# CHAPTER 7

# Issues in Conjunctive Management of Groundwater and Surface Irrigation Systems in Punjab, Pakistan: An Initial Assessment

**Robert L. Johnson and Edward J. Vander Velde**

ALTHOUGH THEY ARE much less readily visible (and often less frequently recognized) than the huge network of canals commanding 14-15 million hectares (ha) of the Indus Basin, groundwater irrigation systems have become a major, even critical, component of Pakistan's contiguous irrigation environment. Over very large areas, the surface irrigation system is supplemented by extensive public and private sector groundwater development. Where groundwater is of suitable quality and is readily available, both large public tubewells and rapidly expanding private tubewell development augment surface irrigation supplies. There are now more than 15,000 deep, vertical drainage public tubewells throughout the Indus Basin. Mostly organized in Salinity Control and Reclamation Project (SCARP) areas, these tubewells are operated by the provincial irrigation departments, but under units separate from those that administer the surface irrigation system. The number of shallow private tubewells owned and directly operated by farmers has increased rapidly in the past decade and now certainly exceeds 250,000.[26] Overall, it is estimated that 40 percent of the irrigation water currently available at the farmgate is derived from pumped groundwater, three-quarters of which is from privately owned tubewells.

The resulting irrigation environments can perhaps be best characterized as ones where de facto conjunctive use of surface water and groundwater irrigation systems predominate. However, the ways in which current private and public tubewell operations intersect with canal system operations in these environments, complementary to or even conflicting with each other, remain poorly understood. There is still in Pakistan a marked absence of reliable, current, empirically based information on private tubewell location, discharge, service area and hours of operations, and virtually none organized on the basis of a major hydrologic or surface irrigation unit, such as a distributary command. In the case of public tubewells, while their locations are well-

---

[26] See Robert Johnson, *Private Tube Well Development in Pakistan's Punjab: Review of Past Public Programs/Policies and Relevant Research* (IIMI Country Paper-Pakistan No. 1, 1989) for a recent summary review of past government programs aimed at stimulating private tubewell development, as well as emerging issues in this irrigation sector.

known, recorded data of their discharge, operating times and command area have become increasingly suspect.

Not surprisingly, then, the relative proportions of publicly and privately pumped groundwater that are combined with surface water by farmers to meet their crop water requirements, in different seasons and for different crops in a canal command, are largely unknown. How do these proportions vary spatially over an entire distributary or canal system command? To what degree, if any, do public and, perhaps more importantly, private tubewell operations compensate for the observed variability and inequity in the distribution of surface supplies? These and related questions of groundwater quality, public tubewell turnover and farmers' access to private tubewell water are the foci of IIMI research begun in January 1988 on groundwater irrigation systems and their interactions with surface irrigation systems in a distributary command of the Lower Chenab Canal system.

## THE RESEARCH LOCALE: CONTEXT AND DATA

The site chosen for initial research activities on groundwater systems was the Lagar Distributary command in the Lower Chenab Canal system where previous field work, focusing upon distributary-level canal performance, had already demonstrated that public and private tubewell development were significant components of the overall irrigated agricultural system. The research locale is wholly within a part of the SCARP I project area, the first Salinity Control and Reclamation Project to be established in Pakistan, in 1960-61. Part of the distributary command traverses the area of the older FAO-assisted Chuharkana public tubewell scheme, one of several early deep tubewell projects in Punjab that led directly to the decision to embark upon the SCARP.

More than 30 operating SCARP I tubewells, as well as Rasul and FAO tubewells (virtually all of which are rebores of previously existing public tubewells), are situated within Lagar's gross command area of 7,465 ha. These wells are under the operational control of the Punjab Irrigation Department (ID) and are located within the administrative boundaries of one or another of three different tubewell subdivisions, all of which overlap some part of the ID's Farooqabad (canal) Sub-Division. A portion of one ID tubewell subdivision, Khanqah Dogran Sub-Division, is the site of the SCARP Transition Pilot Project, the initial effort in a Federal program to turn public tubewells over to the private sector.

With respect to irrigated agriculture patterns, the research locale is situated in Pakistan's rice-wheat agroecologic zone. Rice, especially basmati rice varieties, is the predominant crop of choice in the *kharif* (summer, monsoon) season, and wheat dominates the winter and drier *rabi* season to an even greater extent. Fodder crops are an important component of the total cropping pattern throughout the year. All crops are grown under irrigated conditions with water supplied variously from surface, public tubewell and/or private tubewell systems.

The first step in this research was to plan and implement a tubewell census that covered all of Lagar Distributary command. Data from this census were compiled on a watercourse command basis and they included the specific location of the tubewell (using the unique square and *kila* number assigned to every field in the landownership record), the type of tubewell (electric, diesel, or tractor power takeoff), its age and operational status, and other supplementary information. Completed in early 1988, the initial Lagar tubewell census has been updated by periodic resurveys. This is the first time in Pakistan that a census of private tubewells has been organized for the whole of a large operational unit of the surface irrigation system. Similar censuses were also completed in four IIMI sample watercourses in the neighboring Mananwala Distributary.

The census results provided the basic sampling frame for a program to monitor the operations of all private tubewells in each of four watercourse clusters within Lagar Distributary command. One group of three watercourses, plus an intervening area commanded only by a public tubewell, represents the top-end of the distributary; a second cluster of four watercourses is in the middle reach of the channel; a third cluster of four watercourses is at the tail; lastly, a group of three watercourses is in the command of Jhinda Minor, a small channel offtaking from Lagar about half-way down the main distributary. All operating public tubewells in Lagar Distributary command were also included in the monitoring program which began in mid-1988.

The Irrigation Research Institute (IRI) of the Punjab Irrigation Department joined IIMI in these research activities in late kharif of 1988, in a measurement program to determine tubewell discharges, drawdown, horsepower, and water quality of all tubewells, public and private, that are being monitored. Discharges of surveyed tubewells have been periodically remeasured, using fluming and coordinate methods, by IIMI field staff. Tubewell water quality was initially evaluated at the Department's Directorate of Land Reclamation (DLR); subsequent water quality analyses for resampled tubewells have been done both by DLR and the SCARP Monitoring Organisation (SMO) of the Water and Power Development Authority (WAPDA). Additionally, with IIMI support, IRI conducted a resurvey, in mid-1989, of the small sample of private tubewells in Sheikhupura District first studied and subsequently reported upon by the ID in the mid-1970s.

Tubewell operational data have been obtained by IIMI through several methodologies. Electric meters of operating public and private tubewells (many do not function at all!) have been individually calibrated and are periodically recalibrated for each tubewell to determine the number of units recorded per hour of well operation. Readings of these meters are then regularly recorded by IIMI field staff, and operating hours of those tubewells are determined through a simple arithmetic calculation.

Operating hours of other public tubewells and both electric and non-electric private tubewells have been obtained by installing a simple vibration meter (similar to a pedometer) to the discharge pipe or, in some cases, to the motor of the wells. When operating properly, these meters give a direct reading of operational hours (within +/- 3 percent) of the tubewell. However, in some instances, notably in the case of electric motors, well operation is so smooth that the meter does not vibrate sufficiently to accurately record operating time.

Finally, for many private tubewells, owners are systematically interviewed by IIMI field staff to determine the time that their tubewell was operated the previous day. This is done on a daily basis because, after several months of interview, methodology testing and independent verification, it was found that the accuracy of responses to questions on tubewell operations declined precipitously if the owners were interviewed more than a day after the operation.[27]

A subsample of 45 private tubewell owners in head, middle, and tail watercourse commands of Lagar Distributary was selected in order to identify and quantify the determinants of private tubewell utilization at the farm level. After extensive field-testing of research design and methodology during rabi, 1988-89, data collection for this research was begun in the 1989 kharif season. Detailed water budgets have been maintained for each tubewell owner's farm. Closely coordinated with this study, field investigations were also begun in order to determine more accurately the accessibility of private groundwater resources for those farmers who do not own tubewells. Results from these activities are not available as yet since field work on them has only just been concluded.

## THE GROUNDWATER IRRIGATION SYSTEM WITHIN A SURFACE SYSTEM

As of May 1989, 338 private operational tubewells and 37 public tubewells, of which 31 are operational, were installed in the gross command area of Lagar Distributary. Another 54 operational private tubewells and 4 operational public tubewells have been identified in the four watercourse commands on Mananwala Distributary. All public tubewells are electricity powered using turbine pumps and have bores that are much deeper, (about 90 meters [300 feet]), than those of private tubewells, which are at an average depth of 30 meters (100 feet). Each public tubewell is ostensibly under the operational control of an assigned tubewell operator, an employee in the ID's tubewell operations wing. Most tubewell operators, however, are rarely at the wells for which they are responsible, although public tubewell operational logs give the impression that they are at the right places at the right time.

### Tubewell Distribution

The census revealed that throughout Lagar command, there is an average of one private tubewell per 22 ha of gross command area (GCA)[28] or one per 19.5 ha cultivable command area (CCA). Expressed another way, there are about 45 private tubewells

---

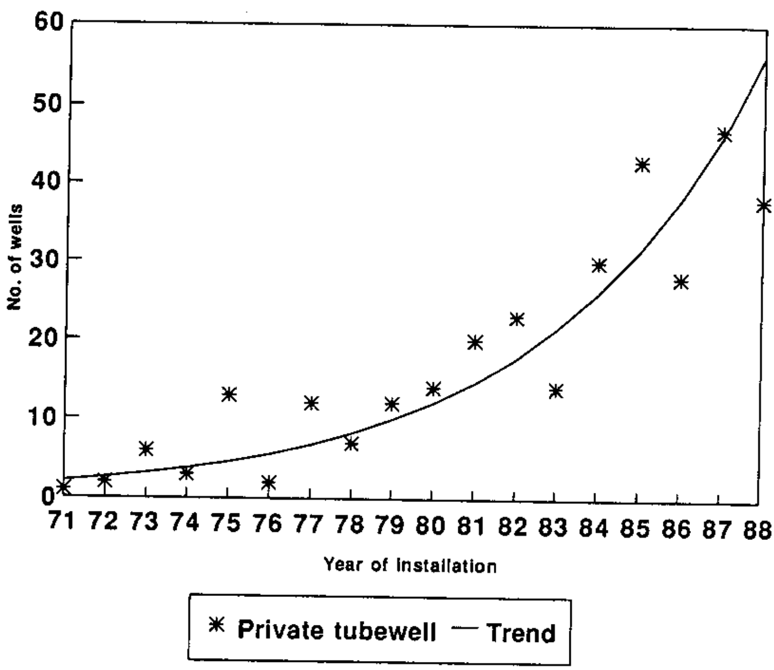
[27] That finding, verified through interviews with respect to several other agricultural activities, has important methodological implications for the organization of much irrigation-related field research, at least in this area of Punjab if not elsewhere in Pakistan.

[28] Watercourse gross command area (inclusive of irrigable area, nonirrigable area, settlement area, etc.) is used here, along with cultivable command area or CCA (irrigable by surface irrigation) because many tubewells were installed to serve areas that could not be irrigated by the surface system and, hence, are not (or were not previously) classified as CCA.

per 1,000 ha GCA or nearly 51 per 1,000 ha CCA. The density of tubewells in the smaller Mananwala sample is somewhat higher than in Lagar Distributary command, with an average GCA per tubewell of about 16 ha (or slightly less than one per 15 ha CCA). These densities are about 50 percent greater than those indicated by the most recent survey of private tubewells in this area, done as part of the feasibility study for the SCARP Transition Pilot Project in 1984-85.

During the 1980s there has undoubtedly been an increase in the number of new private tubewells in Punjab. Figure 7.1 shows this trend for Lagar Distributary command based upon farmers' responses to questions about the year of tubewell installation. The apparent growth rate in the number of tubewells also needs to be balanced with data on the useful life and the proportion of new tubewells that represent replacement of existing wells. These data are not now reliably available, although a period of 7-10 years is frequently cited as the life expectancy of a private tubewell. It also seems likely that private tubewell densities may have been

*Figure 7.1. Growth of private tubewells: Lagar Distributary command.*

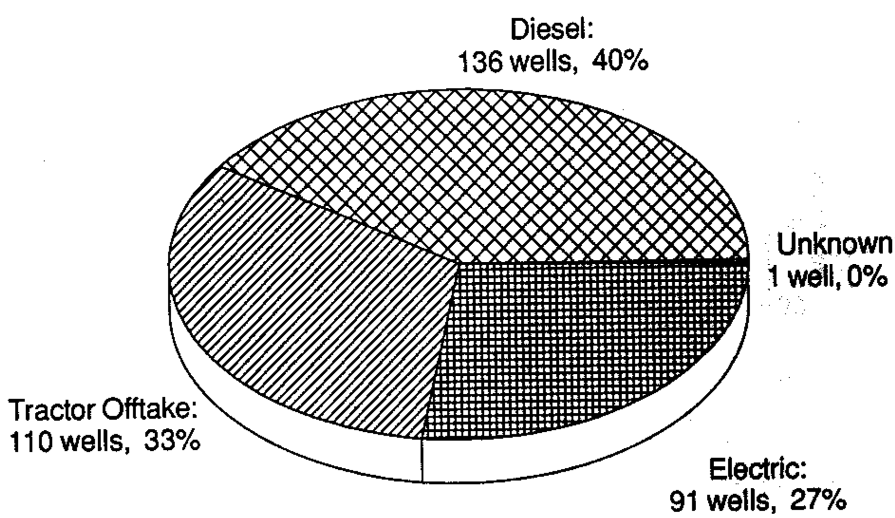


understated in recent studies because of difficulties in the accurate field enumeration of tractor-driven wells, which constitute nearly one-third of all tubewells identified in the IIMI census (Figure 7.2).[29]

Tractor-driven private wells seldom appear to be those of farmer choice, but they are especially interesting for several reasons. They have the lowest installation costs, excluding the cost of the tractor, but the highest operating costs. Despite their high operating costs, there are many locations where tractor-powered wells are the only source of irrigation water for farmers, and, among all tubewells, the variety of arrangements among farmers for their operation is by far the greatest. These include tractor ownership and ownership of one or several bores, tenant ownership of the bore with the landowner providing the tractor, farmers sharing a tractor among their own bores, farmers sharing a bore but each providing his own tractor, and bore-owners renting tractor services.

The spatial density of private tubewells in each watercourse command of Lagar Distributary is shown in Figure 7.3 and Figure 7.4. The data reveal no clear trend toward an increase in private tubewell density between distributary head and tail, even

*Figure 7.2. Private tubewells by power source: Lagar Distributary command.*




[29] Tractor-driven wells typically consist of a shallow hole at the base of which the bore is made and a centrifugal pump is installed; a discharge pipe with a 90° bend then extends from this point a half-meter or so above the surrounding land surface. When such crops as sugarcane, cotton, wheat, rice or maize are approaching maturity, it is often impossible to see such a well unless it happens to be in operation at the time of observation. In previous government publications and other references, no particular mention has been made of this category of tubewell.

though distributary operations data demonstrate conclusively that surface supplies to the tail reach are consistently less in quantity and greater in variability than are deliveries to top-end watercourses. The possibility of such a relationship had been conjectured by several observers. The 1988 Report of the National Commission on Agriculture also specifically recommends incentives to encourage tail-end farmers to use groundwater to "compensate for inequities in the canal water distribution system." As will be discussed later, there appear to be good reasons for the absence of this pattern of tubewell distribution in Lagar command, as well as significant risks in policies that may seek to encourage such a development.

*Figure 7.3. Private tubewell density: Lagar Distributary command.*

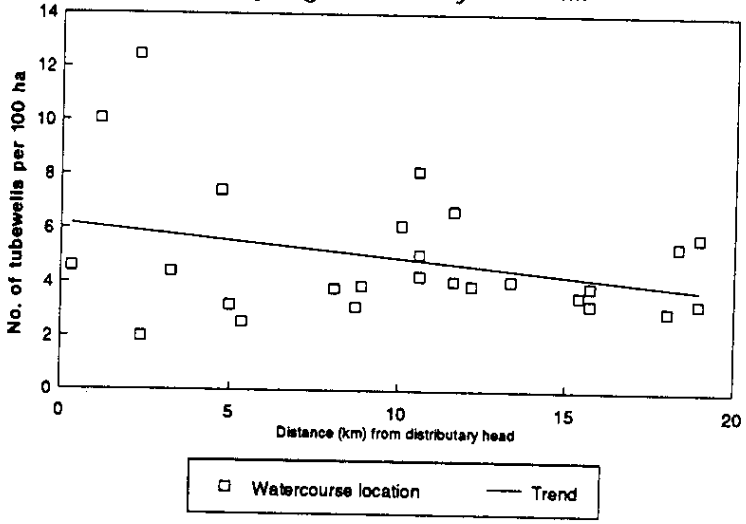
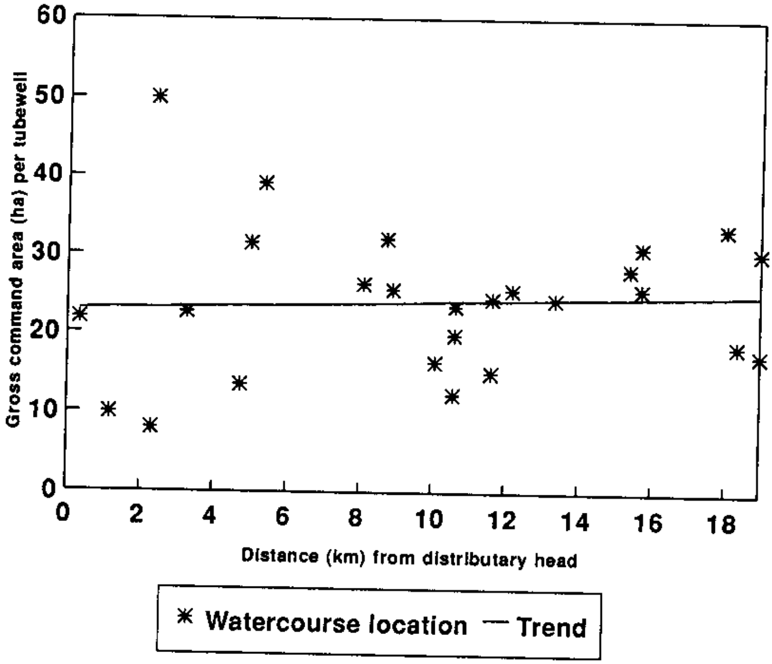



*Figure 7.4. Private tubewell distribution: Lagar Distributary command*



Twenty-four of the public tubewells included in this study are part of the SCARP I project area, either in Khanqah Dogran or Shahkot Sub-Division. Five of these wells are no longer operational, including two in Khanqah Dogran that have been formally turned off or abandoned as part of the SCARP Transition Pilot Project begun there in 1987. Generally, at least one public tubewell was installed in every Lagar Distributary watercourse command, typically located very near to the outlet so that its discharge could be combined with that of the surface system at the watercourse head for distribution throughout the command. Interesting exceptions to this pattern are found both in Lagar Distributary and in other distributary commands in SCARP I, but they tend to complicate any detailed analysis of present public tubewell operations and water use within a hydrologic unit.

This pattern of layout of the public groundwater irrigation system — the principal objective of which was more to manage the water table than to provide irrigation supplies — was not without significant problems (e.g., those resulting from the mismatch between design watercourse flows and greatly enhanced average water-course flow conditions). However, the use of the existing surface watercourse system to distribute public tubewell water to farmers meant that the existing equity principle of access to public irrigation water could, by and large, be maintained through the warabandi system, wherein an equal unit of irrigation time is allocated to each unit of irrigable area in the watercourse command. After more than 25 years of farm-level experience with, and accommodation to, the de facto conjunctive operations of public surface and groundwater systems in which the equity principle has been operative, there is substantial concern that equity in access to groundwater will not be sustained as public tubewells are replaced by increased private development of groundwater.

## Tubewell Discharge and Installed Capacity

For selected watercourse command areas along Lagar Distributary, more detailed data has been collected on both private and public tubewell discharges, depth to water table, and drawdown. Initial measurements were done by IRI on virtually one-half of the private tubewells in the area, and these have been supplemented by subsequent IIMI field observations and measurements.

Average discharge of private tubewells in Lagar command is about 30 liters per second (l/s) ranging between a low of 8.5 l/s and a high of 53.5 l/s. There is only slight variation and no discernible spatial pattern in these values between watercourse commands. The average discharge value is also basically the same as had been previously reported by IRI, based on their Punjab-wide surveys of private tubewells in the 1970s. Public tubewell discharge ranges between a little more than 9 l/s and nearly 110 l/s, averaging about 57 l/s. This average is considerably below the 85 l/s and 113 l/s design discharge for SCARP I tubewells.

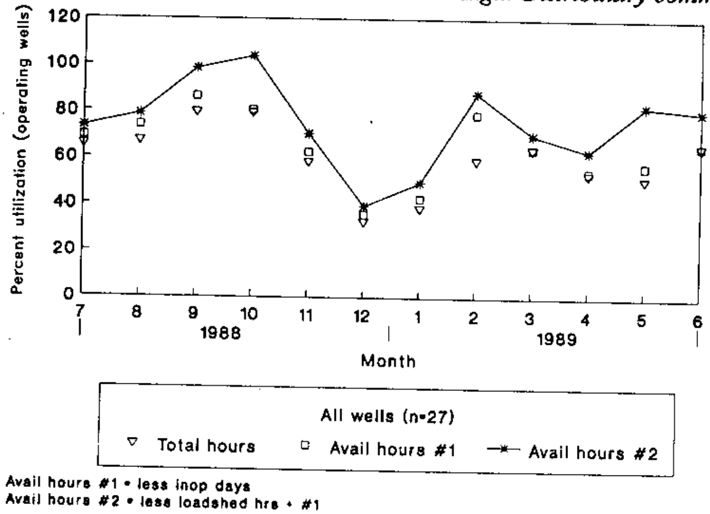
Using the average values to estimate for all operating private and public tubewells in Lagar command, the total installed operational tubewell capacity here is slightly more than 12 cu.m/sec. Public tubewells represent roughly 1.75 cu.m/sec or only about 15 percent of this installed pumping capacity. By contrast, the sanctioned full supply discharge for Lagar Distributary is only 1.08 cu.m/sec, less than one-tenth of the current installed tubewell capacity in its command. In reality, of course, the differential in the actual sources of total irrigation water supply is by no means so great, since tubewells, especially private ones, operate in much less of the available time than does the canal system.

## THE USAGE OF TUBEWELLS

### Public Tubewell Operations

Field measurement and observational data on public tubewell operations in Lagar and Mananwala watercourses for a 12-month period covering mid-1988 to mid-1989, provide considerable insights into operational patterns and problems. A high degree of variability in public tubewell operations between months is very evident (Figure 7.5).[30] Maximum levels of operation were encountered in September and October, undoubtedly reflecting both the overlapping of kharif season and rabi season irrigation demands, especially to finish the rice crop in the former case and to meet pre-sowing irrigation to raise soil moisture to field capacity for wheat in the latter case; these levels of operation also reflected the lower probabilities of significant rainfall in these months when evapotranspiration rates were still relatively high.

*Figure 7.5. Public tubewell utilization between months: Lagar Distributary command.*




[30] Field data have been adjusted as much as possible to reflect accurately the effects of equipment failures both in the tubewells themselves and in the electric meters used to determine operational time, the impact of electric power load shedding, and variable calibration factors resulting from changes in a multitude of environmental conditions (e.g., falling water tables, slow motor deterioration, slow bore failure, meter replacement, motor rewinding, etc.).

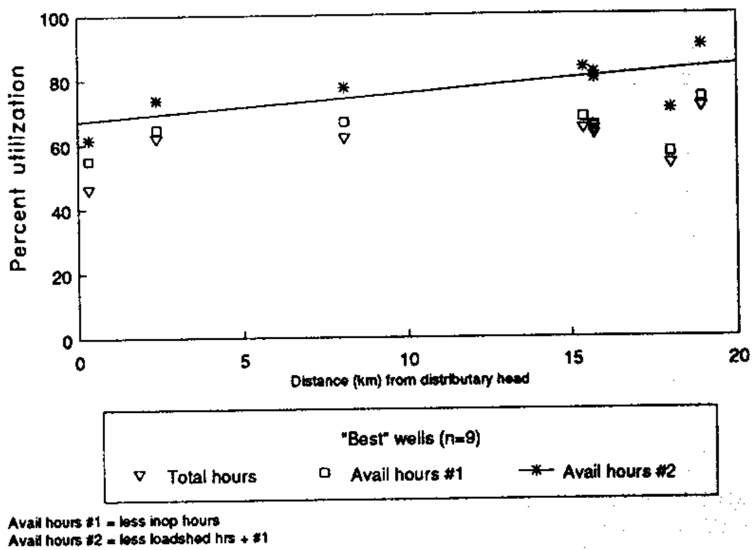
The months of least public tubewell operations were December and January, when they operated less than one-half as much as in the peak months. December and January were also the months when potential evapotranspiration (PET) was lowest. Although most farmers attempt to give the critical first irrigation to rabi wheat in December, usually in the second or third week, the public tubewell system is not "pushed" to deliver water so long as the surface irrigation system is effectively operational and some rainfall has occurred.

Such a conjunctive relationship is largely confirmed by conditions observed in February, the third highest month of public tubewell operations measured. In rabi 1988-89, February also coincided with the closure of the canal in Farooqabad Sub-Division for annual maintenance. While PET was still at a low level — calculated at 2.3 mm/day for February 1989 in Lagar command — public tubewell operations were nearly twice those of the preceding two months as farmers sought to give their wheat crops a second irrigation when the surface irrigation system was not functioning.

For the "best" public tubewells in Lagar command (i.e., those that have been inoperable less than one month throughout the year, due to equipment failure), the average annual utilization rate is nearly two-thirds of the available hours. When power system load shedding is accounted for throughout the year, however, the average annual utilization rate rises to three-quarters of the available hours.

When the location of these public tubewells is examined in relation to the distributary system (Figure 7.6), a gradual though distinct trend toward greater public

*Figure 7.6. Public tubewell utilization according to location: Lagar Distributary command.*



tubewell utilization is evident from head to tail. This trend is strongly associated with the pattern of marked decline in water deliveries by the surface system to outlets from distributary head to tail. Thus far, however, based upon currently available electricity feeder data, it remains unclear whether or not the impact of load shedding schedules has caused a spatial bias in the distribution of public tubewell water within watercourse commands.

Overall there is growing evidence that public tubewells, at least in Lagar command, in fact, constitute a farmer-managed irrigation system. In addition to largely determining their operating hours (e.g., by directly turning public tubewells on and off, or directing the activities of tubewell operators who, without exception, insist they cannot ignore farmer "demands" for fear of retaliation, physical or otherwise), farmers commonly organize to secure the maintenance of public tubewells. Farmers regularly search out the ID tubewell maintenance crews to directly negotiate tubewell repairs, organize transport to move them and their equipment from one site to another, provide meals and other incidentals to crew members, and pool funds to purchase needed parts or to influence key officials. In short, farmers do whatever is necessary to get an inoperable public well functioning again, provided it is still possible to do so.

## Private Tubewell Operations

Preliminary analyses of private tubewell operational data in Lagar command reveal their average annual utilization to be about 12 percent. Based upon installed capacities, this means that for the period for which direct comparisons can be made — at this time, only the last half of 1988 — private tubewells pumped about 15 percent more water than did public tubewells. Moreover, the combined pumping of public and private tubewells from the aquifer underlying the command area yielded water supplies (for farmers to irrigate crops throughout the command area) that were slightly more than double the design full supply discharge for Lagar Distributary. This highlights the extremely important role groundwater now plays in the system of irrigated agriculture in Lagar command.

Most importantly, the data show that there are distinct differences between the ways that private electric, diesel, and tractor-powered pumps are used. Electric tubewells operated during nearly 27 percent of the available time, a utilization rate almost 3.5 times greater than for diesel pumps and more than 10 times the rate for tractor-powered pumps. In short, private electric tubewells are used much more intensively than are either diesel or tractor-powered tubewells. As yet, there is insufficient data to draw firm conclusions about the causes of this pattern of private tubewell usage, but field observation and interview information suggest several plausible reasons for it.

There is some evidence that electric tubewells have more owners, or that their ownership is shared more widely than for other tubewell types. Hence, the average command area per private electric tubewell is greater than for other types of wells. Less certain at this time is whether or not electric tubewell owners use more water per unit area, either by planting crops that require more water or by irrigating the same crops with more water.

Electric tubewell owners also apparently sell more water than do other tubewell owners and they do so at lower costs per hour. Complementary observations suggest that wherever non-well owners have an option to choose between tubewell types when they need to buy water, electric tubewells are more frequently chosen. Many electric tubewell owners pay flat rate power charges which, in fact, is one incentive offered to stimulate further private tubewell development in the SCARP Transition Pilot Project area. Most other electric tubewell owners pay de facto flat rate power charges because their electric meters which were originally calibrated to show correct readings have been tampered with so as to show lower readings. Thus the actual cost of pumping groundwater for electric tubewell owners is a good deal less than the costs encountered by owners of diesel and, especially, tractor-powered tubewells.

Finally, current evidence indicates that private tubewell utilization, especially for the most intensively used types (electric and diesel-powered), is somewhat sensitive to the quality of groundwater being pumped. Private wells that pump good to marginal quality groundwater are worked at least 33 percent more intensively than those where groundwater quality is poor, except in the case of tractor-powered wells. That finding also tends to confirm the observation that tractor-powered wells fill a more site-specific niche in the overall irrigation system, as sources of water to fill recurrent gaps between supplies and demand rather than as farmers' primary sources of irrigation water.

## THE QUALITY OF TUBEWELL WATER

Certainly the most unexpected and immediately significant findings thus far from research on tubewells in Lagar Distributary command concern the quality of groundwater being pumped and used for irrigated agriculture. Although the distributary traverses an area that is commonly referred to as a "fresh groundwater area," the majority of tubewells, and notably private tubewells, pump water that is of marginal quality or unfit for agricultural purposes based upon the standards used by the Directorate of Land Reclamation (DLR) of the Punjab Department of Irrigation to classify groundwater quality.[31] This condition is shown for several standard measures of groundwater quality in Figures 7.7 through 7.10.

[31] Groundwater quality standards for determining the "fitness" of water for agricultural purposes has been a subject of considerable debate in Pakistan for the past three decades. It is fair to say that there is not, as yet, a commonly accepted standard here. In fact, at least three different ranges of values for such measures of water quality as EC, RSC, and SAR have been adopted by the Punjab Department of Agriculture (Soil Fertility Directorate), the Directorate of Land Reclamation (DLR) of the Punjab Department of Irrigation, and the SCARP Monitoring Organization (SMO) of the federal Water and Power Development Authority (SMO) for determining whether or not water is "fit", "marginal," or "unfit" (hazardous) for agricultural purposes. When these classificatory terms are used here, they refer to the standards adopted and used by DLR, which are as follows:

| | Fresh | Marginal | Hazardous |
|---|---|---|---|
| EC: | < 1,000 | 1,000 - 1,500 | > 1,500 |
| SAR: | < 1.25 | 1.25 - 2.50 | > 2.50 |
| RSC: | < 10 | 10 - 15 | > 15 |

*Figure 7.7. Private tubewell water quality - EC: Lagar Distributary command.*

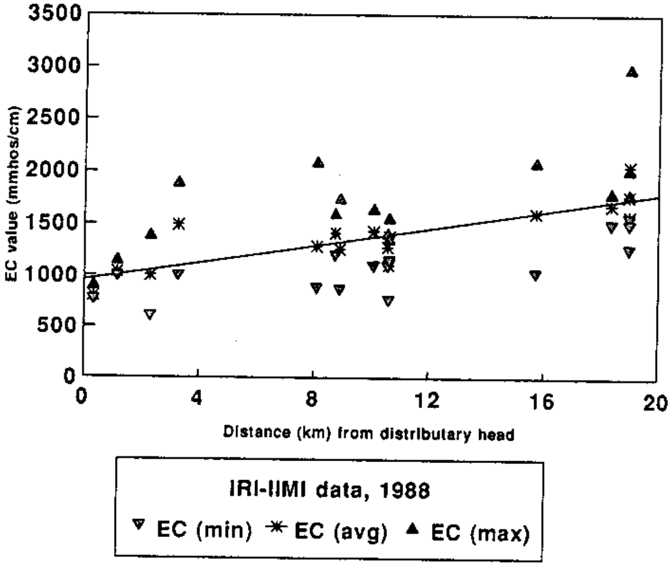



*Figure 7.8. Private tubewell water quality - RSC: Lagar Distributary command.*

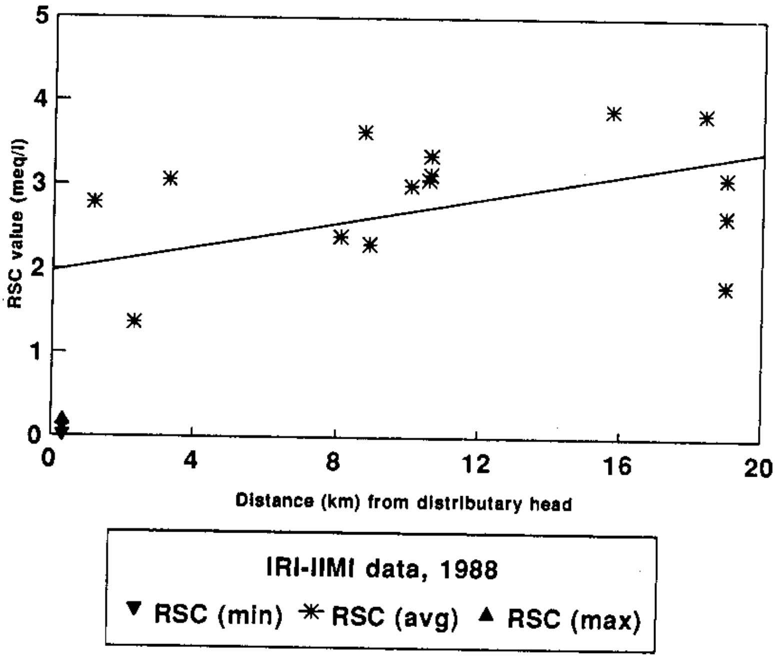


*Figure 7.9. Private tubewell water quality - SAR: Lagar Distributary command.*

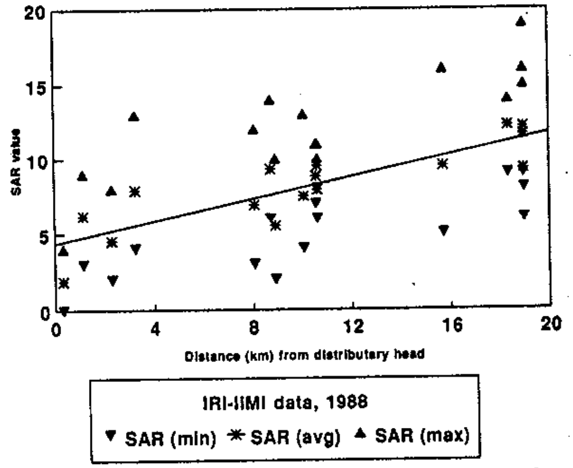
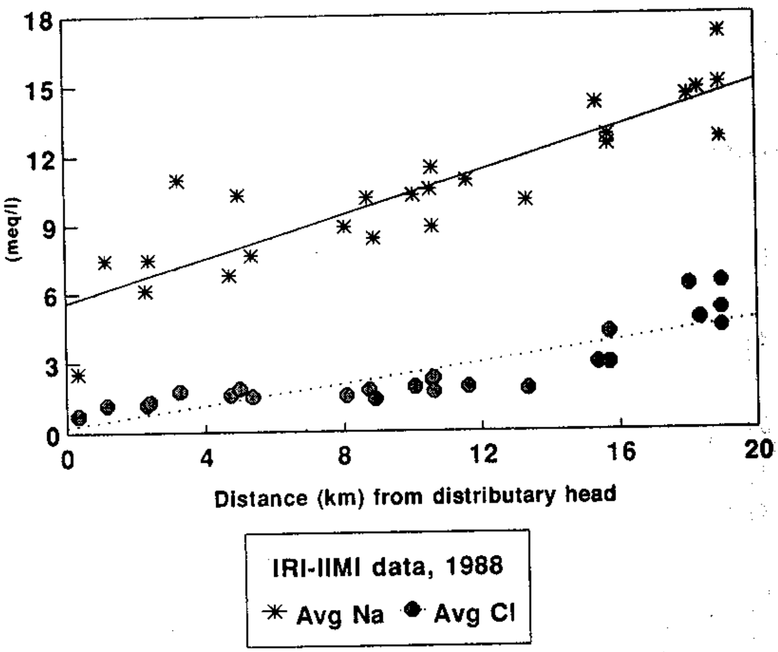



*Figure 7.10. Private tubewell water quality: Na & Cl: Lagar Distributary command.*

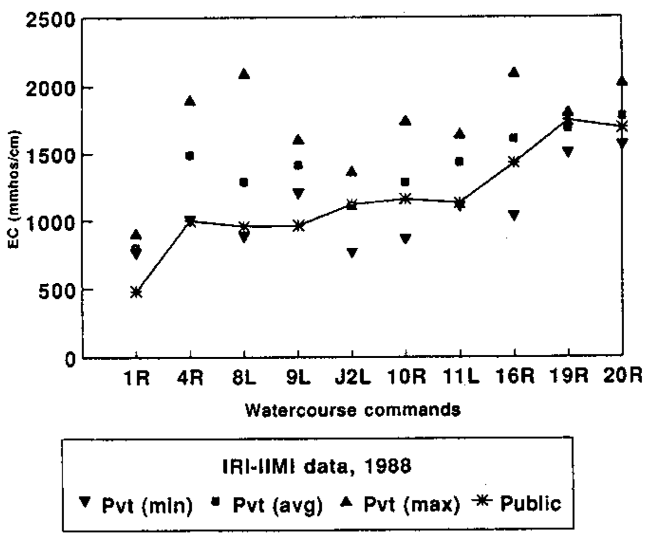



Interestingly, and contrary to a widespread perception of the relative quality of groundwater pumped by public and private tubewells, the average quality of water pumped by shallow private tubewells in different Lagar watercourse commands is not as good as that pumped by the corresponding public tubewells in that command

(Figure 7.11), despite the much deeper bore and greater age of public wells.[32] This finding has particularly important implications for policies and programs that encourage further privatization of groundwater development as an alternative to continuing government operations and maintenance of public tubewells, such as the SCARP Transition Pilot Project currently underway in this locale.

Conventional "wisdom" in Pakistan is that in addition to releasing the government from the heavy burden of increasing O&M costs, the shift from deep public tubewell water to water pumped by shallow private tubewells will bring about an overall improvement in the quality of groundwater used by farmers in any given watercourse command. The evidence from Lagar Distributary command strongly suggests that this may not occur in many cases.

*Figure 7.11. Private and public tubewell water quality: Lagar Distributary command.*




Most ominously for tail-end farmers already struggling with poor surface water deliveries, there is also a strong trend of deterioration in groundwater quality between the head and the tail of Lagar Distributary, as is evident in Figures 7.7 through 7.10.

[32] It is not at all clear why the perception that shallow groundwater is "sweeter" (better) than deep groundwater should have gained such widespread currency in Punjab and Pakistan. Analysis of test bore data for Rechna Doab, the area beween Ravi and Chenab rivers, maintained by WAPDA showed that as early as 1960, the majority of test bores sunk within the Doab had confirmed that the quality of shallow groundwater – aquifers tapped by the typical private well – was usually worse than the quality of deeper groundwater tapped by public tubewells.

The deterioration appears to be closely related to how far different watercourse commands along the distributary are from Upper Gugera Branch.[33] The consequence of this condition, of course, is to exacerbate the existing inequity of access to surface water supplies of tail-end farmers. When these farmers compensate for inadequate and unreliable surface water by using pumped groundwater, they must also do so with a poorer quality water than is found in the top-end watercourses of the distributary.

## CONJUNCTIVE USE OF SURFACE WATER AND GROUNDWATER

Agency-planned, coordinated or managed conjunctive operations of surface and groundwater irrigation systems do not exist in Punjab, and they have in fact been resisted for a variety of reasons (e.g., the "lack of flexibility and control in the gravity surface system," the absence of reliable information, inadequate communication systems, etc.). Nonetheless, there is substantial evidence that where both systems coexist, farmers have developed their irrigated agriculture based upon the conjunctive use of surface and groundwater supplies. As noted above, in the case of both public and private tubewells, the groundwater irrigation system in Lagar Distributary command is substantially under farmer control and management, albeit in the absence of any apparent overarching institutional arrangements to coordinate operations or to solve problems over extensive areas.

In the present environment, the surface system appears to be essentially a passive source of differential water supplies. Virtually everyone understands that location largely determines the amount of water and degree of service that can be expected from the canal system, and little can be done to physically change one's locational advantage. Moreover, farmers also know that even under the best of all possible operating conditions, it would be impossible for the surface system to supply the amounts of water necessary to sustain the present remunerative cropping patterns that emphasize sugarcane and fodders throughout the year, rice in kharif and wheat in rabi, at annual cropping intensities in excess of 100 percent of the command area.

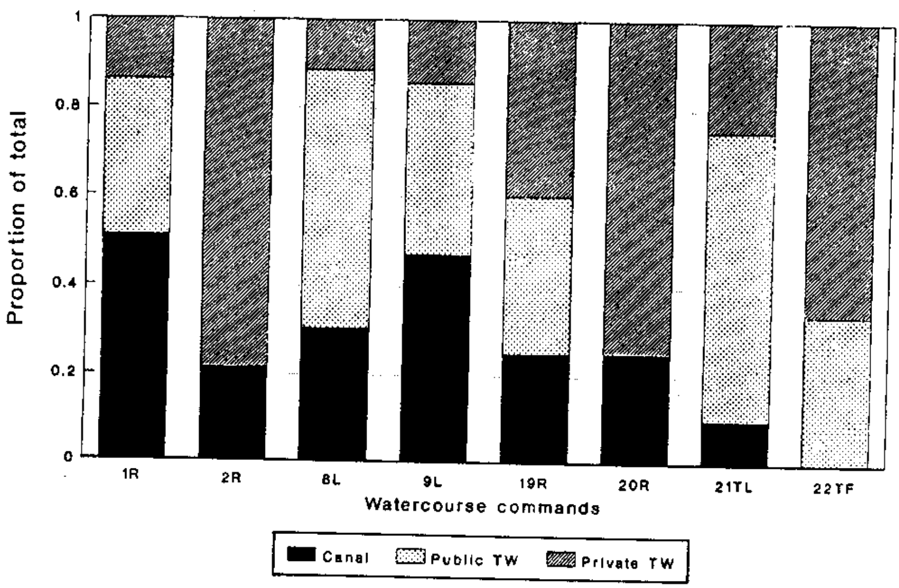
Thus, the canal system remains the "floor" for contemporary irrigated agriculture in much of Punjab, but it is quite a different floor than what it once was. No longer is

[33] This main canal is never more than 5 or 6 kilometres east of Lagar and it begins to assume an alignment roughly parallel to the distributary about 6 kilometres downstream from its head. The assumed relationship is based upon the observation that the decline of private tubewell water quality for watercourse commands on the southeast side of Lagar (closer to UG Branch) is less rapid than on the northwest side of the distributary. It is also based on the assumption that UG Branch and the QB Link Canal, paralleling it immediately to the east and generally carrying more than 500 cu.m/s, are the primary sources of aquifer recharge in the Lagar command area. A decline in the absolute level of the water table both with increasing distance from UG Branch and proceeding down Lagar Distributary also strongly suggests groundwater movement in this direction.

it the "floor" in the late 19th or early 20th century sense, protecting vast areas from crop failure and consequent famine conditions. In the late 20th century, the canal system has become the "floor" in the sense of a foundation upon which the present agriculture system for much of Punjab is constructed. In this context, it is now the groundwater system of both public and private tubewells which is actively operated and managed to meet crop needs. The result, now clearly discernable in Lagar Distributary command is a number of small-scale, relatively discrete de facto conjunctive operation-and-use environments.

Data now permit an evaluation of irrigation water sources for an entire crop season for several different watercourse commands located along Lagar Distributary (Figure 7.12). They demonstrate that from head to tail, canal water supplies provide a decreasing fraction of the total water available to, and used by, farmers. Even in the most locationally advantaged watercourse command, 1R, surface water provided only slightly more than 50 percent of the total amount of irrigation water used by all farmers. In the two most distant watercourse commands served by Lagar, surface water constituted no more than 10 percent of all irrigation water used in the season.[34]

*Figure 7.12. Irrigation water sources: Rabi 1988-89: Lagar Distributary command.*

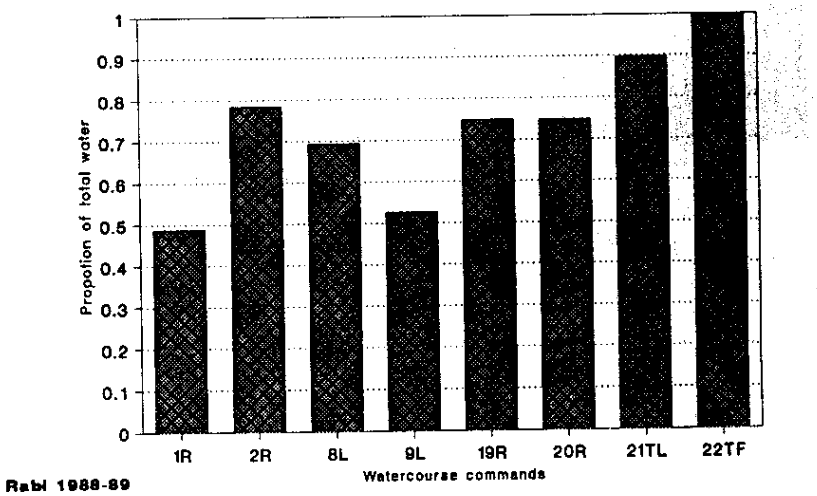



[34] The range of variation of irrigation water sources used by individual farmers within different Lagar watercourse commands is not yet known.

Conversely (Figure 7.13), there is an equally strong trend of increased reliance upon tubewells, differentially public and private, for irrigation supplies from head to tail along the distributary. In one tail watercourse command, only pumped groundwater and rainfall sustain the agricultural system, and a very large fraction of the former (Figure 7.12) is derived from private tubewells. The proportion of irrigation water contributed by the groundwater system elsewhere in the tail is also very large in comparison to proportions in other locations along Lagar, with one significant exception.

Watercourse command 2R is located advantageously in relation to the head of the surface system. It also has the advantage of a paved road that bisects the command, and it contains a large expanse of formerly undeveloped land that was too high to be served by the canal system. Over the past ten years or so, there has been entrepreneurial development of these lands by leaseholders using water from tubewells that they have installed for intensive cultivation of horticultural crops for sale to nearby urban markets. Nearly 80 percent of the irrigation water used in this command in rabi 1988-89 to sustain two successive vegetable crops came from private tubewells, the largest concentration found in any Lagar watercourse, all but one of which was in place before the public tubewell was disconnected as part of the SCARP Transition Pilot Project. In this watercourse command, conjunctive use means an interdependent coexistence of systems where tubewells always supply water to farmland that cannot be served by the surface system, and sometimes supply water elsewhere in the command area to supplement shortfalls in surface supplies.

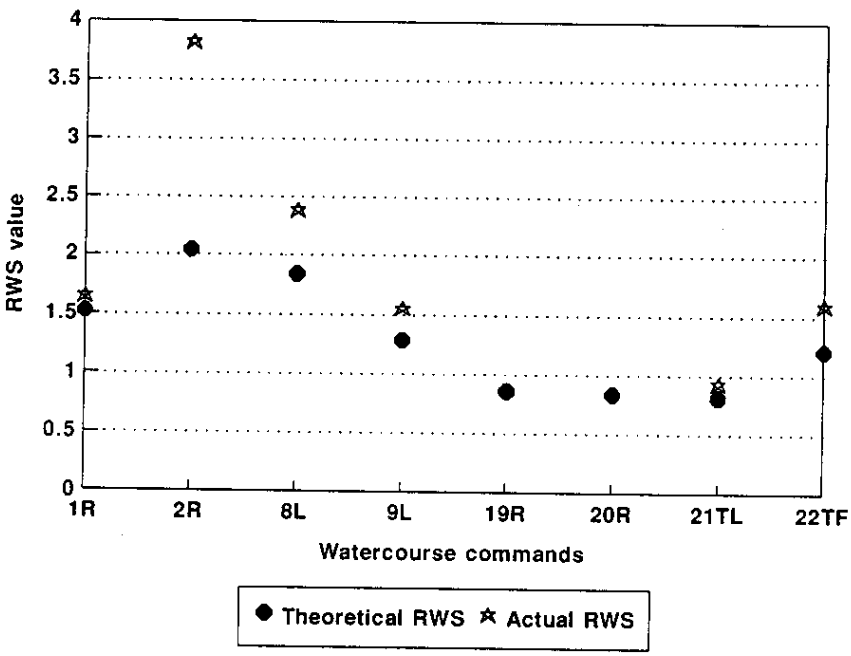
*Figure 7.13. Proportion of irrigation water contributed by tubewells: Lagar Distributary command.*



Private tubewells supply very nearly the same proportion of water for irrigated agriculture in watercourse 20R, virtually at the tail of the canal, as at 2R, but the crops grown there are markedly different. Wheat, not vegetables, is overwhelmingly the rabi crop, along with a small amount of fodder. The public tubewell in this command too was abandoned by the ID several years ago because it was considered irreparable. Farmers here continue to complain bitterly about its loss, because they claim that the water it pumped was of a much better quality than can be obtained now from their shallow tubewells. In this watercourse command the surface system is much more significant than the mere one-quarter of irrigation water that it supplies would indicate. Conjunctive use here commonly means interpenetration, mixing even small quantities of surface water with pumped groundwater to reduce the impact upon crops of the higher salinity of the latter.

The resulting relative water supply (RWS) conditions for different patterns of conjunctive use of surface and groundwater systems in these watercourse commands (Figure 7.14) suggest that in the aggregate, farmers aim for a relatively comfortable condition between 1.5 and 2, whether at the head of the distributary or the tail. While this is consistent with findings in irrigated agriculture systems elsewhere in South and Southeast Asia, these results still need to be considered as tentative and approached

*Figure 7.14. Relative water supply: Rabi 1988-89: Lagar Distributary command.*



with some caution.[35] Nevertheless, the strikingly similar RWS values for three Lagar watercourse commands, 1R, 9L and 22TF (head, middle and tail, respectively) are noteworthy.

At the tail, irrigation water is solely from tubewells, two-thirds of which is pumped by the private sector. In both 1R and 9L, only about 15 percent of all irrigation water is from private tubewells, and the public irrigation system — canal plus tubewell — supplies virtually all other irrigation water. This suggests that even when the total irrigation environment of surface and groundwater systems is evaluated, there remains substantial inequity (by a factor of 4 to 5) between tail-end and head-end areas in terms of access to the publicly provided water resource.

## CONSEQUENCES: POLICY IMPLICATIONS AND OPTIONS

Enough is now known from IIMI's research on groundwater and surface irrigation in Farooqabad Sub-Division of the Lower Chenab Canal system to permit an initial consideration of some management options that have potential to enhance overall system performance, and to permit identification of several issues with significant implications for irrigation sector policies. This paper concludes by beginning that process.

### Management Potentials

Moving from an environment of many separate de facto conjunctive use operations to a more interactive and coordinated conjunctive management of surface water and groundwater systems is likely to be a lengthy and difficult effort. Nevertheless, there exist some apparent starting points for the process, beginning with two periods of the year when it is essential that public tubewells operate at their maximum capabilities to compensate for known, or very likely, disruptions in surface water supplies.

Although efforts are made to schedule the annual closure for canal maintenance in rabi, it does not necessarily mean that during the months of minimum potential evapotranspiration (PET) most crops will not require an irrigation during this period, particularly given that closure periods extend for more than three weeks over many

---

[35] Overall, the RWS values presented here are approximate in the absence of other critical or more reliable data. In calculating RWS for the 1988-89 rabi season, the official calendar season (15 October through 14 April) was used; irrigated area data were from official records (there is some reason to be circumspect about their accuracy) and area planted to different crops was unknown; adjustments could not be made for water distribution inefficiencies and losses beyond the watercourse head or the tubewell discharge pipe; rainfall was assumed to be equally distributed throughout the distributary command (although observation indicates this is often not the case). Thus, for example, the true RWS value for 2R is likely to be rather lower, since about half the area is planted to two crops that span the rabi season and another two to four weeks on either side of it.

distributary commands and that this is the season of maximum planted area. Insofar as the annual closure is scheduled in advance by the Irrigation Department (ID) after consultations with WAPDA and the Agriculture Department, it ought to be a relatively simple matter for the ID to ensure that wherever public tubewells supply irrigation water, they are in the best possible operating condition. In short, a modest effort to target the expenditure of maintenance funds is more likely to achieve system performance improvement than the ad hoc procedures currently being followed. Similarly, since all public tubewells are electric-powered, WAPDA should target feeder line O&M to public tubewells for the same period. Also, if load shedding operations are mandated, they ought to be staggered or rotated so that the same wells are not turned off for the same period every day, every week, which is the current pattern for every WAPDA-mandated load shedding schedule.

The second period of opportunity occurs during kharif and, although perhaps less predictable, it, too, is well-known. During the monsoon or rainy season portion of kharif, canal flows are commonly reduced in response to river conditions to prevent heavy silt accumulations in the main and secondary channels. July, August and early September are the times when these actions occur, a period when crop water requirements are below peak levels but are still very high. Again, added stress often is placed upon public tubewells to make up surface system short-falls, and an organized effort to ensure their continued operations is especially likely to benefit the agricultural system. There is no evidence that this is currently done, nor any suggestion that it could not be done.

With respect to the surface irrigation system, there is a complement to the options that focus on the public tubewell system. In May and June, especially (the months of maximum temperatures throughout the Indus Basin), WAPDA's electric supply system is stressed beyond capacity. All available evidence confirms that this condition will worsen over the next few years before it improves. This is a period of maximum scheduled load shedding for the power supply system. Therefore, it is logical that at this time additional emphasis should be placed upon maximizing efficient canal system operations in order to compensate as much as possible for disruptions in the operations of public tubewells and electric-powered private tubewells. Canal operations data for Lagar Distributary in kharif 1988 demonstrated that sustained levels of near-design discharges in May are possible, and one consequence then was a minimum level of head to tail inequity in surface water supplies. This could also take the form of increased maintenance patrolling, to ensure that weak points in the system are promptly reinforced before breaches occur, and to discourage, if not completely prevent, water theft. The more frequent presence of canal operations officers in the field at this time is an obvious adjunct to such efforts.

## Irrigation Sector Policy Implications

With respect to efforts to develop an effective program of turnover of public tubewells to the private sector, there are several reasons to reconsider the current strategy embodied within the SCARP Transition Pilot Project. Most worrisome is the prospect that the replacement of public tubewells pumping from deeper aquifers by private tubewells pumping from shallow aquifers will result in an overall decline in the quality of irrigation water available in the current agricultural system. The impact of such a development, particularly upon the sustainability of irrigated agriculture, can only be guessed at, but it is highly unlikely to be positive.

Also of concern is evidence that private electric tubewells are used much more intensively than other private tubewells whereas, until now, a 12 percent utilization factor was assumed to be applicable regardless of power source. A turnover strategy which incorporates incentives and subsidies that directly encourage an increase in the numbers of electric tubewells seems certain to add greater stress than anticipated to an already overloaded power supply system.

In fact, tubewell densities throughout Lagar Distributary command strongly suggest that special incentives and subsidies to encourage private tubewell development are simply not necessary. Indeed, it is likely that in many areas, the installed capacity of private tubewells is already more than sufficient to compensate for the termination capacities of public wells so long as equity considerations are not an issue.

Public tubewells, however, are still supplying substantial proportions of the total amount of irrigation water that farmers use in a large number of locations. This is done under a long-accepted equity principle. Terminating public tubewells will therefore almost certainly have important equity implications for many farmers, especially for those without ready access to private water supplies. The absence of a significant effort to address this issue in the current pilot turnover strategy is cause for genuine concern.

Calls for policies that would encourage further private tubewell development in the tail-end areas of distributaries, as a way of compensating for inequities in the surface water distribution system, may not be warranted if the spatial pattern of water quality deterioration for private tubewells pumping from shallow groundwater aquifers in Lagar command is a more widespread phenomenon. At the very least there is an urgent need for a province-wide study in Punjab to evaluate shallow groundwater aquifer conditions and behavior in greater detail. Sources and rates of recharge, in particular, need to be accurately determined so that while they can be protected, water table drawdown from tubewell operations can also be sensibly regulated.

# References


Anson, R. 1983. Pakistan, public and private tubewell performance: Emerging issues and options: Subsector report. World Bank Desk Paper. Washington, D.C.

Johnson, Robert. 1989. Private tube well development in Pakistan's Punjab: Review of past public programs/policies and relevant research. IIMI Country Paper - Pakistan No. 1. Colombo, Sri Lanka: International Irrigation Management Institute.

Johnson, Robert. 1991. Latent groundwater demand in Pakistan's Pubjab: Theory and applications. Unpublished PhD dissertation. Ithaca, NY: Cornell University.

Johnson, S.H. 1982. Large-scale irrigation and drainage schemes in Pakistan: A study of rigidities in public decision making. Food Research Institute Studies. 18(2). 149-180.

Water and Power Development Authority (WAPDA), Planning Division. 1981. Groundwater development and potential in canal commanded areas of the Indus Basin. Lahore, Pakistan: WAPDA

WAPDA, Master Planning and Review Division. 1979. Revised programme for Irrigated agriculture (3 vols.) Lahore, Pakistan: WAPDA

White House, Department of Interior Panel on Waterlogging and Salinity in West Pakistan. 1964. Report of land and water development in the Indus Plain. Washington, D.C.: The White House