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LARGE-SCALE IRRIGATION AND DRAINAGE SCHEMES IN PAKISTAN: A STUDY OF RIGIDITIES IN PUBLIC DECISION MAKING†

The Indus Basin of Pakistan, with its deep alluvial soils and the abundant water resources of the Indus River and its tributaries, is potentially one of the world's most important food-producing areas. It contains the largest contiguous irrigation system in the world, and there is no inherent technological reason why the Indus Basin could not produce up to three times its present output. Pakistan's rapid population growth, as well as that of other countries in South and Southeast Asia, will result in a billion additional people in the region within the next four decades. In order to support this population there must be concern with more than food self-sufficiency. The Indus Basin should be envisioned as one of the great export suppliers of food for the future decades. The potential gains for Pakistan and for the world from better utilization of the Indus are extremely high (Falcon, 1976).

However, in spite of a favorable climate and vast resources of land and water, the Indus Basin agricultural system is responding very slowly to the challenge before it. The "Indus Food Machine" is struggling just to increase food production fast enough to keep up with population growth. A long list of reasons can be developed to explain why agricultural output is increasing so slowly. Variable weather patterns and rapidly increasing energy prices provide short-term explanations, but a more serious long-term impediment to in-

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creased crop productivity is soil salinity (Pakistan, 1978). Due to poor drainage of the vast, nearly flat Indus Plain, waterlogging and resulting salt accumulation in the soil are slowly destroying the fertility of much of the irrigated land. While recognizing this problem, the Government of Pakistan has not been very successful in finding a long-term solution. From the 1930s through the 1950s, the Government experimented with various drilled well (tubewell) drainage schemes. Then in 1960, starting with Salinity Control and Reclamation Project I (SCARP-I), a full-fledged commitment was made to implement the most extensive, and expensive, vertical tubewell drainage scheme in the world.

The objective of this paper is to record objectively the historical development, implementation, and management of Pakistan's SCARPs, using field and management data from SCARP-I, SCARP-II, and Khairpur SCARP. Direct economic feasibility of the SCARPs is considered and compared with that of private tubewell development.

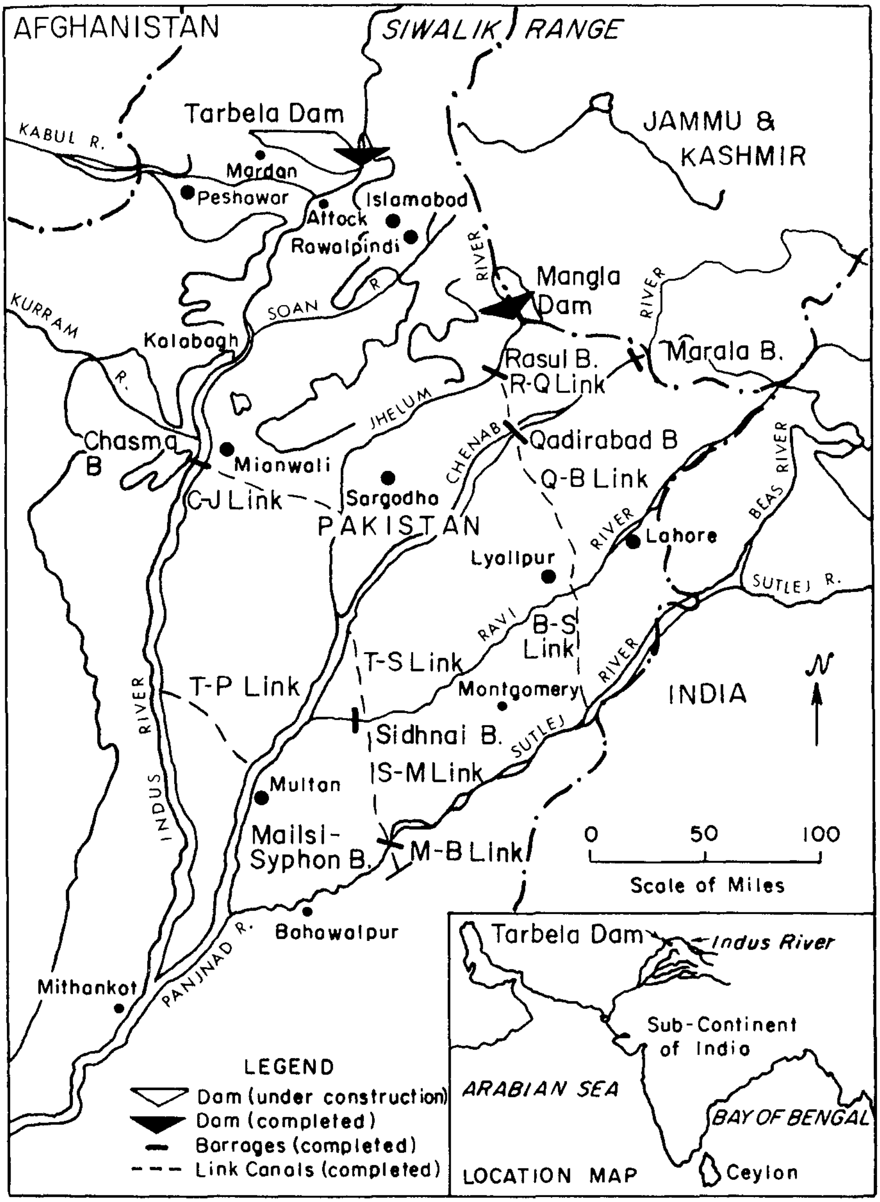
HISTORICAL OVERVIEW

More than two thousand years ago the inhabitants of the Indus Plain had constructed inundation canals to irrigate areas along the banks of the river. However, it was not until 1859 when British army engineers completed the Upper Bari Doab Canal that large-scale perennial irrigation was introduced to the Indus Plain itself (see Map 1). The canal system was designed according to the same principles as other North Indian systems constructed by the British during this period. There were no storage reservoirs, and supply depended on seasonal variation of discharge of the river systems. Canal design was determined by the Government's economic and social objectives, which were to spread the available water as extensively as possible and in such a way as to prevent famine, to "bring to maturity the largest area of crop with the minimum consumption of water," and to ensure equitable distribution throughout the command area (India, 1873). Farmers and their families moved into the newly watered lands by the hundreds of thousands. By 1920 the northern part of the Indus Plain, the Punjab, was called the breadbasket of India (Paustian, 1930). In the south the pattern of land settlement was somewhat different, with large landowners holding most of the land and share-tenants on small parcels, but even here the availability of water turned the barren land into a productive resource.[1]

Between the 1830s and the 1960s the Indus Plain, which encompasses more than 207,000 square kilometers and stretches 1,200 kilometers from the Himalayan foothills to the Arabian Sea, was covered with the world's largest contiguous block of irrigated land. Here the Indus and its tributaries drain a watershed of over 943,000 square kilometers to serve an irrigated area of 13 million hectares (Taylor, 1965). Yet, the bounty of the irrigation system was not perfect. Given the gentle slope of the Indus Plain, 0.2 meter per kilometer, drainage soon became a major problem in many areas. By the late 1800s

[1] Gotsch, et al. (1975) present an excellent review of traditional agricultural practices in the Indus Plain for those interested in micro-level agricultural and irrigation practices.

MAP 1.—INDUS PLAIN: RIVERS, DAMS, AND LINK CANALS



waterlogging and soil salinity had already been recognized as major problems in the Indus Plain, particularly in areas between the rivers known locally as *doabs*. In 1917 a Drainage Board was established in the Punjab to study the problem, and the Irrigation Research Institute at Lahore and the Directorate of Land Reclamation Punjab were created to develop remedial measures. Provincial irrigation authorities took steps to reduce canal seepage losses, and construction of a large network of surface drains was also undertaken. Steady-state conditions in the position of the water table were reached in the 1940s in some areas where evaporation from the water table at or near the land surface balanced recharge from canal leakage (Mundorff et al., 1976).

Soon after independence in 1947, Pakistan became increasingly concerned about the growing waterlogging and soil salinity problems in the Indus Plain. By 1950 over 2 million hectares of irrigated land had gone out of production with additional land going out of production at the rate of 29,000 hectares each year. The Government of Pakistan requested help from the Food and Agricultural Organization of the United Nations (FAO) in finding a solution to the waterlogging and salinity problems. In response, the FAO in 1950 sent a number of drainage and reclamation experts to study the problem. These experts provided some valuable suggestions, but they were frustrated in their study by the lack of technical baseline data. Their main recommendations were to carry out more surveys and investigations and to select a few acres for pilot schemes. In 1952, again at the request of the Government of Pakistan, the United States Bureau of Reclamation sent a drainage engineer, E. R. Maierhofer, to study the damaged areas of the Punjab and the Khairpur-Shikarpur area in the south. He reviewed the proposals of the FAO experts, but opined that actual large-scale projects would be much more worthwhile than an occasional review of the achievements of a few small pilot projects (Maierhofer, 1952).

As a result of these studies, it was recognized in 1954 that both waterlogging and soil salinity were related to the groundwater regime, and that a solution to these problems could only be developed through complete knowledge of the conditions of occurrence of groundwater. Therefore, a comprehensive project of water and soils investigations was begun in 1954 under a cooperative agreement between Pakistan and the United States. The Ground Water Development Organization, which later became the Water and Soils Investigation Division of Pakistan Water and Power Development Authority (WAPDA), was created in August 1954 to serve as the base organization. Broad objectives of the research project were to inventory the water and soil resources of the Punjab, to determine aquifer characteristics, to delineate fresh and saline water zones, and to identify and describe the interrelations of various components of the hydrologic system, including canal seepage, irrigation, waterlogging, and salinity. Insights into the system gained from these studies, briefly summarized in the following paragraphs, have provided much of the scientific and technical base for the various reclamation and drainage projects that are now in operation in Pakistan.

Groundwater Hydrology

The Indus Plain was formed by alluvium deposited by the Indus River and its tributaries—the Jhelum, Chenab, Ravi, Beas, and Sutlej—in an extensive depression lying between the Himalayas and the Salt and Sulaiman mountain ranges. This vast plain is underlain by an extensive aquifer system, in which groundwater may move both horizontally and vertically. Locally, however, lenses of fine-grained materials form horizontal boundaries or semi-confining layers that impede vertical movement of water, resulting in semi-artesian conditions. Near the center of the plain a number of fairly small bedrock hills protrude through the alluvial deposits to form local boundaries to the movement of groundwater; elsewhere the alluvial deposits are from 300 to 500 meters thick (Mundorff et al., 1972).

The climate of most of Pakistan, and particularly of the Indus Plain, is arid to semiarid (less than 200 to 500 millimeters [mm] annual precipitation). Only in the submontane zone of the Himalayan foothills is there precipitation more than moderate; there it may exceed 2000 mm. Along the northern rim of the Upper Indus Plain the annual precipitation ranges from 750 to 1,000 mm. A marked decrease in annual precipitation occurs southward of the rim, being about 475 mm at Lahore and 200 mm at Multan, and in the Lower Indus Plain rainfall of 100 mm or less annually is not uncommon. The bulk of the runoff in the Indus River and its major tributaries is generated in the montane and submontane zones of their headwaters and is derived both from melting snows and ice and from the rains of the southwest monsoon. The Indus River and its tributaries carry huge loads of sediment derived from erosion of the Himalayas, the Hindu Kush, and contiguous mountain ranges, as attested by the vast accumulation of stream deposits in the Indus Plain.

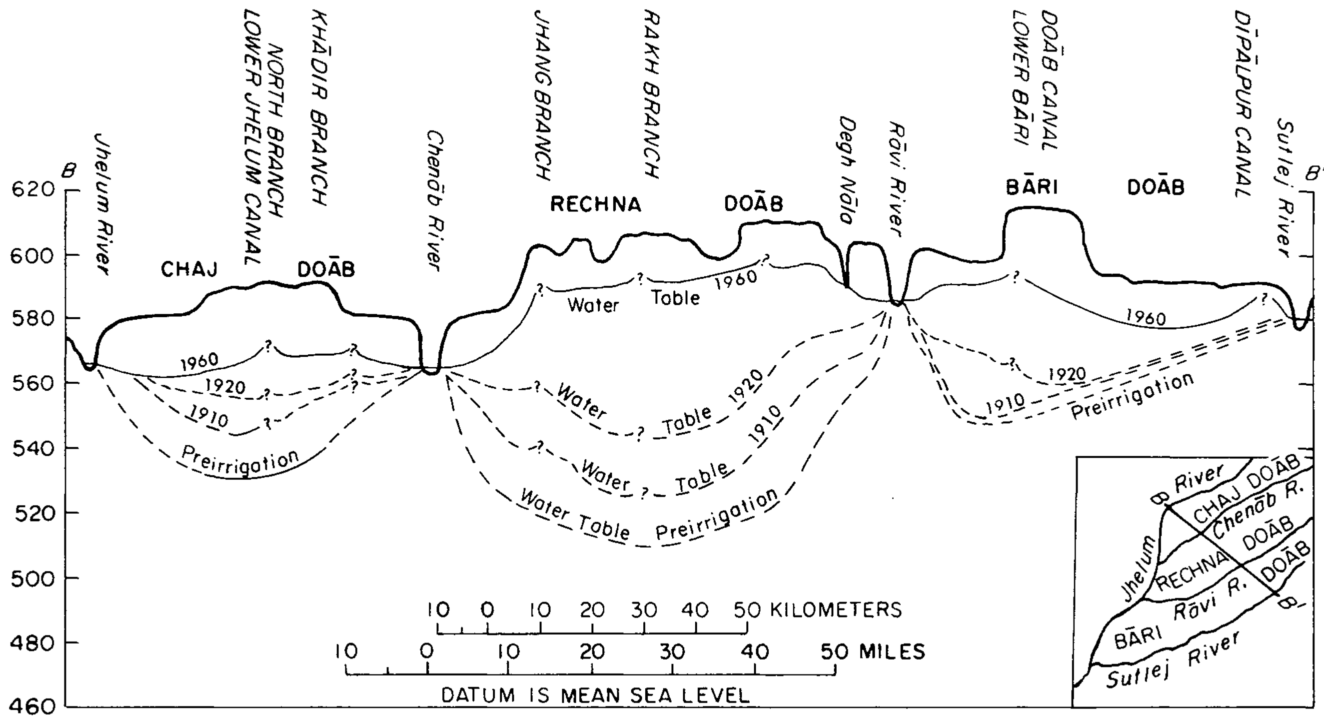
Before the development of canal irrigation in the nineteenth century, the groundwater hydraulic system was in a state of dynamic equilibrium. Over moderately long periods of time, recharge to the groundwater reservoir balanced discharge, and there were no long-term changes in groundwater levels. Equilibrium conditions of the hydraulic system before the introduction of irrigation reflect the compound effects of geology, climate, topography, and drainage. Of particular importance in the hydrologic budget is the distribution of precipitation. Where precipitation is below a threshold value, probably 250 to 350 mm under prevailing temperature conditions, recharge from precipitation was not a significant factor in the groundwater budget, and infiltration of river water was the dominant source of groundwater replenishment.

Irrigation changed the natural hydrologic environment of the Indus Plain. The canal system introduced additional sources of recharge and caused a rise of the water table in and around the irrigated areas. Seepage losses were greatest near the bifurcation points in the upper parts of the doabs because of the greater density of canals and less near the rivers because the water table was already close to the surface (Mundorff et al., 1976).

Chart 1 illustrates the change in depth to water table from preirrigated time to the early 1960s. The water table in the middle of the doabs has risen from 20 to 30 meters during this 80- to 100-year time period. This rise initially was at a constant rate until the water table approached the land surface (Greenman et al., 1967).

As it became evident that the rising water table and the resulting threats of waterlogging and salinity threatened the future of irrigated agriculture in the Indus Plain, a number of studies were made to determine the root of the problem. Carlston (1953) carefully studied previous research and identified three main factors: leakage from the irrigation-distribution system; infiltration of applied irrigation waters, and, to a lesser degree, increased recharge from rainfall runoff due to obstruction of natural drainage courses. Recent studies in-

CHART 1.—WATER TABLE PROFILES ALONG LINE B-B′, CHAJ, RECHNA, AND BARI DOABS



dicate that leakage and infiltration combined contribute about 80 percent of the recharge to the aquifer with the remaining 20 percent coming from rainfall-runoff recharge, link canals, and from the rivers themselves.

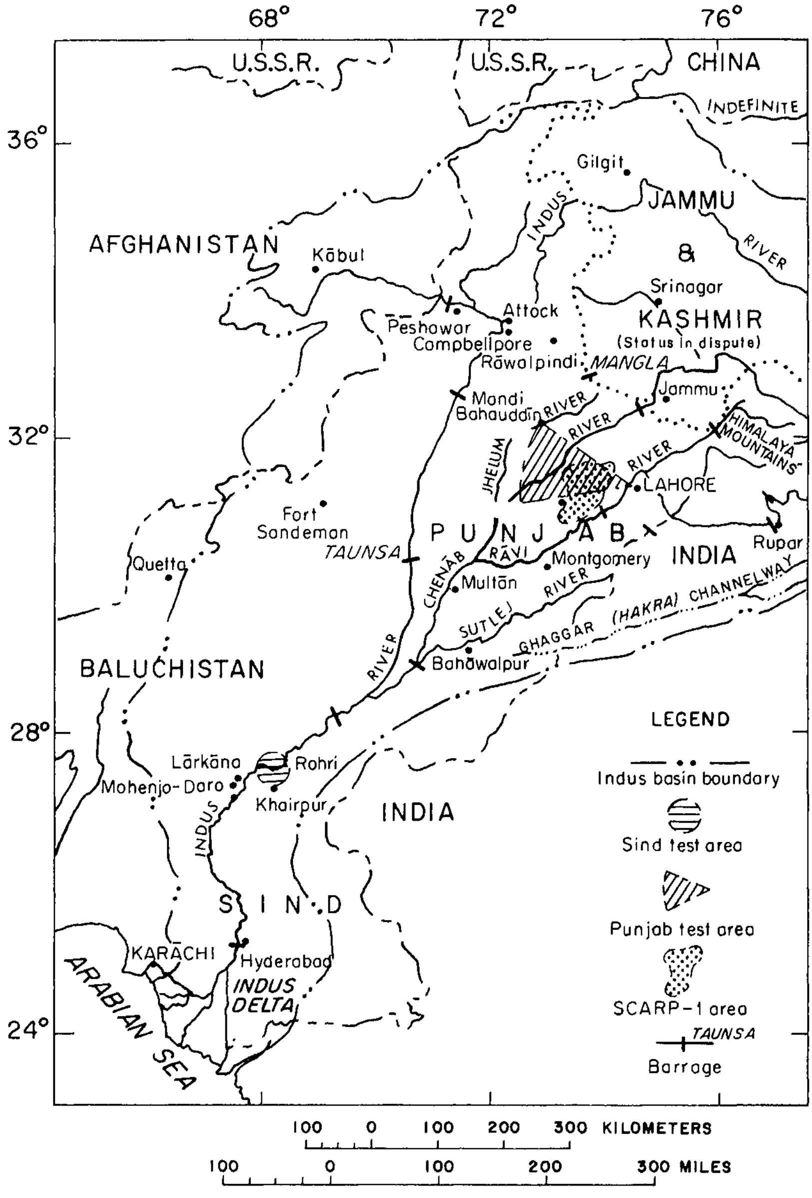
Water-quality studies show that the alluvium beneath about two-thirds of the Upper Indus Plain and less than one-third of the Lower Indus Plain is presently saturated to an average depth of 150 meters or more with waters of acceptable quality for irrigation supply. The average concentration of dissolved solids of the supplies in the Upper Indus is less than 800 milligrams per liter. In the Lower Indus, groundwater of acceptable quality is generally confined to a narrow strip along the rivers. Total annual recharge to groundwater within canal-commanded areas with a diversion of 123 billion cubic meters is estimated to be 59.2 billion cubic meters, of which 40.7 billion cubic meters occurs in usable groundwater zones (WAPDA, 1979).

SCARP STUDIES AND DEVELOPMENT

After 1958, drainage and reclamation works were transferred to WAPDA. In 1961 a plan for eradicating waterlogging and salinity in the whole of Pakistan was prepared by WAPDA with the assistance of its consultants Harza Engineering Company International, Tipton and Kalmbach, and Hunting-MacDonald. However, prior to the completion of the WAPDA plan a project for reclamation of 490,000 hectares of land known as Salinity Control and Reclamation Project I (SCARP-I) was prepared. Using US $15,200,000 made available to the Government of Pakistan by the United States Development Loan Fund, work on SCARP-I was begun in 1960. The project area for construction of SCARP-I was in the center of the interfluvial area between the Ravi and Chenab Rivers known as the Rechna Doab (see Map 2). One of the main objectives of SCARP-I was to demonstrate the effectiveness of vertical tubewell drainage for lowering the water table over a large area and as a means of providing sufficient water for intensified irrigation and leaching of salts from saline-affected soils (Malmberg, 1975).

While SCARP-I was under construction, WAPDA and its consultants were completing their ambitious program for elimination of waterlogging and salinity throughout Pakistan. In this plan, the Upper Indus Plain was divided into 10 reclamation projects of from 0.4 to 1.6 million hectares, the Lower Indus Plain was divided into 16 projects of from 0.3 to 0.8 million hectares. In all, the programs embodied the construction of 31,500 tubewells, 12,500 kilometers of major drainage channels, and 42,000 kilometers of supplemental drains serving more than 12 million hectares in the Northern and Southern Zones (Ahmad, 1974). A panel of experts headed by Roger Revelle (hereafter referred to as the Panel) was sent by the American President to study the problem of waterlogging and salinity in Pakistan. The Panel prepared a comprehensive report on agriculture, drainage, and reclamation in Pakistan which examined technical, institutional, and organizational solutions. Engineering aspects of the report, often called the Revelle Report or the White House Report, were generally along the lines of the WAPDA program, although the Panel used sophisticated computer models to demonstrate that the pumping of groundwater by public tubewells could provide an intermediate solution to

MAP 2.—LOCATION OF SCARP-I



waterlogging and salinity problems. These tubewells could also provide much-needed additional irrigation water (White House, 1964).

In addition to preparing its own proposals, the Panel also reviewed WAPDA's plan. Both were also reviewed and studied by a group of three consulting firms called Irrigation and Agriculture Consultants Association (IACA) appointed by the World Bank in 1963 at the request of the President of Pakistan.

Reports by the three firms were consolidated in a World Bank study headed by Pieter Lieftinck (1968).

Recommendations prepared by WAPDA, the Panel, Tipton and Kalmbach, Harza Engineering Company International, IACA, and various other expert groups contain similar elements. Most agree that the groundwater aquifer of the Indus Plain is a vast, relatively untapped resource that can be used to supplement present surface water supplies. In general, all agree that the aquifer is high yielding with substantial storage capacity, but there is some disagreement about its magnitude. There has always been disagreement about the merits of horizontal drainage versus vertical drainage, but usually, after detailed study of the issue, vertical drainage is selected. Vertical drainage does not remove the salts from the system, however, and some type of horizontal removal system is usually stipulated as necessary for long-term stability. The Panel and Tipton and Kalmbach both suggested pumping highly saline groundwater into rivers during periods of high runoff as well as the possibility of disposing salt in desert salt flats or lagoons. While these alternatives may be technically feasible, they represent such explosive administrative and political issues that they have never gone beyond the discussion stage. The proposal to mine groundwater to a significant depth (30 meters was suggested by the Panel) was one of the most obvious areas of disagreement between the various groups. In some areas this question was settled by the courts. In Khairpur SCARP, for example, the court ruled in favor of farmers who claimed the water table, if held below 4 meters, would damage their date palm orchards. In most SCARPs, however, this question was settled by default as the systems were never operated in such a manner as to come close to seriously mining the groundwater resource. Another matter that was debated seriously was the proper mixture of saline groundwater and fresh surface water. A major issue that continues to be discussed is the relative merits of publicly installed deep tubewells and privately installed shallow tubewells. Public tubewells were almost unanimously recommended largely because the original studies were completed before there were any significant number of private tubewells in the Indus Plain. Nevertheless, a small number of Pakistani and foreign consultants, most notably Dr. Ghulam Mohammad from the Pakistan Institute of Development Economics, argued that public tubewells should only be installed in areas where groundwater was too saline to be applied to lands without dilution with canal water. In areas where groundwater was of good quality, development should be left to private users with the Government providing the electrical grid and credit schemes for purchase of pumps and motors (Mohammad, 1964). More recent studies by groups like the World Bank's Indus Basin Review Mission, the Punjab Government Special Committee on the Working of SCARPs (Punjab, 1971), Mundorff, and the WAPDA Master Planning Division (1979), all have the benefit of hindsight; their stronger arguments for private tubewells rest on changes occurring since the earlier recommendations.

SCARP Design

SCARP-I, completed in 1963, demonstrated that the water table could be successfully lowered by tubewells uniformly distributed over a large area, and

TABLE 1.—IMPLEMENTATION OF PUBLIC TUBEWELL PROJECTS

Project	Zone	Gross area (million hectares)	Tubewells (number)	Period	Installed capacity (m^3/sec)	Costs[a]
SCARP-I	N	.49	2,069	1959–63[b]	180	25
SCARP-II	N	.67	2,205	1963–73	298	90
SCARP-III	N	.43	1,635	1966–73	203	40
SCARP-IV	N	.23	935	1967–73	127	20
Khairpur	S	.18	540	1969–70	48	10
Rohri North	S	.32	1,192	1973–77	69	50
Larkana Sukkur Shikarpur	S	.01	87	1973–75	8	–
TOTAL		2.33	8,663		933	235

Source: Water and Power Development Authority, Central Monitoring Organization (1971), *Review of Completed Salinity Control and Reclamation Projects,* WAPDA Press, Lahore, Pakistan.

[a]These figures do not reflect all associated costs (1977 US $ million).

[b]256 tubewells installed from 1954–58.

additional public tubewell projects were accordingly undertaken in both the Northern and Southern Zones.

Over 8,000 public tubewells covering more than 2.3 million hectares were installed between 1959 and 1977 (Table 1). More than 12,000 tubewells covering 3 million hectares had been completed by 1979, and construction is still underway in 1982. Total costs are estimated to have exceeded US $500 million. Originally the SCARPs were viewed as drainage projects with supplemental irrigation water supplies as a by-product that helped to justify the projects economically. In SCARP-I and some areas of SCARP-II (Lalian, Khadir, and Mona) capacities of the tubewells were set so that the combined water supply from surface and groundwater at the watercourse head was one cubic meter per second for 2,144 hectares. In subsequent SCARPs a cropping intensity for the area was projected and the tubewell capacities were determined to provide the necessary water supply to meet this requirement, either with or without canal supplies depending on the area. Table 2 illustrates the projected changes in cropping intensity expected after the SCARPs were in operation. The larger projected increases in the more recent SCARPs reflect the change in design criteria discussed above.

In general the capacities of the tubewells ranged from 56 to 142 liters per second. The choice of tubewell capacity was made by considering the tubewell requirements of one or more than one adjoining watercourse commands or *chaks.*[2] As chaks vary from 80 to 400 hectares, this often resulted in one

[2] In Pakistan the canal water is distributed through minor canals and flows out of the turnout (*mogha*) to a village level watercourse command (80 to 400 hectares). There are no headgates at the moghas, and if a particular canal has water in it there is water in every watercourse command on that canal. There are more than 88,000 watercourse commands in the Indus Basin.

TABLE 2.—CROPPING INTENSITIES IN SCARP PROJECTS
(Percent)

Project	Culturable cultivated area *(million ha)*	Pre-project intensity	Projected intensity	Actual intensity, 1975–76
SCARP I	.46	89	150	116
SCARP-II	.60	83	130	102
SCARP-III	.37	54	120	97
SCARP-IV	.22	63	150	91
Khairpur	.13	106[a]	135	109[a]
Rohri North	.28	98	150	

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture Report* (3 volumes), WAPDA Press, Lahore, Pakistan.
[a]Questionable value

tubewell serving up to three chaks. Distribution works for each tubewell required structures for proportional allocation of tubewell supplies to watercourses to be served. At first it was thought that link-watercourses which connected the tubewell to the main watercourse channel for each chak would be excavated by the farmers. However, in SCARP-I and parts of SCARP-II farmers were unable, or unwilling, to dig these link-watercourses. They were usually completed by the contractors in the more recent SCARPs. No provisions were made for enlarging the main watercourse channel and distribution system even though it was expected to carry two to three times its previous flow quantity.

SCARP PROBLEMS

In contrast to the elaborate models developed to determine if vertical tubewell drainage would be successful in the Indus Plain, very little effort seems to have been spent identifying how they should be operated and by whom. In particular, minimal attention was paid to issues of organization and human behavior. No effort was made to educate the water users about their role in the system nor, as indicated by the size of the public tubewells, was there any real appreciation of the difficulties of organizing farmers across one or more watercourse areas. Therefore, the performance of SCARPs was much different than had been anticipated by the original planners. The following section, using data from SCARP-II, illustrates some of these project-level problems.

SCARP-II: Project Performance

SCARP-II is in the Upper Chaj Doab between the Chenab and Jhelum Rivers. As mentioned earlier, some schemes within SCARP-II were designed with a fixed water duty of about one cubic meter per second for every 2,144 hectares, while other schemes were designed to meet a projected cropping in-

TABLE 3.—WATER DUTIES FOR DIFFERENT SCARP-II SECTIONS

Section	Chaks per section	Average hectares commanded per inlet	Average design *(liter/second)*	Hectares supplied with one cubic meter per second
Mona	11	266	128	2,078
Lower Hujjan	7	243	113	2,150
Phalia	10	175	95	1,844
Bhusal	19	202	115	1,757
Sohawa	25	179	99	1,811

Source: Data collected in SCARP-II by author and researchers.

tensity which, in general, meant that they had a higher water duty. Water duties for five SCARP-II sections are detailed in Table 3. Phalia, Bhusal, and Sohawa were designed to meet a projected cropping intensity rather than an arbitrary fixed water duty. However, due to decline over time of the pumping capacity of the tubewells, submergence of watercourse channel inlets, improperly designed and constructed link watercourses, and under-capacity watercourse channels, actual flows were often much less than the designed supplies (Table 4).

The weighted average delivery into the channel from this sample is about 78 percent of design capacity. This overestimates actual deliveries because power rationing limited pumping to 40 percent of an assumed utilization rate of 20 operating hours per day.

The measured reduction in flow partially results from a decline over time in the output capacity of the tubewells (Table 5). The decline in tubewell capacity in a sample of 81 tubewells in SCARP-II/A was 21 percent. WAPDA records indicate that the overall decline of tubewell capacity in all SCARP-II/A is more than 30 percent (WAPDA, 1979). Other reasons watercourses do not receive their full design flow are submergence of watercourse channel inlets (either by tubewell flow or by inability of the channel to carry canal water plus water from the tubewell), low flow in the distributary, and poor design and condition of link watercourses. In a sample of 22 tubewells in the Phalia Section that

TABLE 4.—ACTUAL DELIVERY COMPARED TO DESIGN DELIVERY: SCARP-II

Section	Chaks per section	Average design *(liter/second)*	Actual delivered *(liter/second)*	Percent delivered
Mona	11	128	98	77
Lower Hujjan	7	113	92	81
Phalia	10	95	63	67
Bhusal	19	115	89	78
Sohawa	25	99	82	82

Source: Data collected in SCARP-II by author and researchers during 1977.

TABLE 5.—DECLINE IN TUBEWELL OUTPUT: SCARP-II/A

Section	Tubewells sampled *(number)*	Average design capacity *(liter/second)*	Measured output *(liter/second)*	Average percent delivered
Phalia	31	105	91	86
Bhusal	16	116	82	71
Sohawa	27	99	79	80
Lower Hujjan	7	102	74	72
Weighted average				79

Source: Data collected in SCARP-II/A by author and researchers during 1977.

were operating at designed pumping capacity, actual water flow (tubewell water plus canal water) in the main watercourse channel was only 67 percent of designed capacity. The rest of the flow was either lost in the tubewell link watercourses or restricted by submergence of the inlet.

Link watercourse channels.—Connecting watercourse channels to the tubewell outlet in SCARP-II was more difficult than in SCARP-I because the wells in general had higher output capacity and usually served two or more watercourses. The project plan assumed that farmers would construct the link connections between tubewells and watercourses. In practice this has not worked out. All of the tubewells in SCARP-II are connected to watercourses, but many of the connections, especially in SCARP-II/A, are unsatisfactory. The high-capacity tubewells were designed to flow through a sophisticated diversion box which allocated the water to two or more watercourses. In actual practice many of the diversion boxes are being bypassed and the tubewell water is serving only one watercourse (USAID, 1970).

In some instances the water has flooded an area around the tubewell, creating a watering hole from which the water is being diverted into the watercourse. Because of these large flooded areas it is difficult to measure accurately how much tubewell water actually enters the watercourse. Measurements taken in 21 link watercourses in Phalia Section during canal closure, when the only water entering the watercourse was tubewell water, showed an average loss of 19.5 percent of the tubewell discharge.

Once the water enters the watercourse channel, it comes under the control of farmers served by that channel who are supposed to maintain the channel and distribution system. Often this is not done because of neglect, ignorance, and village conflicts. Table 6 summarizes measurements of losses in 107 watercourse channels in SCARP-II. The average watercourse channel losses on unimproved water channels varied from 10 percent to 15.9 percent per 300 meters of length and averaged 13.5 percent. In terms of farmers' needs for water, these losses represent a critical shortage, especially at middle and tail sections of the chak. With losses of this magnitude, by the time the water reaches 1,500 meters from the head of the watercourse, users have lost half of the initial flow entering the system. Assuming an average delivery of 79 percent of the design flow entering the system and losses of 13.5 percent per 300 meters, users 1,500 meters down the watercourse channel are receiving only

TABLE 6.—WATERCOURSE LOSSES AND DELIVERY EFFICIENCY: SCARP-II

Section	Number of measurement	Losses/300 meters (liters/sec)	Losses/300 meters (percent of initial flow)	Delivery efficiency
Mona	6	13.3	13.8	65.8
	20	6.2	10.0	64.0
Lower Hujjan	7	9.9	11.7	
Phalia	30	6.8	12.8	
Sohawa	25	14.7	15.9	
Bhusal	19	13.9	15.6	
Weighted average			13.5	

Source: Data collected in SCARP-II by author and researchers during 1977.

40 percent of their design allocation. A sample of measurements in the Sohawa Section indicates, at 1,000 meters, that farmers are only receiving 44 percent of the design flow. Similarly, a sample from Bhusal Section indicates that farmers 1,000 meters from the junction of the main channel and the link watercourse channel are receiving only 38 percent of design flow.

Operating schedules.—Although high water tables are not a serious problem in SCARP-II, tubewells are designed both to lower the water table and to provide supplemental irrigation water. In areas where the water table is very close to the surface, it is necessary to pump the tubewells more in order to lower the water table. In areas where the water table is more than 3 meters from the surface, the tubewells can be pumped more on demand. Almost all SCARPs followed a pattern of increased groundwater pumping during the initial years and declining groundwater pumping thereafter (Table 7). Pumping in SCARP-II rose to a peak value in 1974-75 and then fell. Given current budget restrictions and declines in pumpage capacity, this trend is likely to continue (Table 8). With respect to changes in depth to water tables within the SCARPs, these pumping figures result in rapidly falling water tables in the initial years and then rising water tables as quantity pumped declined (Table 9). Areas in the Punjab with depth to water table less than 3 meters in June 1959 were about 3.8 million hectares and in June 1978 covered about 3.9 million hectares (WAPDA, 1979). Therefore, even after the development of SCARPs, data indicate no real change in amount of land with high water table over the past 20 years. Similarly, SCARP-II water tables have not changed appreciably over the first 10 years the tubewells operated (Table 10).[3]

SCARP tubewells are supposed to be operated on schedules developed by the Irrigation Department. These vary among wells in perennial canal areas, nonperennial canal areas, and uncommanded areas. Schedules do not allow for rainfall, power failures, or personnel problems and therefore must be considered as no more than general guidelines. Poor performance of tubewell operators is one of the main complaints about SCARP tubewells both from farmers and from the Irrigation Department staff. This makes it difficult to determine how many hours each tubewell is operated. Operators are supposed

[3] WAPDA records the average preproject depth to water table as 2.6 meters (1979).

TABLE 7.—SCARPs TOTAL ANNUAL PUMPAGE AS PERCENT OF ACCEPTANCE CAPACITY

Year	SCARP-I		SCARP-II		SCARP-III		Khairpur	
	Pumpage	Percent	Pumpage	Percent	Pumpage	Percent	Pumpage	Percent
1962–63	2,790	59						
1963–64	3,095	66						
1964–65	3,004	64						
1965–66	3,073	65	503	7				
1966–67	2,088	44	398	5				
1967–68	2,287	48	442	6			196	16
1968–69	2,424	51	897	12			459	36
1969–70	2,401	51	1,781	23			407	32
1970–71	2,386	51	2,121	28			599	48
1971–72	2,293	49	1,989	26	759	14	645	51
1972–73	2,003	42	1,960	26	744	14	558	44
1973–74	1,781	38	2,482	33	2,632	31	567	45
1974–75	1,699	36	3,178	42	2,762	52	331	26
1975–76	1,949	41	2,611	34	1,779	33	447	35
1976–77	1,576	33						

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture*, (3 volumes), WAPDA Press, Lahore, Pakistan. Assuming 20 pumping hours per day. Pumpage in million cubic meters.

TABLE 8.—USEABLE PUMPING CAPACITY SINCE ACCEPTANCE
(Percent of capacity)

Year	SCARP-I	SCARP-II/A	SCARP-III	Khairpur
1969–70	66.8	83.9	—	—
1970–71	62.2	81.4	—	—
1971–72	61.9	78.2	—	—
1972–73	60.3	74.5	85.9	—
1973–74	57.6	71.3	80.8	—
1974–75	51.9	65.2	80.3	—
1975–76	52.1	65.4	74.4	73.7

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture* (3 volumes), WAPDA Press, Lahore, Pakistan.

TABLE 9.—DEPTH TO WATER TABLE IN SCARPS

Project	Year	Percent of water table			Average depth
		0–1.5m	1.5–3.0m	Plus 3m	*(meters)*
SCARP-I	1961	13.5	61.2	25.3	2.5
	1971	0.0	8.1	91.9	5.1
	1977	2.2	30.4	67.4	3.8
SCARP-II	1965	9.1	23.4	67.5	3.6
	1971	0.2	11.2	88.6	4.9
	1977	5.3	26.6	68.1	3.7
SCARP-II/A	1968	14.9	57.5	27.6	2.6
	1971	1.1	34.4	64.5	3.8
	1977	13.4	53.1	33.5	2.7
SCARP-III	1964	41.2	42.5	16.3	1.9
	1975	6.2	19.2	74.6	3.6
	1977	12.0	52.4	35.6	2.8
SCARP Khairpur	1960	29.7	70.3	0.0	1.7
	1977	25.0	62.0	13.0	2.1

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture* (3 volumes), WAPDA Press, Lahore, Pakistan.

TABLE 10.—DEPTH TO WATER TABLE, SCARP-II, 1966 AND 1977

Depth	Percent of area	
(meters)	1966	1977
Less than 1.5	15	14
1.5 to 3.0	57	53
More than 3.0	28	33

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture Report* (3 volumes), WAPDA Press, Lahore, Pakistan.

to keep a daily log of tubewell operating hours, but they are frequently absent from the tubewells for long periods and farmers must operate the tubewell themselves, making the log book often only a rough estimate of actual operating hours. Nor can monthly pumping hours be determined by reading the electric meter connected to each tubewell, for most meters do not function properly and are useless in determining power consumption and pumping hours. Data available on actual operating hours are therefore sketchy and must be used with caution. Keeping this in mind, some general operating characteristics can be described; exact operating schedules cannot be determined from existing data.

The Irrigation Department has two guidelines for the interagency scheduling committees which meet biannually to schedule tubewell operations in SCARP-II: over the year, pumps should run at 40 percent of annual capacity; and on days when pumps are operated, they should run continuously from 12:01 a.m. until 12:00 p.m., with scheduled rest periods between 12 noon and 4:00 p.m. The exact rationale for these guidelines is not at all clear. The first appears to derive from power rationing instituted in 1972 as a result of the war between India and Pakistan. The second guideline may represent an attempt to pacify tubewell operators whose working hours according to official labor legislation are only eight hours, or it may reflect a mistaken belief in the need to rest the tubewell motors. In Mona, where the tubewell rest period is from 5 p.m. to 9 p.m., the most common explanation given is that these are peak hours for electricity consumption.

Given these guidelines the main area of choice is the number of days per month the tubewell should be operated. Schedules should take into account plant-water relationships, rainfall, and expected canal water availability. In fact, the proposed Lalian pumping schedule varies little from month to month and bears little relationship to that proposed by the Land Reclamation Department (LRD), which attempts to match expected water supplies with expected demand.[4] Nor do actual pumping schedules resemble either the proposed LRD schedule or that followed by private pump operators (Table 11). More flexible

[4] The LRD schedule ignores equitable distribution of water throughout the seven-day fixed irrigation water rotation schedule that is in operation for each chak, a significant constraint on the scheduling committee.

TABLE 11.—PLANNED AND ACTUAL TUBEWELL OPERATION: SCARP-II
(Percent working hours as proportion to total available hours)

Month	Proposed schedule, Lalian, 1977–78		Proposed schedule, LRD,	Actual operation, all SCARP-II			Actual operation, Lalian			Private,[a]
	Days	Percent	1967	1974–75	1975–76	1976–77	1974–75	1975–76	1976–77	1977
Wet season										
April	14	39	12	–	56	38	–	58	27	28
May	21	58	31	–	53	40	–	59	40	6
June	14	39	47	–	45	41	–	42	34	6
July	14	39	25	–	35	46	–	36	40	16
August	14	39	19	–	43	24	–	37	28	24
September	14	39	15	–	33	27	–	44	32	26
Dry season										
October	14	39	83	59	45	36	53	55	54	24
November	21	58	73	52	50	40	45	66	50	24
December	14	39	89	38	39	23	38	41	27	27
January	14	39	25	39	36	36	40	54	44	29
February	14	42	35	48	19	40	67	23	40	30
March	14	39	49	57	30	49	62	43	54	26
Annual total		42	41	–	40	37	–	47	39	22

Source: SCARP-II Records and Land Reclamation Department (LRD).
[a]Actual pumping private tubewell in Mona, SCARP-II, 1977.

TABLE 12.—SCARP-II: LOST TIME DUE TO VARIOUS COMPONENT FAILURES, 1972–76
(Percent of capacity)

Section	Year	Total utili-zation	Shutdown due to electrical nonavailability	Shutdown due to burnt motor	Transformer defect	Assorted other components failures[a]
Bhusal	1976	43.0	10.0	12.4	5.4	11.5
	1974	64.0	18.0	6.5	6.5	10.6
	1973	53.0	11.0	7.5	10.1	11.1
Sohawa	1976	44.0	10.0	15.9	10.6	12.8
	1975	51.0	22.0	5.7	11.9	17.2
Lower Hujjan	1976	33.0	11.0	5.9	—	18.9
	1975	50.0	5.0	5.9	3.2	7.7
	1974	45.0	13.0	1.0	8.8	7.0
	1973	21.0	22.0	—	—	—
	1972	30.0	36.0	—	—	—

Source: SCARP-II Records.
[a]Includes motor defect, starter defect, blown fuse, and cable problems.

groundwater pumping, closer to the schedule proposed by LRD, could prevent both over- and under-pumping and potentially could support a higher cropping intensity.

Maintenance problems.—According to WAPDA data, SCARP-II has seen a decline in the utilization rate during recent years from an average of 49.7 percent installed capacity in 1974-75 to 37.0 percent in 1976-77. As electricity charges have increased at a rate exceeding 12 percent per year for the last four years and budget allocations have not kept pace, the utilization rate is expected to continue to decline. Over the same time period the allocation of funds for maintenance and repair work has decreased by 14-15 percent with consequent impairment of operation (Table 12).

SCARP Program Performance

The entire SCARP program has been affected by the poor operating records of individual SCARP projects. However, factors such as unforeseen increases in energy costs, shortened tubewell life, rapid development of private tubewells, and failure to achieve desired cropping intensities have combined to make SCARPs an economic and financial burden.

Economics.—Depending upon the various consultants' assumptions and mandates, their estimated costs for relieving waterlogging and salinity problems throughout the Indus Plain ranged from $1.2 to $2.7 billion. Predicted benefit-cost ratios for these plans were as high as 7.5:1 and as low as 2.25:1.

TABLE 13.—NUMBER OF PRIVATE TUBEWELLS IN PAKISTAN

Year	Punjab and N.W. frontier provinces	Baluchistan and Sind provinces	Total	Annual increase
1965	29,007	3,447	32,524	
1966	36,663	3,806	40,469	7,945
1967	45,103	4,250	49,353	8,884
1968	54,570	4,751	59,321	9,968
1969	63,000	5,267	68,267	8,946
1970	76,509	59,420	82,451	14,184
1971	83,337	6,665	90,002	7,551
1972	92,298	7,442	99,740	9,738
1973	101,425	8,050	109,475	9,735
1974	112,002	8,415	120,417	10,942
1975	122,702	9,694	132,396	11,979
1976	133,807	10,193	144,000	11,604
1977	143,355	10,675	154,030	10,030

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture* (3 volumes), WAPDA Press, Lahore, Pakistan.

As vertical drainage programs of this magnitude had never before been tried, all ratios depended upon the underlying assumptions.

One assumption that was clearly incorrect in almost all of the proposed programs derived from significant underestimation of the number of private tubewells that would be developed even with the implementation of the public tubewell schemes. Ghulam Mohammad's 1964 survey of 23,000 private tubewells in 16 districts of the Northern Zone of West Pakistan established that private tubewells were very profitable and that the number installed would continue to increase (Mohammad, 1965). His findings were confirmed: between 1965 and 1975 the number of private tubewells increased by four times (Table 13). Yet even the Lieftinck Report, written in 1967, failed to appreciate the fact that private tubewells had the potential to replace public tubewells in most of the nonsaline groundwater areas.

Another assumption that was proven wrong concerned the length of life of the public tubewells. Most consultants originally predicted 40- or even 50-year service lives. When it became apparent that the pumping capacity was quickly declining in almost all of SCARP-I and that a number of wells were facing critical problems with encrustation and corrosion of the strainers, the consultants first tried to change strainers from mild steel to stainless steel and fiberglass. It was soon obvious, however, that even these materials were seriously affected by minerals in the groundwater. Therefore, the consultants reduced their estimates of tubewell life to 20 or 25 years. In 1971 the Special Committee on the Working of SCARPs (Punjab, 1971) set 12 years as the average life of a SCARP tubewell. Depending upon the acceptable degree of decline in pumping capacity and the amount public agencies are willing to pay for repairs, life is a relative term, but it seems likely that approximately 15 years will be the practical life for most SCARP tubewells.

TABLE 14. — WATER CHARGES, 1919 AND 1978
(Dollars per hectare)

Crop	1919–20	1978	1919 in 1978 prices
Wheat	1.15	3.24	4.99
Rice	1.77	5.24	7.71
Sugarcane	2.25	10.23	9.78
Oilseeds	–	3.74	–
Cotton	1.00	4.49	4.34

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture* (3 volumes), WAPDA Press, Lahore, Pakistan.

A third erroneous assumption was that concerning increased cropping intensity. Early studies almost all planned to double cropping intensities from 75 to 150 percent. This has clearly not happened; in a few areas cropping intensity rose to as high as 135 percent, but even in those areas cropping intensity has now dropped back to 125 percent.[5]

Unfortunately, while changes to higher valued crops do increase revenue from water charges, higher yields do not. In SCARP areas, as the water supply theoretically has been doubled, double water charges are supposed to be assessed. In fact, many farmers refuse to pay double charges because they claim that by increasing acreage they are already, in effect, paying double water charges. Water charges have not changed since 1969 and are not very significant (Table 14).

Government subsidy to SCARPs. — Failure to increase cropping intensities as much as projected, increase water charges to reflect a general increase in prices, collect water charges effectively, and maintain 40-year life for the tubewells has resulted in a massive government subsidy to SCARP projects. A number of groups using various assumptions have calculated the magnitude of this subsidy. The Committee for Financial Subsidy, Department of Land and Water Development, Government of the Punjab, in 1970 estimated the annual subsidy for SCARP-I (excluding the power subsidy) to be $4.15 million and was $5.41 million including power. Another division of the Land and Water Development Department in 1970 estimated the annual subsidy of $2.56 million for SCARP-I assuming a life of 40 years for the tubewells, and $3.93 million assuming a life of 12 years, excluding the power subsidy (Punjab, 1971). WAPDA estimates that the total annual subsidy for SCARP-I has varied from $2.5 to $3.8 million, or from $5.15 to $7.82 per hectare (Table 15). The average annual subsidy over the period is estimated at more than $3.0 million, or $6.20 per hectare.

Data for SCARP-II indicate a similar level of subsidy for that project. Operating expenditures for 1976-77 were $5.58 million and recovered water charges were $2.91 million. If capital costs are amortized using the same assumptions as for SCARP-I, the annual net subsidy for SCARP-II exceeds

[5] How much of the increase in crop yields is a function of new high-yielding varieties and how much is a function of additional groundwater supplies is unknown.

TABLE 15.—COSTS AND REVENUES FROM SCARP-I
(million dollars)

Year	Water supplied *(billion m^3)*	Costs: Power only	Costs: Total operating and maintenance	Costs: Total including annualized capital[a] [A]	Water charge revenue collected[b] [B]	Net subsidy [A – B]
1964–65	3.01	1.21	2.08	3.85	.41	3.44
1965–66	3.07	1.27	2.19	3.96	.73	3.23
1968–69	2.42	1.06	1.97	3.74	1.20	2.54
1971–72	2.29	1.52	2.31	4.12	1.27	2.85
1973–74	2.01	1.44	2.27	4.04	1.17	2.87
1974–75	1.70	1.49	2.09	3.86	1.26	2.60
1975–76	1.95	2.07	3.31	5.10	1.27	3.83

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture* (3 volumes), WAPDA Press, Lahore, Pakistan.

[a]Annualized capital costs at 8 percent over 15 years. Includes an adjustment for 1972 devaluation of Pakistan rupee.

[b]Attributed to SCARP water supply; that is, after deducting water charge revenue attributed to surface water supplies.

TABLE 16.—OPERATIONAL STATUS OF PUBLIC AND PRIVATE TUBEWELLS

Division	Government tubewells		Private tubewells	
	Total	Percent operational	Total	Percent operational
Rawalpindi	868	81	2,300	96
Sargodha	1,527	67	10,700	93
Lahore	3,202	66	20,400	97
Multan	1,586	17	26,510	94
Bahwalpur	174	49	4,060	93
Punjab total	7,357	57	69,030	95

Source: Land and Water Development Board, Government of the Punjab (1971), *Report of the Special Committee on the Working of the SCARPs,* WAPDA Press, Lahore, Pakistan.

$5.3 million, or more than $8.50 per cultivable hectare. For SCARP-II in 1975-76, recovered water charges were 77.8 percent of 1975-76 demanded water charges and 62 percent of current year plus previously overdue charges. However, even if SCARP-II personnel had been able to collect 100 percent of demanded water charges, the amount would still have been almost $1 million short of annual operation, maintenance, and repair costs.

With approximately 3 million hectares under SCARP schemes, and an annual subsidy of $7.50 to $8.50 per hectare, the annual national subsidy for SCARP schemes exceeds $22 million. Newer SCARPs were more expensive and were purchased with funds provided at a significantly higher interest rate, making these estimates extremely conservative, but they do indicate the magnitude of government subsidy.

Public compared to private tubewells.—The rationale underlying the recommended public sector role in groundwater development was that private development:

(1) would be inequitable and therefore not benefit most small farmers;

(2) would be haphazard and probably not accomplish the desired drainage function;

(3) could deteriorate the groundwater aquifer through uncontrolled pumpage; and

(4) could not be expected to proceed at the rapid rate desired.

In the early 1960s when Pakistan had limited experience with private or public development of groundwater, this seemed reasonable. By the mid-1960s, there were more than 30,000 private tubewells, and some experts, both local and international, urged that private development in areas overlying fresh groundwater be stressed over public development (Eaton, 1965). This advice was noted by the World Bank report, but it was not strongly supported and therefore was, in effect, rejected. By 1978, Pakistan had acquired substantial groundwater development experience in both sectors.

Results of private tubewell development have been demonstrated to serve the needed drainage function and also to improve cropping intensities. The public sector program has lagged far behind original and revised goals and has only partially performed its drainage function. Private tubewell investment has

TABLE 17.—TUBEWELL DEVELOPMENT AND CROPPING INTENSITIES IN AND AROUND SCARP-I

Section	Area (hectare)	Private tubewells (number) 1964	Private tubewells (number) 1975	Cropping intensity (percent) 1964	Cropping intensity (percent) 1975
Upper Rechna	162,000	900	4900	103	131
Tandlianwala	110,000	500	1800–2000	125	144
SCARP-I	468,000	570	3000	105	117

Source: Water and Power Development Authority, Master Planning and Review Division (1979), *Revised Action Programme for Irrigated Agriculture* (3 volumes), WAPDA Press, Lahore, Pakistan.

continued in SCARP areas as centralized management has been unable to meet the flexible needs of the water users (Hussain et al., 1976).

The operational status of public and private tubewells is strikingly different and goes far to explain why farmers have opted to install private tubewells even in areas served by public tubewells (Table 16). Only a few of the numerous post-project benefit-cost type analyses of SCARP-I have attempted to compare SCARP-I with an equivalent private tubewell area: that is, with one where private tubewells supplement canal supplies. As part of the development of the Revised Action Programme for Irrigated Agriculture by WAPDA (1979), SCARP-I was compared both with the perennial commanded area in Upper Rechna Doab (162,000 hectares), which borders SCARP-I, and with the adjacent Lower Rechna Doab (Tandlianwala) area (110,000 hectares). In the Upper Rechna Doab there was one private tubewell per 33 hectares, and in the Tandlianwala one per 55 to 61 hectares in 1975 (Table 17). There are private tubewells within SCARP-I.

Growth in the number of private tubewells and increases in cropping intensity have been faster in both areas than in SCARP-I. From this it can be inferred that the development of public tubewells slowed investment in private tubewells in the SCARP-I area. Assuming that, if SCARP-I had not been built, private tubewells in that area would have developed to a density of one tubewell for every 67 hectares, WAPDA calculated a rate of return for SCARP-I of 6 percent. When WAPDA data are used but tubewell density is increased to that of Tandlianwala (i.e., one tubewell for every 50 hectares), the rate of return on SCARP-I is less than 3 percent. Even with a density of one tubewell per 67 hectares, the predicted cropping intensity in 1976 would have been 122 percent compared to an existing intensity of 117 percent, and groundwater withdrawals would have increased by over 22 percent.

MANAGEMENT PROBLEMS

Many factors have contributed to the disappointing performance of the SCARPs—unprecedented increases in energy costs, technical design faults, foreign exchange constraints—but most of the underlying problems can be traced to poor organization and management. The planning process, especially planning for management and administration of the systems, did not attempt to address some of the most critical issues. Questions related to local level participation in activities such as construction of link watercourses, organization of farmers' groups, location of tubewells, and choice of tubewell technology, appear not to have received sufficient attention by the planners. The fact that operation and maintenance manuals were never prepared for the majority of the SCARPs and that no attempt was made to achieve optimal conjunctive use of canal and tubewell water illustrate that planning was deficient.

Management Structure

The Panel recommended that the SCARPs be managed as a project under a project management board with the authority to cut across line agencies at the field level. Of the northern SCARPs only SCARP-I was organized under a Project Director with administrative control over all services related to irrigation, agriculture and cooperatives. Khairpur SCARP was also organized under a Project Director, but surface irrigation management was under a separate Senior Engineer. In SCARP-I the project approach did not succeed, and in 1970 the management structure was changed to a system of separate responsibility for irrigation, agriculture, and cooperatives by the respective government departments.

Management circles. —One of the problems that plagued SCARP-I and certainly was a major problem with SCARP-II and Khairpur SCARP was that separate mangement circles were established for canal irrigation and for tubewell operation. In each case boundaries of the two management circles were different. SCARP-II straddled part of the Upper Jhelum Circle as well as falling within part of the Lower Jhelum Circle. Both circles are managed by Senior Engineers and have no direct interaction of lines of authority. Operating SCARPs and canal systems as separate circles practically guarantees that there will be no attempt at integrating groundwater and surface water use.

Planning Faults

In all the SCARPS, including Mona which is organized as a research area and Khairpur which is perhaps the best managed SCARP, no real attempt has been made to optimize the potential for conjunctive use of canal and tubewell water. Khairpur does monitor depth to groundwater in each well each month and adjusts pumping schedules as needed to maintain a desired groundwater level. Yet even here, as elsewhere, pumping schedules are not adjusted to reflect estimated canal supplies and crop water requirements. In many areas it would be possible to divert canal supplies to water-short commands and to make up for this deficit by pumping extra hours. Separate canal and tubewell management circles make this type of operating procedure almost impossible, and thus severely restrict potential benefits of the conjunctive system.

Field staff management. —Tubewell operators comprise the largest number of staff working in SCARP circles. SCARP rules stipulate that the operator must be a local person, but he cannot come from the village or villages served by the well. In order to reduce danger of misallocation, the rule restricts tubewell operators from working within a radius of 24 kilometers from their place of origin. Yet as the operator is always supposed to be present when the tubewell is in operation, normally 20 hours per day, this rule is clearly counterproductive. It forces the operator either to cheat by leaving the system jammed open, thereby circumventing safety devices, or to turn off the tubewell even if water is scheduled. Usually farmers and operators work out some type of compromise which invariably costs farmers money (Johnson et al., 1977). An additional problem is that tubewell operators are highly unionized and therefore difficult to punish or dismiss. It has also been suggested that another reason why officials find it difficult to control their subordinates is that a substantial portion of the operators' exactions are passed up the line. Whatever the truth of these allegations, it is clear that day-to-day operations of tubewells are very loosely, if at all, supervised. An absence of effective control over activities of field staff either by senior officials, by standardized cross-checking procedures, or by the farmers through some ability to reward or penalize, all demonstrate that planners did not think out how tubewells were to be operated and maintained in practice.

Watercourse level organization.—Tubewells that potentially could serve over 500 hectares and as many as 100 farmers reflect the fact that planners gave little thought to local level conditions. Even the most cursory investigation would have revealed that farmers along a single watercourse had difficulties organizing for operation and maintenance. The bulk of court cases originating from rural areas concern conflicts over water and associated land. Provision of large, publicly owned and operated tubewells that were designed to serve two or more watercourses immediately created a potential for all sorts of new conflicts. Investigation of farmers' organizational capacities, as well as their technical ability to deal with larger flows of water, would have indicated that smaller capacity, more localized tubewells were better suited to existing conditions. The argument that larger public wells are more "economic" than smaller private wells rests on the unproven assumption that management under both systems would be the same. Planners failed to recognize, or ignored, farmers' limited capacity to cooperate at the watercourse level as well as the technical difficulties in redesigning watercourse channels to carry higher flows. This was plainly a gross error of planning and goes far toward explaining failures of SCARPs to be utilized properly at the local level.

Financial Problems

Within the irrigation system, relatively large sums are now being spent on special and emergency repair work as opposed to ordinary system maintenance. This supports the commonly expressed view that in the past the Irrigation Department's allocation for recurrent expenditure has been inadequate for an effective program of preventive maintenance. Even with additional funds for a special five-year maintenance program aimed at strengthening canal banks, senior irrigation officials feel the bulk of maintenance funds are being spent on essential maintenance of main and branch canals. This leaves little for strengthening of main canals, much less for work on distributaries and minor canals or drains, which are in poor condition and vulnerable to breaching. System-wide maintenance cycles which should be completed every 3 to 5 years will take more than 20 years at present funding levels.

With current water fees and collection rates, total revenue from water charges is insufficient to cover even operation and maintenance charges. Addition of SCARP operation and maintenance expenses to the already overburdened Irrigation Department operation and maintenance budget has further increased the department's deficit. In 1975-76 the Punjab Irrigation Department spent approximately $1.3 million on ordinary operation, maintenance, and staffing on 628,400 hectares served by the Lower Jhelum Canal. An additional $3.2 million was spent on operations and maintenance as well as staffing to provide tubewell drainage of 360,000 hectares served by SCARP-II within the Lower Jhelum Canal Command. Combined operation, maintenance, and staff budget for 1975-76 in the Lower Jhelum Canal Circle was therefore $4.5 million. With recovered water charges of approximately $2.9 million, the deficit was $1.6 million. If emergency capital charges including emergency operation and maintenance costs are included, the deficit increases to about $2.2 million. This deficit does not take into account capital repayment costs for the SCARP system, and it assumes that all capital costs for the irrigation system are already sunk costs. For the entire Punjab the deficit in the Punjab Irrigation Department budget was $17 million in 1978-79 and was estimated to be more than $20 million for 1981. For all of Pakistan the annual deficit may exceed $40 million, again excluding past capital expenditures.

These deficits are the responsibility of individual provinces but the provinces' ability to raise revenue has not increased enough to meet them. In the short run, the provinces have subsidized tubewell operation by underfunding required canal system maintenance and agricultural extension and crop and livestock research. They have also gone into debt to WAPDA for SCARP electric charges. The provinces must either increase their revenue from water charges or reduce their costs of operating and maintaining tubewells, or both. They have already restricted funds for SCARP operation and maintenance, but this forces a reduction in utilization rate and slows the rate at which tubewells are repaired. The result is a reduction in total pumpage and an increase in per-unit water and drainage costs.

OPTIONS

Although SCARPs have played an important role in demonstrating the potential for groundwater development, private tubewells have actually pumped more groundwater than have public tubewells. WAPDA has conceded that most of the reclamation of salt-affected land in the last 15 to 20 years is due to improved water supply and individual farmer initiative rather than to sustained public agency programs (WAPDA, 1979). With the magnitude of critical information available concerning SCARPs, and given the extent of the public subsidy required to keep SCARPs operational, the government now needs to explore its options.

Freshwater zones.—More than 3 million hectares of land in Pakistan are served by SCARP tubewells with a sunk cost of more than $500 million. After 15 years of SCARP operations, waterlogging and soil salination within the SCARPs appear to have improved marginally, at least in the less salt-affected areas. Yet, SCARP tubewells are becoming older and less efficient and they must be pumped more hours each month even to hold their own, while the price of energy is increasing rapidly. WAPDA has recommended a phased replacement of existing public tubewells in freshwater zones with private tubewells as SCARP tubewells are exhausted (WAPDA, 1979). Moreover, they have recommended increased operating funds to permit higher utilization factors, use of private workshops to reduce duration of breakdowns, and distinct efforts to better integrate operation of surface water and groundwater supplies. They have also suggested that pilot studies might be made of replacement of public tubewell operators by farmer groups that have a stronger incentive to keep the well operating.

Unless the Government can locate and invest vast sums of money to replace and rehabilitate SCARP systems, these systems are inevitably going to decline. Private tubewells will be built where the groundwater is of good quality and markets are available for increased output. There is no justification for continuing to subsidize SCARP systems in areas where private tubewells have already been installed and SCARP tubewells are in their final years. Farmer groups could be given the option of paying energy costs, establishing their own schedules, and operating the tubewells until the group decided this was no longer economic. However, SCARP tubewells are located at the head of the watercourse, while private tubewells are located down the channel close to the owners' fields, making distribution losses considerably higher for SCARP tubewells. Therefore, only farmers in the head end of the watercourse command will normally be willing to pay to continue to operate SCARP tubewells. Farmers located away from the SCARP tubewell, given increasing maintenance costs and excessive energy costs per unit of water delivered to their fields, will quickly find that owning their own tubewell or sharing a tubewell with close neighbors is more economic.

In areas where tubewells are newer and there has been less private development, more effort could be made to form farmers' groups to operate SCARP tubewells until private tubewells become a better alternative. Giving farmers freedom to operate the public tubewells on demand or to install their own tubewells should lead to a significant increase in total pumping from groundwater in the freshwater areas. This would accomplish desired goals of the SCARP program at a mere fraction of the cost to the Government, as has been demonstrated in non-SCARP areas of the Punjab and across the border in the Indian Punjab. Inevitably there will be areas where development is slow or where certain target groups appear to lag behind. WAPDA's Action Plan has recommended an intensified agricultural credit program to support private tubewell installations in areas not yet fully exploited. This would be administered through commercial banks with medium-term loans at commercial interest rates. While this type of program can serve some select groups, perhaps a credit subsidy to manufacturers to produce better, and cheaper, equipment, especially small diesel engines and high-efficiency electric motors, would have a better chance of accelerating the spread of private tubewells. Similarly, efforts to make certain rural electrification schemes take groundwater quality into account when setting construction priorities could speed tubewell development. Encouraging and legalizing the market for selling and trading water at the watercourse command level would also provide a strong incentive for small farmers or groups of small farmers to invest in tubewells.

Saline water zones.—In saline water zones farmers find no incentive to install tubewells. Drainage, either by vertical tubewell or by surface drain, requires large-scale outlet channels to remove saline effluent, although freshwater skimming wells can serve a drainage role in some areas. The World Bank and WAPDA have estimated the rate of return for surface drainage in the Sukh Beas Scheme at 13 percent and 15 percent, respectively. However, while drainage may be economic most of the capital investment would have to come from the Government. Based on past history, WAPDA questions whether the Government would allocate sufficient funds for operation and maintenance for either drainage tubewells or surface drains (1979). As drainage does not generate significantly higher incomes, but merely prevents degradation of existing incomes, farmers are reluctant to pay much to support public drainage schemes. However, farmers might be willing to provide some support and, even if only a few dollars per hectare (more than 8 million hectares may need drainage), they could contribute a large amount of the operating funds.

While drainage needs are more immediately obvious in saline groundwater zones, they also exist in the freshwater zones. Eventually a drainage department fully as competent as the irrigation department is going to have to be created for all of the Indus Basin. Priority for saline effluent disposal must be of the same magnitude as the provision of irrigation water. Drainage activities need to reach a point where career bureaucrats perceive equal potential for advancement through drainage activities as they currently do through irrigation-related activities.

CONCLUSIONS

Pakistan, due to its unique size and flat topography, selected public vertical tubewell drainage as a medium-term solution to its immediate waterlogging and soil salinity problems. The decision to implement public vertical tubewell drainage over other alternatives was not made without careful study and considerable debate, but it did represent a new technology never attempted on that scale before. With the information available at the time original design parameters appeared realistic. However, as it became apparent that assumptions such as the willingness of farmers to invest in private tubewells, the economic life of tubewells, the availability of power, the costs of maintenance, and the level of cropping intensity were proving incorrect, there was sufficient justification to question the original design. Recognized management problems with tubewell operators, and jurisdictional conflicts between irrigation and tubewell circles, should have led to needed internal administrative adjustments, but the bureaucracy did not respond.

Failure to change design and operational procedure was primarily a result of the administrative structure associated with large-scale water projects and its relationship to the public decision-making process. The decision to invest in SCARPs and the establishment of priorities for construction were central government decisions, and construction itself was also under the control of a central government organization (WAPDA). Operational responsibility lay with provincial irrigation bureaucracies that had no control over project design and construction. Nor had they historically been actively involved at the watercourse command area level where the tubewells actually operate. The situation was further complicated by tubewell operators forming unions and demanding rights that other irrigation employees had never been granted. As the political system discouraged feedback from rural water users and provincial governments did not have the power to influence a rigid public decision-making process, it was extremely difficult to change a decision once it was made. International funding agencies must also bear a share of the blame as they were aware of many of these shortcomings, but continued to fund SCARPs without demanding major revisions in either design or management.

A number of lessons for future development of additional SCARPs as well as large-scale irrigation or drainage schemes in other countries can be learned from Pakistan's experience. The most important are:

1. In selecting a technology, particularly a new one, a system to monitor project implementation is a necessity. In conjunction with the monitoring system, a mechanism to alter design parameters and operation procedures as new information becomes available is also necessary.
2. Administration of large projects also requires an internal organization to maintain constant project review. An external monitoring organization is not usually very effective as it lacks power within the bureaucracy and therefore rarely is able to influence decisions related to sensitive administrative adjustments.
3. Administrative jurisdiction must be clearly defined with no areas of ambiguity or overlap. Where questions arise there needs to be a recognized decision-maker that can quickly resolve the issue. New administrative organizations that attempt to take power from old, established bureaucracies can only succeed if the transfer of power and responsibilities is complete, if it is accepted by all concerned parties and if career decisions for all personnel rest with the new organization.
4. On projects that involve lengthy planning and construction periods, it should be recognized that farmer expectations and behavior change over time. As economic circumstances alter, farmers' reactions to perceived economic incentives will alter. Project success depends upon the ability to adjust to changing farmer behavior.
5. Water pricing and collection policies need to be tied to costs so that users who benefit from the system pay for the services. Subsidies will invariably lead to larger and larger requirements for public funds and seem to result inevitably in inadequate maintenance and repair programs.

Even with improved management of the SCARPs, more private tubewell development, further expansion of surface water supplies, and increased intensification of agricultural production, salts are continuing to accumulate in the soil and associated groundwater. Only when equality between salts flowing into the system and salts flowing out of the system is reached will long-term irrigated agriculture be possible.[6] This fact was known and plainly stated in the Revelle Report, but it has been ignored in the rush to develop SCARP areas. SCARPs are not a long-term solution; they only delay the eventual need to remove salts from the irrigated area.

Technologies to reduce salts in the system include flushing saline effluent down the rivers (Kemper et al., 1978), diverting effluent to designated salt flats or lakes and draining effluents by surface drains to the sea. This last alternative is environmentally the least destructive but the most expensive. All three methods will have to be used eventually to maintain a positive salt balance in the Indus Basin. Even with a least-cost mix of alternatives, drainage will require massive investments in human and physical capital, and users of the system will have to pay significantly more for water and for drainage.

The Government will also have to provide additional funds and, even more important, commit additional administrative and technical personnel. Given a population which is expected to exceed 130 million by 2000 and a precarious food supply situation, Pakistan has no choice but to invest in protecting the long-term productivity of its most valuable natural resource, agricultural land in the Indus Basin. To make this investment both economically and financially feasible, however, users who benefit need to be persuaded to pay most of the costs. Provincial governments can no longer subsidize these services from other resources, as the SCARP experience has proven.

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