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**SOURCES OF
FUTURE GROWTH
IN INDIAN
IRRIGATED AGRICULTURE**

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EXECUTIVE SUMMARY

Modern Indian irrigation development goes back in time at least to the construction of the Western Yamuna Canal near Delhi in 1355 by Ferozshah Tughlaq. Much earlier irrigation development in the subcontinent was undertaken by the Harappa and Mohen-jo-daro civilizations of 2500 B.C. and the builders of irrigation tanks in South India and Sri Lanka (Rogers 1983). By 1900, British India[1] had about 13.2 million ha of total irrigated area, including 7.5 million ha of public works (4.5 million ha from large-scale public works and 3.0 million ha from minor public works) and 5.7 million ha of private works (4.0 million ha from private wells and 1.7 million ha from other private works) (India, Ministry of Irrigation and Power 1972).

Around this time in the United States, interest in using irrigation development as a means for opening the American West was beginning to swell. In 1890-91 an engineer named Herbert Wilson of the United States Geological Survey was sent to India to learn about its large-scale canal irrigation. This visit was followed in 1902 by the creation of the U.S. Bureau of Reclamation, which was established to "reclaim the arid West." In the 85 years that followed, the Bureau constructed irrigation schemes that supplied water to 4 million ha of western farmland. In October 1987, the Bureau of Reclamation made the startling announcement that it was transforming itself "from a construction company to a resource management organization" and would henceforth concentrate on managing existing projects, conserving water, ensuring water quality, and protecting the environment. In doing this it would cut its staff by half and transfer its headquarters from Washington, D.C., to Denver (Shabecoff 1987).

Although new construction that had already been authorized will continue in the United States for some years, this shift marks the end of an era in which capture and control of water resources were major federal and state development efforts. No direct parallel with the Indian experience is being suggested, but most of the factors that led the Bureau of Reclamation to this decision—shrinking opportunities for new construction, rising costs, agricultural surpluses, large federal budget deficits, and negative environmental impacts and environmentalist opposition to new construction—are present in India.

This paper assumes that in India these kinds of forces will gather strength in the next ten to twenty years until the expansion of irrigated area becomes less important as a source of growth in agricultural output than other kinds of changes within the irrigation sector. It also assumes that the subsector of irrigated agriculture will necessarily continue to shoulder a major share of the burden of increasing agricultural production. The latter assumption is supported by the static nature of the agricultural land base—around 143 million ha of net sown area (India, Planning Commission 1985b)—and requires that growth in output come almost entirely from increased productivity.

[1] This includes the areas of present-day Pakistan and Bangladesh and is therefore not strictly comparable with subsequent figures for modern India.

To explore the implications of this notion, this paper first reviews past sources of irrigation-related growth in Indian irrigated agriculture and the nature of remaining potential for expansion. It then speculates on potential sources of future growth.

1. OVERVIEW OF GROWTH PATTERNS SINCE 1950

1.1 Agriculture

Foodgrain production in India has grown at a compound rate of about 2.7 percent per year since 1950. This has more than kept pace with the population growth rate (about 2 percent) and has reversed the long trend of declining per capita food production that prevailed from the 1920s through the 1940s. There seems to be general agreement that these gains, particularly those attributed to the green revolution, are closely tied to the pace of irrigation development. Estimates of irrigation's contribution to this growth in production vary, ranging downward from Seckler and Sampath's (1985) estimate of 60 percent, but few would deny the importance of irrigation. Daines and Pawar (1987, 2) assert that although "attribution is difficult to assign. . . . few analysts would give irrigation less than half the credit for the progress agriculture has made in India during the last three decades."

I do not treat this issue further here. For the purpose of the general case being made, it is not necessary to know precise details of the connection between irrigation and agricultural productivity—only that it exists, that it is driven largely by expansion of the area under irrigation, and that it is reasonably strong.

1.2 Irrigation

From 1951, when central planning began, until 1983, net irrigated area expanded at a compound rate of 2.2 percent per year (Table 1). This overall figure masks, however, some interesting shifts in the composition of this growth. Over the period 1951 to 1983, the area irrigated by government canals increased at a steady compound annual rate of 2.4 percent, while tank-irrigated area decreased at 0.5 percent per year, and well irrigation grew at a strong 3.9 percent. This growth performance led well irrigation to surpass canal irrigation in net area served for the first time in 1973/74 (Table 2). Since then, the gap between area irrigated by wells and that irrigated by canals has continued to widen.

Disaggregating the growth rate into two periods (1951-65 and 1968-83, see Table 1)—essentially before and after the green revolution[2]—shows that the total net area increased slightly more rapidly (2.4 percent per year) during the second period than during the first (1.7 percent). Among different types of irrigation, creating canal irrigation command proceeded at an even pace—about 2.3 percent per year—during both periods. Tank area grew at a similar rate of 2.4 percent during the first period and then declined at a rate of 1.7 percent during the second. Well irrigation, on the other hand, shows the opposite trend, growing at a modest 1.6 percent during the first period and accelerating to 4.4 percent during the second. Given this pace of growth and the large base that was built, well irrigation will increasingly dominate the irrigation picture in India. Irrigation from private canals declined throughout and at an

[2] The years 1966 and 1967 were periods of severe drought across India, and their omission in time series such as this is common.

increasing pace after 1965. Changes in total, total canal, tank, and well irrigation are shown graphically in Figure 1.

Regionally, expansion of net irrigated area has been uneven, as seen in Tables 3 and 4. Regional figures, with the regions defined in Figure 2, were developed by estimating compound growth rates between decade endpoints (Table 4), based on the average of three years of data for each point (Table 3). The years were selected to achieve a reasonable match in rainfall conditions for each period.

Growth was strongest in a band stretching transversely across the western peninsula of India up through Uttar Pradesh. For all of India, growth was roughly twice as rapid in the areas irrigated by wells as in the canal command, except in the western region, where canal irrigation grew most rapidly. In the south, expansion was virtually nil as shrinking tank and "other" irrigation was compensated for by increased well irrigation. In eastern India also, strong growth in the area irrigated by wells was partially offset by the contraction of the area under tank and "other" sources. It would be interesting to know the extent of actual geographic overlap in these areas of contraction and expansion.

As of 1982-83, net irrigated area (Table 5) was relatively evenly distributed among these regions. This is, of course, partly an artifact of the way in which regional boundaries are drawn. Gross irrigated area shows, however, a slightly different pattern, with Uttar Pradesh and eastern India assuming much greater prominence; they contain some 46.0 percent of the nation's gross irrigated area, but only 39.5 percent of its net irrigated area. Presumably this is due to the higher rainfall that prevails over much of this combined area, which produces higher cropping intensity, and the extensive alluvial aquifer that lies below it. The Gangetic basin holds the most gross irrigated area in the nation.

Unfortunately, these figures show only the nominal area of irrigated coverage and do not address the critical problem of the quality of the irrigation service provided—that is, the ability of the service to produce agricultural output. An area receiving a single irrigation delivery is indistinguishable from one receiving unlimited water on demand. Typically, studies deal with this issue by ascribing a special quality to well irrigation, based on the greater measure of reliability or of farmer control it is felt to have. This, although clearly an inadequate proxy, is about all that the generally available secondary data sources can support. Increasingly, this issue will have to be addressed directly by encouraging the generation and analysis of data on the quantity and timing of irrigation water deliveries over geographic space. Progress in both analysis and in practice depends on it.

2. IRRIGATION POTENTIAL

The figures given above show the steady growth in irrigated area as a result of both public investment in canals and largely private (though heavily subsidized) investment in well irrigation. They also suggest the general and increasing importance of well irrigation in India since 1965, in particular its extremely strong rates of growth in eastern and central India in recent years.

To assess the importance of these trends requires, however, examining them against the backdrop of the limits to their continued growth. This ceiling is comprised of a number of factors, including the sheer physical availability of the water resource, the proximate availability of suitable land to irrigate, the economics of resource development and the technology imbedded in these calculations,[3] the political will to develop the resources, the political relationships among neighboring riparian states and countries, and institutional constraints on the ability to add to or to sustain in operation the capacity already created.[4] This is a complicated and interlinked set of factors. At the risk of oversimplification, I focus on what is, to an engineer at least, the most fundamental of these—the water resource.

The ultimate irrigation potential of India is assessed at 113.5 million ha, distributed regionally as shown in Table 6. As of 1984/85, about 60 percent of the ultimate irrigation potential was being used. Groundwater use was about 70 percent, and surface water use was 54 percent. Only in the eastern and central regions did the unexploited potential exceed 50 percent of the ultimate, and the average of unexploited potential for the entire country was just over 40 percent. In the eastern region the unexploited share of groundwater was largest, while in the central region that of surface water was the greatest. In both cases, however, the bulk of the absolute amount of remaining potential lay on the surface.

The northern and southern regions and Uttar Pradesh have the least remaining unexploited potential, although as the limit is approached, these estimates of remaining potential probably become increasingly unreliable. For example, Table 6 indicates that groundwater in

[3] This factor is related to the first two, of course. If unused water and unused land are available some place, but not necessarily in the same place, they can always be brought together for productive agricultural purposes. The cost one is willing to bear is the determining factor. Normally, implicit rules of thumb limit planners to considering only resources with a particular measure of proximity to each other. As such opportunities are exhausted, their thinking may range more widely to consider, for example, transbasin diversions of the type being considered in India.

[4] In a real sense, land area both enters and leaves the category of installed capacity or potential. It enters in the obvious way and leaves as canal and reservoir capacity is reduced due to siltation, area is unserved due to ineffective water allocation and delivery, or land becomes unusable due to salinization. This in a sense results from natural processes and requires a positive input of financial and managerial resources to forestall. Thus, one can envision a situation in which inadequate recurrent resources allow potential to be lost at a rate that balances additions to capacity and forms, in a sense, a dynamic ceiling.

Uttar Pradesh is almost fully exploited, although experience indicates that some potential remains.

In spite of the promise of permanence implied by the term ultimate, estimates of ultimate irrigation potential do not remain constant. Table 7 shows how this value has expanded since 1972, with the total ultimate potential growing by 40 percent between 1972 and 1985. An additional 34.5 million ha are being considered for inclusion (India, Planning Commission 1985b).

Can we expect this tendency to continue indefinitely? If so, the limit on expansion of irrigated area that is being hypothesized here may not be reached for some time. However, major continuing growth in potential estimates seems unlikely, at least for surface water, for several reasons. First, a large portion of the increase in estimates simply represents a refinement based on better techniques and better information. The amount of surface water (not irrigable land) that the First Irrigation Commission estimated was available eighty-five years ago (144.3 million ha m) was only 25 percent less than the current estimate (181.1 million ha m). This represents a marginal increase, given the time that has elapsed, not a dramatic discovery of vast new resources.

Second, a significant part of the 34.5 million ha expansion of ultimate surface potential currently being mooted is supposed to come from major transbasin diversion schemes, which are typically very expensive and from transnational schemes that require international agreements and cooperation, which have proved elusive in the past.

Third, the cost of surface water development is rising as the easily exploitable sites are exhausted and the objective of development shifts from protective to productive, or more intensive, irrigation. The overall real cost of building major- and medium- scale schemes has more than doubled in the thirty years between 1950 and 1980. At 1970-71 prices, Sawant (1986) reports that the per hectare expenditure for major- and medium-scale irrigation construction was Rs 2,770 in the First Five-Year Plan, and Rs 5,880 in 1979-80. The anticipated expenditure for the Sixth Plan was Rs 6,696. Since undiscovered sources are likely to be more expensive to develop than known ones, exploitable potential probably will not continue to increase significantly.

In the groundwater sector, the situation is not so clear-cut. Here, where the resource is hidden from view and assessment is inherently more difficult and imprecise, exploration and quantification did not begin until the early 1970s. The interaction between surface water and groundwater resources makes this assessment even more difficult, especially when surface irrigation itself contributes significantly to groundwater recharge. Since 1972, the estimate of ultimate groundwater potential has nearly doubled (Table 7) and it will probably continue to expand.

In some states, like Uttar Pradesh, groundwater development has already reached the ultimate potential targeted earlier, but experience indicates that significant potential remains to be developed (Desai, chapter 4). In Tamil Nadu, on the other hand, groundwater development in some districts is already constrained, and the overall rate of irrigation expansion in the southern region as a whole is negative. Most authorities agree that water resources in the state are fully allocated at present levels of use efficiency (Kandaswamy 1987).

In addition, irrigation is not the only sector to claim the nation's water resources. In chapter 4, Desai indicates that nonirrigation uses of water (domestic, industrial, and cooling) are expected to increase significantly in the years ahead. Not only is the absolute use increasing, but the share is as well. By the turn of the century, just a decade from now, nonirrigation uses will require nearly one-sixth of the nation's tapped water resources. To be sure, not all of these uses will be consumptive, so there will be some scope for reuse. As the total relative share of other uses increases, however, the share consumptively used will probably grow as well and water quality considerations will become increasingly important. This means that in some states, such as Tamil Nadu, irrigation will have to run in place just to stand still.

There has long been a gap between potential created and potential used in the figures developed by the state irrigation departments. Persistent efforts to close this gap, notably through command area development programs, have met with only limited success. One may, therefore, speculate on the remaining scope for expanding irrigated area if one internalizes this gap into the values of ultimate potential.

To make this adjustment, ultimate potential figures for each region were reduced by the percentage of the existing gap in use as given in C.G. Desai (1988). This adjustment means that the efficiency estimates used in computing the ultimate potential are higher than can be justified by actual experience and adjusts them downward. The results are shown in Table 8.

As can be seen, the ultimate irrigation potential drops to 101.1 million ha, and unexploited potential is reduced from 40.2 percent to 32.9 percent. The effect on surface irrigation potential, which falls 17 percent, is even more profound than that on groundwater potential, which drops only 6 percent, based on the gap levels prevailing in 1984/85. The revised values of unexploited potential by region are shown in Table 8. Until the potential gap can be closed, these values are the most appropriate ones to use.

3. COSTS OF IRRIGATION DEVELOPMENT

The marginal cost of developing a hectare of irrigated land integrates a number of the factors that influence the feasibility of developing surface irrigation further. These factors include the separation distance between arable land and water source, the difficulty of exploiting the site, the extent of displacement of existing settlements, and the level and cost of the available technology.

The all-India expenditure on constructing major and medium irrigation projects between 1950 and 1990 (projected) is shown in Table 9. Figures indicate that the expenditure per hectare of potential created (in 1980 Rs) rose from Rs 6,780 per ha in the First Five-Year Plan to an estimated Rs 15,347 per ha in the Seventh, a compound annual rate of 2.2 percent.

These figures must, however, be treated with caution. Since the construction of an irrigation project sometimes takes more than one, or even two, five-year plan periods to complete,[5] expenditures shown in the table do not necessarily correspond to the potential created as a result of that expenditure. If the investment level is relatively constant from year to year, this difference does not matter a great deal. When the level of investment is growing, however, as it was in this case, this procedure will seriously overestimate the cost of a hectare of potential created.

Table 10 presents a better estimate of the real cost of creating an irrigated hectare, although it too possesses certain deficiencies. To estimate these figures, the cost stream associated with each project completed during a plan period was summed to estimate the cost of developing that project. The cost streams for all projects completed during the plan period were then aggregated and divided by the potential created during that period to obtain the area-weighted unit cost. This establishes a direct relationship between the costs incurred and the area actually developed by those expenditures.

Because the data were already aggregated by project, no correction for inflation could be applied **within** each project cost stream. To compare expenditures among periods, a price index for the middle year of each period was applied to the aggregated cost of the projects completed during the period. Thus to the extent that investment in a particular project also took place during preceding plans, these values underestimate the real per hectare cost of development.

[5] Pant (personal communication) indicates that the actual duration of project construction typically ranges between twelve and twenty years rather than the five to ten years usually shown in project planning documents.

Nevertheless, the figures do represent the relative values of this parameter across regions for a given plan.[6] The western and southern regions have the highest cost of irrigation development, while the eastern region has the highest growth of the cost per irrigated hectare.

Table 11 shows the estimates of expenditure and cost per planning period derived from Tables 9 and 10, which should bracket the true cost of development. As can be seen, the first estimate increased by a factor of 2.16, in real terms, in the thirty years between the First and the Sixth Five-Year Plans, while the second increased by a factor of 1.79. For the Sixth Plan, the two show unit costs of Rs 24,123 and Rs 12,124 (1986) per hectare, respectively.[7]

The estimated real cost per hectare given in the second column of Table 11 remained constant for almost twenty-five years and then virtually doubled between the Fifth and Sixth Plans (from US$1,100 to $1,913). This suggests that the economics of building medium- and large-scale systems will become increasingly less favorable as the ultimate potential ceiling is approached. Estimating the elasticity of cost per irrigated area relative to average unexploited potential using data from Table 10 suggests that a decrease of 1 percent of unexploited potential produces an increase of approximately 2.8 percent in the development cost of an irrigated hectare.

Estimating the cost of developing groundwater is more difficult. Groundwater development is the dominant component of the minor irrigation sector in India, and private wells account for the bulk of minor irrigation development. Table 12 shows the expenditures in each five-year plan and the total institutional lending for minor irrigation. If groundwater development costs are a proportionate share of total government expenditures for minor irrigation,[8] the state investment required to create one hectare of land irrigated with well water was approximately 3,000 (1980) rupees during the Seventh Plan.[9] The unit cost had declined significantly from its peak of 10,700 (1980) rupees per hectare during the Second Plan. This could indicate decreased reliance on institutional sources of credit for private groundwater development, but the magnitude of the drop, expanded use of less expensive electrically driven pumps, and improved pump and motor technology suggest that real reductions occurred as well.

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[6] This assumes that the duration of project construction is similar in different regions.

[7] This measure of cost increase, represented in constant 1986 rupees, largely eliminates the cost escalation attributed to extended periods of project construction, where inflation is to blame. Extended construction periods can still lead to higher, but usually unspecified, costs per hectare due to the inefficient nature of stop and go construction activity.

[8] During the Sixth Plan, 88 percent of the minor irrigation program was devoted to groundwater development.

[9] Investment from personal savings and informal credit sources also occurs, although because of subsidized interest rates, much of the borrowing is probably institutional.

4. FUTURE SOURCES OF GROWTH

Continued growth in agricultural output will be assumed necessary in the indefinite future, and, as indicated earlier, the irrigated sector will be required to bear a major share of this burden. Given the current population growth rates, the continuing need to generate new employment in rural areas, and the traditional emphasis placed on self-reliance in the production of food, especially foodgrains, the first part of this assumption seems self-evident. Professor B. D. Dhawan (1988a) makes a concise and convincing argument for the second point.

The days in which expansion of irrigated area can drive increases in agricultural production seem to be drawing to a close. The prospective portion of the Seventh Plan anticipates that the currently assessed ultimate potential will be fully exploited by 2010. Only about one-third of India's currently assessed ultimate potential remains to be exploited through raw expansion of area, as does only one-fourth of the higher-quality groundwater potential. Moreover, the real per hectare costs of developing the more abundant unexploited surface potential will probably continue to rise as well.

The value of the increased production resulting from this expansion may rise commensurately with the costs of exploiting new water sources, but this is by no means assured. More likely, improvements in the quality of irrigation service, especially from surface sources, will be required to induce increases in purchased input application and a shift to higher value crops. Future gains must increasingly come from improving the quality of irrigation service, using water on existing cultivable command area more efficiently, and recycling water not beneficially used for crop evapotranspiration or leaching.

Ironically, most of these changes will increase the assessed level of ultimate potential itself. The proposed increase of 34.5 million ha is based in part on improved water management. Thus progress on this front will increase the ultimate potential as well as the intensity of irrigation,[10] the production per unit of water, and other measures of specific productivity. These efficiency-based increases in potential will not, however, occur automatically, and they should be reflected in figures only when there is some reasonable assurance that they can be realized.

The foregoing leads logically to a review of potential sources of continued growth. In addition to continued but decelerating expansion of irrigated area from newly developed water sources, these alternatives include (1) the conjunctive use of groundwater and surface water; (2) the improved performance of existing surface systems; (3) the improved use of existing groundwater extraction machinery; (4) the interaction of irrigation service with other factors, such as fertilizer use and choice of crop; and (5) the improvement of irrigation technology. This last category is dependent on the others and acts largely through them. In the last sections of

[10] Intensity of Irrigation is defined by the 1976 National Commission on Agriculture as the gross irrigated area in an agricultural year, expressed as a percentage of the project's cultivable command area.

this chapter, I discuss briefly the first two of these sources—conjunctive use and improved efficiency of surface systems.

4.1 Conjunctive Use of Groundwater and Surface Water

I leave the task of laying out the principal case for conjunctive use to other chapters in this volume. Professor Dhawan, in particular, has examined conjunctive use extensively in recent years. Instead, I illustrate the importance of shallow groundwater pumping for reusing water that is lost from surface irrigation systems. This is undeniably an attractive notion, but one that is not always fully understood or appreciated. Conjunctive use can be thought of as a mechanism for increasing the efficiency of the surface system that serves as the original source of water. At the same time, it is an important part of the solution to the problems of waterlogging which are felt increasingly in many areas in India.

The following model illustrates the importance of the interaction between surface water and groundwater and the way in which they complement each other. It represents the fraction of canal water supplied to a given area that is eventually used to benefit agricultural production and how this fraction responds to changes in the technical efficiency of the surface irrigation system and the portion of groundwater that is pumped. For simplicity, groundwater that occurs naturally, that is, not attributable to losses from canal irrigation, is ignored.

The terms used are defined as follows. Values of the parameters used are shown in parentheses following the appropriate definition.

Bg = groundwater beneficially used by crops,
Bs = surface water beneficially used by crops,
Eg = overall efficiency of groundwater irrigation (0.7).
Es = overall efficiency of surface irrigation (0, 0.25, 0.35, 0.45),
Qg = groundwater available for extraction,
Qs = surface water delivered to area,
U = fraction of percolating water that is unrecoverable (0.20), and
X = percentage of reusable groundwater that is extracted.

The dependent variable is R, the ratio of canal-derived water beneficially used to the supply delivered by the canal.

$$R = (Bs + Bg)/Qs. \tag{1}$$

Beneficially used water is a function of the supply available, the respective overall efficiency, and, in the case of groundwater, the amount of water pumped.

$$Bs = Qs\ Es, \text{ and} \tag{2}$$
$$Bg = Qg\ Eg\ X. \tag{3}$$

The quantity of groundwater (derived from canal sources) is inversely related to the efficiency of surface irrigation and the fraction that is unrecoverable once it reaches the groundwater aquifer.

$$Qg = (1 - U)\,(1 - Es)\,Qs. \tag{4}$$

Substituting equation (5.4) into equation (5.3) and then equations (5.2) and (5.3) into equation (5.1), which defines the overall use ratio, results in the following expression.

$$R = Es + (1 - U)\,(1 - Es)\,X.$$

The efficiency of groundwater use, Eg, was eliminated because the groundwater not used by the crop was assumed to be lost to deep percolation and then returned to the groundwater aquifer. If several iterations of reuse are allowed, the groundwater use efficiency term approaches unity.

This simple model was then used to plot the curves shown in Figure 3. As can be seen, when the efficiency of surface water use is zero, the fraction of the available surface water used is a function of the amount pumped and peaks at a maximum level of 80 percent of the supply delivered. This example represents a water spreading operation with no crop being grown and as such is somewhat unrealistic. Since it also ignores evaporation during infiltration, which is unproductive in this case, the peak R value is reduced somewhat. Enterprising farmers probably would not, however, allow extensive water spreading to take place without taking advantage of the opportunity to produce a crop.

At three more realistic (and fairly typical) values of surface irrigation efficiency, 0.25, 0.35, and 0.45, the fraction of delivered water that is used productively begins at a higher value, rises less rapidly, and peaks at between 85 and 87 percent of the amount delivered by the canal. The peak use attainable rises as surface irrigation efficiencies rise because it is assumed that water is ultimately lost from the system only through subsurface flow of groundwater out of the region.

Obviously far more sophisticated, site-specific models are needed to represent this interaction for predictive purposes. This simple presentation illustrates how conjunctive use, or reuse, of canal water and groundwater can raise the technical efficiency of very inefficient canal irrigation systems to levels equivalent to those of modern well-managed trickle and drip systems. In that, it is quite realistic.

The other interesting feature shown on this graph is that the use ratio (R) at any given pumping fraction (X) depends on the efficiency with which the surface systems ultimately supplying the water is operated. This suggests that conjunctive use and efficient operation of surface systems are complementary innovations that partially offset each other and therefore must be considered together. It might be reasonable to regard conjunctive (re)use as a short- to mid-range solution strategy, while in the longer run taking steps to carry out the difficult task of improving the operational efficiency of the surface systems themselves. Improving the efficiency of surface irrigation may be a more efficient approach given the reduced exposure to unrecoverable losses and the energy economies of each approach.

Substitutability is not, however, complete, and some losses from surface system operations are inevitable. Although the scope for efficient conjunctive reuse may first increase and then decrease over time, some scope will always remain, especially in paddy areas.

There is another sense, however, in which conjunctive use can be seen as augmenting storage within a particular basin for use on a subsequent crop. In this case, high losses in the surface irrigation system would not only be tolerated, but actively encouraged. This is the gist of an idea that Roger Revelle (1975) proposed in "The Ganges Water Machine." The major attractions of such a scheme are that the associated conjunctive reuse increases cropping intensity and thereby increases and spreads both production and labor demand. Water would probably have a higher value in this case than it would if used during the wetter crop season. Formidable problems are, however, involved in planning, organizing, and implementing such an effort.

4.2 Improved Performance of Surface Systems

Although conjunctive use provides an extremely promising and attractive option for gains in production and efficiency over the short to medium run, intrinsic inefficiencies are associated with it. When water moves below the ground surface it loses potential energy, and raising it to the surface inevitably incurs costs.[11] Since these costs are paid in energy as well as money, and since energy is also a scarce and constraining resource in many parts of India, we should also look at energy-efficient alternatives to improving performance.

Alternatives for improving the performance of existing systems can operate through measures that increase the area served by a given supply of water, increase yields, increase the value of the crop mix grown, or increase cropping intensity. The first three of these can be the result of improvements in the temporal and spatial pattern of water distribution **or its predictability** within a given season. The latter requires some form of storage.[12]

Most observers estimate the overall technical efficiency of medium and major surface irrigation systems to be around 25 or 30 percent. This means that some 70 to 75 percent of the water diverted from the river or released from the reservoir is not used beneficially, that is, it does not contribute to filling the crop evapotranspiration requirements within the command area of the system. Some of these losses, such as percolation in puddled rice fields or seepage from

[11] This is strictly true only if the water is used in the same area from which it was lost. Some of this water can be recovered by standard gravity diversions from natural watercourses downslope of the point at which subsurface flows are intercepted by these channels.

[12] Increased cropping intensity can also be achieved, to some extent, by changing the irrigation and cropping calendars without storage and by shortening the duration of the first system-wide cropping season and that of between-crop turnaround to allow two crops to be taken during periods of high rainfall and river discharge.

unlined channels, are unavoidable. These losses are legitimate candidates for recovery through shallow groundwater pumping. On the other hand, uneven spatial allocation of water across large systems and inordinately variable deliveries are important and preventable sources of technical inefficiency in many cases. Questions of equity are obviously involved as well.

Achieving these improvements can combine physical rehabilitation, changes in administrative or managerial practices, or institutional improvements. Moreover, they can be targeted below the outlet or above it. A variety of measures including one or more of these components has been developed, experimented with, and applied over a period of many years. These include programs of land leveling, water course improvement, and canal lining; rotational irrigation scheduling based on the North Indian warabandhi framework; command area development authorities and programs; and expanded government responsibility and control. The record, I think it fair to say, is mixed but not predominantly successful.

Part of the explanation for this is the tremendous range and number of circumstances found in irrigation systems across India, which make standardized approaches likely to fail in most of the circumstances in which they are applied. Another major reason may be the failure in many cases to address physical, managerial, and institutional issues together. Moreover, the larger context in which improvement programs are undertaken simply may not be conducive to their growth.

This leads to a fundamental issue that Sundar (1984) has called the "commitment to manage," or what might be described as the perceived need to manage. Aircraft operation and maintenance, for example, would rank very high on this scale. It possesses a well-established system of accountability, and the penalties of system failure are dramatic and highly visible. In the case of irrigation system operation and maintenance, on the other hand, the consequence of failure can be just as serious, but responsibility is diffused and operations and maintenance personnel are rarely evaluated on the basis of the failure of a system to irrigate. The feeling is inescapable that the larger sociopolitical system does not attach a high priority to effective irrigation management.

Improving irrigation management at the system level requires, in addition to physical control facilities, knowledge, analytic tools, resources (personnel and operating expenses), and the ability to establish appropriate goals and act to achieve them. Beyond that, however, it requires that a value be placed on successful performance and that a system of accountability and a climate of incentives exist to reward success. Just how successful efforts to improve system management can be without addressing the questions of what constitutes successful performance and how an accountability system should tie system performance to managerial performance is a critical and unresolved challenge.

The forces hypothesized earlier for enhancing the importance of improving the agricultural performance of existing irrigation systems may also provide the pressure necessary for these kinds of changes to take place. In the meantime, it is important to begin to search for and experiment with organizational and procedural models that can be applied when the pressures for improved performance become sufficiently powerful to ensure that they are installed.

5. CONCLUSIONS

India has an enviable record of engineering accomplishments in the field of irrigation, and those accomplishments deserve much of the credit for the nation's impressive growth in foodgrain production since its independence. Since 1965, well irrigation has been increasingly responsible for this growth in agricultural output, while tank irrigation has declined significantly and net area served by canals has expanded at a steady pace.

Compared with current estimates of ultimate irrigation potential, the area remaining to be brought under irrigation is dwindling. As of 1984-85, about three-fifths of India's ultimate potential were already being exploited. If the estimate of ultimate potential is adjusted downward by the extent of the "utilization gap" currently prevailing in completed projects, then the ultimate potential that remains falls from 40 to 33 percent.

The real marginal costs of creating new surface irrigation capacity are increasing, and economic justification for exploiting the remaining surface water resources is becoming increasingly difficult. The marginal costs of developing groundwater, on the other hand, are falling, though water resource constraints loom here.

India is approaching a crossroads where it must choose a new path to sustaining growth in irrigated production. This path leads toward improving the operational performance of existing surface systems by encouraging conjunctive use of surface water and ground-water (particularly the groundwater that derives from surface system losses), by improving directly the operational efficiency of surface systems themselves, and by improving the use of existing groundwater pumping capacity. Somewhat paradoxically, such programs, once they have demonstrated their effectiveness, will increase the computed level of India's ultimate irrigation potential and reduce the share classed as exploited.

Reusing water lost from canal irrigation can result in very high rates of use of the surface water diverted. However, significant additional investment and operating costs are involved in exercising this option. Thus a long-term strategy might rely on conjunctive use over the short run, coupled with gradual improvement in canal operating efficiencies over the long run.

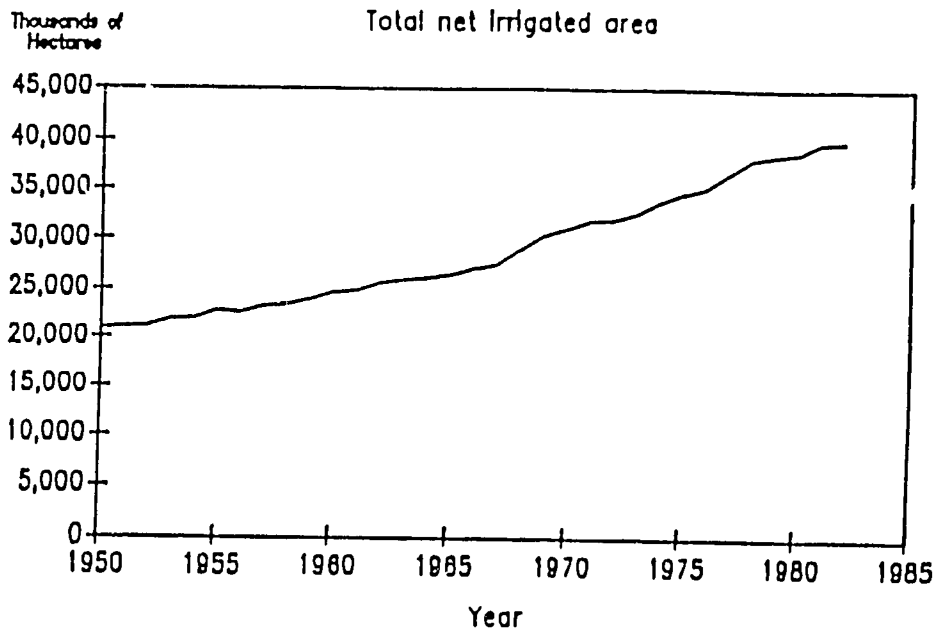
A variety of measures can be used to improve canal performance. Ultimately, the sustained success of a significant number of these may depend on creating incentives for irrigation officials and farmers that include a system of accountability for actual performance measured against a set of mutually agreed goals. This may sound simple and straightforward, but in practice it is exceedingly difficult to implement and affects the character of irrigation departments and their relationship with both farmers and the larger administrative and political structures.

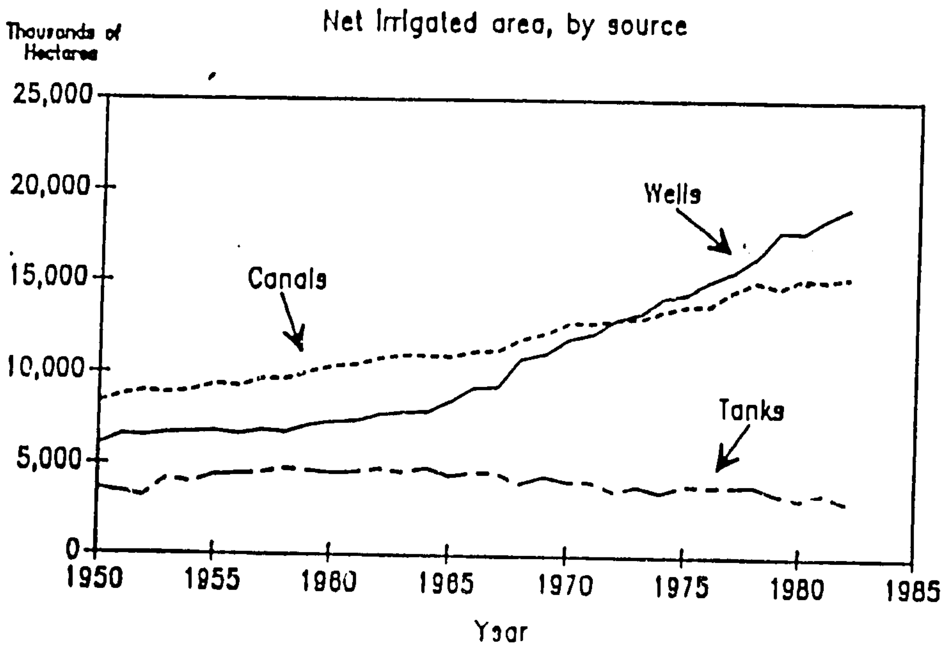
Other areas in which continued growth can be sought include improving the use of existing groundwater extraction machinery through, for example, privatization and development of water markets and pump irrigation societies; applying new technology to the irrigation process; and improving further the availability of complementary inputs and the coordination of input services.

TABLES AND FIGURES

FIGURE 1

Area Irrigated, by source, 1950-82





Sources: Table 5.2 and India, Department of Agriculture, Indian Agriculture in Brief, 21st ed. (New Delhi, 1987).

FIGURE 2

Regions of India

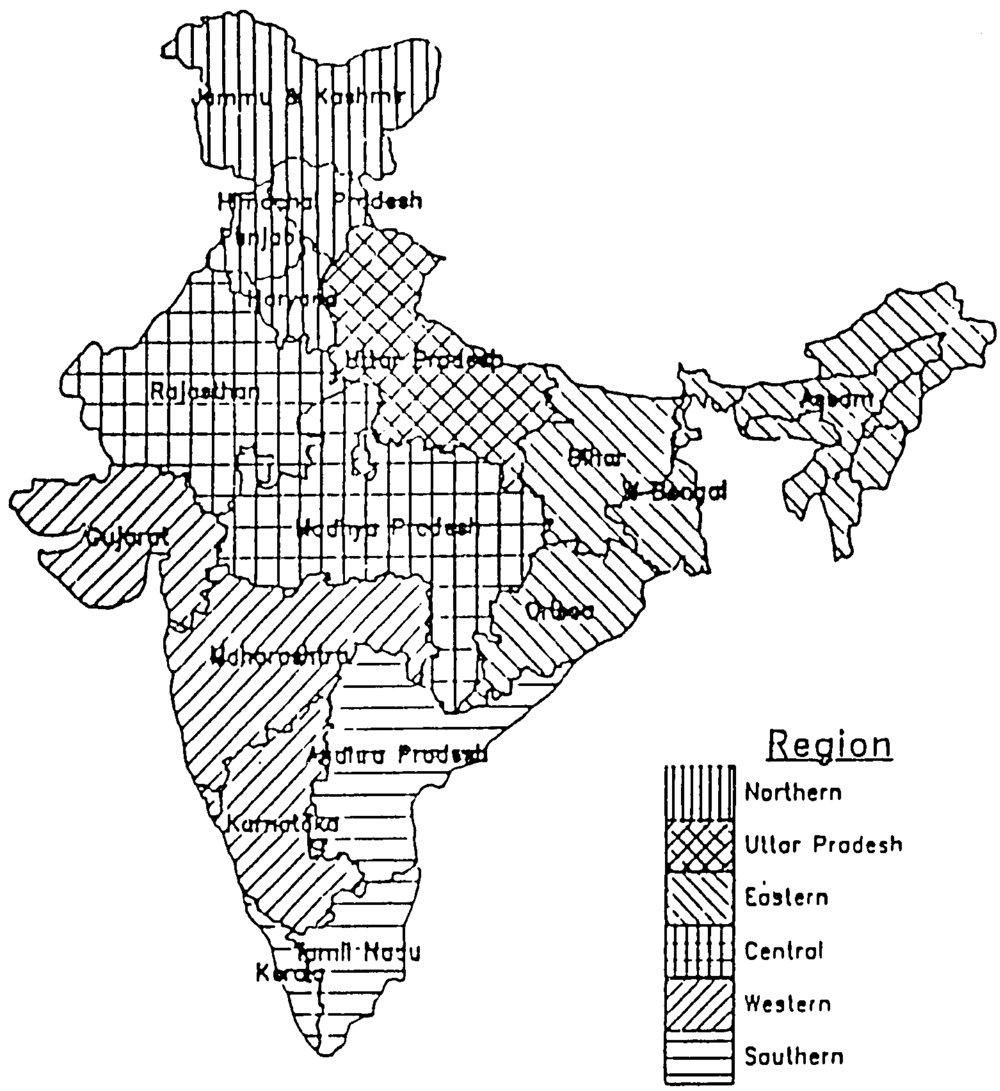
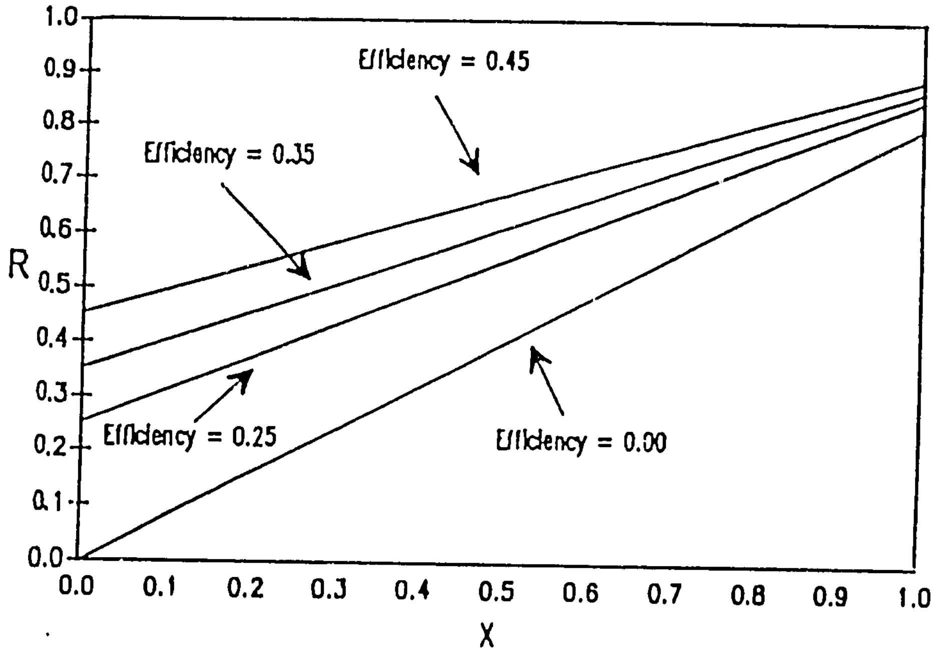


FIGURE 3

Contribution of Conjunctive Use to Crop Water Availability



Note: R = total fraction of canal water beneficially used; X = fraction of reusable groundwater extracted.

TABLE 1

Percentage Growth and Average Statistics for Net Irrigated Area, by source, 1951-83

Variable	1951-83 Growth	1951-83 Average	1951-65 Growth	1951-65 Average	1968-83 Growth	1968-83 Average
	(percent)	(1,000 ha)	(percent)	(1,000 ha)	(percent)	(1,000 ha)
Total net irrigated area	2.2	28,881	1.7	23,321	2.4	34,352
Net area irrigated by						
Private canals	-2.2	1,037	-0.5	1,241	-3.4	842
Government canals	2.4	10,677	2.3	8,465	2.3	12,835
All canals	2.0	11,714	2.0	9,706	2.0	13,677
Wells	3.9	10,667	1.6	6,941	4.4	14,412
Tanks	-0.5	4,095	2.4	4,312	-1.7	3,837
Other	0.2	2,394	-0.0	2,361	0.4	2,425
Dry land	0.2	123,000	1.1	121,000	-0.3	125,000

TABLE 2

Net Irrigated Area, by source, 1950-83

Year	Canals			Tanks	Wells	Other Sources	Total
	Government	Private	Total				
			(1,000 ha)				
1950-51	7,158	1,137	8,295	3,613	5,978	2,967	20,853
1951-52	7,534	1,194	8,728	3,444	6,517	2,360	21,049
1952-53	7,599	1,352	8,951	3,214	6,485	2,427	21,077
1953-54	7,559	1,314	8,873	4,187	6,640	2,087	21,788
1954-55	7,833	1,161	8,994	4,002	6,702	2,261	21,959
1955-56	8,025	1,360	9,385	4,423	6,739	2,211	22,758
1956-57	7,916	1,357	9,273	4,492	6,566	2,202	22,533
1957-58	8,303	1,349	9,652	4,536	6,818	2,150	23,156
1958-59	8,391	1,279	9,670	4,759	6,686	2,286	23,401
1959-60	8,752	1,305	10,057	4,648	7,083	2,208	23,966
1960-61	9,170	1,208	10,378	4,561	7,290	2,440	24,661
1961-62	9,338	1,162	10,500	4,613	7,352	2,420	24,885
1962-63	9,686	1,146	10,832	4,781	7,650	2,403	25,666
1963-64	9,848	1,158	11,006	4,597	7,786	2,484	25,871
1964-65	9,861	1,136	10,997	4,815	7,824	2,520	26,156
1965-66	9,827	1,133	10,960	4,441	8,445	2,595	26,441
1966-67	10,200	1,000	11,200	4,600	9,200	2,200	27,100
1967-68	10,279	1,025	11,304	4,599	9,264	2,356	27,523
1968-69	10,900	1,000	11,900	4,000	10,800	2,400	29,000
1969-70	11,300	1,000	12,300	4,400	11,100	2,500	30,400
1970-71	11,972	866	12,838	4,112	11,887	2,265	31,103
1971-72	11,949	901	12,850	4,140	12,235	2,607	31,891
1972-73	12,192	863	13,055	3,621	13,024	2,249	31,949
1973-74	12,200	900	13,100	3,900	13,300	2,300	32,600
1974-75	12,664	861	13,525	3,548	14,214	2,423	33,730
1975-76	12,933	858	13,791	3,972	14,444	2,386	34,593
1976-77	13,016	845	13,861	3,901	15,087	2,300	35,149
1977-78	13,727	843	14,570	3,899	15,603	2,479	36,551
1978-79	14,289	839	15,128	3,936	16,427	2,569	38,060
1979-80	13,914	837	14,751	3,482	17,817	2,418	38,478
1980-81	14,456	836	15,292	3,190	17,734	2,585	38,806
1981-82	14,701	496	15,197	3,581	18,549	2,597	39,924
1982-83	14,875	495	15,370	3,112	19,112	2,375	39,969

Sources: The Ford Foundation, Data on the Indian Economy, 1951-1969 (New Delhi: Ford Foundation, 1970); India, Department of Agriculture, Indian Agriculture in Brief, 21st ed. (New Delhi, 1987); India, Ministry of Irrigation and Power, Report of the Irrigation Commission, vol.2 (New Delhi, 1972); India, Central Statistical Organization, Statistical Pocket Book of India (New Delhi: Department of Statistics, Ministry of Planning, 1980); TATA Services Limited, Statistical Outline of India (New Delhi: Department of Economics and Statistics, 1987).

TABLE 3

Average Net Irrigated Area, by region and source

Region and years averaged	Canals			Tanks	Wells	Other	Total
	Government	Private	Total				
			(1,000 ha)				
Average of 1969/70, 1971/72, 1973/74							
Southern	2,628	11	2,639	1,955	1,391	289	6,273
Northern	2,367	201	2,569	6	2,173	119	4,867
Uttar Pradesh	2,462	1	2,453	339	3,949	256	7,016
Central	1,518	1	1,519	353	1,772	133	3,776
Eastern	1,860	670	2,530	881	686	1,306	5,403
Western	955	23	978	617	2,218	217	4,029
All India	11,782	910	12,692	4,160	12,161	2,480	31,512
Average of 1978/79, 1980/81, 1982/83							
Southern	2,660	6	2,666	1,671	1,826	193	6,356
Northern	2,723	179	2,901	3	2,911	119	5,934
Uttar Pradesh	3,206	1	3,207	188	5,698	316	9,410
Central	2,058	1	2,059	303	2,885	220	5,467
Eastern	2,532	512	3,044	608	1,360	1,101	6,113
Western	1,332	25	1,357	634	3,020	283	5,293
All India	14,534	723	15,257	3,407	17,753	2,494	38,912

Source: India, Department of Agriculture, Indian Agriculture in Brief (New Delhi, 1987).

TABLE 4

Compound Growth Rates of Irrigated Area, by region, 1971/72-1980/81

Region	Canals	Tanks	Wells	Other	Total
Southern	0.12	-1.73	3.07	-4.39	0.14
Northern	1.36	-7.97	3.30	0.00	2.23
Uttar Pradesh	3.02	-6.31	4.16	2.39	3.31
Central	3.44	-1.67	5.57	5.72	4.20
Eastern	2.07	-4.03	7.90	-1.88	1.38
Western	3.71	0.31	3.49	3.01	3.08
All India	2.07	-2.19	4.29	0.06	2.37

Note: The compound growth rate was estimated using the three-year averages presented in Table 3.

TABLE 5

Gross and Net Irrigated Area, by region, 1982/83 and 1984/85

Region	Gross Irrigated Area, 1984/85		Net Irrigated Area, 1982/83	
	Number of hectares	Regional share	Number of hectares	Regional share
	(1,000 ha)	(percent)	(1,000 ha)	(percent)
Southern	9,289	15.3	6,041	15.1
Northern	9,238	15.3	6,317	15.8
Uttar Pradesh	16,490	27.3	9,884	24.7
Central	6,588	10.9	5,874	14.7
Eastern	11,316	18.7	5,940	14.8
Western	7,202	11.9	5,568	13.9
All India	60,462	100.0	39,969	100.0

Source: India, Department of Agriculture, Indian Agriculture in Brief, 21st ed. (New Delhi, 1987).

Notes: Gross irrigated area was taken from the use of benefits from all irrigation schemes. Percentages do not sum to 100 percent because several small states were not included in regional figures.

TABLE 6

Unexploited Irrigation Potential, by region

Region	Irrigation Potential		Groundwater Potential		Surface Water Potential	
	Ultimate	Unexploited	Ultimate	Unexploited	Ultimate	Unexploited
	(1,000 ha)	(Percent)[a]	(1,000 ha)	(Percent)[b]	(1,000 ha)	(Percent)[a]
Southern	15,200	36.0	4,000	36.0	11,200	35.8
Northern	12,335	22.6	5,200	15.0	7,135	28.1
Uttar Pradesh	25,700	36.7	12,000	5.0	13,700	46.0
Central	15,350	50.5	5,000	43.0	10,350	54.2
Eastern	27,160	53.1	8,700	60.0	18,460	49.8
Western	16,650	45.7	4,700	33.0	11,950	50.4
All India	113,500	40.2	39,762	30.0	73,738	45.7

Sources: Groundwater estimates are from India, Ministry of Water Resources, Ground Water Development in India (New Delhi, 1986). Unexploited irrigation potential was estimated using 1984-85 use data from India, Department of Agriculture, Indian Agriculture in Brief, (New Delhi, 1986). Surface water potential was estimated subtracting groundwater potential from total irrigation potential. Surface water use was estimated subtracting groundwater use from total use. Unexploited surface water potential was estimated subtracting surface use from surface potential. Total irrigated area was estimated from the use of potential created.

[a] Refers to 1984/85.
[b] Refers to 1985.

TABLE 7

Estimates of Ultimate Irrigation Potential for Surface Water and Ground Water, various years, 1972-88

Year	Source	Surface Water	Ground Water	Total
			(million ha)	
1972	Irrigation Commission	59.0	22.0	81.0
1975	Fifth Five-Year Plan	72.0	35.0	107.0
1985	Seventh Five-Year Plan	73.5	40.0	113.5
1988	Planning Commission	98.0	50.0	148.0[a]

[a] Assumes optimal use of available water resources by allowing interbasin water transfer and international cooperation for joint river development and improved management (Seventh Five-Year Plan).

TABLE 8

Unexploited Achievable Potential, by region

Region	Irrigation Potential		Groundwater Potential		Surface Water Potential	
	Achievable	Unexploited	Achievable	Unexploited	Achievable	Unexploited
	(1,000 ha)	(percent)[a]	(1,000 ha)	(percent)[b]	(1,000 ha)	(percent)[a]
Southern	14,455	32.7	3,840	33.3	10,562	31.9
Northern	11,928	19.9	5,112	13.5	6,778	24.3
Uttar Pradesh	22,539	27.8	10,992	0.0	11,083	33.2
Central	13,324	42.9	4,785	40.4	7,970	40.1
Eastern	24,118	47.2	8,030	56.6	15,691	40.9
Western	13,270	31.9	4,451	30.3	7,493	20.9
All India	101,128	32.9	37,376	25.5	61,202	34.6

Sources: Groundwater estimates are from India, Ministry of Water Resources, Ground Water Development in India (New Delhi, 1986). Unexploited irrigation potential was estimated using 1984-85 use data from India, Department of Agriculture, Indian Agriculture in Brief, (New Delhi, 1986). Surface water potential was estimated subtracting groundwater potential from total irrigation potential. The unexploited surface water irrigation potential was estimated subtracting groundwater use from total irrigated area. Total irrigated area was estimated from the use of potential created. Achievable figures were estimated by adjusting ultimate potential by the use gap (the percentage of potential created that is irrigated).

[a] Refers to 1984/85.

[b] Refers to 1985.

TABLE 9

Expenditure on Major and Medium Irrigation Projects, by Five-Year Plan

Period	Total Expenditure at Current Prices	Average Annual Expenditure at 1980 Prices[a]	Average Annual Potential Created	Expenditure[b] per Hectare Potential Created	Irrigation Expenditure as Percent of Total Plan Expenditure
	(Rs Million)		(Million ha)	(Rs)	(percent)
First Plan	3,000	3,390	0.50	6,780	15.3
Second Plan	3,800	3,781	0.42	9,002	8.1
Third Plan	5,810	4,557	0.46	9,906	6.8
Annual Plans	4,340	4,098	0.50	8,196	6.6
Fourth Plan	12,370	5,241	0.52	10,078	7.8
Fifth Plan	24,420	8,635	1.04	8,303	6.1
1978/79	9,770	11,785	1.00	11,785	8.8
1979/80	10,790	11,430	0.80	14,288	8.9
Sixth Plan	75,160	11,725	0.80	14,656	8.4
Seventh Plan (target)	115,555	13,199	0.86	15,347	8.8

Source: Documents from India's Planning Commission.

[a] Expenditures were corrected for inflation using the Domestic Price Deflator for Industry, 1950-87, to give constant 1980 prices.

[b] For planning periods, see Table 7.

TABLE 10

Major and Medium Irrigation Investment in India, by region and Five-Year Plan [a]

Region	Second Five-Year Plan			Third Five-Year Plan and Annual Plans			Fourth Five-Year Plan			Fifth Five-Year Plan and Annual Plans			Sixth Five-Year Plan		
	Total Area Benefited	Unexploited Potential	Cost[b] per Hectare	Total Area Benefited	Unexploited Potential	Cost per Hectare[b]	Total Area Benefited	Unexploited Potential	Cost per Hectare[b]	Total Area Benefited	Unexploited Potential	Cost per Hectare[b]	Total Area Benefited	Unexploited Potential	Cost per Hectare[b]
	(1,000 ha)		(Rs)	(1,000 ha)		(Rs)	(1,000 ha)		(Rs)	(1,000 ha)		(Rs)	(1,000 ha)		(Rs)
Southern	3,405	4,095	10,763	3,838	3,662	13,237	4,153	3,347	6,225	4,938	2,562	9,868	5,076	2,424	18,281
Northern	2,604	3,696	3,914	3,395	2,905	n.a.	3,642	2,658	14,926	4,122	2,178	3,306	4,535	1,765	8,067
Uttar Pradesh	3,412	10,765	4,397	3,607	8,893	3,019	4,103	8,397	4,949	5,478	7,022	5,270	6,813	5,687	7,074
Central	1,169	7,831	4,574	1,963	7,037	9,616	2,154	6,846	4,105	3,194	5,806	9,295	3,614	5,386	13,707
Eastern	2,734	10,780	3,922	3,511	10,004	2,488	4,759	8,756	6,511	6,074	7,441	6,925	6,206	7,309	10,844
Western	1,236	8,364	14,020	1,835	7,765	17,024	2,571	7,029	13,753	3,796	5,804	11,430	4,233	5,367	18,882
All India	15,287	43,188	6,706	18,154	40,321	6,974	21,397	37,078	7,838	27,644	30,831	6,719	30,497	27,978	12,882

Source: Estimated from data provided by the Irrigation Section of the Planning Commission, 1988.

n.a. Not available

[a] For planning periods see Table 7.

[b] In 1986 Rs.

TABLE 11

Costs and Expenditures per Irrigated Hectare in Major and Medium Systems, by Five-Year Plan

Period Covered	Expenditure per Irrigated Hectare[a]	Cost per Irrigated Hectare[b]
	(1986 Rs)	
First plan	11,160	6,780
Second plan	14,817	6,706
Third plan	16,305	6,974[c]
Annual plans	13,490	n.a.
Fourth plan	16,588	7,838
Fifth plan	13,866	6,719[d]
1978/79	19,398	n.a.
1979/80	23,518	n.a.
Sixth plan	24,123	12,124
Seventh plan	25,261	n.a.

Source: India, Planning Commission, and Tables 5.9 and 5.10.
Note: Costs and expenditures are in 1986 Rs. The 1986 exchange rate was U.S.$1 = Rs 12.61.

n.a. Not available
[a] From Table 9.
[b] From Table 10.
[c] Average for the period covering the Third Plan and the annual plans.

[d] Average for the period covering the Fifth Plan and the two following annual plans.

TABLE 12

Plan Expenditures and Public Finance for Minor Irrigation

Period Covered	Total Government Expenditure (Current Prices)	Total Institutional Finance[a] (Current Prices)[a]	Total Investment (Current Prices)[b]	Average Annual Investment[c]	Average Annual Potential Created	Total Investment Per Hectare Potential Created[c]
		(Rs Million)			(Million ha)	(Rs/ha)
First plan	660	...	660	745	0.23	3,239
Second plan	1,420	190	1,610	1,602	0.15	10,680
Third plan	3,280	1,150	4,430	3,474	0.44	7,895
Annual plans	3,260	2,350	5,610	5,297	0.66	8,025
Fourth plan	5,130	6,610	11,740	4,974	0.90	5,527
Fifth plan	6,310	7,800	14,110	3,991	0.76	5,251
Annual plans	4,970	4,900	9,870	5,738	1.35	4,250
Sixth plan	18,020	15,440	33,460	5,220	1.48	3,527
Seventh plan (target)	28,050	17,000	45,050	5,145	1.72	2,991

Source: Documents from India's Planning Commission.

[a] Primarily loans to private farmers for tubewell development.

[b] Excluding self-financed investment and financing from noninstitutional sources.

[c] In constant 1980 prices.

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