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Managing Conjunctive Water Use in Canal Commands: Analysis for Mahi Right Bank Canal, Gujarat

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This chapter presents an empirical analysis of the interaction between canal irrigation and groundwater systems in canal commands. The externalities produced by canal irrigation projects are widely recognized; indeed, increasing awareness of the diseconomies imposed by waterlogging and the consequent buildup of salinity on top soils has contributed in substantial measure to the growing disenchantment with major irrigation projects (see, for example, Bowonder and others 1987, 331-341; Joshi 1986, 416-423; Joshi and others 1987, 198-206). External economies of canal irrigation are also recognized; in fact, in building a convincing case for canal irrigation, Professor Dhawan argues that a major chunk of the benefits that may justify further investment in canal projects emanates from the highly salutary effect of those projects on the productivity of private investments in groundwater irrigation (Dhawan 1988b, 23).

INTERACTION BETWEEN CANAL PROJECTS AND GROUNDWATER SYSTEMS

Conjunctive use of ground and surface water has for long been talked about as something that would lessen the diseconomies and maximize the positive externalities of canal irrigation. An operational strategy to promote such conjunctive water use is, however, nowhere in sight. The way the term conjunctive use is defined and understood is part of the problem: at least three concepts of conjunctive water use are in vogue:

(1) The first implies that farmers use wells as an on-demand irrigation system, when canal water is inadequate, unreliable, or both, to reduce moisture stress and maximize irrigated crop yields. Kolavalli (1986) and Brahmbhatt (1986), for example, use the term in this sense. The effect of such conjunctive use would essentially be to insulate the canal irrigators from the vagaries of the canal system, especially at the tail ends.

(2) The second concept of conjunctive use implies that groundwater is pumped into the canals to augment the canal water resources. This is, for example, done along the Satlej-Yamuna canal in Haryana (Michael 1983). In the Khairpur Irrigation Project in Pakistan, saline groundwater is pumped into fresh canal water to augment the latter's supply without increasing the salinity levels of the blended waters beyond acceptable levels (O'Mara 1984). In

the process, such conjunctive use also helps lower the water table.

(3) The third and, in my view, the most important concept of conjunctive use is implied in the works of scholars like Burt (1964, 80-93; 1966, 632-646) and Dasgupta (1986), which suggest viewing a canal command as a watershed and aiming at optimal use of canal and groundwater resources in the entire region. Professor Dhawan's emphasis on designing canal systems for extensive rather than intensive irrigation can be seen as a derivative of this concept of conjunctive use.

The operational and policy implications of this third concept of conjunctive water use are radically different from those following from the first two. Exploring them would involve detailed analyses of the interaction between ground and surface irrigation systems within different parts of a canal command. Some of these implications are explored in Shah (1988a) on a conceptual plane. The remainder of this chapter examines empirical evidence pertaining to some of the hypotheses suggested in Shah (1988a) in the context of the Mahi Right Bank Canal system encompassing the bulk of Kheda District in Gujarat.

THE SETTING

Gujarat has five major irrigation projects. Of these, the Mahi-Kadana Project is the largest in investment and cultivated command area (CCA). The first phase of the project, completed in the 1940s, involved the construction of a pickup weir on the river Mahi at Vanakbori in the Balasinor taluka of Kheda District. The Kadana reservoir (Panch Mahal District), completed in 1980 in the second phase, made additional live storage of 1,470 million m^3 available for irrigation. The system covers seven talukas of Kheda District (Thasra, Anand, Nadiad, Petlad, Matar, Borsad, and Khambhat) through a canal and distributary network of 5,600 km. The canals are not lined below 250 cusecs (7 cumecs), and the canal system extends up to 40 ha blocks, which may be reduced to suit the stream size. Figure 19.1 shows a map of the Mahi Right Bank Canal (MRBC) system.

Initially, the project provided protective irrigation largely for Kharif crops and, to a limited extent, for Rabi crops; however, with the completion of the second phase, water was also supplied in Rabi and Summer. The irrigation potential created by the project is some 260 thousand ha; in reality, however, the maximum irrigation achieved was just 135 thousand ha in 1982-83, or about 52 percent of the design potential. Table 19.1 presents trends in the area irrigated by the system during 1963/1986 period; Figure 19.2 shows the changes over time in the quantity of water released at the head in different seasons. To be noted is the sharp rise in water available for irrigation during Rabi and Kharif seasons since the early 1980s. Canal irrigation is used for paddy (53 percent), jowar, bajra, and other Kharif cereals (11 percent), wheat (9 percent), and cash crops such as cotton and tobacco (18 percent).

Table 19.1--Increase in canal-irrigated area in the Mahi Right Bank Canal command, 1963-86

Average for Years	Kharif	Rabi	Summer	Total
		(ha)		
1963/64-1969/70	26,175	6,984	915	34,073
1970/71-1974/75	48,790	13,550	1,990	64,311
1975/76-1979/80	57,512	19,864	1,947	79,324
1980/81-1984/85	75,384	25,647	23,707	124,738
1985/86	66,389	26,011	16,711	109,112

Figure 19.1--Map of Mahi Kadana Irrigation Project, Gujarat

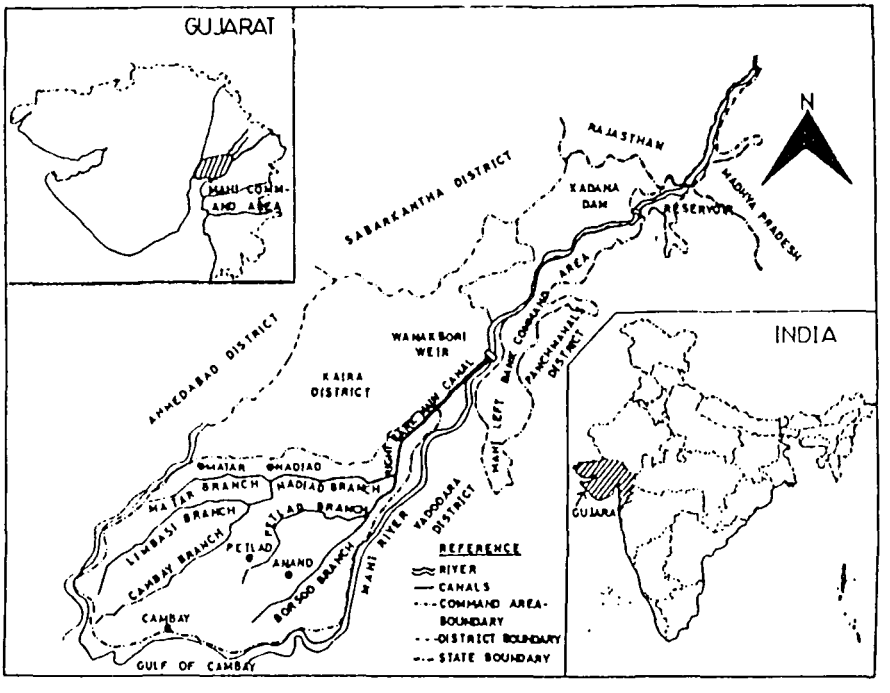
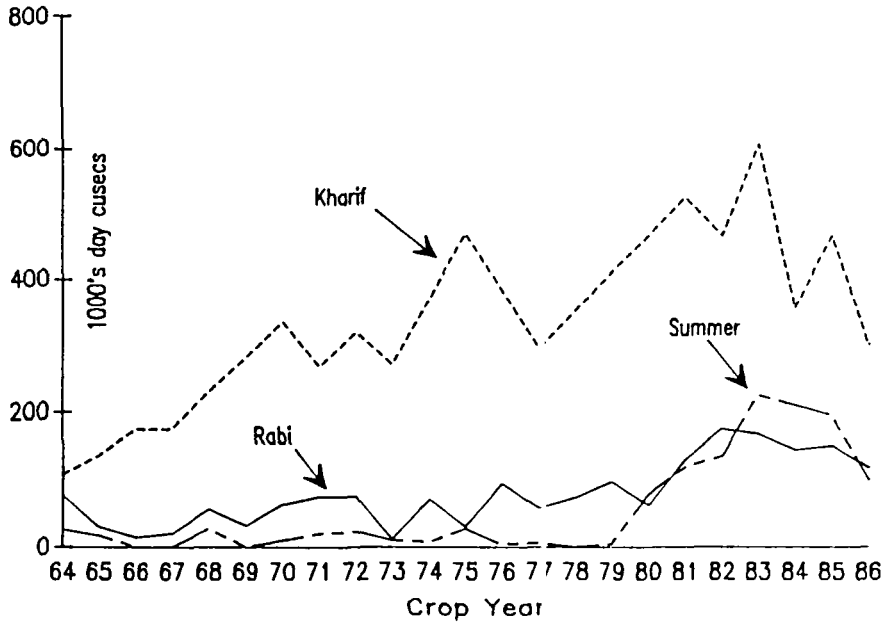


Figure 19.2-- Water released in the head reaches of the Mahi Right Bank Canal Command, 1964-8(



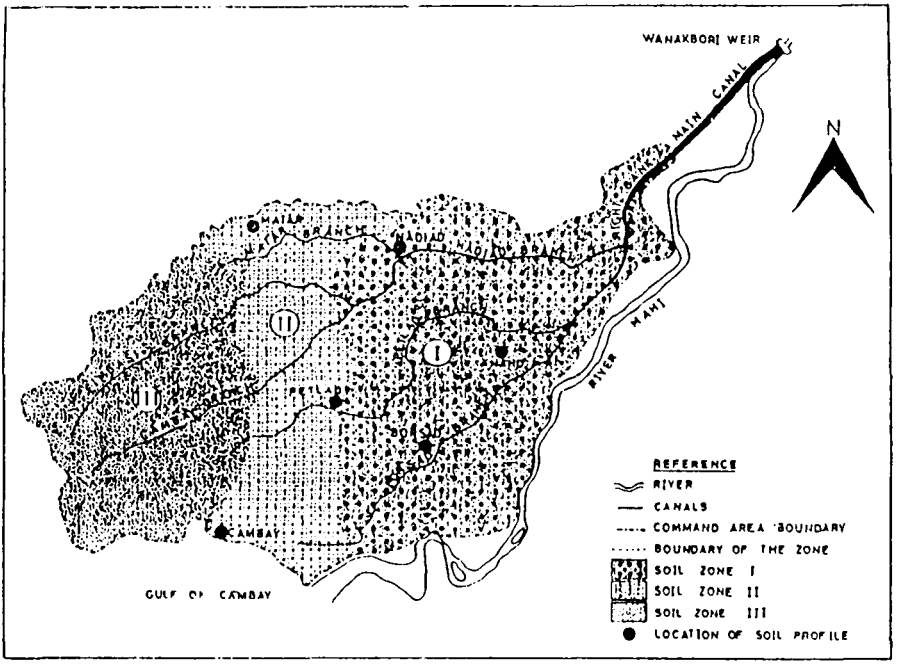
Source: Data from Irrigation Department, Mahi Right Bank Canal Project, Vadodara

The climate of the MRBC command area is dry and semiarid except during the southwest monsoon season, when the region receives 96 percent of the annual average of 823 mm of rainfall spread over 35 days. Several parts of the command often suffer a consecutive period of two to three years of substantially less rainfall than normal. The soils in the area are deep, formed as they are by alluvial deposits carried by Mahi and Sabarmati rivers. The soil profile varies from loam to sandy loam; 61 percent of the area has soil with a moisture holding capacity of 38 to 44 percent by weight; the remaining has a moisture holding capacity in the range of 44 to 56 percent. Nearly half of the area toward the west has hydraulic conductivity of less than 0.03 cm per hour; but 39 percent, mostly in the northeastern part, has hydraulic conductivity values between 0.5 and 5.0 cm per hour (Water Technology Centre 1983, 52-76).

Extensive investigations of soil samples from the MRBC command by the Water Technology Centre, Delhi, divide the area into three

soil zones (Figure 19.3). Zone 1 represents well-drained, noncalcareous, sandy loam soils with low salinity; this zone covers all of Thasra and Anand talukas and over half of Nadiad, Petlad, and Borsad talukas. Zone 2 represents somewhat calcareous soils, varying from sandy to clayey loam with moderate salinity; it includes much of Matar and small parts of Borsad and Petlad talukas. Zone 3, consisting of imperfectly drained clayey soils with relatively high salinity and $CaCO_3$ contents, is comprised almost entirely of Khambhat taluka (Water Technology Centre 1983, 68).

Figure 19.3--Soil zones in the Mahi Right Bank Canal Command Area



IMPACT OF MRBC OPERATION ON WATER TABLE CHANGES

An excellent system of monitoring the variations in the subsoil water table evolved and implemented by the Gujarat Irrigation Department since 1957 highlights the direct and substantial impact of canal irrigation on groundwater conditions. Two readings are taken each year of the depth of the water table from the ground

surface--one before the onset of the monsoon and one after its completion--on a sample of 1,450 wells in the MRBC command area. A standard analysis prepared routinely by the Department's soil survey officer compares the situation in 1957 with that prevailing in the year being reported. A typical example of such analysis, with minor modifications, is presented in Table 19.2.

The rise in the water table between post- and premonsoon levels during a given year measures the change in storage as a result of, for example, seepage of rainfall and seepage from canal irrigation (conveyance and field irrigation return flow), net of groundwater withdrawals during the monsoon months. Likewise, the fall in the water table between the postmonsoon level and the premonsoon level of the following year represents the depletion of the aquifer as a result of net groundwater withdrawals minus canal irrigation seepage during the dry months of the Rabi and Summer seasons. Subsurface flows also play an important part in explaining water table movements (Central Ground Water Board 1984, 17).

In areas where the groundwater table has risen to less than 1.5 meters from the ground surface, the process of upward salt movement under the thermal gradient and its accumulation in the root zone assumes critical proportions; in areas where the water table is in the 1.5 to 3.0 meter range, the situation is less critical but quite serious, especially when the water table is rising over years (Water Technology Centre 1983, 207).

Table 19.2--Rise in the groundwater table in the Mahi Right Bank Canal command, 1957-84

Depth of Water Table from the Ground Surface	1957/58		1983				1984	
			Premonsoon		Postmonsoon		Premonsoon	
(m)	(ha)	(percent)	(ha)	(percent)	(ha)	(percent)	(ha)	(percent)
Less than 1.5	0.0	0.0	3.8	1.3	20.6	7.0	2.9	1.0
1.5-3.0	2.6	0.9	43.8	14.9	74.1	25.2	34.4	11.7
3.0-6.0	18.1	6.1	74.4	25.0	66.7	22.7	79.1	26.9
6.0-9.0	15.3	5.2	41.7	14.2	132.5	45.1	44.9	15.3
More than 9.0	257.9	87.8	131.1	44.6	0.0	0.0	132.5	45.1
Total	293.9	100.0	293.9	100.0	293.9	100.0	293.9	100.0

Source: Gujarat Department of Irrigation, Soil Survey Division, "Mahi Right Bank Canal Project: Report on the Behavior of the Sub-soil Water Table, 1983/84" (Vadodara, 1984).

Table 19.2 shows that no more than 1 percent of the MRBC command had a water table depth of less than 3 meters and that 88

percent had a water table lower than 9 meters in 1957-58; by 1983, however, over 32 percent of the command area had a water table depth of less than 3 meters and 7 percent had one less than 1.5 meters. Further, almost the entire command is experiencing a long-term, secular rise in the water table, although at varying rates (as shown in Table 19.3). Nearly 40 percent are experiencing an average rate of water table rise of over 0.35 meters a year. This trend conforms with what is reported in many other canal commands. For example, Bowonder and others (1987) have observed similar increases in the areas with a critically high water table in the command areas of four major canal irrigation projects; indeed, in the Nagarjuna Sagar Project command, they found a direct and strong relationship between canal water releases in different years and a rise in the water table (Bowonder and others 1987, 334).

Table 19.3--Secular rate of rise in the groundwater table in the Mahi Right Bank Canal command, 1957-84

Rate of Rise per Year (Average in Meters)	Area in Ha	Area as percent of Total
More than 0.69	1,175	0.4
0.35 to 0.68	111,079	37.8
0.0 to 0.34	146,050	49.7
No change	21,451	7.3
Fall of 0.0 to 0.34	14,105	4.8
Total	293,860	100.0

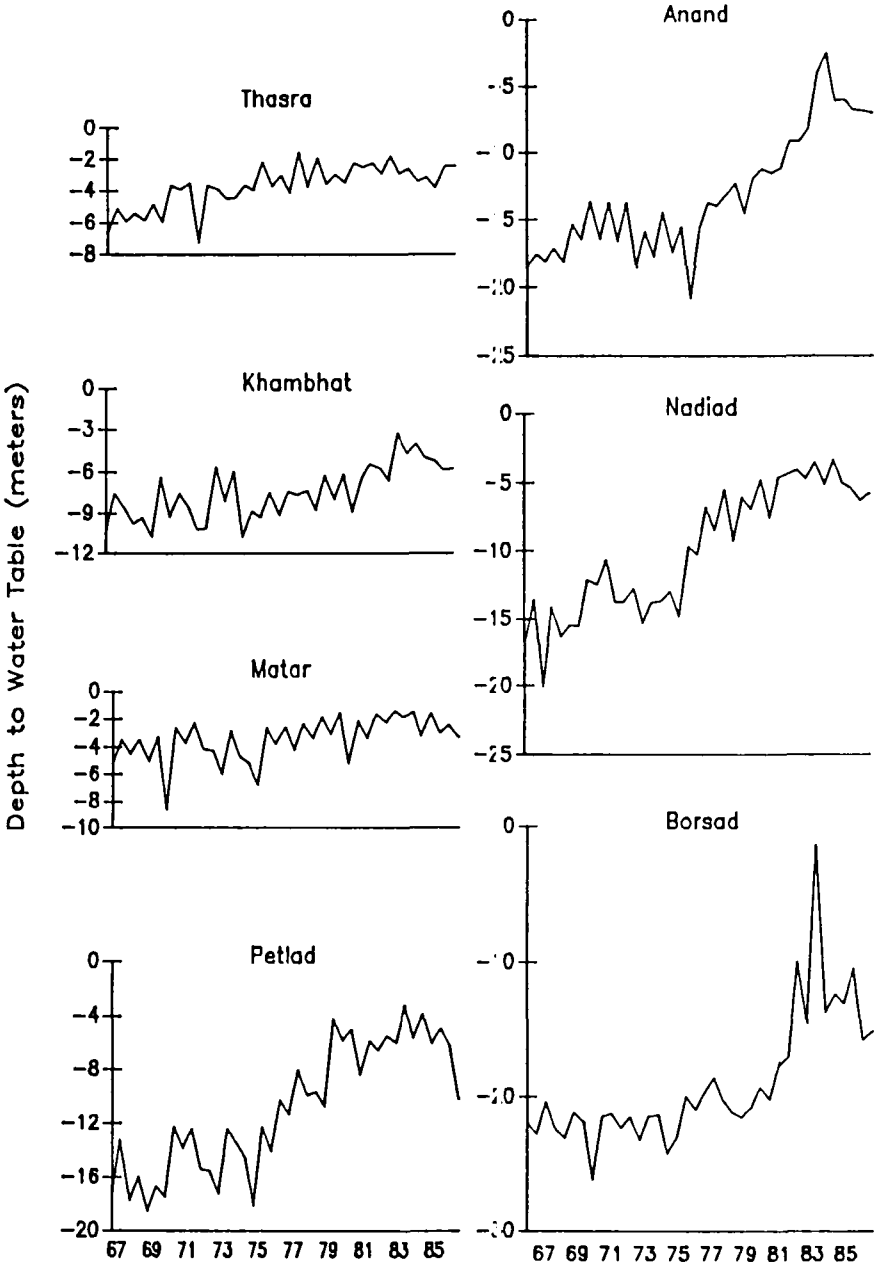
Source: Gujarat Department of Irrigation, Soil Survey Division, "Mahi Right Bank Canal Project: Report on the behavior of subsoil water table: 1983/84" (Vadodara, 1984).

SPATIAL PATTERNS IN WATER TABLE MOVEMENTS

Figure 19.4 plots the movements in water tables in each of the seven MRBC talukas over the 1967-85 period. A random sample of 155 wells was chosen out of a total of 1,450 for which data on water table fluctuations are available. The observations plotted are simple averages of the readings for sample wells falling in each taluka. The first sample of 1,450 wells was well dispersed across villages so that the simple average used is a good indicator of water table changes in the taluka. Note that the levels of the water table at different locations would be affected by topographical features, but that temporal changes would not.

Several features of Figure 19.4 must be noted. First, in talukas like Thasra, which is located at the head of the canal

Figure 19.4--Behavior of the groundwater table in the seven talukas in the Mahi Right Bank Canal Command: 1967-85



system, and Matar, the bulk of which has only imperfectly drained soils, the water table was already quite high in 1970 when this analysis begins. Second, the trend rate of rise in the water table has been far slower in these talukas than in Borsad, Anand, and Nadiad talukas where the water table was lower at the start. The carrying capacity of the aquifer has been rapidly reached, as it were, and many parts of these talukas can now retain only small portions of seepage from rainfall precipitation and canal flows. In many low-lying areas of these talukas--such as the villages of Kalsar, Agarwal, and others in Thasra and much of Matar and neighboring villages from Khambhat and Petlad--the diseconomies of waterlogging have already reached serious proportions. In the low-lying lands in some Thasra villages, many fields have long since been abandoned and are devoid of much vegetation even during the summer. Third, the areas that are far away from the head and have well-drained soils also have experienced a rapid rise in the water table, but this has had an entirely salutary effect of the type that Professor Dhawan describes for the Mula command: stimulating rapid and major investments in groundwater irrigation (Dhawan 1987a, 37-52).

Extensive analyses aimed at identifying dominant patterns in time series data on water table movements in each of the seven MRBC talukas yield insight into the interaction between surface water and groundwater flows. The monsoonal rise in the water table is explained largely by monsoon precipitation and canal water releases at the head during the Kharif season; also, the monsoonal rise tends to be greater in areas with deeper groundwater tables. These analyses also show that during the Rabi and Summer seasons, the water table declines everywhere; such decline is accelerated where groundwater pumping is substantial and is arrested when canal water is released during the Rabi and Summer seasons. Substantial differences mark the manner in which this equilibrating process operates in different parts of the command. Away from the head, in the villages of Borsad, Nadiad, and Petlad, where premonsoon water tables are low, the monsoonal rise in the water table is large; but heavy groundwater pumping during the Rabi and Summer pulls the water table down, while at the same time Rabi and Summer canal irrigation have little impact since many of these areas do not receive canal water except during Kharif. Near the head, where premonsoon water tables are already high, the monsoonal rise tends to be marginal, as does groundwater pumping during the Rabi and Summer.

The extent to which groundwater is pumped varies across talukas; regression analysis indicates a strong quadratic relationship between the buildup of pumping capacity and the depth of the water table. An equation with high t-ratios but low explanatory power indicates the following:

$$\underset{(2.91)}{WEM = 9.4} + \underset{(3.37)}{2.5\ WL} - \underset{(-2.64)}{0.086\ WL^2} \qquad (19.1)$$

$$R^2 \text{ (adjusted)} = 0.126 \quad F = 8.4$$

WEM (water extraction mechanisms) represents the number of energized wells per 1,000 ha of farmland in a given year; WL

represents the postmonsoon water level in that taluka in the corresponding year. Data were pooled for all seven talukas for the 1970-84 period; dummy variables for the taluka terms were found insignificant and dropped. Several problems with this equation prevent a firm conclusion; the explanatory power is low because several other relevant variables were omitted due to lack of data. WEM itself is a poor indicator of actual pumping in a given year; the capacity composition of energized wells may vary greatly across talukas and over years, and so may their actual use. In spite of these problems, the equation has some value in that it suggests an inverted U-shaped relationship between the buildup of pumping capacity and secular changes in the water table. It indicates that groundwater pumping tends to be less intensive in areas where the water table is either too high or too low than in areas where it fluctuates around 12-17 meters. As the water table recedes to 25 meters or below, the economics of groundwater pumping become increasingly unfavorable; capital costs of tubewells increase, and the water yield obtainable with a 15 or 20 hp motor decline sharply. Moreover, a private farmer cannot bore to a depth greater than 45 m. While overcoming this restriction is not impossible, it does cost money and hence acts as a deterrent. On the other extreme, where water tables are high, groundwater pumping is either not economic as in Thasra, at the canal head where cheap canal water is plentiful and reliable, or not possible as in Matar and parts of Khambhat and Petlad, where groundwater is saline.

The time series analysis suggested great scope for fruitful work by bringing into the analysis many variables excluded in the present exercise. Conclusions based on the analysis here would suffer from poor statistical properties, and therefore none is attempted. Certain trends are clearly indicated, however: for example, if larger reservoir capacity could permit increased canal water releases during the Rabi and Summer at the expense of Kharif releases, the overall efficiency in the use of water would improve. It would also lessen the buildup of water tables near the head reach.

VILLAGE-LEVEL ANALYSIS OF CROSS-SECTIONAL DATA

An alternative mode of analysis was used to check if the set of relationships postulated earlier held under a different formulation using different data. A subsample of 71 villages was chosen from the original sample of 155 so that all areas (though not all talukas) were proportionally represented. For each of these villages, the percentage of cultivated area under canal irrigation (C) was computed from the 1981 district census handbook. Data on total installed tubewell capacity (hp) were compiled from the local offices of the Gujarat Electricity Board and used to compute the ratio of installed hp per ha of cultivable land (HPHA) for each village. Then, from a large map of the MRBC system, the distance in km that canal water travels along the main canal, branch canal, distributary, minor, and subminor to reach each of the 71 sample villages was estimated. The hypothesis was that a village served by the tail end of a distributary emanating from the tail end of a

branch gets less canal water than one served by a distributary starting from the head of a branch, and so on. Finally, for each village, the total rise in the water table--pre- as well as post-monsoon--was computed over the entire 1967-84 period. The basic objective was to examine whether the system has a built-in tendency to move toward an equilibrium in which the water table is contained within an upper limit above which land productivity would suffer due to waterlogging and upward movement of salt, and a desirable lower limit, which would stimulate rapid and sustainable groundwater development. Cursory examination of data and visits to sites in various areas of the command indicated that there is no such tendency and that, in fact, the system might over time become highly unstable. As one moves to villages away from the canal head and the main canal, the abundance and reliability of canal irrigation declines, as does the secular rise in the groundwater table. Further, the buildup of water extraction capacity, the only major antidote to a monsoonal rise in the water table, is inversely related to the distance from the head and the main canal.

Extensive analysis of cross-sectional data from 71 sample villages suggests a strong tendency for the system to move away from equilibrium. From a number of equations estimated, four are of special interest and reported here.

Long-term rise in the water table 1967-84

$$\underset{(-0.58)}{RWL = -0.915} + \underset{(1.83)}{0.0211\ CI} - \underset{(2.16)}{0.843\ HPHA} + \underset{(6.84)}{0.582\ WL67} \qquad (19.2)$$

$$R^2 \text{ (adjusted)} = 0.475 \quad F = 27.88$$

$$\underset{(-0.060}{RWL = -0.121} + \underset{(1.71)}{0.039\ DMNBR} - \underset{(-4.00)}{0.301\ DDIMISM} + \underset{(8.44)}{0.501\ WL67} \qquad (19.3)$$

$$R^2 \text{ (adjusted)} = 0.569 \quad F = 31.79$$

The rise in the water table over the 1967-84 period (RWL) in 71 sample villages is explained by two equations with different sets of independent variables. In equation (19.2), the differences across the sample villages in the long-term rise in the water table are directly related to the proportion of farmland under canal irrigation (CI) and inversely related to the buildup of pumping capacity in the village (HPHA). More significant than these two was the initial water level in 1967, which has a large positive coefficient.

This is also true for equation (19.3), which indicates that the rise in the water table tends to remain constant as one moves to villages away from the head but along the main or branch canals (DMNBR), but it decreases sharply as one moves to villages farther along the distributaries, minors, and subminors (DDIMISM). In particular, as the distance that the canal water travels in the distributary, minor, and subminor before it reaches a village increases by 1 km, the rise in the water table in that village tends to be one-third of a meter less than elsewhere, other things remaining the same.

recursive model clearly suggests that, left to itself, the MRBC system would continually move away from the water balance equilibrium defined earlier. Rising water tables would engulf increasing areas near the head, and groundwater exploitation would keep lowering the water table (or preventing it from rising to economically optimal levels) at the peripheries.

TOWARD A STEADY STATE WATER BALANCE EQUILIBRIUM

Planning and investing in elaborate drainage works and the lining of canals are widely recommended as a precondition for optimum use of water and land resources in a canal command. The preceding analysis for the MRBC project suggests that more than drainage and canal lining is involved. Drainage only removes unwanted water to areas where it cannot damage land productivity, but cannot make it available to far-flung areas where water may have high value. Lining of canals may be somewhat more beneficial; it reduces seepage and makes more canal water available at the tail ends. Professor Dhawan's argument in favor of designing canal systems for extensive, rather than intensive, irrigation makes great sense in the context of this analysis, but the main question still is how to operationalize this suggestion. Clearly, designing the system for a particular pattern of use is not the whole answer, since even as it is designed, the MRBC system cannot supply water to a large number of peripheral villages where the minors and subminors have hardly ever become wet.

Establishing a long-term water balance equilibrium over the entire command would require discouraging canal irrigation use and encouraging groundwater irrigation near the head and along the main and branch canals. This would be an antidote to water table buildup and the most effective way to secure an extensive spread of canal water resources. Achieving this at the head and along the main and branch canals automatically improves the service to the tail ender as much as a canal system (with a certain configuration) possibly can. In the process, it obviates the need to make huge investments in drainage and lining; ensures as much equity as possible in the spatial distribution of access to water (directly from the canal system or indirectly through groundwater); and finally, minimizes the diseconomies of waterlogging and soil salinity.

Clearly the 'default' pattern that tends to emerge in the absence of deliberate and well-directed policies aimed at altering it is the opposite of this equilibrium pattern. Near the head and along mains and branches, the use of canal water tends to be very intensive and groundwater irrigation is resorted to only sparingly (See, for example, Brahmabhatt 1986 for canal and groundwater use at the head, middle, and tail reaches of the MRBC). Field visits to villages in Thasra taluka, in fact, revealed substantial disinvestment in wells in the head reach (Saiyed 1988, personal communication); once canal water supplies were assured and available, several farmers actually filled up their wells to bring the land so released under crop cultivation. Low water rates for canal irrigation, abundance and ease of canal water supplies, and facility of deferred payment (often, of no payments) for canal water, were among the oft-

cited reasons for the declining preference for groundwater irrigation in the head reaches.

On the other hand, the rapid increase in the HPHA--the installed hp of pumping capacity per ha of cultivable land--from less than 0.1 in the head reach to 0.6 to 1.2 in Borsad, Anand, Nadiad, and parts of Petlad talukas located far from the head conceals the existence and operation of highly complex social institutions for private exploitation and sharing of groundwater in these latter villages (described in detail as village-level groundwater grids by Shah 1988a, 1988b). Typically, each village has 25-40 private tubewells, powered by 20-30 hp motors, which irrigate all or the bulk of the village farmland through a complex network of crisscrossing underground pipelines. Irrigation is supplied on a sale basis at a price reflecting a surprising degree of uniformity not only within a village but within a whole region. Intense competition among sellers contains arbitrary or collusive behavior and ensures access to groundwater to the land-poor farmers who cannot afford investing in their own wells. In Navli, typical among such villages and studied intensively by IRMA, 24 private water sellers irrigate some 283 hectares of highly fragmented holdings for the equivalent of 2.4 seasons through privately established and maintained underground pipeline networks of some 60 km (Shah 1988b, 6). On equity as well as efficiency grounds, these highly developed groundwater markets have attractive and socially desirable properties.

A major complaint against these water markets--that the water sellers in Gujarat charge unusually high water prices compared with their pumping costs and with the prices charged by water sellers in other states (Shah 1985)--was removed when the Gujarat Electricity Board recently switched from metered power tariffs to flat rates. This switch resulted in a state-wide 30-60 percent reduction in the price of groundwater sold by private wellowners. In much of MRBC, where water markets are active, water prices fell from Rs 25-30 per hour of pumping to Rs 15-18 per hour for 20 to 25 hp wells and resulted in the substantial redistribution of the irrigation surplus in favor of the generally resource-poor water buyers (for evidence of this, see Shah 1988b, 19).

The emergence and development of groundwater markets tend to be strongly influenced by canal irrigation. In the head reaches of the MRBC, water markets exist in primitive and limited forms only in uplying villages or areas where canal water is neither reliable nor adequate. Even here, cheap canal irrigation keeps exerting a constant downward pressure on groundwater prices. Shah and Raju (1988, A-27) found prices charged by well owners in a Thasra village that were 40 percent lower than in Anand and Borsad talukas. Over time, one can expect some of these well owners competing with canals to withdraw from the water markets.

The dramatic impact of canal irrigation on groundwater markets was recently demonstrated in Anklav, a village in Borsad taluka falling at the tail end of a subminor. Although the village had two canals, little land was actually irrigated by canal water, which seldom reached one of them; a very active groundwater market operates in the village and irrigates some 486 hectares with 45 private wells. Last year, as part of its action research program, the irrigation department made structural improvements that in-

creased the availability of canal water in a part of the village served by six private tubewells. In a short period of time, these well owners found their buyers increasingly unwilling to buy water from them. While all other sellers cut their prices from Rs 25 to Rs 15-18 per hour consequent to the change in the power tariff policy, these six cut their prices down to Rs 6 per hour in a bid to keep their unwilling clients. It looked to be only a matter of time before they wound up their operations altogether and the water market disappeared from this part of the village.

In many parts of Gujarat and several other states, groundwater markets produce important economic, social, and ecological effects, the most important being that they open up access to groundwater irrigation to many more farmers than own wells. In most areas, this implies that much more groundwater is pumped by existing wells than would have been the case in the absence of markets. In areas like Mehsana District in Gujarat and Coimbatore in Tamil Nadu, water markets are correctly seen as contributors to the overexploitation of the aquifer. By the same token, active water markets can greatly enhance the value of private tubewells in supplying vertical drainage in waterlogged and high water table areas. The catch involved in bringing this about, as these analyses show, is that such water markets seem to operate the least well in precisely the areas where they could produce the maximum social benefit. Like all market institutions, groundwater markets are the outcome of the interplay of economic stimuli; and in the present arrangement, most economic and noneconomic stimuli encourage water markets where they can do the least ecological good and discourage them strongly where they can produce the maximum social good.

MANAGING CONJUNCTIVE WATER USE: POLICY OPTIONS

Most existing canal system management policies and practices militate against the water balance equilibrium necessary to use water and land resources efficiently in a canal command. An example is offered by the pricing of drain water. Along many branch canals in the MRBC, constructed surface drains remain filled when the canals are full. The only way to dispose of the water from these drains is by encouraging the neighboring farmers to use it for irrigation; it is necessary to do so because the drains function well only if the large bodies of water they hold are removed periodically. Yet, the farmers who use drain water for irrigation pay more than those who use canal water: they have to pay half the canal irrigation charges and pay for pumping water from the drains, which are usually lower than the canal and the neighboring fields, often by hiring diesel engines. Naturally, few farmers, especially along the canal banks, choose to use drains for irrigation; as a result, drains remain permanently full and drain surplus water less effectively. One could think of no logic in this system of charging for drain water irrigation. Actually, the irrigation department should pay farmers along the canals to irrigate from drains and not from canals, since if the irrigation department were emptying the drains regularly, they would incur substantial costs, which are saved when farmers irrigate with drain water.

The greatest obstruction to making the transition to equilibrium is the lack of coordination between the agencies managing the canal system and those in charge of groundwater development. Private investments in pumping capacities in different locations are governed by the relative--and not absolute--availability, reliability, and economics of groundwater compared with canal irrigation. When the per crop-ha charges for canal water are substantially lower than the costs of groundwater irrigation, they encourage profligate use of canal water, choice of water-intensive crops, and strong preference for canal water irrigation in areas close to the head and along main and branch canals, where it is reliable and plentiful. Encouraging groundwater irrigation in these areas is largely a question of changing the relative economics.

These considerations are absent in the policies followed by canal as well as groundwater managers. The siting and licensing norms used by the latter agencies are for example, the same in Thasra villages, where new private tubewells can create big positive externalities, as they are in Borsad. A tubewell in Thasra cannot be bored deeper than 45 m; a farmer cannot get a license for a tubewell that falls within the theoretical command of a state tubewell; the spacing required between two private tubewells is the same in Thasra as elsewhere in the district. Needless to mention that no special rebates or subsidies are offered either on capital or operating costs to potential well owners in the head reaches and along the main and branch canals nor are efforts made to prevent existing well owners from filling their wells.

To be sure, the utility of tubewells in controlling water table movements is recognized by irrigation sector managers. Under a special program, the Gujarat Groundwater Resources Development Corporation undertook to establish public tubewells in the MRBC command area as a means to promote conjunctive water use and to act as an antidote to water table buildup One would have expected these tubewells to be concentrated in areas suffering from already high or rapidly rising water tables. In reality, the majority were located in areas where private water markets were already doing a roaring business, where canal irrigation was not available, and where these tubewells could operate viably. Only 6 of the 283 public tubewells specifically established under the MRBC program were located in 44 villages that the soil survey officer had declared as having a water table less than 1.5 meters from the surface; and none were established in some 90 villages where the water table was between 1.5 and 3.0 meters (Gujarat, Department of Irrigation, Soil Survey Division 1984; Groundwater Resources Development Corporation 1986). Although the question remains of their quantitative significance even if they had been located right, there seems little point in such tubewells seeking commercial viability that is in direct conflict with the social goal of promoting groundwater irrigation. Two clear implications are that: (1) public tubewells in canal commands should be located primarily where water tables are rising dangerously and not where private tubewells are already doing well, and (2) public tubewells located thus should aim to achieve maximum groundwater irrigation as a means to discourage canal irrigation by subsidized pricing of water.

One approach to generating a large-scale impact might be to reward private farmers for producing water table control as a positive external effect of groundwater irrigation. This approach would require several reversals. It would imply encouraging farmers along the canals to irrigate from drains without charging them (if not by paying incentives). A major aim would be to alter the economics of canal versus groundwater use especially in the head reach and along the main and branch canals. The leeway available to do this is limited in the absence of volumetric pricing of canal water, which is assumed to be beyond the realm of practicality in the foreseeable future. But a substantial increase in canal water charges and their effective recovery would help make groundwater irrigation somewhat less unattractive to farmers who can choose between the two.

Clearly, the existing tendency of groundwater agencies to treat all parts of the command equally is inappropriate; rather than controlling or regulating groundwater development activity in the head reach and along canals, they should actively encourage it by removing all restrictions and minimizing the hassles involved in establishing wells. If this were accompanied by substantial subsidies for capital as well as operating costs of tubewells, specifically in areas with high or rapidly rising water tables and fresh groundwater, it is highly likely that the groundwater grids that, at present, operate away from the canal network as in Anand, Borsad, and Nadiad talukas would spring up in villages in the head reach and along canals and provide lateral drainage as a byproduct of irrigated farming. These subsidies have a clear purpose--to promote groundwater use in the parts of the canal command where, on their own, farmers would not find investing in wells worthwhile--and a clear spatial dimension; confusing them with antipoverty subsidies defeats their purpose.

The likelihood that such a mix of policies would establish equilibrium tendencies is high for several reasons. Private farmers are known to have a strong preference for well irrigation because it offers them control over the timing and quantity of water application--so much so that farmers in the middle reaches of MRBC often prefer to use well irrigation even though it may cost 7 to 8 times more than canal irrigation (Water Management Synthesis Project 1983, xvii). With sufficient incentives and favorable administration, the response of private farmers would be greater in magnitude than public tubewells could ever achieve. Even where they are today, public tubewells in the MRBC do not account for more than 10-15 percent of groundwater irrigation in any village. Further, as groundwater irrigation increases in the head reach and along canals, more canal water will reach the peripheral areas. This would achieve more extensive spread of canal waters and also improve recharge to the groundwater reservoirs in the peripheries.

In parts of Matar and Khambhat, where soils are imperfectly drained and groundwater saline, the problem will persist. Perhaps public tubewells should be concentrated only in such areas and should promote the second variety of conjunctive water use such as that tried (not very successfully, it would seem) in Pakistan, where public tubewells pumped saline water in canals, thereby lowering the water table and augmenting canal water resources with acceptable

salinity levels. If successful, such a scheme would reduce the salinity levels in top soils over time, especially if the saline water pumped were drained and fresh canal water used for irrigation.