impact on Soil Salinity in the Punjab, Pakistan: Is Salinity here to Stay?"

STROSSER PIERRE AND RUTH MEINZEN-DICK. ***7993*** Ground Water Markets in Pakistan: An Analysis of Selected Issues

REHMAN GAUHAR AND EDWARD J. VANDER VELDE. ***7993*** Remote Sensing Applications for Irrigation Management in Asia

STROSSER PIERRE AND THIERRY RIEU. ***7993*** A Research Methodology to Analyze the Impact of Water markets on :he Quality of Irrigation Services and Agricultural Production

VANDER VELDE, EDWARD J. AND MARK SVENDSEN. ***7993*** Goals and Objectives of Irrigation in Pakistan: A Prelude to Assessing Irrigation Performance.

JACQUES REY., MARCEL KUPER AND MANJU HEMAKUMARA. Setting-Up an Information System at the Main Canal Level: Participatory Approach in Sri Lanka and Pakistan

RIVIÈRE, NICOLAS introduction of a Management Information System at the Main-Canal Level; a Study in the Chishtian Sub-Division, Fordwah/Eastern Sadiqia Area, Punjab, Pakistan

BANDARAGODA D.J *1993_* The Role of Research-Supported Irrigation Policy in Sustainable Irrigated Agriculture: An Interpretive Precis of the Case of Pakistan.

6. FINANCIAL REPORTING

Final project financial reporting is presented in Table **6.1** summarized under the expenditure categories previously used in project reporting.

TABLE 9.1

IIMI-PAKISTAN
MANAGING IRRIGATION SYSTEMS TO MINIMIZE WATERLOGGING AND SALINITY PROBLEMS
EXPENDITURE STATEMENT
AS AT DECEMBER 31.1993

	GRANT 11-May-88 I	1ST REALLOCATED BUDGET 28-Nov-91 $	2ND REALLOCATED BUDGET 09-Apt-93 I	1ST * ADJUSTED BUDGET 30-Jun-93 f	2ND ADJUSTED BUDGET 31-Dec-93 $	ACTUAL EXPENSES 1989 $	ACTUAL EXPENSES 1990 $	ACTUAL EXPENSES 1991 $	ACTUAL EXPENSES 1992 $	ACTUAL EXPENSES 1993 $	TOTAl
SALARIES	1,529,000	1,529,000	1,586,000	1,478,600	1,531,311	135.494	300.005	389.072	374.135	323.935	1,531,311
TRAVEL	90.000	90.000	109.000	109,000	97.435	14,392	[illegible]	[illegible]	23,555	13,003	97,435
S&SERVICES	306.000	359.000	391.000	376,000	378.341	44.815	73.947	85,688	91.521	82.590	379.341
EQUIPMENT	80,000	155,000	118,000	105,000	99,734	21,381	12,707	20.282	43,097	2.287	99.734
LEASEHOLD	20,000	20,000									
CONTINGENCIES	202.000	77.000	23.000	23.000	0						
	2,227,000	2,227,000	2,227,000	2,091,600	2,106,821	215.852	410.047	527.949	531.789	421.495	2,106,821

*

f. Actual loss of 120k due to strengthening of Dutch Guilders against US Dollars

Pakistan

Annexure-1

Introduction of a Management Information System at the Main-Canal Level; a Study in the Chishtian Sub-Division, Fordwah/Eastern Sadiqia Area, Punjab, Pakistan

Nicolas Rivière

ABSTRACT

Competing demands for water in the contiguous irrigation systems of Pakistan's Indus Basin, which annually irrigates an area of more than 14 million hectare, have raised concerns regarding the irrigation efficiencies of the system, presently estimated at levels as low as 30-50 %. There is a need to manage available water resources in a more optimal way.

Recently, a number of computer-based programs have been developed in the field of irrigation to support irrigation managers in taking decisions on operation and maintenance of their systems in allocating, scheduling and distribution of supplies. However, comparatively few of these programs, usually called Decision Support Systems (DSS), have been adopted by irrigation managers, and there appears to be a need for improved implementation strategies to facilitate DSS adoption.

To address this issue, the International Irrigation Management Institute (IIMI) initiated research activities in the Fordwah/Eastern Sadiqia area in south-east Punjab. After a diagnosis phase, in which system performance was evaluated and a collaboration with system managers established, IIMI and the Punjab Irrigation Department decided to jointly launch a pilot intervention in the area, focusing on providing system managers with real-time information to better support decisions on water management issues.

This study describes the process and the initial results of the pilot intervention in the Chishtian sub-division. An appropriate data collection process has been organized and a communication network to transmit the data from the field to the decision-making centre has been established. This included a joint measurement programme to calibrate control structures.

The processing and analysis of data at the decision-making level has been facilitated by the installation of a computer. Target data are now routinely displayed at the decision-making centre.

The implementation of the pilot intervention through a participatory approach has created a better understanding among staff of the irrigation agency of the gaps between desired and actual water distribution, and the scope for improvement therein. The knowledge gained through this pilot activity should be used to effect improvements in water distribution patterns, increasing reliability and equity of canal water supplies for the farmers.

Annexure- 2

Setting up an Information System at the Main Canal Level: Participatory Approach in Sri Lanka and Pakistan

Jacques Rey, Marcel Kuper and Manju Hemakumara

ABSTRACT

In recent years, a substantial number of computer-based decision support tools has been developed by irrigation researchers. The advent of modern computer technology at reasonable prices provides new opportunities for implementation of Decision Support Systems (DSS) in irrigation schemes. However, relatively few DSS are routinely used by irrigation agencies, presently, for water management tasks.

Reasons explaining this slow rate of adoption of DSS by irrigation agencies are numerous. It appears that the lack of a practical model for management intervention, used to transfer DSS to irrigation practitioners could explain this apparent mismatch between the availability of relatively sophisticated tools and the low level of utilization in the field. This study attempts to formalize such a model and test it in two different irrigation environments.

This model formed the foundation for deriving an "action package", targeting the improvement of water management at the main canal level in irrigation systems. This particular action package is aimed primarily at strengthen ngthe agencies' capabilities and confidence in operating their canal system. The package is presently pilot tested in two main canals in Sri Lanka (Kirindi Oya irrigation system) and one branch canal in Pakistan (Fordwah Branch Canal).

Pilot implementation of the action package has yielded valuable lessons. The documentation and first evaluation of the experiences provide elements for improving the action package itself, which includes both computer tools and a methodology of intervention. Apart from the application of the management intervention model to the area of main canal operations, lessons can also be derived for Decision Support activities in other fields. A third level of analysis gives us interesting insights into the problems of transferability of tools and methodologies to national agencies in both countries.

Annexure-3

Improving Canal System Management: An Intervention to Calibrate Control Structures in Punjab, Pakistan

Bagh Ali Shahid, Marcel Kuper and Edward J. Vander Velde [3]

ABSTRACT

The different canal systems comprising of the Indus Basin irrigation system range in age from a few decades to more than a century. Although surface water availability (diversions plus storage) for irrigation and domestic use is limited, the demand for water continues to increase with the growth of population and industry. In general, the overall performance of the Basin's gravity irrigation system is low. This can be attributed to the interaction of physical defects, poor operations and maintenance, weak planning of water deliveries, the interventions of politics and influence, and changes in output expectations.

In late 1991, the Punjab Irrigation Department (PID) and IIMI agreed to jointly implement an intervention intended to enhance management's capacity to improve canal system performance. This intervention directly addressed the widespread absence of accurate information essential for planning and monitoring within system water deliveries, particularly at the main - secondary interface. The non-availability of reliable and timely data on water deliveries at main system handover points, at secondary canal head gates, and within distributary canals meant that there was no basis for within agency accountability in meeting water distribution objectives, let alone between agency officials and farmers.

The IIMI - PID intervention focussed upon the field calibration of canal control structures and the development of agency capacity at the lowest level management unit, the sub division, to carry out this work. This action activity has been implemented in two stages in both the Lower Chenab Canal system and the Fordwah Canal system. Short intensive water measurement training sessions for teams of selected ID field staff were followed by a systematic program of control structure calibration measurements that followed priorities set at the sub-division level. The second stage of this activity will be completed before the end of 1993.

The results of this jointly implemented calibration program revealed that the gaps in essential water delivery information were more serious than heretofore recognized. They also have demonstrated that an agency water measurement capacity can be created and mobilized at the sub-division level to effectively provide data required to improve canal system management. Finally, it is clear that only a modest investment of existing resources are necessary for this purpose.

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3. The authors are, respectively, Principal Irrigation Engineer, Associate Expert and Senior Irrigation Specialist, IIMI Pakistan

Annexure-4

Hydraulic Changes and Economic Impact of Lining of Secondary Canals in Punjab, Pakistan[4]

D. Hammond Murray-Rust and Edward J. Vander Velde

ABSTRACT

Observations on the hydraulic changes of lining of secondary canals in Punjab, Pakistan show that performance improvement objectives are not always achieved. If lining is justified on the basis of water savings through reduced seepage losses, then tail end areas should receive improved water deliveries. Observations in two distributary canals following lining do not demonstrate significant improvements in tail end conditions. Justification of lining on the basis of more stable water conditions is also hard to identify; reduction in the variability of discharges was not observed.

Financial analysis of a recent canal lining experience in Punjab indicates that water savings would have to be unrealistically high and sustained for long periods if the initial capital cost is to be repaid through improved water conveyance efficiency. Furthermore, the hydraulic improvements achieved through alternat ve interventions appear to strengthen the argumentthat lining can be justified only under special conditions, rather than adopted as a wholesale approach to solving water distribution problems. Whatever the intervention, management control must be strengthened; lining is not a substitute for effective canal operations and maintenance inputs.

[4] Paper presented to the IWASRI - HR Wallingford "Workshop on Canal Lining in Pakistan," 18-21 October 1993, Lahore, Pakistan

Annexure-5

Farmer Irrigation Practices and their impact on Soil Salinity in the Punjab, Pakistan: Is Salinity here to Stay?[5]

Marcel Kuper and Erik G. van Waijjen

ABSTRACT

Irrigated agriculture in the Punjab represents a conjunctive use environment, in which scarce surface water resources are augmented by groundwater, tapped through public and private tubewells. Research, conducted under the Dutch-funded project "Managing irrigation systems to minimize waterlogging and salinity problems", followed through on suggestions by various agencies (e.g. Soil Survey of Pakistan) of a possible threat of salinization, caused by the use of groundwater of doubtful quality for irrigation. This occurred in areas of low groundwater tables also, effectively dis-associating waterlogging and salinity.

The paper studies this threat and shows that there are encouraging signs of farmers managing salinity successfully. Soil salinity levels in 12 sample watercourses in two different irrigation systems, are at similar or lower levels than they were 1-3 years ago. Field level investigations indicate that farmers are using tubewells, the irrigation source they control directly, as a tool to mitigate the effect of salinity on crop production. There is a need to channel and reinforce the localized efforts of farmers to take on salt management, calling for a more comprehensive framework at a system level to link salinity problems with irrigation management,

Alarmingly high sodication levels are found at a much larger scale than for salinization. Sodication damage for prevailing soil types is difficult to assess, and remedies are not yet widely adapted by farmers.

A high spatial and temporal variability in soil salinity was observed, indicative of the fact that water-salinity-yield relations, established in experiments under controlled conditions, are obscured in real-life settings by irrigation and agricultural practices of farmers. This also explains the often considerable difference between the field observations and the output of a computer simulation model used in this study. However. this model is shown to be useful for long-term predictions of the effects of different irrigation practices under different conditions.

The paper stresses the importance of further qualifying the potential threat of salinization through irrigation with poor-quality groundwater. This will contribute to the understanding of salinity processes and prevent the unconditional appropriation of this hypothesis by various agencies or policy makers, as experienced in the case of the long-standing association of problems of waterlogging and salinity.

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5. Paper presented at the Internal Program Review of IIMI, Colombo, Sri Lanka, November 29 - December 1993.

Ground Water Markets in Pakistan: An Analysis of Selected issues

Pierre Strosser and Ruth Meinzen-Dick

ABSTRACT

The major transformation that has taken place in the irrigation sector in Pakistan during the last decade is the increasing role of private tubewells for supplying irrigation water, as an answer to the deficiencies of the publicly administered irrigation system. The development of private tubewells has been accompanied by the emergence of localized and informal markets for ground water. Although tubewell owners first use ground water for their own needs, they sell their surplus water, mostly to adjacent non-tubewell owners. To date, very little research has been undertaken to analyze ground water transactions and their impact on agricultural productivity in Pakistan, and to estimate the potential for ground water markets development.

The present paper investigates the functioning of ground water markets in Pakistan, based on two case studies and a review of the literature. Following the description of current ground water markets, a conceptual framework to analyze the impact of key factors on ground water market activities is proposed. The framework is then used to analyze the influence of specific technical, economic and social factors on ground water transactions. The relationships between ground water markets operation and factors such as the canal water supply, variables of the physical environment, and socio-economic characteristics of farmers are emphasized.

The impact of ground water markets on the quality of irrigation services, agricultural productivity and environmental variables is evaluated. The main finding is that, although ground water markets improve the quality of irrigation services and agricultural productivity, tubewell owners exert more control over their ground water supplies and consequently have a higher agricultural productivity than water purchasers.

The different elements analyzed in the study provide a good basis for addressing issues related to the potential for ground water markets development in Pakistan. The section on Policy implications stresses the need for a disaggregated regional approach to such development, based on agro-ecological variables which affect water market activity. However, further research on the operation and impact of ground water markets will still be required. Potential areas for further research are proposed and discussed.

Annexure-7

Remote Sensing Applications for Irrigation Management in Asia [6]

Gauhar Rehman and Edward J. Vander Veide [7]

Abstract

The sustainable management of irrigation systems has much to do with the ability to assess the performance of systems. A management perspective involves consideration of not only variations in consumptive use patterns of increasingly scarce supplies and often rigid irrigation-related water allocations, but also the threats to sustainability through land degradation, With increased emphasis upon system rehabilitation and progressive system management to sustain more intensive irrigated agriculture, it is essential to develop approaches that augment the degree of control available to the irrigation community. Such approaches also should facilitate economic valuation and assessment of the extent of impact management interventions are likely to have on the farming community.

The use of space-borne sensors for irrigation management is not new and, with continuing advances in spatial, spectral, and temporal resolution, a substantial volume of research now has established that enhanced prospects exist for more effective performance monitoring of irrigation systems. The implications in the Asian context are significant where inadequate information gathering mechanisms have long hampsred decision making on changing water allocations for increased agricultural productivity, for improving water use efficiency, and increasing repayment of recurrent costs. This paper highlights some remote sensing-related irrigation systems research in the major grain-producing areas of Asia and, relatedly, concurrent efforts to adapt it to subjects of most immediate concern.

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6. Paper presented at the Experts Workshop sponsored by CEMAGREF, UNFAO on the Use of Remote Sensing Techrology for Irrigation and Drainage

7. The authors are, respectively, GIS Specialist and Civil Engineer and Senior Irrigation Specialist, IIMI Pakistan

Annexure-8

A Research Methodology to Analyze The Impact of Water Markets on The Quality of Irrigation Services And Agricultural Production

Pierre Strosser and Thierry Rieu

ABSTRACT

The poor delivery performance of existing irrigation systems has became an issue of major concern in Pakistan. In the complex conjunctive use environment of the country, the most serious problems related to the recorded level of performance are: the low and rather stagnant agricultural productivity, compared to an increasing demand for agricultural products; the degradation of the resource base in existing systems (through waterlogging, salinization and mining of the aquifer).

While technological solutions still gather most of the financial resources allocated to the search of solutions, there is an increasing interest in more software-oriented solutions. In this context, water markets are seen as a promising means to increase irrigation efficiency and provide incentives for improved resource management. This interest in water markets is illustrated by a recent World Bank report identifying water markets as appropriate means to improve the efficiency and self-sustainability of the irrigation sector in Pakistan.

The present paper looks at water markets from three different angles: water markets described in the literature, water markets incorporated in the proposal of the World Bank, and existing water markets in irrigation systems in Pakistan. The conclusions of this analysis are that the differences between existing water markets and water markets proposed by the World Bank are substantial, and that very little is known about the impact of water markets on the quality of irrigation services, on the agricultural production, and on the environment. Thus, there is an urgent need to develop research programs and protocols to address issues related to water markets before any further development and/or institutionalization of these markets in Pakistan.

To assess the potential for water markets development in Pakistan, a research methodology is proposed. Analyzing the impact of water constraints on farming systems, the approach combines technical and economic aspects of irrigation water supply and demand at watercourse (tertiary canal) level. Specific water markets development scenarios will be proposed and their operational feasibility tested. The impact of these water allocation scenarios on the quality of irrigation services and on the agricultural production will be evaluated.

Annexure-9

Goals and Objectives of Irrigation in Pakistan: A prelude to Assessing Irrigation Performance [8]

Edward J. Vander Velde and Mark Svendsen [9]

Abstract

This paper reports the results of an initial effort to document and critically examine the hierarchy of goals which presently govern irrigation operations management and investment in Pakistan. Such an activity is central to a more comprehensive and systematic assessment *of* irrigation performance in the country.

There have been three basic components to this review: (1) documentation of goals-objectives-targets for the water resource subsectors of irrigation and irrigated agriculture through (a) an examination of published official report:; and documents and (b) the interpretation given stated goals and objectives by irrigation system managers; (2) a brief review of recent trends in agriculture production, particularly for foodgrains, over the most recent five year plan; and (3) the assembly of recent research results that document objective or target achievement in Punjab irrigation systems. The resulting information from these components has been analyzed to assess the relevance and consistency of current goals and objectives at various system levels.

The paper also details the methodology that was developed and used for this study, identifying its relative strengths and weaknesses with respect to possible adoption and wider use in IIMI's performance assessment program.

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8. Paper presented at the Ninth Internal Program Review of the International Irrigation Management Institute, Colombo, Sri Lanka, November 29 - December 1, 1993.

9. The authors are, respectively, Senior Irrigation Specialist, IIMI Pakistan and Research Associate, IFPRI.

As noted in the main body of the progress report, the following material is illustrative of different features of the Database Managemert System developed and adopted at IIMI Pakistan to manage access to all primary data collected and used by IIMI in its irrigation management research activities.

MAIN MENU

Database management system & overview of existing database

1. Introduction
2. Information about data & databases
3. File archive and extract
4. View a sample file
5. EXIT

Highlight the option with ↓ or ↑ and press ←
or press appropriate menu number

MENU LEVEL 2

Menu--L2: To select a major data type of existing database

1 = "Surface Water"
2 = "Ground Water"
3 = "Rainfall"
4 = "Command Area Information"
5 = "Return to main menu"

Highlight the option with ↓ or ↑ and press ←
or press appropriate menu number

MENU LEVEL 3

Menu--L3: Submenu to retrieve information about canal data

1 = "IIMI Sample Canals"
2 = "Canal Daily Monitoring data (Stage)"
3 = "Canal Physical (Topography Surveys)"
4 = "Canal Structure Calibration (Disch. measurements & RC)"
5 = "Geometry of Offtakes & Structures"
6 = "Canal Operations (Gates & Structures)"
7 = "Special Observations (Canal Msnagement)"
8 = "Return to main menu"

Highlight the option with ↓ or ↑ and press ←
or press appropriate menu number

MENU LEVEL 3

Menu-L3: Submenu to retrieve information about Tubewelldata

1 = "Tubewell Basic Information"
2 = "Tubewell Monitoring Data"
3 = "Tubewell Water Quality"
4 = "Tubewell Secondary Data (SMO)"
5 = "Water Tables"
6 = "Ground Water Data Files"
7 = "Return to main menu"

Highlight the option with ↓ or ↑ and press ←
or press appropriate menu number

NOTE: After a selection from Menu Level 3, the program displays additional brief information about the type of data selected.

DATABASE MANAGEMENT SYSTEM TREE DIAGRAM

```
DATAINFO.PRG
├──────LITEBAR        (procedure in INDMENU.PRG)
│
├──────INTRO          (procedure in DATAINFO.PRG)
├──────SYSINF.PRG
│   │   ├──────CANAL       (procedure in SYSINF.PRG)
│   │   │   BASINFO.DBF (database)
│   │   ├
│   │   ├──────MONITOR          (procedure in SYSINF.PRG)
│   │   │   │   CANAL.DBF (database)
│   │   │   │   CANALREF.DBF (database)
│   │   │   │   PVTPEROD.DBF (database)
│   │   │   └──────UPPER()
│   │   ├──────TOPO         (procedure in SYSINF.PRG)
│   │   │   │   HYDSURV.DBF (database)
│   │   │   │   CANALREF.DBF (database)
│   │   │   └──────UPPER()
│   │   ├──────FLUME        (procedure in SYSINF.PRG)
│   │   │   │   CANALDIM.DBF (database)
│   │   │   │   CANALREF.DBF (database)
│   │   │   ├
│   │   │   └──────RFILES
│   │   ├──────WCDIM        (procedure in SYSINF.PRG)
│   │   │       DIMSTR.DBF (database)
│   │   ├──────CANALOPR          (procedure in SYSINF.PRG)
│   │   ├──────SPOBS        (procedure in SYSINF.PRG)
│   │   └──────FILES.PRG
│   │
│   ├──────TWELL.PRG
│   │
│   │   ├──────TWBASIC      (procedure in TWELL.PRG)
│   │   │   │   TW-BASIC.DBF (database)
│   │   │   │   CANALREF.DBF (database)
│   │   │   ├
│   │   │   └──────UPPER()
│   │   ├──────TMONT.PRG
│   │   ├──────QUALITY          (procedure in TWELL.PRG)
│   │   ├──────SMO          (procedure in TWELL.PRG)
│   │   ├──────WTABLE          (procedure in TWELL.PRG)
│   │   └──────TFILES       (procedure in TWELL.PRG)
│   ├──────RAIN.PRG
│   ├──────COMMAND                (procedure in SYSINF.PRG)
│   └──────MANAGE.PRG
├──────FRMINF.PRG
│   ├──────CROPSURV             (procedure in FRMINF.PRG)
│   │       DCROP.DBF (database)
│   ├──────KHASRA          (procedure in FRMINF.PRG)
│   │       KHASRA.DBF (database)
│   ├──────IRRIAPPL             (procedure in FRMINF.PRG)
│   │       IRRAPL.DBF (database)
│   ├──────YIELD          (procedure in FRMINF.PRG)
│   │       YIELD.DBF (database)
│   ├──────SECO                 (procedure in FRMINF.PRG)
│   ├──────SALINITY         (procedure in FRMINF.PRG)
│   │       SALINITY.DBF (database)
│   └──────FFILES               (procedure in FRMINF.PRG)
└──────IINFO              (procedure in DATAINFO.PRG)
```

DATA RETRIEVAL UTILITY

.....

Select and retrieve (or view) a file on a floppy disk

.....

(Selections to retrieve data on your floppy)

Select Drive you wish to use for data retrieval (unzip & backup) from drive C:
A: , B:
>
>Select the type of data you want to retrieve
>Codes are given below for your reference

>H (=Stage & Q for disty head)
>Q (=outlet Q)
>H&Q (=outlet Head & Q)
>T (=Topographic surveys)
>F (=discharge measurements)
>DI (=structure Dimensions)
>SO (=Special Observations)

H,Q,H&Q,T,F,DI,SO
>

>Select a canal & location abbreviation of your interest
>or '*' for all locations

LG,MN,PM,JN,KR,JD,FT,FD,AZ,*

> Select a year
>or '*' for all years

87,88,89,90,91,92,93,*

>UNITS ?
FT,M

>extract or view the flie
e,v

.....

*Return to Main Menu

? Exit to Main Menu
Press ENTER key

.....

Conclusions of the consultancy of Mr. J. Beekma, summarized from his mission report, "Soil Salinization and Sodification in Tubewell Irrigated Fields, Punjab, Pakistan"

1. Model simulations with SOWATSAL can offer an interesting prediction of soil salinity developments under different scenarios. However, the model needs to be properly calibrated in all such applications, preferably on soils not under groundwater influence. It is not clear if the model will be useful for IIMI in the long term when a more integrated analysis of sustainability of present tubewell irrigation is needed. It is recommended that IIMI seek more expert advice on this subject.

2. Salinity trends seemingly are downward. The limited sampling depths, however, do not permit any firm conclusions in this respect. Soil salinity trends in the deepest samples might be a stronger indication, but are not conclusive either. If salinity increases considerably during fallow periods for most fields, the salinity clearly is not under control. It is strongly recommended to investigate this aspect in the near future, preferably for fields where salinity was previously determined.

3. Farm-level irrigation practices that jeopardize sustainability of crop production by emerging salinity can not be detected at present. It seems, however, that if a continuous water supply can be ensured, soil salinity is unlikely to pose a major threat on tubewell irrigated lands. For soil sodicity, no conclusions can be drawn as yet because sufficient time series data are unavailable. It is recommended to continue regular measurements on these aspects, consistently following the same fields.

Recommendations of the consultancy of Ir. J.C. van Dam, extracted from his mission report, "Simulation of Water and Solute Transport to Investigate Irrigation Management in Punjab, Pakistan"

1. In recent years IIMI collected a large amount of data concerning irrigation management and salinity and sodicity levels at different research sites in the Punjab Province. The measurements are valid for the soil, climatic condition, crop type, irrigation regime, water quality, etc. at the specific fields. The time seems ripe to employ agro-hydrological models to analyze the processes behind these data in order to transfer the measurements to other fields and alternative management practices and to predict long term effects for salinization and crop yield.

2. The agro-hydrological simulation model should be physically based, cover whole growing seasons and simultaneously describe water and solute transport. As the farmer cultivates and irrigates each field differently, the field is an appropriate scale of the agro-hydrological model. A geographical information system (GIS) can be employed to integrate the water and salt balance fluxes of the composing fields to a regional water and salt balance. The amount of data collection can be decreased by identifying classes of fields with the same hydrological behavior. Relevant characteristics, which are the criteria for the classes, might be derived by a sensitivity analysis with an agro-hydrological model in the study area.

3. On regional level the canal irrigation system and the use of tubewells should be investigated. This allows the formulation of realistic management options and prediction of the water distribution to the tertiary units. Next, together with the mentioned agro-hydrological model/GIS combination, the effect of various management options on regional salinization, crop growth, recharge to the groundwater, risks for sodication etc. might be evaluated.

4. The model SWATRE has some advantages with respect to SOWATSAL. SWATRE is more flexible in defining the upper and lower boundary conditions, heterogeneity of soils and effects of salinity on root water uptake. The FORTRAN code of SWATRE is more structured, and the program is actively maintained, documented and improved by the SWATRE group in Wageningen, the Netherlands. The program is used in various countries. IWASRI/NRAP has experience with the performance of SWATRE for Pakistani conditions.

5. Simulation of the sodication process requires a large amount of soil chemical data and skilful and experienced researchers to run the model. This seems beyond the responsibility of IIMI. Sodication might be more directly evaluated by measuring the unsaturated hydraulic conductivity in soils with a high SAR value or by adopting relations from literature.

6. It is worthwhile to extend the project "Managing Irrigation Systems to Minimize Waterlogging and Salinity Problems" for a second period. Although in some areas large investments in drainage and disposal of saline water seem inescapable, alternative ways should be found to prevent waterlogging and salinization. The measurements and simulations in this report support that appropriate water management alleviates salinization and waterlogging. New trends in Punjab with private tubewells and marketing of water rights increase the flexibility of water distribution.

7. Cooperation with IWASRI/NRAP in the Fordwah/Eastern Sadiqia site is encouraged. IIMI may profit from the expertise of IWASRI/NRAP in measuring soil physical data, simulating unsaturated flow and analyzing regional groundwater flow. IWASRI/NRAP may take advantage of IIMI's experience with irrigation management both on field and regional scale, their extensive data of soil salinity and sodicity, and the geographical information system used by IIMI. IWASRI/NRAP has experience with drainage aspects of (potentially) waterlogged and/or rather severely salinized areas. IIMI emphasizes prevention of waterlogging and salinization/sodication by using appropriate irrigation management. In the Fordwah/Eastern Sadiqia area both slightly saline soils with groundwater deeper than 3 m and highly saline soils with shallow groundwater tables are present. In order to alleviate the costs needed to reduce salinization and sodication, it is worth to investigate the merits and drawbacks of both approaches in this area.

Fordwah Distributary Command
Chishtian Subdivision

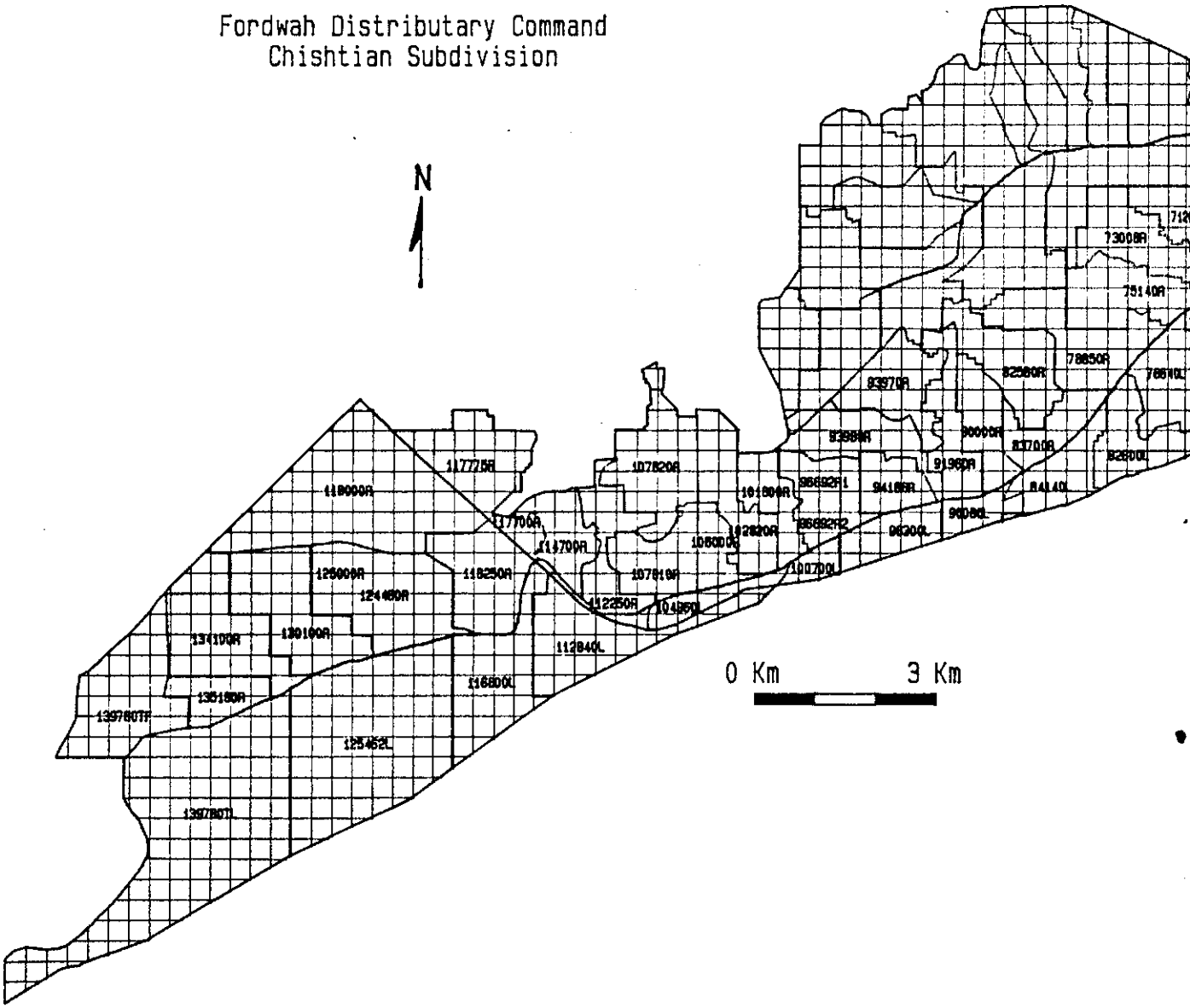


Figure 1

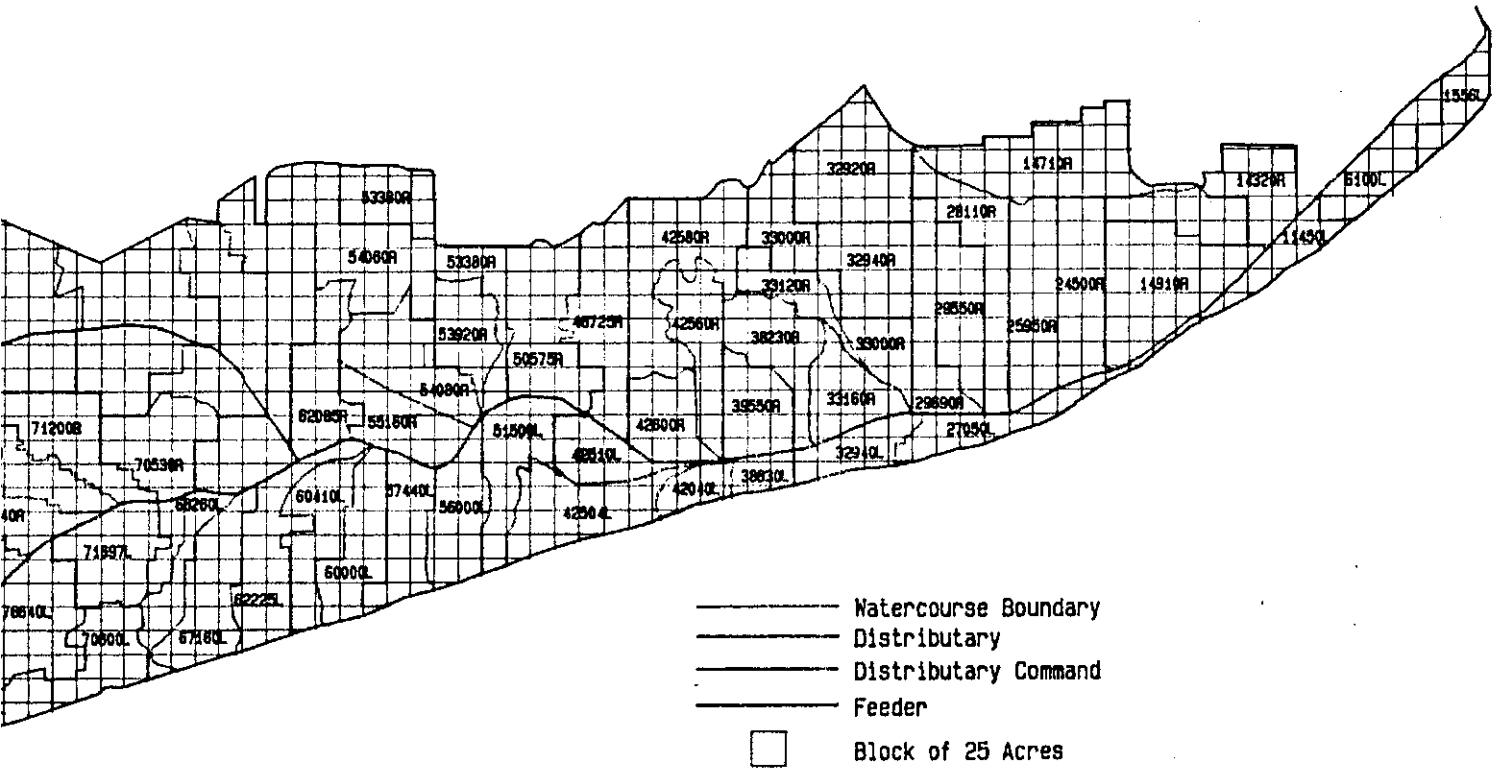
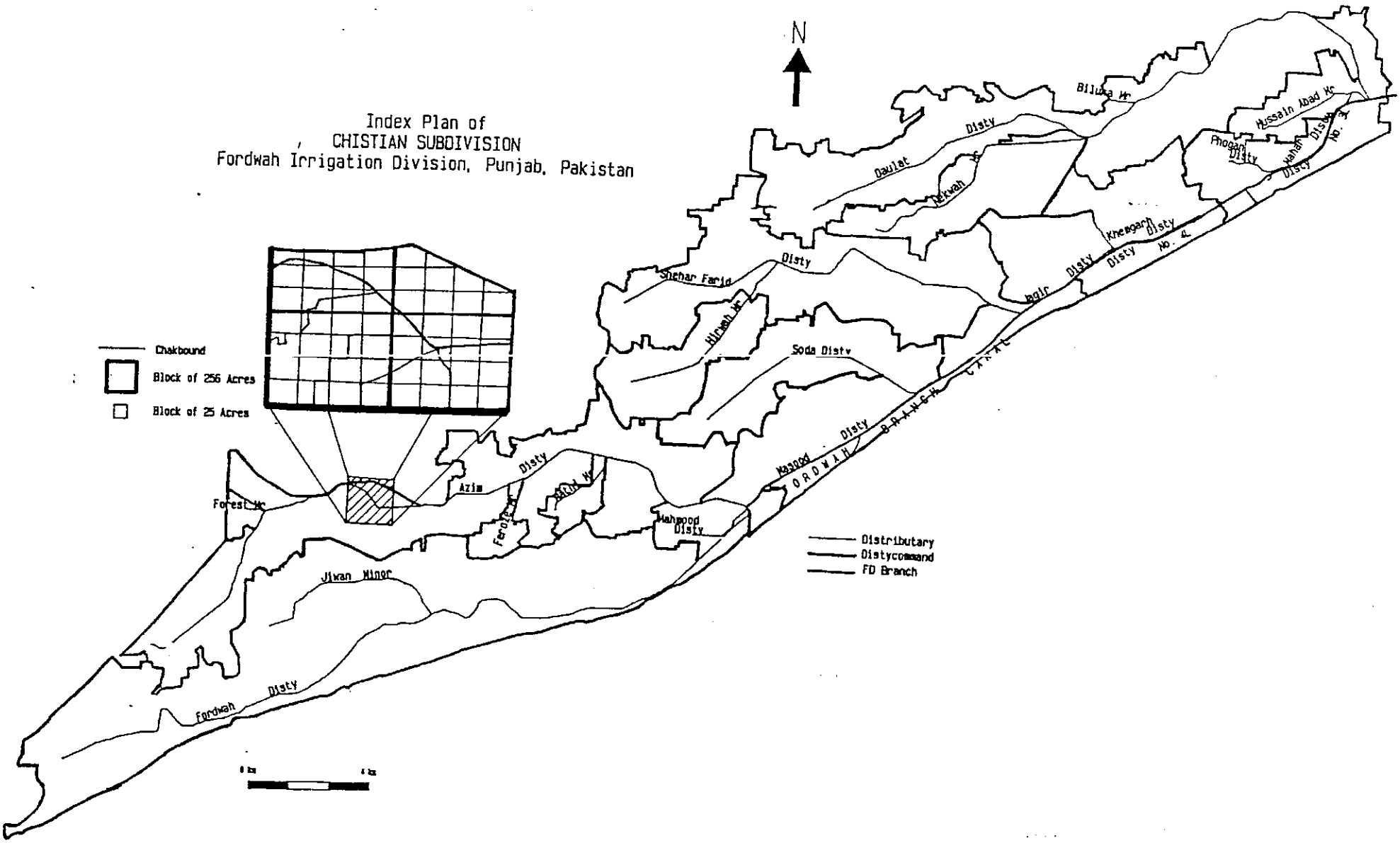
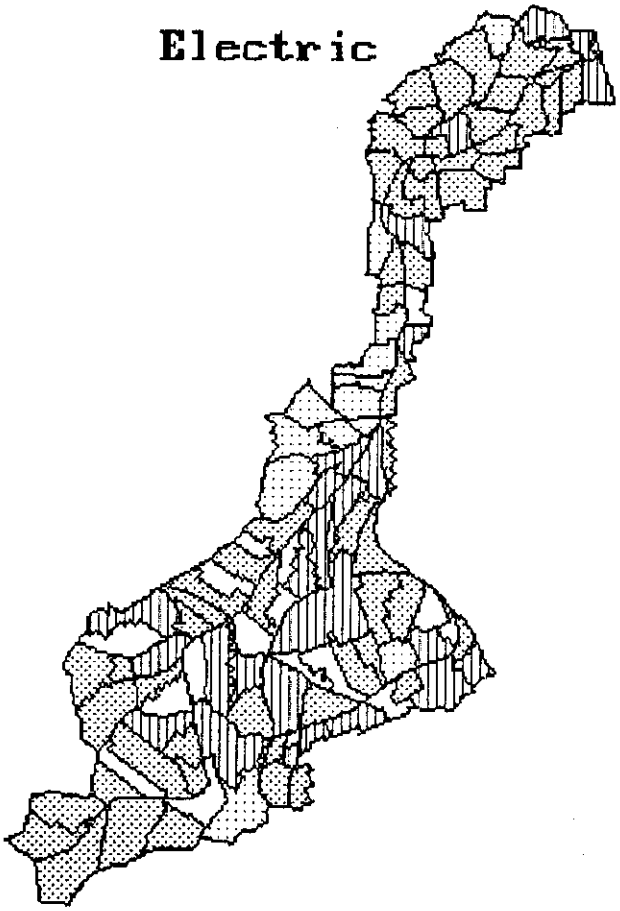

Watercourse Boundary
Distributary
Distributary Command
Feeder
Block of 25 Acres

Figure 2

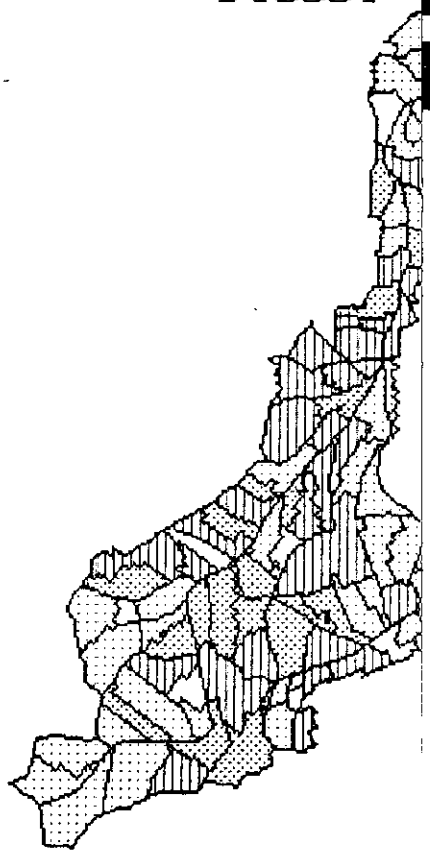

Index Plan of
CHISTIAN SUBDIVISION
Fordwah Irrigation Division, Punjab, Pakistan
N
Chakbound
Block of 256 Acres
Block of 25 Acres
Distributary
Distycommand
FD Branch
Forest Mr
Jiwan Minor
Fordwah Disty
Azim Disty
Shehar Farid Disty
Hiroh Mr
Soda Disty
Mahmood Disty
Daulat Disty
Bilura Mr
Khesgarh Disty
Hussain Abad Mr
Phogani Disty
Kahan Disty No. 3
Disty No. 4

Khar

Electric

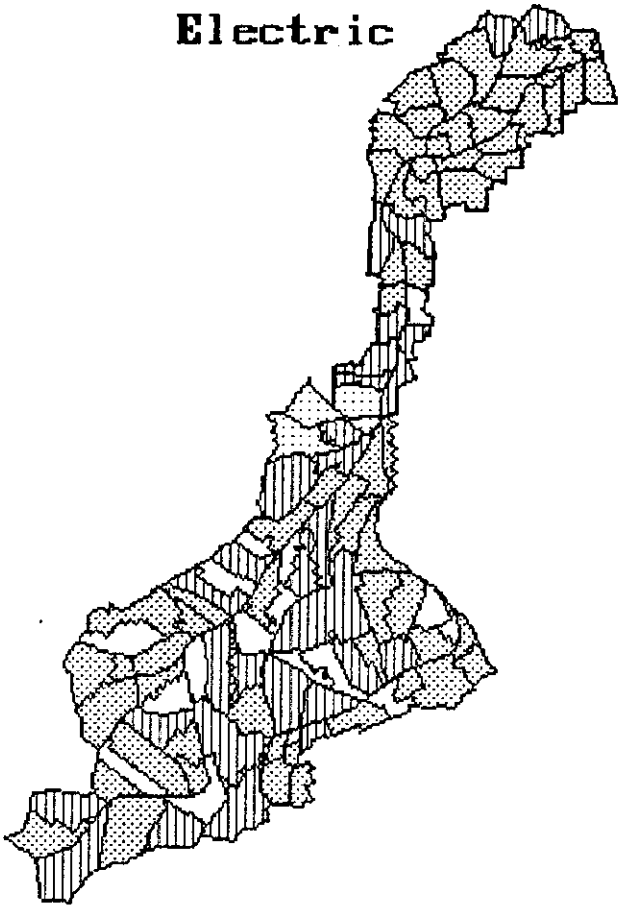


Diesel



Rabi

Electric



Diesel

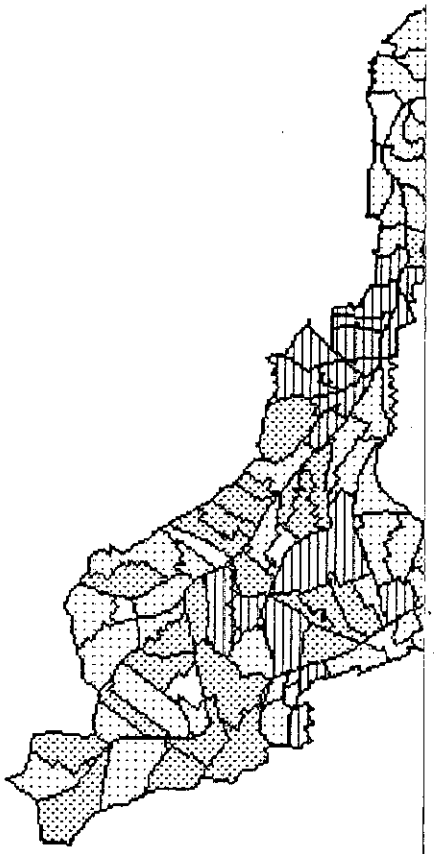
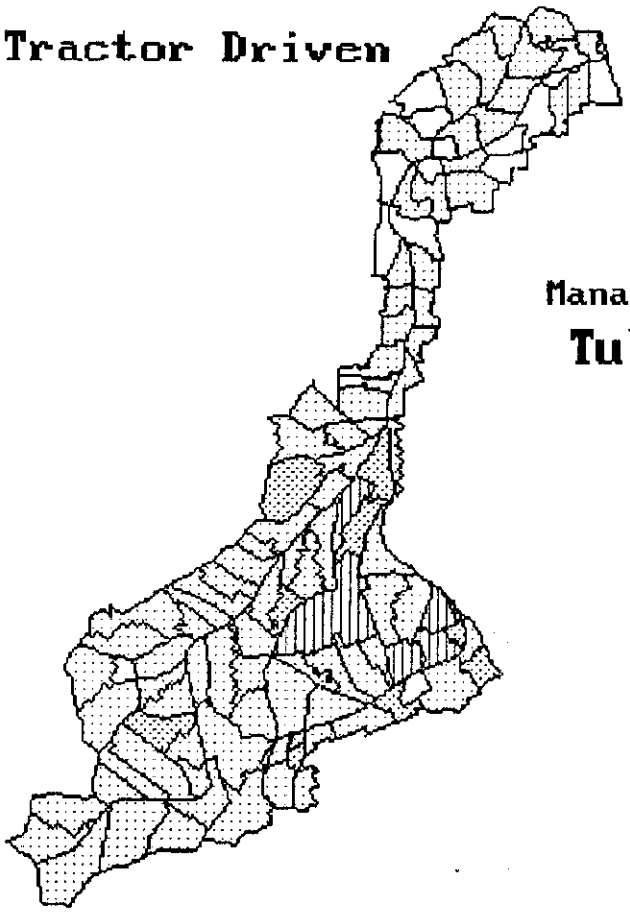


Figure 3

if Season

Tractor Driven

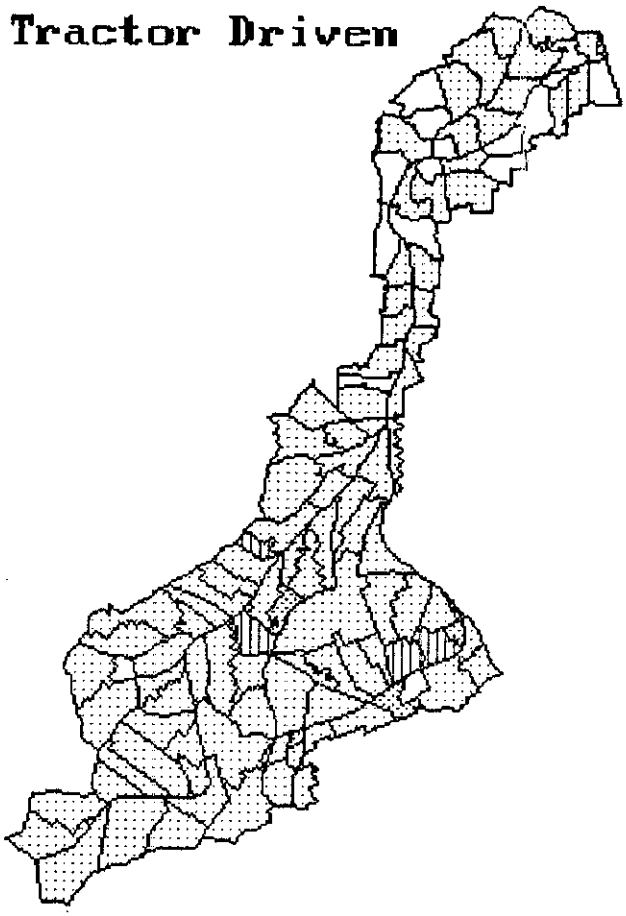


Mananwala Distributary Command

Tubewell Utilization

Season

Tractor Driven

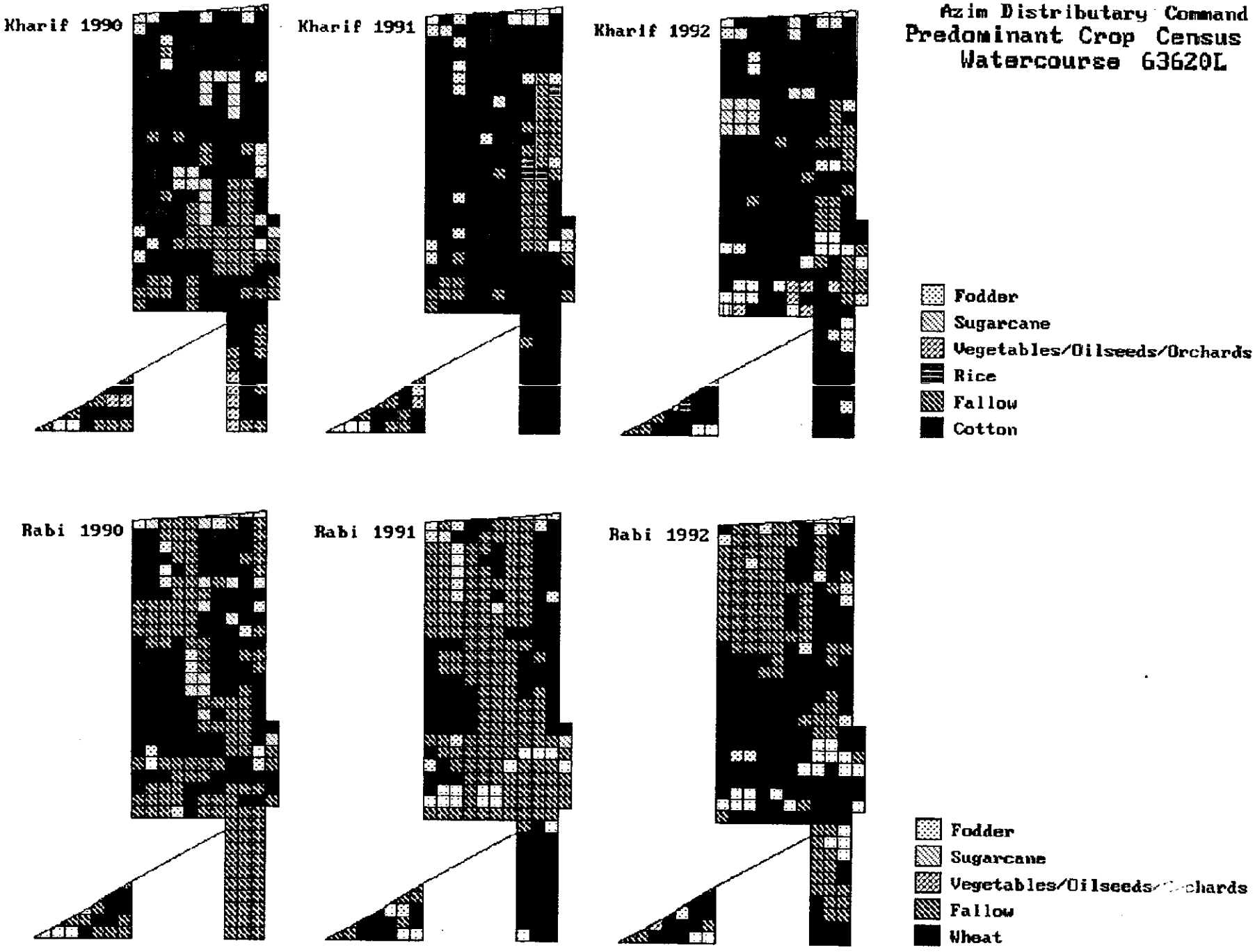


Utilization

- Low
- Medium
- High

Figure 4a

Azim Distributary Command
Predominant Crop Census for
Watercourse 63620L

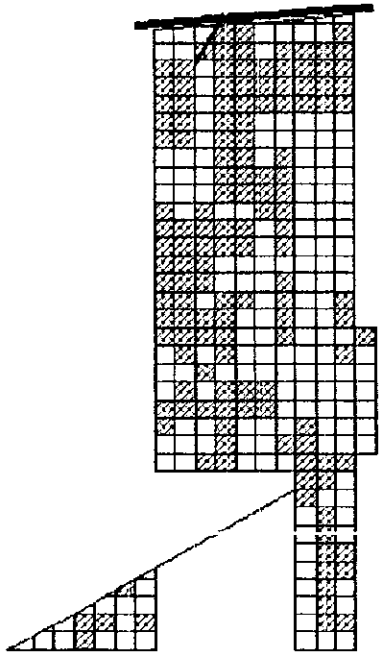


Cropping Pattern Changes

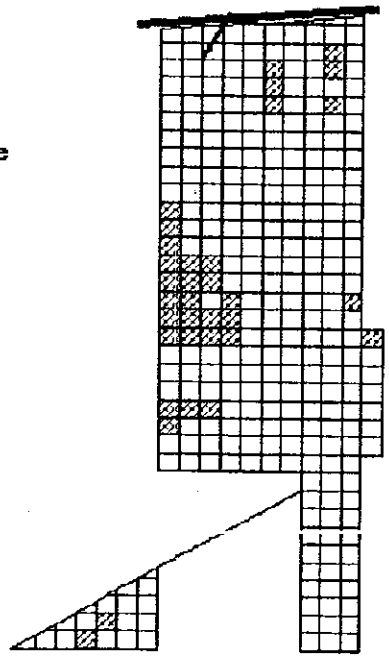
Azim Distributary

Watercourse No. 63620L

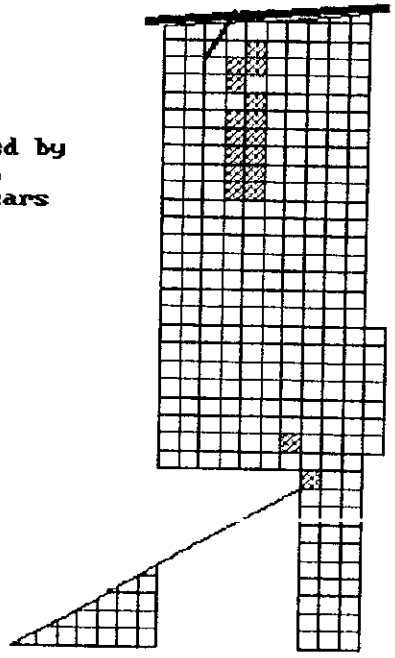
Figure 4b



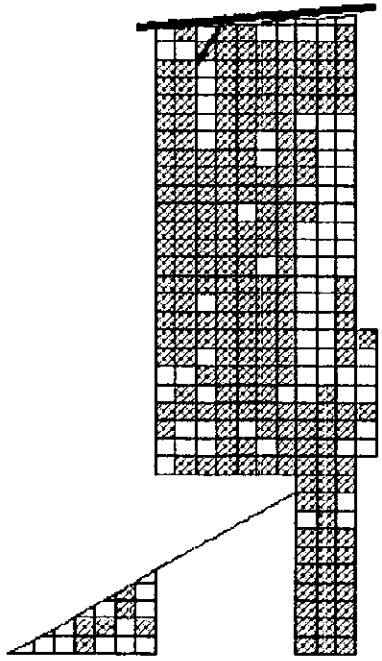
Cotton in three consecutive Kharif seasons



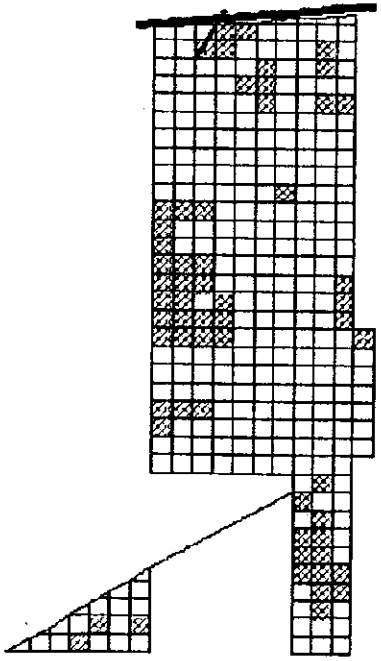
Cotton followed by Wheat in three consecutive years



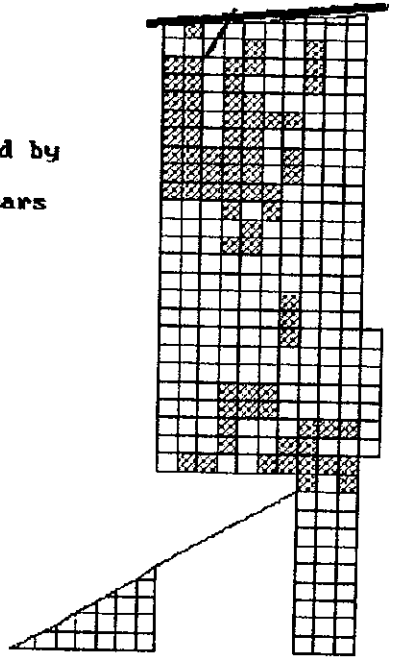
Cotton followed by Fallow in three consecutive years



Cotton in two consecutive Kharif seasons



Cotton followed by Wheat in two consecutive years



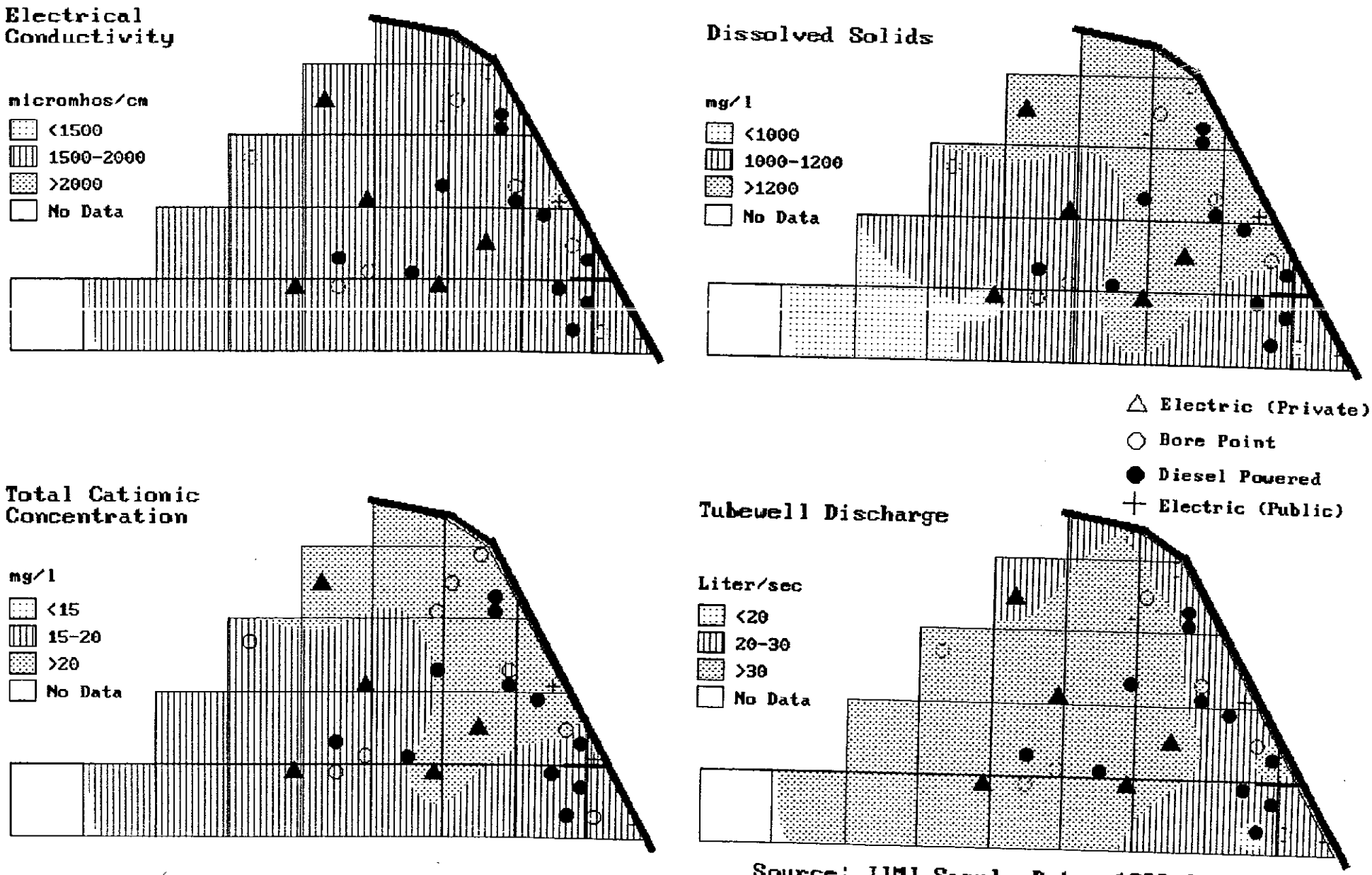
Cotton followed by Fallow in two consecutive years

Source:

IIMI Crop Survey
Kharif 1990-Rabi 1992

Figure 5

Junejwala Minor
Watercourse No. 46935L
Tubewell Water Quality Conditions

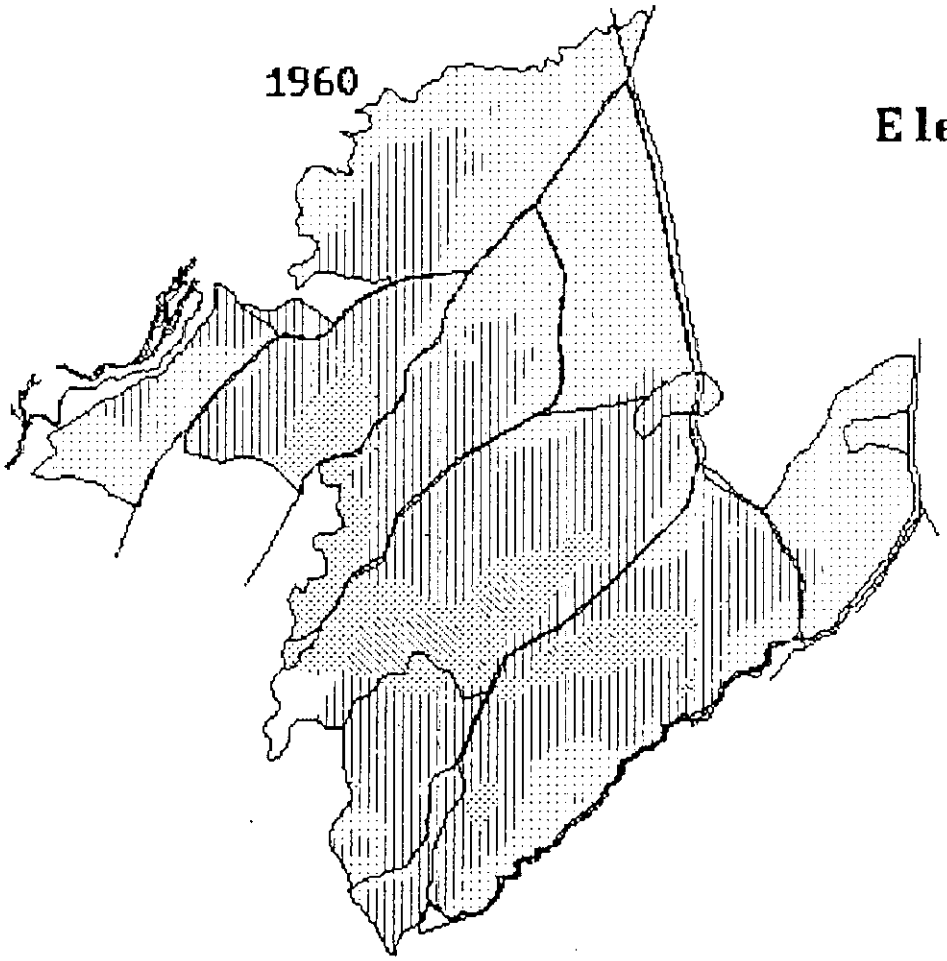


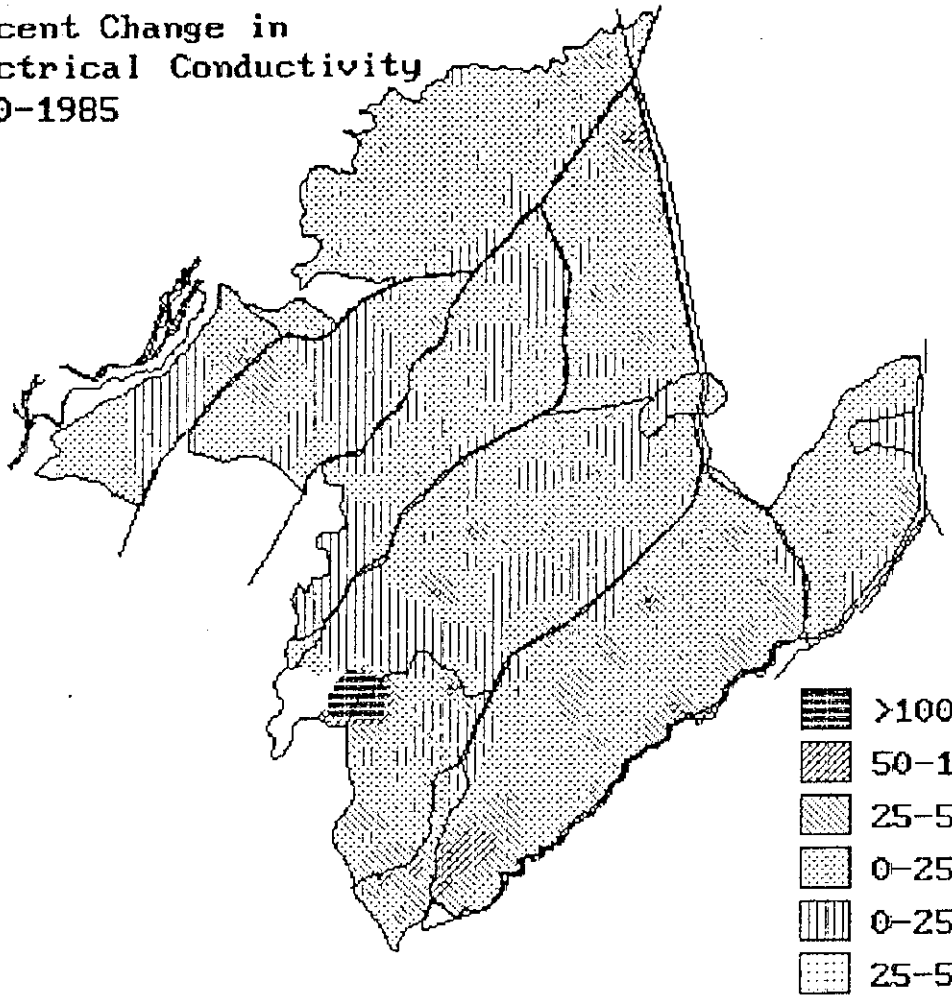
Source: IIMI Sample Data, 1989 & 1990

S

Electrical

Gro



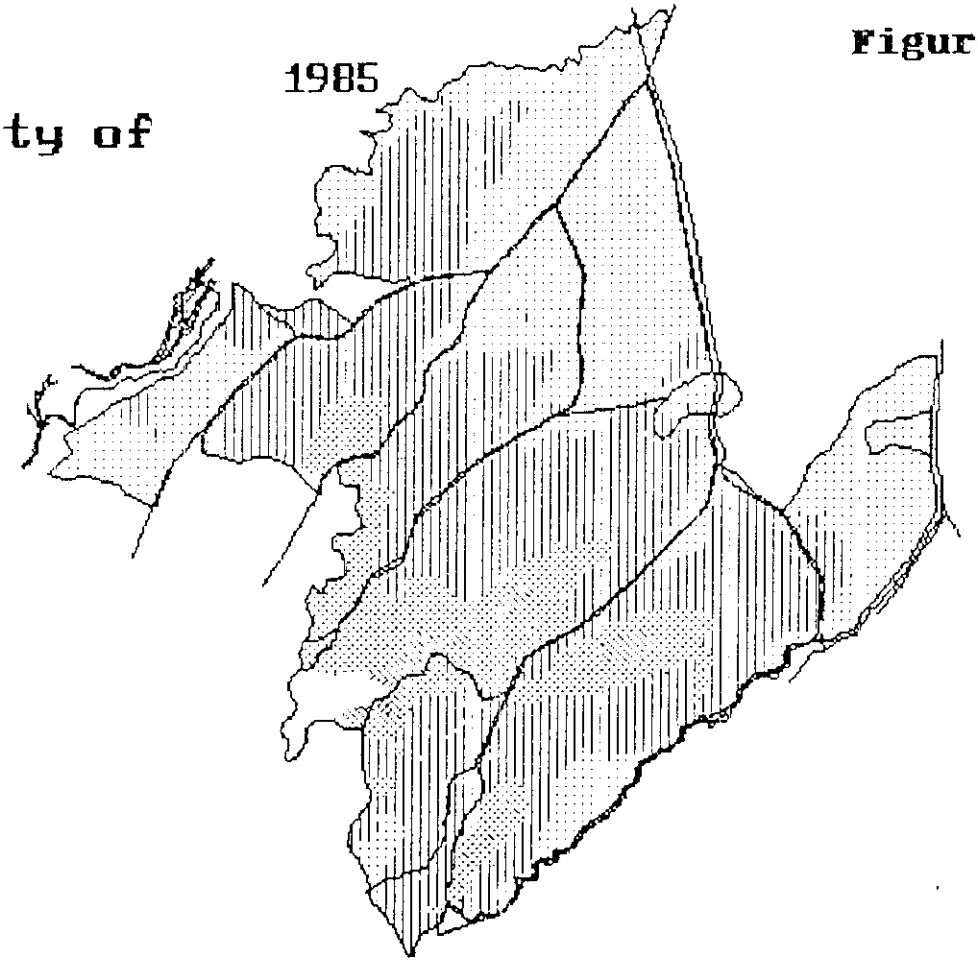


CARP-I

Conductivity of

undwater

Figure 6



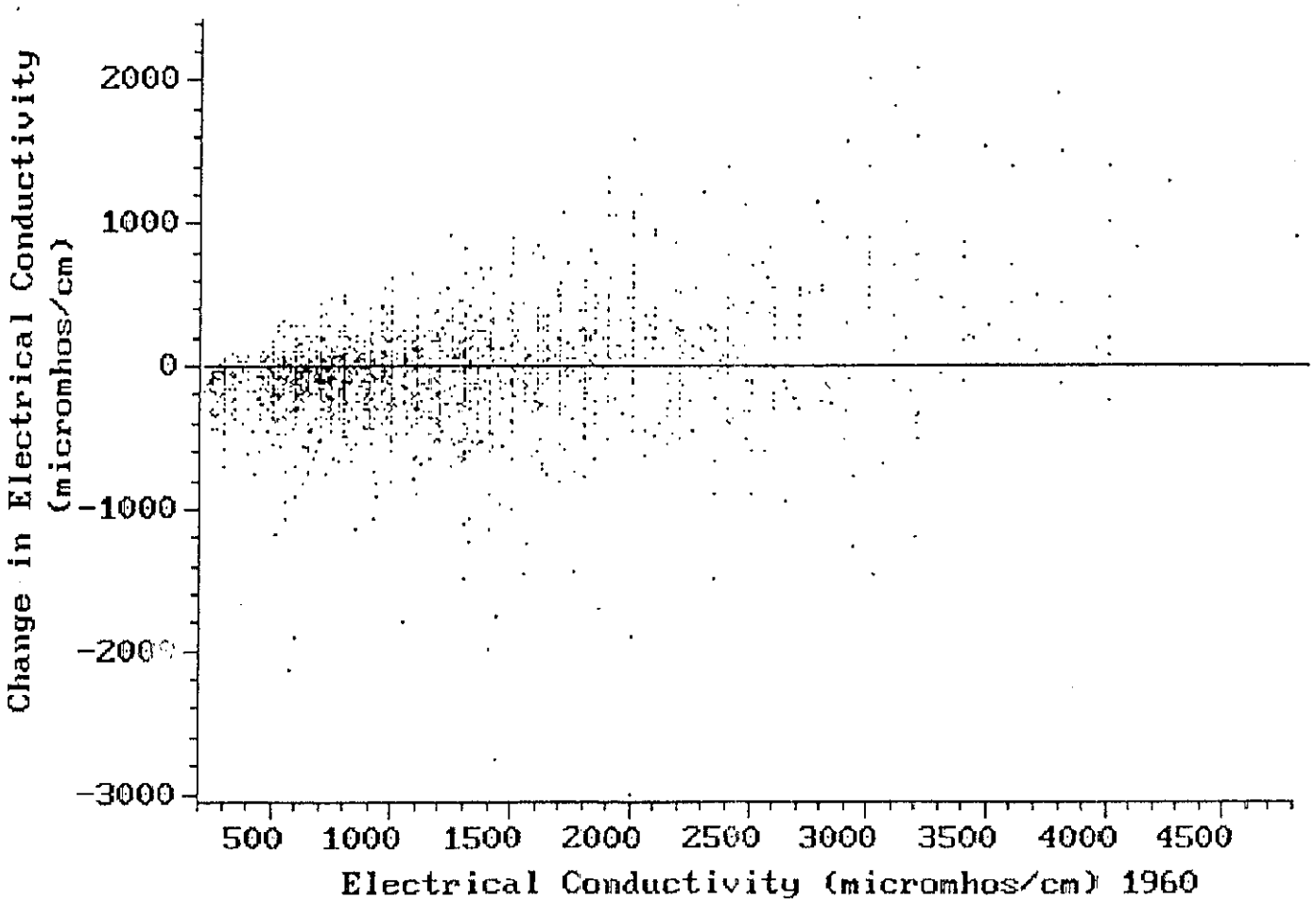
0 micromhos/cm

-2000

-3000

-4000

-4500



Source: Soil Monitoring Organization, WAPDA