Economic Return to Investment in Irrigation in India

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ABSTRACT

This paper reports on an investigation into the efficiency of investment in irrigation, both surface and groundwater, both public and private, in India. The authors first present a brief history of the development of irrigation in India discussing physical achievements and financial expenditures. Economic rates of return to investments in irrigation are then analysed using rates calculated in World Bank project appraisal and completion reports, Planning Commission project evaluation studies, and other Indian sources; and using the results of an econometric analysis undertaken by the authors. Factors limiting the efficiency of investments are analysed, separately for surface and groundwater development; and policies for increasing the efficiency of the investments are discussed.

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ANNEX
A. SUMMARY

Investment in irrigation has a long history in India and by now it has endowed the country with the largest irrigation system in the world. A large part of the system was originally designed and built to protect the sizeable rural population from droughts and the resulting famines. Only relatively recently have new objectives for the sector begun to develop to meet more exacting requirements of water for high productivity and modern agriculture. The design and management of irrigation systems is still based largely on the original objective of protection, but is now beginning to evolve to meet these new requirements.

Reliable data that estimate rates of return to investments in irrigation are scarce. The available data suggest that investment in irrigation is economically appropriate and advantageous. Rates of return to investment in public surface irrigation projects are low but acceptable. Rates of return for groundwater development are higher. While these findings are encouraging, agreement is virtually unanimous that rates of return are lower than they could be and that much can be done to increase returns to irrigation.

For surface irrigation, completing projects speedily will raise rates of return. This can be done without raising overall budget commitments to the sector by simply allocating sufficient funds for rapid completion of ongoing projects, and avoiding the tendency to start too many new projects at once. Returns can also be raised by raising performance standards of infrastructure in new projects. Designs can be improved by including better facilities to distribute water reliably, efficiently and equitably to farmers, and by providing capabilities for more flexible and responsive operation to enable rapid adjustment to changes in water supply and demand. The first steps toward more efficient and responsive operation include upgraded design standards for the conveyance structures, improved canal regulation capabilities, better control structures, and more effective communications equipment throughout the system. Better reliability and efficiency of delivery of water to consumers would be assisted by Government construction of the water delivery system to a point within reach of individual farmers. For existing projects, years of deferred maintenance and declining performance is cause for serious concern and at the same time offers an area of high returns to investment. Many of the above improvements can be beneficially incorporated in existing projects through rehabilitation and modernization. It is important to avoid creating future projects which replicate present deficiencies.

Improving the management of surface systems is a key element in obtaining maximum benefits from present and future surface irrigation investments. Better management can be enhanced by improvements in design standards, and development of professional cadres which are adequately trained in water management at all levels of the system. Many systems are scarcely manageable by modern standards, and even the better systems suffer from the limitations inherent in the original designs. For many systems a major engineering effort is needed to provide the physical facilities required for more efficient management and a major organizational effort to train and motivate the management cadres. Many systems suffer from poor performance today due to a lack of adequate operating procedures and of organized distribution of water from the outlet to each farmer. Improved operation will
require efficient water scheduling throughout the system and equitable water allocation practices below the outlet, as well as strong efforts to overcome resistance to re-allocation of water by farmers now benefiting disproportionately from the existing distribution of water. Improving the distribution of water among farmers has two major requirements below the outlet: the introduction of a reliable, disciplined and equitable system of water allocation among all users so that each farmer on an outlet has the opportunity to receive his fair share of the water available, and construction of watercourses from the outlet to farm holding to enable each farmer to receive his allocated share. To facilitate cooperation among farmers for water allocation below the outlet, the canal network must be able to provide controlled and reliable water supplies to each outlet. In addition, water distribution practices must be clearly established, recognizing farmers' right to a share of water.

Investments in groundwater development are planned, financed (through banks) and managed by individual farmers for the most part. Raising rates of return to those investments involves improving the supply of factors complementary to the investments. Greater reliability of electricity supplies to connected pumpsets and tubewells, and extending rural electrification, are important steps. Other measures include improvement in the technical design standards of private tubewells, increase in the availability of institutional credit to finance private groundwater investments, and provision of better advice through the agricultural extension system. Consequently, the pace of groundwater development will be greatly influenced by progress in improving these services, particularly for electricity supplies. On the other hand, improving the power efficiency of tubewells can contribute to dampening the demand for electric power, particularly peak demand. These supporting services are particularly weak in the areas where groundwater development is generally underexploited—India's eastern region.

Another problem which affects private groundwater development, particularly in the eastern region, is the small size of agricultural plots. Land consolidation can help in the long run but progress has been very slow. Further reductions in the technically efficient size of pumping equipment are possible but not likely to make a rapid or significant difference. Public tubewells have the potential for easing this constraint. In certain aquifers, public tubewells can operate at much higher levels of overall efficiency than private tubewells. Unfortunately, managerial and technical problems have limited their effectiveness in the past. Recent improvements hold the promise for overcoming these problems. As in public surface projects, achieving high returns from public tubewell investments will depend on continued adoption of substantially improved engineering and design of physical facilities, and strengthened and more effective management and institutions.

This paper has much the same content as a chapter in the World Bank's 1982 Economic Report on India. It is being published as a Staff Working Paper to make it available to readers who do not have access to the Economic Report, an official document of the World Bank available only to its member governments and staff.
B. HISTORY OF IRRIGATION DEVELOPMENT IN INDIA

Pre-Independence

Irrigation has been practiced in India for many centuries. By 1800, tanks, dams and wells were irrigating around 0.8 million hectares. During the British period, development of surface irrigation accelerated through the renovation of several existing canals early in the 19th century and later with the construction of several major irrigation works. Groundwater irrigation was also increasing at this time, with the addition of the first engine-driven shallow tubewells to the existing large stock of traditional-lift dug wells. The 1880 Famine Commission and the Irrigation Commission of 1901, established in the wake of severe famines, encouraged the growth of protective irrigation through the construction of public surface schemes, which could be justified as measures to avoid famine. At the same time, productive public works, satisfying standard financial return criteria, were being further developed. The expansion of private irrigation as a means to avoid famine, later echoed in the 1928 Royal Commission on Agriculture and the Famine Enquiry Commission of 1944, was also given emphasis. Achievements by 1900, and subsequent expansion through 1945 are outlined in Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Public Works</th>
<th>Private Works</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>7.6</td>
<td>5.7</td>
<td>13.3</td>
</tr>
<tr>
<td>1921</td>
<td>10.4</td>
<td>8.9</td>
<td>19.3</td>
</tr>
<tr>
<td>1945</td>
<td>13.5</td>
<td>10.0</td>
<td>23.5</td>
</tr>
</tbody>
</table>


It is clear from the foregoing that many Indian farmers are long accustomed to irrigation. But much of the irrigation, whether termed protective or productive, was designed to provide some protection from long breaks in the monsoon by delivering river water through earthen canals over long tracks of land during the monsoon period. The idea was to give as many farmers as possible at least some water to save their crop when the rains failed. The emphasis on the drought insurance aspect of irrigation has had not surprisingly a lasting influence on the selection and design of irrigation projects. The older systems, nevertheless, have proved to have certain advantages in their relatively straightforward operation, well-established distribution of water and their in-built incentives to farmers to use water efficiently, due to its scarcity.

Post-Independence

After partition in 1947, India was left with 83% of the population of undivided India and 84% of net land area but only 69% of irrigated area, amounting to 19.4 million hectares. Over half of all area irrigated by government canals in undivided India was located in Pakistan. As many agriculturally surplus areas ended up in Pakistan, the need to accelerate the
rate of irrigation development was acutely felt after Independence. Several large river development projects, such as Bhakra-Nangal, the Damodar Valley and the Hirakund schemes were begun between 1947 and the start of the First Plan. With the beginning of planning in 1951, many more irrigation projects were started throughout the country. Each plan period saw successive increases in the number of projects initiated, while public support for the development of private irrigation was progressively increased through investment in essential infrastructural and institutional services. As a result, India now has the largest and most ambitious irrigation program in the world (Table 2).

Striking features of this development are the steady decline in the growth of area irrigated by publicly funded major and medium surface irrigation projects through the mid-1970s, followed by a marked acceleration thereafter; the rapid growth of groundwater irrigation (mainly private) since the mid-1960s, tailing off somewhat in recent years; and the tentative revival of minor surface irrigation after almost 20 years of near stagnation. The net result has been an acceleration of increase in total area irrigated since 1951, together with a rise in the proportion covered by groundwater.

Table 2: DEVELOPMENT OF IRRIGATION POTENTIAL SINCE 1951 /a

<table>
<thead>
<tr>
<th>Year</th>
<th>Major/Medium Surface /b</th>
<th>Minor Surface /b</th>
<th>Groundwater</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Million Hectares</td>
<td>Annual % Change</td>
<td>Million Hectares</td>
<td>Annual % Change</td>
</tr>
<tr>
<td>1950/51</td>
<td>9.7</td>
<td>-</td>
<td>6.4</td>
<td>-</td>
</tr>
<tr>
<td>1955/56</td>
<td>12.2</td>
<td>(4.7)</td>
<td>6.4</td>
<td>(0.0)</td>
</tr>
<tr>
<td>1960/61</td>
<td>14.3</td>
<td>(3.2)</td>
<td>6.5</td>
<td>(0.3)</td>
</tr>
<tr>
<td>1965/55</td>
<td>16.6</td>
<td>(3.0)</td>
<td>6.5</td>
<td>(0.0)</td>
</tr>
<tr>
<td>1968/69</td>
<td>18.1</td>
<td>(2.9)</td>
<td>6.5</td>
<td>(0.0)</td>
</tr>
<tr>
<td>1973/74</td>
<td>20.7</td>
<td>(2.7)</td>
<td>7.0</td>
<td>(1.5)</td>
</tr>
<tr>
<td>1979/80</td>
<td>26.6</td>
<td>(4.3)</td>
<td>8.0</td>
<td>(2.3)</td>
</tr>
<tr>
<td>1984/85</td>
<td>(target) 32.3</td>
<td>(4.0)</td>
<td>9.0</td>
<td>(2.4)</td>
</tr>
</tbody>
</table>

/a Investment creates irrigation potential when the system can deliver water to the canal outlet. Irrigation potential is the theoretical gross cropped area that can be irrigated by the infrastructure constructed and is therefore the cultivated area to be irrigated multiplied by the cropping intensity. Potential is counted as utilized when farmers actually convey water from the outlet and apply it on their fields.

/b Minor surface irrigation projects are those with a cultural command area (CCA) up to 2,000 hectares. Medium projects are those with a CCA above 2,000 hectares up to 10,000 hectares. Major projects have a CCA greater than 10,000 hectares.

Source: Central Water Commission.
Major and Medium Surface Irrigation

A major determinant of growth in area irrigated by major and medium surface irrigation is the volume of public investment in such projects (Table 3). Annual expenditure in real terms and per hectare of irrigation potential created rose steadily throughout the period of planning, except during the Annual Plans (1966-1969), when few new projects were started, and in the Fifth Plan in terms of per hectare of potential created, when pressure to finish nearly completed projects was stepped up, thus raising potential created from existing investments.

Table 3: EXPENDITURE ON MAJOR AND MEDIUM IRRIGATION PROJECTS

<table>
<thead>
<tr>
<th>Period</th>
<th>Total Expenditure in Current Rs million</th>
<th>Average Annual Expenditure in Constant 1970/71 Rs million</th>
<th>Average Annual Potential of Potential created in Constant 1970/71 million hectares</th>
<th>Expenditure as a % of Total Plan Expenditure</th>
<th>Expenditure as a % of GDP in Market Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Plan</td>
<td>3,000</td>
<td>1,385</td>
<td>0.5</td>
<td>2,770</td>
<td>15.3</td>
</tr>
<tr>
<td>Second Plan</td>
<td>3,800</td>
<td>1,500</td>
<td>0.4</td>
<td>3,571</td>
<td>8.1</td>
</tr>
<tr>
<td>Third Plan</td>
<td>5,810</td>
<td>1,804</td>
<td>0.5</td>
<td>3,922</td>
<td>6.8</td>
</tr>
<tr>
<td>Annual Plans</td>
<td>4,340</td>
<td>1,687</td>
<td>0.5</td>
<td>3,374</td>
<td>6.6</td>
</tr>
<tr>
<td>Fourth Plan</td>
<td>12,370</td>
<td>2,276</td>
<td>0.5</td>
<td>4,377</td>
<td>7.8</td>
</tr>
<tr>
<td>Fifth Plan</td>
<td>24,420</td>
<td>3,483</td>
<td>1.0</td>
<td>3,483</td>
<td>6.1</td>
</tr>
<tr>
<td>1978/79</td>
<td>9,770</td>
<td>4,934</td>
<td>1.0</td>
<td>4,934</td>
<td>8.8</td>
</tr>
<tr>
<td>1979/80</td>
<td>10,790</td>
<td>4,704</td>
<td>0.8</td>
<td>5,880</td>
<td>8.9</td>
</tr>
<tr>
<td>Sixth Plan (target)</td>
<td>84,484</td>
<td>7,366</td>
<td>1.1</td>
<td>6,696</td>
<td>8.7</td>
</tr>
</tbody>
</table>


Sources: Central Water Commission, Planning Commission, and Central Statistical Organization.

The rise in real expenditure per hectare of irrigation potential created is the result of three forces: a progressive increase in the number of projects under construction, meaning an increasing proportion of funds are spent on the early stages of projects, before they begin yielding benefits; a proportional shift to more difficult and higher cost projects as the easier and cheaper opportunities for irrigation development were used up; and improved standards of design and construction in order to capture greater agricultural benefits.

At the beginning of the First Plan, 9.7 million hectares of potential had been created by major and medium irrigation projects. Around 75% of this potential was accounted for by 24 major projects alone, while 70%
was concentrated in four States—Andhra Pradesh, Punjab, Tamil Nadu and Uttar Pradesh. A substantial number of projects were started immediately upon Independence and during the First and Second Plans. During the 1960s and first half of 1970s, however, the number of projects under construction rose only modestly. The additional 11 million hectares of potential created between 1950/51 and the end of the Fourth Plan 1973/74 stemmed from the commissioning of 100 major and 510 medium projects, and the completion of 25 major and 355 medium schemes. While just over 50% of potential created was located in the above four States, significant increases had also been achieved in several other States, including Bihar, Orissa, Rajasthan and Madhya Pradesh. In the mid- to late-1970s, a very large number of projects were started, including 292 projects (46 major and 246 medium) under the Fifth Plan. By 1979/80, irrigation potential of at least 1 million hectares had been created in all major States. Development has now reached 46% of ultimate major/medium surface irrigation potential ¹/ for India as a whole, although individual State development levels range from 24% in Madhya Pradesh to nearly 80% in Punjab and Tamil Nadu.

**Groundwater Irrigation**

As a predominantly private investment activity, the pace of groundwater development is determined primarily by financial returns accruing to the individual farmers making the investment. Over time, however, the role of Government has expanded through the provision of infrastructure (e.g., rural electrification), subsidy programs for small farmers, and institutional support in the form of technical groundwater services, long-term credit for the financing of investments and extension.

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¹/ Ultimate irrigation potential has been estimated recently at 113.5 million hectares, based on current conditions of irrigation technology and the ultimate development plans of State Governments in India. This ultimate potential can well change and increase as new technologies are introduced and as other solutions to river development freed of the limit of State boundaries are adopted.
### Table 4: Indicators of Groundwater Irrigation Development Since 1951

<table>
<thead>
<tr>
<th>Year</th>
<th>Dugwells Thousands of Units (Cumu-lative)</th>
<th>Average Annual % change</th>
<th>Private Tubewells Thousands of Units (Cumu-lative)</th>
<th>Average Annual % change</th>
<th>Public Tubewells Thousands of Units (Cumu-lative)</th>
<th>Average Annual % change</th>
<th>Electric Pumpsets Thousands of Units (Cumu-lative)</th>
<th>Average Annual % change</th>
<th>Diesel Pumpsets Thousands of Units (Cumu-lative)</th>
<th>Average Annual % change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950/51</td>
<td>3,860</td>
<td>-</td>
<td>3 (Cumu-lative)</td>
<td>-</td>
<td>2 (Cumu-lative)</td>
<td>-</td>
<td>21 (Cumu-lative)</td>
<td>-</td>
<td>66 (Cumu-lative)</td>
<td>-</td>
</tr>
<tr>
<td>1960/61</td>
<td>4,540 (1.6)</td>
<td>22 (22.1)</td>
<td>9 (Cumu-lative)</td>
<td>16.2 (Annual)</td>
<td>1,090 (Cumu-lative)</td>
<td>25.3 (Annual)</td>
<td>230 (Cumu-lative)</td>
<td>13.3 (Annual)</td>
<td>720 (Cumu-lative)</td>
<td>15.3 (Annual)</td>
</tr>
<tr>
<td>1968/69</td>
<td>6,100 (3.8)</td>
<td>360 (41.8)</td>
<td>15 (Cumu-lative)</td>
<td>6.6 (Annual)</td>
<td>2,430 (Cumu-lative)</td>
<td>23.6 (Annual)</td>
<td>720 (Cumu-lative)</td>
<td>15.3 (Annual)</td>
<td>1,750 (Cumu-lative)</td>
<td>19.4 (Annual)</td>
</tr>
<tr>
<td>1973/74</td>
<td>6,700 (1.9)</td>
<td>1,140 (25.9)</td>
<td>22 (Cumu-lative)</td>
<td>8.0 (Annual)</td>
<td>3,300 (Cumu-lative)</td>
<td>8.0 (Annual)</td>
<td>2,350 (Cumu-lative)</td>
<td>7.7 (Annual)</td>
<td>2,650 (Cumu-lative)</td>
<td>6.2 (Annual)</td>
</tr>
<tr>
<td>1977/78</td>
<td>7,425 (2.6)</td>
<td>1,700 (10.5)</td>
<td>30 (Cumu-lative)</td>
<td>8.1 (Annual)</td>
<td>3,950 (Cumu-lative)</td>
<td>9.4 (Annual)</td>
<td>2,650 (Cumu-lative)</td>
<td>6.2 (Annual)</td>
<td>3,550 (Cumu-lative)</td>
<td>6.0 (Annual)</td>
</tr>
<tr>
<td>1979/80</td>
<td>7,780 (2.4)</td>
<td>2,110 (11.4)</td>
<td>36 (Cumu-lative)</td>
<td>9.5 (Annual)</td>
<td>4,640 (Cumu-lative)</td>
<td>10.3 (Annual)</td>
<td>3,550 (Cumu-lative)</td>
<td>6.0 (Annual)</td>
<td>3,550 (Cumu-lative)</td>
<td>6.0 (Annual)</td>
</tr>
<tr>
<td>1984/85 (target)</td>
<td>8,980 (2.8)</td>
<td>3,310 (9.4)</td>
<td>51 (Cumu-lative)</td>
<td>7.2 (Annual)</td>
<td>6,460 (Cumu-lative)</td>
<td>10.3 (Annual)</td>
<td>3,550 (Cumu-lative)</td>
<td>6.0 (Annual)</td>
<td>3,550 (Cumu-lative)</td>
<td>6.0 (Annual)</td>
</tr>
</tbody>
</table>

**Note:** The electric and diesel pumpsets are used on various types of wells, so that the total number of wells is the sum of dugwells and tubewells both public and private. The total number of power pumped wells is the sum of diesel and electric pumpsets. Pumpsets are also used for surface lifts (i.e. where no wells exist).

**Source:** Report of the Working Group on Minor Irrigation for the Sixth Five Year Plan 1980-85; Sixth Five Year Plan 1980-85.
Table 4 presents data on the growth of groundwater development since 1951. These data document the high growth of private tubewells and pumpsets from a very low base in 1951; the particularly rapid overall growth in the last half of the 1960s and early 1970s, followed by some lessening of the rate of increase; and the rising relative importance of electric pumpsets, which now operate on about 60% of mechanized wells.

While groundwater irrigation occurs in most areas of India, both the pace and type of investment has varied considerably between regions and States. The spread of dwarf wheat varieties in the mid-1960s, and later, of high-yielding rice varieties in Punjab, Haryana, western Uttar Pradesh and in the alluvial areas of Andhra Pradesh and Tamil Nadu in the south, was accompanied by rapid growth in private tubewell development. This growth has continued during the 1970s, although at a somewhat reduced pace, due to the approaching saturation of tubewells in the areas mentioned above. Other areas of India, particularly eastern Uttar Pradesh, Bihar, West Bengal, Orissa, and Assam have the aquifer and agro-climatic conditions to exploit the same high-yielding technology. Although HYV cereals are spreading to these areas, tubewell growth has been much slower due to higher rainfall and hence less dramatic benefits from irrigation, smaller and more fragmented holdings, less rural electrification, and weaker credit and other support services.

Until the mid-1960s, the main forces accelerating tubewell development were of a cost-reducing kind. Expansion and technical progress in the domestic pumpset and well construction industries brought cheaper and lower capacity equipment on to the market, enabling more small farmers to capture the benefits of private irrigation. Additional stimuli were provided by the spread of cheap power through rural electrification, and rapid progress in land consolidation in north-western States, together with the emergence of waterlogging problems caused by widespread surface irrigation.

After the mid-1960s, the main engine of growth was the greatly enhanced profits from newly available high-yielding wheat and rice varieties under conditions of high fertilization and good water management. At the same time, institutional credit for minor irrigation began to grow rapidly. Funds for refinance to, and onlending by State Cooperative Land Development Banks, and later commercial banks, were increasingly channelled through the Agricultural Refinance and Development Corporation (ARDC). From negligible levels, ARDC refinance for minor irrigation rose to 50% of total institutional financing for minor irrigation by 1974, and to 90% by 1980/81. ARDC has also played an important role in establishing appropriate loan appraisal techniques and encouraging better loan collection by the participating banks. Along with plan outlays—mainly for public tubewells and minor surface irrigation—and private expenditures, institutional credit is an integral part of total investment expenditure on minor irrigation (Table 5).
Table 5: PUBLIC FINANCING FOR MINOR IRRIGATION SINCE 1951
(Rs million)

<table>
<thead>
<tr>
<th>Plan</th>
<th>Plan Expenditure</th>
<th>Institutional Finance</th>
<th>Total</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Annual Expenditure (Constant Prices)</td>
<td>Average Finance (Constant Prices)</td>
<td></td>
<td>Average Annual Finance (Constant Prices)</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Total Expenditure (Current 1970/71 Prices)</td>
<td>Total Finance (Current 1970/71 Prices)</td>
<td></td>
<td>Total Finance (Current 1970/71 Prices)</td>
<td></td>
</tr>
<tr>
<td>First Plan</td>
<td>660</td>
<td>305</td>
<td>Negligible</td>
<td>Negligible</td>
<td>660</td>
</tr>
<tr>
<td>Second Plan</td>
<td>1,420</td>
<td>659</td>
<td>190</td>
<td>88</td>
<td>1,610</td>
</tr>
<tr>
<td>Third Plan</td>
<td>3,280</td>
<td>1,292</td>
<td>1,150</td>
<td>454</td>
<td>4,430</td>
</tr>
<tr>
<td>Annual Plans</td>
<td>3,260</td>
<td>1,684</td>
<td>2,350</td>
<td>1,216</td>
<td>5,610</td>
</tr>
<tr>
<td>Fourth Plan</td>
<td>5,130</td>
<td>923</td>
<td>6,610</td>
<td>1,185</td>
<td>11,740</td>
</tr>
<tr>
<td>Fifth Plan</td>
<td>6,310</td>
<td>899</td>
<td>7,800</td>
<td>1,112</td>
<td>14,110</td>
</tr>
<tr>
<td>Annual Plans</td>
<td>4,970</td>
<td>1,177</td>
<td>4,900</td>
<td>1,151</td>
<td>9,870</td>
</tr>
<tr>
<td>Sixth Plan</td>
<td>18,100</td>
<td>1,578</td>
<td>17,000</td>
<td>1,482</td>
<td>35,100</td>
</tr>
</tbody>
</table>

/a Primarily loans to private farmers for tubewells development. Excludes farmers' own contribution.


These data portray the rapid growth in public expenditures and institutional finance for minor irrigation from the First Plan onwards but particularly in the 1960s. Real outlays and credit disbursement reached their peak just prior to the beginning of the Fourth Plan. Plan outlays declined significantly in real terms during most of the 1970s, although some recovery is evident for 1978/79 and 1979/80. While recently declining somewhat from its late-1970s peak, the real level of institutional credit has been broadly maintained over the last decade.

One determinant in the growth of groundwater irrigation has been the spread of electricity to rural areas. In the 1960s, the Government's rural electrification program gave increasing priority to the supply of power for agricultural purposes. With the establishment in 1979/80 of the Rural Electrification Corporation (REC) to provide special finance, growth in pumpset connections was given additional impetus. Now 46% of the villages are electrified and the scope remains considerable to intensify connections beyond the current level of 4 million pumpsets.

Major and Medium Irrigation in the Sixth Plan

In the Sixth Plan, projected outlays of Rs 84.5 billion (in 1979/80 prices) are being directed towards the creation of an additional 5.7 million hectares of irrigation potential and towards closing the current gap between utilized and created irrigation potential. This is to
be achieved through a combination of measures: priority allocation of funds for the completion, and where necessary, modernization of existing schemes; the provision of adequate funds for maintenance; emphasis on the reduction of storage and distribution losses, as well as better drainage; and improvement of on-farm water usage through continued strengthening and expansion of the Command Area Development Program, including the construction of land development works and field channels on 5 million hectares of irrigated area.

Progress in the first two years of the Plan (1980/81 and 1981/82) has been satisfactory. Additional surface irrigation potential amounting to about 2 million hectares has been created during the two years. The Government has also continued the close monitoring of 66 ongoing major projects, with a view to speeding up their completion. This policy has contributed to the higher rate of growth in irrigation potential in recent years, compared with the early 1970s. At the same time, the rapid increase in the number of projects started after 1976 left a total of 150 major and 400 medium projects unfinished at the start of the Sixth Plan, with a combined remaining cost of these unfinished projects of Rs 113 billion. The policy of concentrating funds on projects nearing completion, which has recently been further stressed, has not fully succeeded in limiting the number of project starts, although it has succeeded in maintaining the enhanced pace of potential created achieved in the mid-1970s.

Groundwater Irrigation in the Sixth Plan.

The increase of 7 million hectares in area irrigated by groundwater projected under the Plan is expected to result from total expenditure amounting to Rs 30 billion. This consists of Rs 4.5 billion in public sector outlays (mainly for public tubewells and support for technical groundwater institutions) and Rs 16 billion in institutional credit, with the balance of Rs 9.5 billion, accounted for by private investment expenditures. The rate of increase of physical units—wells and pumpsets—is broadly in line with recent achievements, with the exception of electric pumpsets, where anticipated growth is much higher. The Government of India estimates that by 1984/85 73% of ultimate groundwater potential will have been developed.

The pace of groundwater development in 1980/81 and 1981/82 has fallen short of expectations only slightly. Compared with an original target of 2.65 million hectares over the two years, an estimated 2.45 million hectares have been added to existing irrigated area. This has been matched by estimated shortfalls of about 15% in the disbursement of institutional credit compared with Rs 6.3 billion target. Limited eligibility of lending banks, due to poor loan recovery, escalating capital costs of irrigation equipment and possibly a sharp drop in farmers' cash balances following the severe 1979 drought are the main causes of these shortfalls. Credit performance in 1980/81 and 1981/82 has continued the trend which began after 1978/79 of somewhat declining real disbursements for minor irrigation. In light of these developments the targets for additional area irrigated by groundwater and credit disbursements have been revised downwards for 1982/83. This suggests that achievement of overall plan targets for groundwater development is likely to prove difficult.
Long-term Prospects

Ultimate irrigation potential in India from all sources is estimated at 113.5 million hectares, 54% of ultimate gross cropped area (Table 6).

Table 6: EXISTING AND ULTIMATE IRRIGATION POTENTIAL (million hectares)

<table>
<thead>
<tr>
<th>Surface Irrigation</th>
<th>Major &amp; Medium</th>
<th>Minor</th>
<th>Groundwater</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981/82 (estimate)</td>
<td>28.6</td>
<td>8.4</td>
<td>24.5</td>
<td>61.5</td>
</tr>
<tr>
<td>Ultimate</td>
<td>58.5</td>
<td>15.0</td>
<td>40.0</td>
<td>113.5</td>
</tr>
<tr>
<td>% Potential Created</td>
<td>49.0</td>
<td>56.0</td>
<td>61.0</td>
<td>54.0</td>
</tr>
</tbody>
</table>


The Sixth Five Year Plan envisages creating remaining potential at a total cost of Rs 400 billion over the 20-year period 1980-2000. The Government has, however, raised the possibility of a more ambitious approach to irrigation development, termed the National Perspective for Water Resource Development. This plan involves deployment of currently under-utilized surface water to areas where water is scarce and would utilize an additional 22 million hectare meters of water at a cost of Rs 500 billion in 1979/80 prices. Integrated river basin development schemes, separately designed for Himalayan and peninsular rivers and involving international agreements for the Himalayan rivers with Nepal and Bangladesh, would be formulated. Implementation of this National Perspective Plan would expand the ultimate potential of gross irrigated cropped area by 35 million hectares. While studies of the feasibility of this approach have just begun and the total cost is unknown but likely to be high, it offers hope for further expansion of surface irrigation in India beyond the limits previously estimated. As the studies themselves are major undertakings, actual physical work on the proposal would begin only after the Sixth Plan. The future of groundwater irrigation will be closely tied to the development of surface potential. With many of the most profitable opportunities for private irrigation already taken, further growth is likely to occur at a reduced pace. Planning for conjunctive use, with surface irrigation replenishing aquifers and groundwater irrigation reducing waterlogging and drainage problems, can be used for a higher combined benefit. At the same time, barriers to further development of private irrigation presented by small farm size in north-eastern States and less favorable aquifer characteristics in hardrock areas will need special attention if growth is to be maintained. With continuing technological change both in agriculture and in surface and groundwater irrigation techniques, and the changing characteristics of the irrigation potential remaining to be exploited, there is an ongoing need for India to
review carefully the alternatives available to develop its groundwater and surface resources fully.

C. ECONOMIC RETURNS TO INVESTMENT IN IRRIGATION

This section discusses the direct economic returns to irrigation in India. The focus is on estimating the additional value of output generated by investment in irrigation. The approach is a broad macro-level analysis supplemented by project-specific analyses of rates of return.

Capital Output Ratios

Table 7 shows the estimated incremental capital-output ratios (ICORs) (i.e., the amount of additional investment required to produce an additional unit of output) for the agricultural sector and the economy as a whole. These estimates suggest that, ceteris paribus, a given investment in agriculture yields a higher increase in output than investments in other sectors of the economy, a result consistent with many earlier studies which indicate that at India's present stage of development, agricultural production is generally less capital intensive than production of power, most industrial products or infrastructural services. The table also suggests that over time the ICOR for agriculture may have risen somewhat.

<table>
<thead>
<tr>
<th></th>
<th>1951-60</th>
<th>1961-70</th>
<th>1971-80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2.45</td>
<td>2.74</td>
<td>2.99</td>
</tr>
<tr>
<td>Whole Economy</td>
<td>3.37</td>
<td>3.66</td>
<td>4.13</td>
</tr>
</tbody>
</table>


These results are broadly consistent with the historical trends in irrigation described above: a gradually increasing real capital cost for irrigation as irrigation development moves to increasingly difficult areas but costs which are offset substantially by major technological changes in agriculture and in the real value of crop output. Unfortunately, the analysis does not take one much beyond this as far as irrigation is concerned, for it includes much more than irrigation investment on the investment side and more than irrigated crop production on the output side. Irrigation investment constitutes less than one-third of total

1/ Discussions of returns to irrigation within India often focus on the important, but more narrow topic of the revenue earnings of public irrigation systems in relation to their costs, a topic which is treated below in the sections on groundwater and surface irrigation.
annual capital formation in agriculture (other items include tractors, implements, farm structures, land improvements and livestock). Moreover, the sectoral ICOR estimates include rainfed agriculture, forestry, livestock, marine and inland fisheries under agriculture, activities whose capital-output relationships are not likely to parallel those of irrigated crop production. Consequently, the ICOR analysis sheds little light on returns to investment in irrigation. It is helpful to explore another more direct approach to estimate the returns to irrigation.

Irrigation Benefits

The benefits of irrigation are well recognized, particularly by farmers. Reliable and timely water supplies enable farmers to get higher yields from existing crops to use higher levels of complementary inputs, particularly fertilizers, which further enhance yields, to shift to higher yielding varieties which are more responsive to good moisture conditions, to shift to crops which have higher water requirements and higher value, to increase cropping intensity so that crops can be grown in two or more seasons on the same land, to bring new land under cultivation, and to achieve all this increase in productivity with greater certainty. Irrigation thus provides farmers with a way to increase the productivity of their limited land significantly. These benefits to individual farms are reflected in the economy as a whole in the form of increased production and decreased prices of food and fibers to meet the needs of a growing population, to limit the need to use scarce foreign exchange for agricultural imports and to provide scope for agricultural exports. In addition to direct production benefits, irrigation normally generates increased demand for labor and indirectly stimulates a broad range of economic activities in surrounding areas. It is no accident that the Sixth Plan places such high priority on irrigation development or that the first point of the Prime Minister's recently announced new 20-Point Program is to "increase irrigation potential".

While the benefits of irrigation are widely recognized, their very nature, stemming from simultaneous changes in technology, input use, resource allocation and behavior makes them very difficult to quantify and attribute to any one factor such as irrigation. The interactive effect of a number of factors--technology, complementary inputs, land, labor and water--creates an effect that is greater than the sum of any of the factors acting alone. With the available data it is impossible to separate out these factors. It is possible, however, to estimate the extent to which variations in agricultural output can be explained by differences in irrigation, providing indirect measures of the productivity differences on irrigated and rainfed land. After checking these macro estimates for consistency with other data and studies, they can be compared with various cost estimates to provide a broad idea of the returns to investment in irrigation.

To obtain estimates of the differences in net value added per hectare between irrigated and rainfed land, the statistical relationship of net value of output from agriculture in the various States of India to the amount of irrigated land and rainfed land was estimated. The results indicate that a gross cropped hectare of irrigated land produces, in 1979/80 prices, about Rs 2,950 per year more than a hectare of rainfed
land. If one takes into account the higher cropping intensity of irrigated land by analysing the productivity of differences in terms of net area, the difference is about Rs 4,480.\(^1\) It is important to keep in mind the limitations of such estimates. First, the method of estimation implies shifting land out of rainfed cultivation into irrigated cultivation. To the extent that irrigation brings new lands under cultivation, this approach understates the total benefits of irrigation. Second, the aggregate data for irrigated area used in these equations cover a wide range of actual irrigation conditions in the field: land irrigated by private tubewells, giving farmers virtually all the water they need when they need it, is lumped together with land which may receive only one irrigation a season, and that not necessarily when the farmer most expects it. Thus the estimated coefficients provide an indication of the average actual productivity levels, not the levels which could be achieved if the constraints on irrigation efficiency could be removed. Finally, these estimates indicate only direct production effects evaluated in domestic prices, and do not attempt to include additional benefits from employment, stimulation of other economic activity or other indirect factors.

It is also important not to interpret the productivity differential as arising from irrigation alone. The productivity differential reflects the combined effects of irrigation, complementary inputs, technology and farm labor on output per hectare. If fertilizer had not been available, or new, more productive technologies not developed and disseminated to farmers, the productivity of irrigated land would have been far less. Finally, it should be noted that the size of the productivity differential arises in part from the very low productivity of rainfed agriculture, which offers substantial scope for improvement. Since even by the end of the Sixth Plan rainfed land will be 64% of total cropped area, improvements in productivity in these areas cannot be ignored.

Table 8 shows alternative estimates of the increase in value added per hectare anticipated from a number of irrigation projects appraised by the World Bank. These were estimated at the project level, using estimates of projected cropping patterns, future yields and crop prices. Given the differences in approach, in project composition (e.g., the Punjab and Haryana projects have components for improving deliveries to existing irrigated areas which are large relative to the new areas brought under irrigation) and in the agro-climatic conditions in different States and project areas, these figures are broadly consistent with those estimated from the aggregate State level data. The estimates used in the Sixth Plan for increased production from irrigated and rainfed gross cropped area for the country as a whole imply a productivity differential

\(^1\) That is, the lower estimate relates to a cropped hectare shifted to irrigation and the higher estimate to a shift of one hectare of cultivated land which may be cropped more than once. The equations were estimated using data from 19 major States. The \(R^2\) were above .90 and the \(t\) statistics indicate the coefficients are statistically significant at the 99% level. See Annex 1 for details.
between irrigated and rainfed land about the same as that estimated from the regressions described above. 1/

Table 8: ESTIMATED VALUE ADDED PER HECTARE IRRIGATED FROM SPECIFIC PROJECTS (in rupees)

<table>
<thead>
<tr>
<th>Project/Area</th>
<th>Year</th>
<th>Value added per net ha</th>
<th>Value added per gross/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rajasthan Canal</td>
<td>1979/80</td>
<td>n.a.</td>
<td>3,018</td>
</tr>
<tr>
<td>Madhya Pradesh (med.)</td>
<td>1980/81</td>
<td>n.a.</td>
<td>2,710</td>
</tr>
<tr>
<td>Karnataka Tanks</td>
<td>1980/81</td>
<td>4,360</td>
<td>n.a.</td>
</tr>
<tr>
<td>Haryana</td>
<td>1981/82</td>
<td>2,751</td>
<td>1,775</td>
</tr>
<tr>
<td>Punjab</td>
<td>1978/79</td>
<td>2,082</td>
<td>1,437</td>
</tr>
<tr>
<td>Maharashtra II</td>
<td>1979/80</td>
<td>4,085</td>
<td>3,174</td>
</tr>
</tbody>
</table>


Benefits, Costs and Returns

The benefits associated with irrigation estimated above are derived from productivity levels reached when much of the irrigated area had been irrigated for some time and the benefits of farmers adjusting their practices and crops have had time to arise. For example, as Table 2 above indicates, more than 80%, or 44.2 million hectares of the total 52.6 million hectares irrigated by 1979/80, had been irrigated by 1973/74. The rate of return on new irrigation projects will depend on several factors: how much the project costs per hectare, how soon the area is actually irrigated, and how rapidly and effectively farmers can make use of the irrigation.

Costs of developing irrigation vary widely depending on type of irrigation (groundwater or surface), the difficulty of the terrain, the design standards and whether the project is a new one or the modification or modernization of an old one. Most of the surface projects listed in Table 8 have a cost range of about Rs 8,000 to Rs 20,000 per hectare. The Sixth Plan implies an average capital cost at 1979/80 prices of about Rs 15,000 per hectare of surface irrigation potential created. The capital costs for groundwater development also vary greatly, from around Rs 5,000 per hectare for a shallow tubewell to Rs 9,000 per hectare for a dugwell. These costs compare quite favorably with the productivity increases from irrigation estimated above. Depending on the costs of a particular project and the rate of buildup of the benefits, the returns to

1/ Sixth Five Year Plan, p. 41, Table 3.12 provides productivity differences on irrigated and unirrigated land for most, but not all, major crops. For those crops for which data are given, the productivity difference in 1979/80 prices would be Rs 2,370 per gross cropped hectare. If other crops were included, the figure would be closer to the one estimated from the regression equations.
irrigation can be favorable. To carry the analysis further, however, it is necessary to look at specific investments in different types of irrigation in different conditions.

Table 9 summarizes the results of a number of *ex ante* and *ex post* analyses of the returns to investment in groundwater, in terms of both the returns to the economy as a whole and the returns to the individual farmer making the investment. 1/ The conditions and methodologies of these studies vary as they were carried out at different times, so are not strictly comparable, but they serve to give a broad indication of the level of returns to private groundwater investment. The returns are quite high, particularly for shallow tubewells (STW). Actual *ex post* returns, calculated from field survey data, are generally equal to or higher than anticipated returns. Returns to the farmers are also attractive and broadly similar to the returns to the economy.

Table 9: ANTICIPATED AND ACTUAL RATES OF RETURN TO PRIVATE GROUNDWATER INVESTMENT

<table>
<thead>
<tr>
<th>Shallow Tubewell with Pumpset</th>
<th>Anticipated Returns to the Economy</th>
<th>Anticipated Returns to the Farmer</th>
<th>Actual Returns to the Economy</th>
<th>Actual Returns to the Farmer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bihar</td>
<td>50+</td>
<td>48 n.a.</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Gujarat</td>
<td>23</td>
<td>30</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Haryana</td>
<td>22-27</td>
<td>39-66</td>
<td>50+</td>
<td>16-129</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>16-41</td>
<td>17-44</td>
<td>50+</td>
<td>22-33</td>
</tr>
</tbody>
</table>

| Dugwell with Pumpset         |                                   |                                 |                               |                             |
| Andhra Pradesh               | 27-30                             | 18-26                           | 37-50+                        | 16-50+                      |
| Gujarat                      | 23                                | 26                              | 15                            | 12                          |
| Karnataka                    | 12                                | 19                              | 26                            | 21                          |
| Madhya Pradesh               | 17                                | 35                              | 41                            | 37                          |
| Maharashtra                  | 23-50                             | 23-40                           | 18-50+                        | 11-50                       |
| Tamil Nadu                   | 19-20                             | 28-29                           | 26                            | 16                          |


Studies analyzing rates of return to surface irrigation projects in India are rare, particularly studies presenting *ex post* rates. In part, this reflects a number of methodological problems, for while a tubewell investment is a small, discrete investment with positive returns flowing in one or two years, major irrigation projects take place over a much longer time during which many related variables change. The investment also brings about fairly radical changes throughout a large project area. To provide an indication of the returns to some surface irrigation projects, Table 10 summarizes *ex ante* data from recent World Bank

1/ Returns to the economy are those that accrue to society and include costs and benefits priced at opportunity costs rather than at the financial prices faced by the farmers.
appraisal reports. For the last two projects in the table, Pochampad and Kadana, ex post rates of return have been estimated at 14% and 12% respectively. An analysis of two completed major irrigation projects in Maharashtra indicated their actual rates of return were around 12%-14%. These rates of return are favorable, though generally lower than those estimated for STW development. The Planning Commission carried out an evaluation of eight surface irrigation projects in 1965. The study found that using a 10% discount rate (then considered on the high side), only one project had a benefit cost ratio below 1.0 (at 0.92) while the seven other projects had benefit cost ratios ranging from 1.22 to 4.18, with four projects having ratios above 2.0.

Table 10: SUMMARY OF ANTICIPATED ECONOMIC RATES OF RETURN ON SURFACE IRRIGATION PROJECTS

<table>
<thead>
<tr>
<th>Project</th>
<th>Ex Ante Rates of Return (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rajasthan Canal</td>
<td>30</td>
</tr>
<tr>
<td>Madhya Pradesh (med.)</td>
<td>18</td>
</tr>
<tr>
<td>Karnataka Tanks</td>
<td>20</td>
</tr>
<tr>
<td>Haryana</td>
<td>32</td>
</tr>
<tr>
<td>Punjab</td>
<td>36</td>
</tr>
<tr>
<td>Maharashtra II</td>
<td>15</td>
</tr>
<tr>
<td>Pochampad</td>
<td>14</td>
</tr>
<tr>
<td>Kadana</td>
<td>12</td>
</tr>
</tbody>
</table>


These data indicate that the economic returns to irrigation are generally attractive. Nevertheless, there remains substantial scope for more efficient implementation of irrigation projects and utilization of irrigation water. Capturing these opportunities for increased productivity will become increasingly important as construction costs rise and as India seeks to exploit the substantial potential for irrigation in the more difficult agro-climatic and geological conditions. The remaining sections focus on the factors which limit returns to surface and groundwater irrigation and the ways to remove these constraints.

D. FACTORS LIMITING RETURNS TO INVESTMENT IN SURFACE IRRIGATION

While these estimates of returns are encouraging, there is virtually unanimous agreement that returns are lower than they should be.

1/ A third project, the Godavari Barrage project showed an ex post rate of return of 56% compared with an anticipated 44%. But since the project involved replacement of the barrage and not the attendant delivery system which was already in place, its return is not typical of most surface projects.
The Sixth Five Year Plan States that: "In spite of the large investment made in the irrigation sector and the phenomenal growth of irrigation during the past 30 years, the return from the investment both in terms of yield as well as finance are very disappointing. 1/

Understanding the reasons for the low returns is a pre-requisite to finding workable ways to raise them. India’s irrigation sector is huge, diverse and bristling with many major issues. To better understand the nature of the problems, it is helpful to compare systems that yield quite good results with others that exhibit the main problems limiting returns. For ease of presentation, the systems are distinguished as "northern systems", characteristic of the Punjab, Haryana and western Uttar Pradesh and "southern systems", which in actuality are characteristics of those existing in much of the rest of India. This does not mean that all irrigation systems in the South are equally subject to the problems described. Some southern systems work very well, such as the Krishna and Godavari delta projects; but many of the projects built since the early 1950s outside of the north-western area are subject to the problems discussed below.

Northern irrigation systems are typically designed and built to provide irrigation through run-of-the-river canals as protection against long breaks in the monsoon. These systems were designed for very low irrigation intensities (as low as 30% of the commanded area in one season) giving a little water to a large number of farmers. These systems deliver water to the irrigation outlets on a fixed schedule. The conveyance system is a fairly simple one, which can be operated to deliver water to outlets selectively so that any given availability can be equitably shared. Outlets themselves are not operated and do not require adjustment; they either receive water or they do not. Within the block (chak) a system of rotational water supply (warabandi) ensures each farmer gets a share of the water delivered to the outlet in strict proportion to his land area in accordance with laws and customs which have been in practice for generations. The available water is sufficient for each farmer to irrigate only a fraction of his area (e.g., 30% in each season); but how the farmer uses his water, on what crops and on how many hectares is a matter of his own management. There is no attempt by the irrigation authorities to differentiate administratively between crops, to influence the farmers to grow something other than they desire or to control how much of the commanded area the farmers actually irrigate.

Many southern canal systems provide contrast to those in the north. They are typically designed for much higher irrigation intensities and for at least some crops with heavy water requirements, such as paddy, sugarcane and bananas. The systems more often have storage reservoirs behind dams and usually have more elaborate conveyance systems with, for instance, outlets that can be adjusted to varying discharge rates. The system of water distribution is based on concepts of crop sanctioning or localization whereby the irrigation authorities approve a cropping pattern

which is theoretically consistent with overall water availabilities. The irrigation department in theory then undertakes scheduled delivery of water in the quantities required for the approved cropping pattern.

In even starker contrast to the different objectives of the northern and southern irrigation systems is the differing degree to which the actual performance of the systems approaches their objectives. The northern systems work much as intended and the water use efficiency is even higher than originally assumed because farmers have learned to stretch the available water over more land than was originally thought. Farmers are highly aware of their rights to water and, in light of its scarcity under these systems, zealously safeguard their rights, insisting on their turn to the water reaching the outlet. The schedule of water deliveries is rigid and reliable, yet, by not attempting to require farmers to grow a given set of crops or to indicate in advance his cropping pattern, affords farmers some scope to adjust their crop mix in response to changing technical and economic opportunities.

In many southern canal systems performance falls short of the original intention. Some systems use all the water allocated on one-half or three-quarters of the intended area, with little or no water reaching farmers furthest from the outlets, the outlets furthest down the branch canals or the branch canals furthest down the main canals. At the same time farmers at the upper reaches of the system have as much water as they want, often irrigating all of their land with a crop having heavy water requirements, and using water quite extravagantly. Cropping patterns bear little resemblance to those approved by the irrigation departments, as those farmers with access to the water grow whatever crops pay the most, disregarding the cost of water (which is not a significant consideration for farmers who do not face water scarcity, given the lack of volumetric pricing and the generally very low levels of water charges), their approved cropping pattern and the suitability of their soils for efficient irrigation. They often get good yields and incomes as a result of the plentiful irrigation available to them but at the expense of farmers further downstream, who are forced into a less profitable cropping pattern approaching that of rainfed conditions. In some areas excessive water use leads to drainage problems and waterlogging, limiting the range of crops that can be grown in affected areas to those which can withstand lots of water, such as paddy. Overall benefits of the project also suffer, as much water is simply wasted and used without regard to its cost.

The remainder of this section discusses the reasons for these factors limiting returns to investment in surface irrigation. It also discusses solutions the Government of India and the States have evolved. Although the problems are highly interrelated, three categories—management, design and planning—are distinguished to make the discussion more tractable. Each of these categories is quite important and the order in which they are discussed in no way indicates their priority.

Management of Surface Irrigation Systems

Improving the management of India's irrigation system is one way of increasing returns to investment in irrigation. Managing industrial production in factories, even quite large ones with many suppliers and
thousands of workers, is a simple task compared to managing the distribution of river water over thousands of hectares to hundreds of thousands of farmers each of whom has differing needs for water. Yet much less explicit attention is devoted to managing irrigation systems than to most industrial factories. The discussion of irrigation management can be broken into three parts: the distribution of water below the outlet, the distribution system between the source of water and the outlet; and storage reservoirs, where they exist.

Managing the distribution of water below the block outlet attracted much attention during the 1970s. Many thought that the root of the problem of inefficient water use was the gap between the point where the responsibilities of the irrigation departments left off—the outlet—and the point where the farmer's own responsibility began—at the edge of his fields. It is now widely recognized that delivering water to the outlet reliably is a very important aspect of efficient water distribution. But good water management below the outlet is also necessary. In the north the system of warabandi (rotational water supply) involving a watercourse and schedule of turns had been successfully established and incorporated into law by the irrigation departments at the beginning of the operation of the project and had been maintained by the farmers with only rare intervention by irrigation department. Similar systems of water distribution were implicitly assumed to develop in the southern systems but in fact never did, basically for lack of anyone to organize them. This led to the disorganized distribution of water below the outlet whereby farmers close to the outlet dug channels to their land, utilized as much of the water as they desired and then allowed it to flow on. Farmers furthest from the outlet received little, if any, of the water (or sometimes too much water due to poor drainage; but little in a controlled manner).

Improving the efficiency of water distribution below the outlet is one way of increasing rates of return to the investment in irrigation. Some solutions are matters of system design. However, half of India's surface irrigation potential is already constructed, most of it with outlets serving large areas, requiring some solution to the problems of water distribution below the outlet.

The Command Area Development (CAD) program was devised in the early 1970s as a solution to problems of inefficient water use below the outlet and low agricultural benefits from irrigation. In its original conception and implementation, CAD was quite a comprehensive and ambitious program concerning all aspects of managing land, water, agricultural

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1/ The block outlet is the point where the water leaves the Government constructed (minor) canals, below which farmers distribute the water among themselves to reach their fields. In some systems the area served by the outlet is quite large, 120 to 200 hectares with 50-100 farm families. More typically in many existing systems the average outlet serves about 40 hectares and 20 farm families or so. In some newer projects, outlets are being constructed so less land (5-8 hectares) and fewer farmers (2-4) are served.
inputs and outputs to raise returns to irrigation. This included rectification of land records; land consolidation; field rectangulation; land levelling; chak development, including construction of water courses; extension of agricultural advice; provision of agricultural credit, coordination and integration of agricultural inputs such as seeds, pesticide and fertilizers; and improvement of marketing facilities, including construction of market roads and market yards. However, CAD's goals were highly ambitious given the nature of the problem, the time available and the human and financial resources devoted to the agencies. They also were established outside the traditional line departments of Government using staff deputed from those departments, causing problems when responsibilities overlapped. CAD's mandate to operate the system and to develop farmer organizations to use water was often unclear.

The Command Area Development Program soon got bogged down in implementation. CAD had the general problems of a new government organization created to coordinate, and to some extent oversee, the activities of several well-established departments, each of which tended to preserve zealously its traditional responsibilities from CAD encroachment. Correcting land records, a prerequisite to land consolidation, ran into problems both from the revenue departments, whose responsibility they were; and from farmers, who feared upsetting the status quo with investigations into recorded ownership of land. Land consolidation progressed very slowly, even where there was Government determination and farmers' willingness to proceed. Where either was lacking, little land consolidation was accomplished. CAD had big problems financing communal works below the outlet, in particular the construction of field channels. A prevalent approach was for the CAD Authority (CADA) to let contracts for the work and try to convince farmers to assume loans to pay for their attributed part of the cost. This farmers were reluctant to do, particularly when the arrival of the water to flow through these field channels remained only a Government promise. Furthermore, some farmers who had defaulted on past loans were ineligible for credit, creating great difficulties and delaying the construction. The CAD involvement in provision of agricultural advice, credit and inputs sometimes produced improvements (particularly in extension), but often simply created another layer of bureaucracy rather than improving the provision of these services.

The effect of these problems was very slow progress in achieving the goals of CAD. The program was formulated and begun early in the 1970s and became well-established only in the Fifth Plan (1974/75 to 1978/79). Achievements have built up slowly and even now are not keeping pace with new additions to irrigated area, much less rectifying the conditions of India's large existing capacity. CAD needed a change in strategy, as the original program of a thoroughgoing transformation of the chak was going very slowly. The basic shift in strategy is to simplify the program by directing the main effort toward delivering water from the outlet to the farm fields in a timely, reliable and equitable fashion. This means less stress by CAD on other components, giving regular line departments increased scope to provide these services.

The approach adopted to ensure the reliable delivery of water is Government construction of field channels and the introduction of equitable and disciplined water allocation procedures, where they do not
already exist. Some administrators of CAD programs noticed that farmers were much more willing to cooperate in the watercourse development aspects of CAD after they were assured of a reliable supply of water. A main element of the strategy is to introduce clear water allocation procedures. One method that has worked in some parts of India is warabandi whereby each farmer on a chak receives water on a fixed schedule from the outlet in proportion to his total area in the chak. Other solutions are possible, some of which provide more flexibility of supply. The strategy of having CAD concentrate on developing and applying a reliable system of water delivery and constructing field channels to deliver the water near the farmer’s field often has led farmers to undertake the land preparation required on their own fields. Financing the construction of field channels on Government account overcomes the very severe problems of farmers’ qualifying for and accepting loans for their construction.

Another idea that grew out of efforts to improve the operation of CAD programs is the organization of an effective agricultural extension system. Originally formulated and introduced in the Chambal, Rajasthan, Command Area Development Authority, the training and visit (T&V) system of agricultural extension has proven quite successful in raising yields not only in irrigated area but in rainfed areas as well. The system has been or soon will be introduced in most of the major States of India as the basic Statewise system of agricultural extension in addition to having been introduced in many CADAs. The T&V system of agricultural extension could be termed a third major element, along with construction of field channels and reliable water supply, of the Government’s efforts to raise agricultural benefits of irrigation below the outlet. Training and placement of subject matter specialists in water management in the extension service in irrigated areas could improve its ability to respond to the farmers’ needs.

Increasing returns by improving the management of the distribution of water between the reservoir and the outlet is one of the most neglected of the various opportunities to raise returns to investment in irrigation. It is clear that managing the distribution of water so that it reaches the outlets in an efficient, reliable, timely and equitable manner is virtually a prerequisite for efficient, reliable and equitable water distribution below the outlet. It is also clear that there are ways to improve water distribution above the outlet even with the less than optimum designs built in many of the existing systems. In fact, many of the existing distribution systems have (or could have with modernization and rehabilitation) greater capacity to respond to better management than is achieved at present.

Although some irrigation systems in India operate quite well, in many systems there is often a great variation in discharge at the outlets with some receiving much more than the designed discharge while others receive much less and still others receive none at all. Over the system as a whole, there may be a surplus of water in some parts while in others there may be considerable scarcity. A prevalent syndrome, particularly in some southern canal systems where paddy is a major crop, is very heavy use of water in the upper reaches of the system, decreasing further down (because there is little water left) and virtually no water reaching the tail end.
Wasteful water distribution below the outlet is often viewed as the main culprit in the maldistribution of water throughout the system. State departments of irrigation often concur as it places the problem outside their traditional purview, which ends at the outlets. If each farmer used only the amount of water assumed and with the care assumed in the original design (forgetting for the moment other flaws in design assumptions) then water would reach all parts of the system. But in practice, no effective means, whether economic, social or administrative, exists to ensure that these assumptions work in practice.

These are complex problems derived from the basic conceptual design. Under localization and crop sanctioning, systems are designed to meet the desired cropping patterns with the assumed crop water requirements and conveyance losses. These are often optimistic yet the operational design does not have the capacity to adjust to the increased requirements or reduced availabilities of water as necessary. Hence no procedures are formulated to distribute the resulting scarcity of water efficiently and equitably. In addition, the upper reaches of an irrigation system are invariably opened early in the project as the canals needed for water to reach the areas close to the dam or diversions are completed. Farmers in the upper reaches of the project thus begin irrigation when there is plenty of water. It may be a decade (or longer) before enough of the project is completed to reveal the scarcity in the overall system. In the meantime, the upstream farmers often adopt a cropping pattern and habits of irrigation using much more water per hectare than the system can supply to the whole project area. They feel they have acquired rights to a continuation of the pattern of water distribution, despite its wasteful use of water in the upper reaches, a cropping pattern of uneconomically high water intensity, and under-utilized capacity in the lower reaches.

In thinking of solutions to these problems it is important to distinguish between systems that are already built and those that are still being planned. The designs of existing systems can be changed to a limited extent through modernization. In addition changes in operation and management can make some improvements. Where the design of a system is still open, changes are possible in the basic concepts of water distribution. This latter possibility is discussed below under design standards.

The point of modernization is to raise the returns to existing surface irrigation systems by improving performance capabilities and operating characteristics. This can mean different changes in different systems, depending on the existing problems. Modernization can include changing the cross-section of major canals, building parallel canals, canal lining, increasing control structures, changing the design of gates, constructing a higher proportion of the distribution system to reach closer to the farmer, conjunctive use of groundwater and many other changes. The degree of change depends on the economic returns possible. Modernization can yield quite high rates of return if it overcomes constraints to reliable and efficient water distribution.
Along with design changes it is sometimes possible to change the operation and management of systems to improve reliability and efficiency. In some systems such as those described above based on crop localization and with the tail-end problem, canal administrators are experimenting with operating rules that move water to the tail end simply by closing temporarily some part of the upper reaches of the system. This is a basic change in the original operating principle, which was to deliver water to each farmer in the system in accordance with the crop he was to grow under the crop localization. Although the results of the change may be far from the ideal, the change improves the reliability, efficiency and equity of the distribution of water.

Managing a reservoir behind a dam supplying water for irrigation is a highly complex operation that can often be improved to increase returns to irrigation. Many kharif (wet season) crops give higher yields if planted in June rather than July. Late planting of kharif crops also delays planting of rabi (winter) crops, which in turn depresses their yields, especially those of wheat. The planned planting of kharif crops in June would require releases from reservoirs in early June, before the current year’s monsoon rainfall could have added to reservoir supplies, meaning some water would have to be carried over in storage during the hot season. This was thought to be costly in terms of water lost to evaporation. A simulation model of one reservoir was constructed to test the effects of shifting the beginning of the kharif irrigation season to early June. The result was that both total area irrigated and yields increased under the new regime. Not only did both kharif and rabi yields benefit from the earlier planting dates, the irrigated area increased as the higher evaporation losses were more than offset by lower crop water requirements for the earlier planted crops.

Design Standards

The design of large irrigation projects is one of the most challenging tasks in the world, as the issues are complex and the implications for farmers’ incomes are enormous. As India intends to complete the development of most irrigation sources by the year 2000, (meaning a doubling of surface irrigation potential from about 29 million hectares now to 58 million hectares) and given the long gestation period of major irrigation projects, the designs adopted now will have a profound influence on the nature of irrigation in the future. Although much of India’s irrigation system was built to serve the agriculture of the nineteenth century, the current need is for designs based on performance standards that will serve the twenty-first century.

The reliability, efficiency and manageability of the existing northern systems are very appealing aspects of their designs. Although some of their features are specific to the prevailing agro-climatic condition and therefore may not be easy to incorporate elsewhere in India, they illustrate how design concepts can enhance productivity. The northern systems are designed so they can deliver a small amount of water to a large number of farmers without a very elaborate canal administration or need for much official discretion at the local level. The reliability and efficiency of northern systems derive in large part from the establishment of clear-cut, legal water rights and the imposition of scarcity for each
farmer. Although no farmer may get as much water as he wants and may not always get that when he wants it, he at least knows how much he will get and when he will get it. That his allocation is always less than he could beneficially use on his land means each farmer has a powerful incentive to use water in ways most efficient to raise his family income. The design standards of new systems can be raised to add some flexibility of water deliveries so farmers' changing needs can be met. Nevertheless, the good features which already exist in some of India's better systems should be incorporated in the design of new systems.

In the long run, achievement of high water efficiency will require the delivery of water in ways responsive to individual farmers demands. In terms of both engineering and management, this is difficult to do economically given the large number of farmers and small individual holding served by major irrigation projects. But experiments with system design which move in this direction are possible and indeed are already under consideration. The basic designs of major systems formulated now need to include features in anticipation of more responsive systems in the future. For instance, opportunities should be seized at the design stage for including in the conceptual design the number and types of control structures including down-stream controls and in-system storage reservoirs needed for a demand-based system of water management to respond rapidly to changing conditions. Not all of the infrastructure need be built at once but the system can be designed to ensure that eventual inclusion of needed facilities is economically possible.

Most of India's irrigation systems has been designed using assumptions of cropping patterns and water seepage losses that have proved to be overly optimistic. Recently a program of measurement of actual water losses in the various parts of several irrigation systems has shown that the efficiencies with which water has been used in these projects were about half those assumed in planning the projects. For example, the World Bank has found overall project efficiency (the proportion of the water diverted from its source that actually reaches the plant) in several southern projects to be 25% to 30%, while planning assumptions typically have been in excess of 50%, usually 60%-65%. The implication of this difference is that systems planned with more optimistic assumptions over-estimate irrigation potential by as much as 50% to 100%, an order of magnitude actually found in some irrigation projects.

Another design issue is the extent of the command area. A system can be designed for high intensity irrigation in a compact area or lower intensity on a more extensive area. Higher intensities on a more compact block mean shorter conveyance systems which in turn mean lower costs and water loss; lower intensities mean a larger number of beneficiaries. If the efficiency of on-farm water use were the same in both alternative, the higher intensity system would yield higher returns as the costs are less and benefits greater when more water reaches the fields due to lower conveyance losses. Nevertheless, low intensities, combined with reliable and equitable water delivery, give farmers strong incentives to economize in water application that are not provided by India's system of pricing for irrigation water. Low intensities also provide scope for extending the area if more water somehow becomes available (e.g., through storage or lining) or if the farmer finds ways to improve water use efficiency on his
farm. Furthermore, low intensities allow for and encourage the conjunctive use of surface and groundwater irrigation in areas with suitable aquifers.

In many irrigation projects the design of the distribution system between the main canals and the outlets has suffered from inadequate attention and resources. This portion of the system is most critical in operating a reliable and flexible system but receives typically only one-tenth of the engineering effort invested in the project as a whole. This means the distribution system is seriously under-engineered which considerably undermines the capacity of the system to respond to farmers' needs.

In many systems the alignment of channels and placement of outlets are poor, due to insufficient investigation of the topography and inadequate engineering. The result is that some areas that could be commanded with proper alignment and location are not, resulting in needlessly extensive command area. This in turn contributes to long water courses, high water losses, the tail end problems, and consequent tampering with the system by farmers. These irregularities simply enhance the unreliability of the already unreliable distribution system.

The design of the distribution canals, and the inclusion of cross regulators, wasteways and water measuring devices are not always adequate to allow efficient canal operation. Because of design flaws the actual carrying capacity of canals is less, in a few cases by as much as 40% less than assumed in the project. The lack of enough control structures means that when the system is operating at less than the design flow, many outlets then cannot draw their full discharge, causing highly uncertain and inequitable delivery of water to outlets. Lack of adequate provision for drainage structures, particularly culverts or aqueducts crossing the distribution system, is another reflection of the low priority given to the design of the distribution system and one which contributes to serious drainage problems in some areas.

One promising change in design standards to improve water distribution is to reduce the size of the area served by each outlet by having the Government construct a higher proportion of the distribution system, leaving less to be organized cooperatively by farmers. Another is to line a higher proportion of the distribution system both to reduce losses and to increase the reliability of water deliveries, although the extent of lining is a matter which must be decided in the context of each project (depending on soil and water balance conditions and other factors). As an example, the World Bank compared the effect of different proportions of canal lining on water efficiency and cost per hectare irrigated in several projects located in Maharashtra. The results presented in Table 11 are that costs per hectare irrigated decline with smaller outlets and a higher proportion of the system lined. The water saved increases the area irrigated faster than total costs rise.
Table 11: WATER USE EFFICIENCY AND SIZE OF OUTLETS

<table>
<thead>
<tr>
<th>Outlets Serving 40 ha</th>
<th>Bhima</th>
<th>Krishna</th>
<th>Kukodi</th>
<th>Average Cost per Irrigated hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main &amp; Branch Canals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lined</td>
<td>37</td>
<td>35</td>
<td>35</td>
<td>15,000</td>
</tr>
<tr>
<td>Lined to Outlets</td>
<td>44</td>
<td>43</td>
<td>44</td>
<td>13,100</td>
</tr>
<tr>
<td>Lined to Outlets</td>
<td>52</td>
<td>50</td>
<td>51</td>
<td>12,000</td>
</tr>
</tbody>
</table>

/a Percentage of water diverted from source reaching plants.


Investment Planning and Financing

The most important way in which the planning and financing of investment in surface irrigation affects economic returns is the way they affect the speed with which projects are completed and the agricultural benefits of irrigation start accruing. When more projects are started than can be expeditiously completed with the available level of funding, each project is slowed, wastefully delaying the benefits of each. Prolonging the period before the benefits become available reduces the rate of return on the investment. The phenomenon of project proliferation and delay of project completion has long been recognized as a problem in India.

The Government of India studied the reasons for delay in selected major irrigation projects started in the First and Second Plans which had been under implementation for a period much longer than had been originally scheduled. /1/ The study found that in all the projects construction had been carried out at a pace far less than optimum, mainly due to an inadequacy of funds. This took place, despite generally rising expenditures on irrigation, due to the proliferation of projects under construction, as State Governments succumbed to pressures to take up new projects wherever possible in the State. By concentrating funds and other resources on projects nearing completion the overall return to investment could be raised. The Government of India repeatedly has pressed States to complete ongoing projects first before starting more projects than needed to maintain an adequate pipeline. Some progress has been made in

/1/ The projects studied are Nagarjunasagar (located in Andhra Pradesh, started in 1955), Gandak (Bihar, 1961), Kosi (Bihar, 1955), Malaprabha (Karnataka, 1961), Kallada (Kerala, 1961), Tawa (Madhya Pradesh, 1956), Rajasthan (1958) and Kangsabati (West Bengal, 1956).
this direction in the recent past, resulting in the acceleration of potential created from the mid-1970s onward. Nevertheless, the jump in the number of major projects started between 1976 and 1981 indicates that the problem persists.

An institutional need that cuts across all three elements of management, design and planning is training of irrigation manpower. India has a large and well-trained engineering cadre with a wealth of experience. Nevertheless, the development and implementation of new, more efficient concepts and methods of water management, system operation and design, involve changes in approach and attitude that can best be brought about through education, or training. Improved and re-oriented training is thus needed at all levels, including junior engineers and field staff, middle-level irrigation managers and senior irrigation engineers, who formulate policies. This change must start at the university level through more contact with field conditions; better understanding of agricultural operations and farmers' needs; and increased exposure to modern irrigation engineering and management. The emphasis should be on training irrigation engineers, rather than construction or civil engineers.

The pace of surface irrigation development is limited by the availability of resources for public investment outlays. In order to raise resources and prevent irrigation from being a drain on the budget, the Seventh Finance Commission (1978) advised, and the Sixth Plan concurred, that by 1983/84 "receipts should not only cover working expenses (of the Government irrigation system) but also provide for a return by way of interest at 1% on the total capital invested by the states at the end of 1978/79." It also recommended that expenditure on maintenance should reach a minimum standard (at least Rs 75 per hectare of command area). Working expenses should reflect an adequate maintenance charge. Some States spend much less than this and in fact do not adequately maintain existing investments. However, under the constitution, irrigation is a state subject. The ability of State Governments to recover the costs of irrigation is severely constrained by intense political pressure from farmers to keep water charges low. The result is that, while some systems make money, the Government irrigation system as a whole incurs heavy losses, with irrigation charges covering only 34% to 45% of operating expenses in the period 1976/77-1978/79 (Table 12). The percentages would be lower if adequate maintenance expenses were included.

The unreliability of water supply in many systems makes improving water pricing procedures most difficult, while also creating further resistance to the idea of raising water charges. Improvements in the procedures for allocating water to farmers could create a climate more conducive both to efficiency and cost recovery. The introduction of a system which provides less water than can be used, would force farmers to face the opportunity cost of water, while making supply more reliable.
Table 12: OPERATING ACCOUNT OF THE GOVERNMENT IRRIGATION SYSTEM 1976/77-1978/79
(Current Rs million)

<table>
<thead>
<tr>
<th></th>
<th>Operating Costs of the Irrigation System</th>
<th>Irrigation Charges</th>
<th>Operating Deficit</th>
<th>Revenues as a % of Expenses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976/77</td>
<td>2,946.5</td>
<td>1,329.6</td>
<td>1,616.9</td>
<td>45.1</td>
</tr>
<tr>
<td>1977/78</td>
<td>3,521.0</td>
<td>1,304.9</td>
<td>2,216.1</td>
<td>37.1</td>
</tr>
<tr>
<td>1978/79</td>
<td>4,015.0</td>
<td>1,373.7</td>
<td>2,641.3</td>
<td>34.2</td>
</tr>
</tbody>
</table>


The overriding rationale for raising water charges is rather that the Government irrigation system represents a sizeable, largely untapped, base for raising additional resources. State budgets are in need of additional sources of funds for development. Even given the present deficiencies in the system, water rates are extremely low in relation to the incremental output generated by irrigation. Water charges are but one element in an array of possible measures, including land betterment levies, market taxes, and other indirect taxes, that can be used to mobilize resources. While recognizing the politically sensitive nature of the water charges issue and that progress can only be gradual, recent developments indicate this potential. In 1981/82, higher irrigation charges in several states generated extra revenue of Rs 166 million. Further measures to raise the cost of irrigation to those who benefit from it would also have favorable equity effects, reducing the existing burden on general taxpayers.

There are other aspects of investment planning that affect the rate of completion of projects. A variety of these can be summed up as inadequate or faulty forward planning and project preparation. Often projects are taken up without sufficient prior investigations into their engineering and hydrological aspects, resulting in delays while solutions are found to unexpected problems. Some projects are built according to preparation reports completed decades earlier without benefit of information on improved techniques that since have been developed. Construction is often delayed for lack of key materials. Sometimes land acquisition proceedings are started late, holding up completion of projects. There has also been lack of detailed construction planning before the start of a project.

There is a tendency for States to concentrate planning, engineering construction and financial resources on major structures like dams, barrages and main canals while progress on the other parts—minor canals and water distribution below the outlets—are under-engineered, under-funded and allowed to lag behind. The major structures are more visible and their construction easier to supervise than the other elements. The result is that often the major structures are taken up and completed much in advance of the remainder, thus creating missing links in delivering water to farmers. There is considerable scope to avoid delays
in the accrual of benefits by more careful phasing of construction of a project's various components.

Just as states are often subject to pressure to start more projects than they can adequately fund, they are sometimes under similar pressures to locate the command area of projects in areas other than those which economic considerations alone would suggest. The nature of the terrain can affect project costs profoundly and investing in a project which seeks to deliver water in difficult (e.g., rolling terrain) areas has a much lower return than using the same funds to develop irrigation in more favorable areas.

E. FACTORS LIMITING RETURNS TO GROUNDWATER INVESTMENT

Introduction

Although returns to investment in groundwater are fairly high (Table 9), the remaining potential for groundwater development is increasingly in areas where the costs may be higher or the benefits lower than in areas already developed. Consequently it is important to examine factors which at present limit the return to investment in groundwater and identify ways to improve them.

Physical Factors

Access to land and water limits the returns to investment in groundwater development. These limits play an important role in determining inter-regional differences in the pace, type and profitability of groundwater investment. Farm size can be an important factor. The benefits of HYV technology, together with reductions in the size and cost of pumpsets over the last 30 years, have reduced the minimum size of farms which can profitably use private irrigation equipment. Despite these trends, millions of farmers in areas with plentiful groundwater supplies are unable to bear the capital cost of irrigation equipment because of small and fragmented holdings. Moreover, many farmers for whom such investment is profitable under-utilize their equipment in a physical sense for similar reasons—their holding size is simply too small or fragmented to use the pump capacity fully. Along with other factors, the depressing effect of fragmentation and small holding size on the pace of, and rates of return to private groundwater investment is particularly evident in eastern Uttar Pradesh, Bihar, West Bengal and Orissa. Solutions to this problem lie in both the private and public sectors and indeed considerable development is taking place. However, rates of return to, and hence development of, private groundwater irrigation in these areas will be lower than it would be in areas with larger fields.

Groundwater availability is principally determined by geology. In India, the availability of groundwater and its extraction cost are closely linked with two broad categories of groundwater occurrence: areas of thick alluvial deposits in the major sedimentary basins (e.g. the Gangetic Plain) and on the coastal deltas; and areas of crystalline "hardrock" in
the Deccan Plateau. Investment in shallow tubewells (STWs) has been concentrated in alluvial tracts, where groundwater is relatively abundant and easier to extract. Groundwater exploitation in alluvial areas has not, however, been equally distributed. Development has been slow in the north-east for a variety of reasons, including both small farm size and the generally better natural soil moisture due to higher rainfall in those areas. In the northwest, on the other hand, tubewell growth has been rapid and, in some parts of Punjab, Haryana and western Uttar Pradesh, is approaching saturation. In these areas there exists the possibility that rates of return to further development will be reduced if excessive extraction causes aquifer levels to decline. While previous estimates of acceptable extraction levels appear to have been unduly pessimistic, continuous close monitoring by State groundwater organizations is required to prevent such overdevelopment. On the other hand, the increasing attention being paid to the mutually reinforcing characteristics of surface and groundwater irrigation, and the need to develop both conjunctively, may delay the emergence of this problem.

Rates of return in "hardrock" areas are inherently lower on account of less favorable aquifer characteristics and generally higher extraction costs. Widespread private extraction of groundwater from such aquifers using dugwells is unique in the world to India. Its importance lies in the fact that hardrock areas cover the greater part of peninsular India. Moreover, many hardrock areas are drought-prone, making irrigation essential for reliable cropping. To a considerable extent, therefore, the successful development of India's remaining groundwater potential requires the identification of profitable irrigation opportunities through groundwater surveys. In hardrock areas, groundwater occurrence differs according to location, usually varies seasonally with rainfall and is not always economically exploitable. As a result, while complete well failures are usually avoided, low water yields, limiting extraction to relatively short periods of time, are frequent. Given the higher investment costs and greater risks, rates of return in hardrock areas are likely to be lower than in alluvial areas.

Institutional and Sectoral Factors

A critical feature of growth in groundwater irrigation has been a major shift away from usage of traditional (i.e. human or animal-powered) energy towards electric power and fuel oil. Over this period, electricity has emerged as the dominant source of power for irrigation pumping, accounting for 60% of pumpsets. The Government's rural electrification program has been responsible for an enormous increase in the demand of the agricultural sector for electric power. Electricity consumption for irrigation pumping has grown at an annual rate of 13%, rising from 9% of India's total annual electricity demand in 1970 to nearly 17% in 1980. This growth, along with a number of technical inefficiencies associated with private pumpset operation, has contributed to the rapid increase in power demand over the last two decades and to the existing power shortages. For much of the last decade, despite GOI's policy of allocating power to the agricultural sector on a priority basis, these shortages have limited the reliability, capacity utilization, and output of electric irrigation pumpsets as well as public tubewells in many areas. Rates of return have been further limited by connection delays and material
shortages leading to installed irrigation equipment lying idle over unduly long periods.

Power shortages have been particularly severe in the north-eastern States, such as Bihar, West Bengal, and Orissa. State Electricity Boards in these areas suffer from serious weaknesses in operational and financial management, partly caused by the high costs of rural electrification. Along with material shortages, these weaknesses have contributed to poor implementation of rural electrification schemes. Power shortages and low availability of electricity in rural areas have been among the determinants of the relatively low rates of return and slow development of tubewells in the northeast, compared with states in the north-west. Table 13 shows the impact of progress in village electrification and pumpset connections on tubewell development.

**Table 13: GROUNDWATER DEVELOPMENT AND RURAL ELECTRIFICATION, 1979/80**

<table>
<thead>
<tr>
<th>States</th>
<th>Level of Groundwater Development (% of potential)</th>
<th>Villages Electrified (%)</th>
<th>Pumpset Connections (Thousands of Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-west</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punjab</td>
<td>82</td>
<td>100</td>
<td>262</td>
</tr>
<tr>
<td>Haryana</td>
<td>80</td>
<td>100</td>
<td>203</td>
</tr>
<tr>
<td>North-east</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bihar</td>
<td>35</td>
<td>31</td>
<td>152</td>
</tr>
<tr>
<td>Orissa</td>
<td>19</td>
<td>38</td>
<td>13</td>
</tr>
<tr>
<td>West Bengal</td>
<td></td>
<td>19</td>
<td>36</td>
</tr>
</tbody>
</table>

**Sources:**
2. Rural Electrification Corporation.

High and broad based growth in the pumpset industry have presented farmers with wide choices in the make, size, quality and cost of equipment. In states such as Punjab, Haryana, and Gujarat, where other factors have created a strong impetus for rapid growth in private irrigation, high demand for equipment has itself contributed to the development of the pumpset industry and the wider availability of cheaper pumpsets and drilling services. This has, in turn, reinforced the momentum for high groundwater development in these areas.

Obtaining full benefits from pumpset investment is critically dependent on a choice of well, pump and engine in a combination which can achieve a reasonably high level of technical efficiency. In practice, however, this is rarely achieved, due to lack of adequate technical advice for farmers. Uninformed choices by farmers, together with wide variation in the standards of equipment due to lack of quality control in the small-scale manufacturing sector, create many opportunities, as well as incentives, for mismatching of pumps, motors and other equipment. These
problems tend to be particularly serious in regions such as the north-east where local experience with groundwater development is relatively recent and not widespread. Studies by ARDC 1/ indicate that on an average, less than 50% of theoretically attainable technical efficiency is achieved, and that improper pump settings, excessive friction losses in pipes, and improper maintenance are frequent causes of efficiency losses. Improper maintenance is related to shortages of spare parts and lack of after-sales service in many areas. It is also widely observed that farmers buy engines with greater capacity than is warranted by their individual irrigation needs. This practice helps the private investor cope with the consequences of an unpredictable power supply, notably power surges and restrictive pumping time. However, replication of this practice on a wide scale places an extra burden on an already strained power supply. Some other inherent technical features of private irrigation pumping may have exacerbated these problems. These features include a minimum scale on which equipment can operate if irrigation is to be effective (regardless of farm size), and the generally higher energy consumption linked with small-scale operation. The net result of these various technical inefficiencies is to impose higher energy and maintenance costs on pumpset users, while the economy loses scarce energy and power subsidies.

Technical guidance is an essential input into the formulation of a profitable groundwater investment. Over the last decade the level of technical support for groundwater irrigation has been strengthened. By 1980, 70% of the area coverable by survey had been systematically surveyed by the Central Groundwater Board (CGWB), which drilled nearly 4,000 exploratory wells. At the same time, State Groundwater Organizations (SGO) have been created and strengthened, with responsibility for conducting more field investigations, as well as providing technical advice at the farm level. More recently, ARDC technical staff has expanded significantly and banks participating in minor irrigation credit have begun to acquire technical capability to guide farmers to make more profitable investments.

Despite these achievements, rapid growth has imposed strains on resource availability, manpower levels, and organization, particularly at the field level. Technical staff of ARDC and participating banks are still in short supply. Assistance from SGOs is limited by the fact that CGWB survey results are usually too broad-based to help identify specific investment possibilities at the field level. The result of these factors is that technical appraisal and supervision for individual investors in terms of site selection, well design, and equipment choice needs further strengthening.

Over the past decade institutional credit for minor irrigation (mainly groundwater), has expanded its volume and changed significantly in its structure. The increased concentration of agricultural credit operations refinanced through ARDC, together with the growing involvement of

commercial banks responding to Government directives, were logical and effective responses to the rapid growth in demand for long-term credit, particularly for groundwater irrigation. However, the high level of overdues threatens the viability of participating banks as the main institutional lenders for minor irrigation, and undermines resource availability for future lending, thus limiting the pace of further groundwater development. Moreover, the weakened circulation of credit has adverse equity consequences, excluding many farmers. The Government and ARDC are seriously concerned with this problem and are introducing incentives for improved recovery. These include more rational restrictions on lending eligibility by participating banks and sanctions against undue political interference.

In most areas, where electricity is metered or where diesel is used, incentives for the efficient use of water under private irrigation are generally provided by payment of pumpset operating costs for each unit of water. Under public tubewells, where water charges are only a small proportion of full operating costs, incentives for efficient water use can nevertheless be provided by appropriate rationing procedures, such as rotational water supply. Even with private tubewells, there exists great scope for improvement in water use efficiency. Particularly in areas new to irrigation, farmers need information on how to make the best use of their irrigation with respect to timing, crop varieties, and method of irrigation (border strip or ridge and furrow instead of traditional flooding). Such knowledge can help reduce costs and increase incomes. Land improvements, through levelling, bunding, and the construction and maintenance of water channels, which could reduce seepage losses and wasteful run-off, have been lagging. The sizeable capital costs of land development have probably deterred many farmers, already faced with indebtedness for basic irrigation investment. In public tubewells there may not be sufficient incentives for small farmers for land improvements. Arbitrary control, untimely absences, and malpractices by tubewell operators have frequently caused unreliable delivery of water. This uncertainty has been compounded by failure to organize workable rotations of water supply within groups and by power shortages. Moreover, inter-dependence of small farmers with mutual access to water channels requires cooperative action which usually has been missing.

Policies

Government targets for irrigation development require an acceleration of groundwater development, particularly in areas where the above limiting factors are strongest. Consequently improvements are needed to ease these limiting factors and further raise rates of return to investment in groundwater development. The quickest and most important boost to investment returns could probably be achieved through increased power supply. More rapid rural electrification would accelerate the rate of groundwater development. Reduction of subsidies by raising connection

1/ However, in some states, such as Uttar Pradesh, electricity is a fixed cost, being charged on the basis of engine horsepower. This provides no incentive for efficient use of energy, and hence water.
costs and power tariffs would contribute to this by alleviating the financial problems of State Electricity Boards. However, peak power demand will outstrip supply for the foreseeable future implying the continuation of shortages regardless of priority allocation of power to the agricultural sector.

Short-term improvements in the efficiency of groundwater irrigation equipment are likely to be few. Through its efforts to establish technical guidelines for well and pumpset installation, ARDC is encouraging a better climate for technical efficiency. These efforts are especially important in view of the extra demand for power created by technical inefficiencies. Indeed, as irrigation pumping continues to expand, continuous monitoring and study of the implications for national power demand will be necessary. Nevertheless, progress will be slow for several reasons. Availability of technical staff, essential for flexible interpretation of average guidelines, is weak in many areas. Most important, the mainly private nature of groundwater development and the difficulty of controlling quality in the small-scale manufacturing sector are not conducive to short-term acceptance of technical guidelines. Over time, competition among suppliers and knowledge among farmers should improve the technical efficiency of irrigation equipment.

The requirements for improved technical support vary in different areas. More detailed water table monitoring and further investigation of the potential for optimal conjunctive use of ground and surface water resources in areas of high development, such as Punjab and Haryana, are needed. In hardrock areas, support for individual investors in terms of site selection and well location needs to be strengthened in order to minimize the risks of partial well failure. In both cases technical cadres attached to SCOs, ARDC and participating credit institutions should be strengthened through expanded training and recruitment programs. Improvements in field level technical capability are among the measures which could most effectively raise returns in the next few years. Technical advice to make the best use of available water once the investment has been made can be provided by the improved extension systems being introduced in many states in India.

The strengthening of State, regional and field level credit institutions is also required to resolve weaknesses in the institutional credit system. This includes improved training and recruitment procedures for rural banking staff, broadened use of appropriate loan appraisal techniques, and incorporation of monitoring, evaluation, and reporting procedures into existing banking systems. Most important, improvement of loan recovery will continue to be necessary for the development of a more effective credit system.

Public tubewells offer several potential advantages. First, the capital requirements of private investment are frequently high in relation to the land available to individual farmers. Second, economies of scale

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1/ A National Standing Committee was recently established by Government of India to review quality control in pumpssets.
can be exploited, thereby countering some of the technical inefficiencies inherent in private irrigation. In particular, the higher pumping efficiencies of larger wells in theory can lead to lower energy consumption per unit of water lifted. Indeed, even under the current low rates of capacity utilization, the cost of water lifted from deep tubewells is approximately equal to that of STW water.

However, these potential advantages of public irrigation have rarely been captured in practice. The performance of public tubewells, mainly concentrated in the northern states in good aquifer conditions, generally has been disappointing. Cumbersome management, inefficient and inequitable water distribution policies, and poor design and maintenance, have led to reduced command areas, low capacity utilization, and unreliable water supply. Under private irrigation, individual control enables water to be applied in a timely and flexible manner and incentives to efficient water use are normally automatic. As a result, private wells, which can be more flexibly managed in response to power cuts and supported if necessary by standby diesel engines, are often installed in public tubewell command areas. Field data 1/ indicate that the rates of return to private tubewell irrigation have in the past exceeded public tubewells by a wide margin. Solutions to the low rates of return to private tubewells caused by small farm size have also emerged. Mobile pumpsets operating on low cost tubewells are popular in Bihar and Uttar Pradesh. Water sales by well owners in Uttar Pradesh 2/ are frequent, while farmers in many areas spread the capital cost of engines over multiple uses. Still there remains substantial scope to improve the performance of public tubewells through better design and operation and management procedures. In principle, public tubewells can be designed to provide an efficient and, above all, reliable irrigation service to everyone within the command area. Moreover, progress is now being made. Particularly promising are the technical and design improvements recently introduced in some wells in Uttar Pradesh and the establishment of better rotational water supply systems in some existing public tubewell areas in various States. The whole issue of the relative merits of private and public groundwater development could be studied usefully in light of changing conditions.

Long-Term Development Prospects

On current estimates of groundwater availability, the potential for further rapid growth of private irrigation in Punjab, Haryana, western Uttar Pradesh, Gujarat and Tamil Nadu is limited. While conjunctive use of surface and groundwater can offer further opportunities, the vast bulk of the unexploited potential remains outside these areas. Development of private irrigation in hardrock States such as Madhya Pradesh, Maharashtra,

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2/ It has been found that farmers owning private tubewells sell about 25%-30% of the water they pump.
and Karnataka will require strengthened institutional support—both technical and financial. However, most of the remaining potential for cheap and efficient groundwater exploitation lies in the groundwater-rich alluvial basin in the East, comprising eastern Uttar Pradesh, Bihar, West Bengal, and Orissa. It is in these areas, also, that many of the factors currently limiting returns are most evident. Measures to alleviate power shortages, promote rural electrification, eliminate weaknesses in institutional support, and encourage water use efficiency through land consolidation and development are needed to raise rates of return and increase the pace of growth. In addition, efforts to overcome the problem of small farm size will form an important component in the future development of India's remaining groundwater potential. The scope of this problem and the remaining potential necessitate that solutions be sought wherever possible, both in the private sector through reductions in the capital cost per unit of land irrigated, and through improvements in the efficiency of public tubewells.

F. CONCLUSION

Irrigation accounts for about 8% to 9% of total investment in India and about 11% of total Plan expenditure. The rate of return on this investment in the form of increased agricultural production has an important effect on the growth rate of the economy as a whole. The expansion of area under irrigation is seen as necessary for obtaining the growth in agricultural production required to feed and clothe India's growing population. Most agricultural growth has to come from increased yields, as there is little increase likely in cropped area, and that too mainly a result of newly irrigated lands. Increasing yields is largely dependent on irrigation, which is the key to unlocking the growth in productivity from high yielding varieties of crops, which are quite responsive to good water control and high fertilization. Nevertheless, the question of whether the investment in irrigation has paid an adequate return, given its heavy capital costs, the long gestation period, particularly of surface irrigation, and the low levels of efficiency achieved by some of India's irrigation systems, merits continual review.

One response would be that even if the rates of return as conventionally measured are low, there is no alternative to investing in irrigation, as it is impossible to conceive of a country the size of India importing a large and increasing proportion of the agricultural products needed to sustain the population, which would be the result of shifting funds from irrigation to other investments. Fortunately the evidence does not force such a dreary justification. Although it is difficult to reach either precise or categorical conclusions, the rates of return to investment in irrigation generally exceed conventional criteria of acceptability. Rates of return for groundwater development are quite attractive. The available estimates of rates of return for surface irrigation projects, while generally lower, are above the minimum acceptable. While the calculations of individual projects presented here cannot give a completely reliable indication of the rates of return on the total investment in irrigation in India, all the available evidence supports the view that investing in irrigation is economically appropriate and advantageous.
It is also clear that there is great scope for improvement. In groundwater the main factors limiting returns are those that support the farmer in installing and using his own tubewell. Greater reliability of electric supply to currently developed areas to allow higher utilization of pumps already installed and the extension of rural electrification to underdeveloped areas would allow farmers to capture the benefits of electric power. These benefits would not disappear if the subsidy to rural electric supply were reduced by increasing tariffs. For farmers throughout India, but particularly those in hardrock areas, where returns to investment are lower and risks greater, there is a need for more and better technical support, as well as more detailed hydrogeological information. A strengthening of the rural credit system is required to provide the organized financing for the farmer's investment. This will require better credit supervision and increased loan repayment. The overdues problem has grown to major proportions and requires vigorous steps to solve.

Easing the problem of small and dispersed fields could make an important contribution to raising rates of return to groundwater development. There are several possible approaches. One is consolidation of land parcels. This is an ongoing program in many States and should be pressed ahead. But the pace of land consolidation is inevitably slow and even after consolidation much land remains in parcels below the optimum size for power tubewells. Some further reductions in the technically efficient size of pumping equipment are possible but unlikely to make a significant difference in the near future. Public tubewells hold the potential for overcoming these problems as well as for capturing some inherent benefits of large scale operation, including more economical energy consumption. However, they have generally failed as yet to fulfill this potential for lack of adequate design and management. There are quite promising recent developments in some public tubewells projects that deserve support and encouragement such as piped delivery and better management. Another emerging solution is water-selling among farmers, which is becoming quite common in areas of greatest land fragmentation.

Many of the factors which limit the rates of return to groundwater development are most severe in eastern India—eastern Uttar Pradesh, Bihar, West Bengal, Assam and Orissa. As it is this same region that has the bulk of the unexploited groundwater potential and has the greatest scope for adopting improved agricultural technologies, the pace of groundwater development in India will be determined to a great extent by the progress made in easing these constraints in this region.

The main factors limiting rates of return to investment in surface irrigation are the planning, design and management of the systems. The proliferation of projects spreads the available funds too thinly resulting in the prolongation of project construction and wasteful delays of benefits. The Government of India has been pressing States to concentrate funds on projects nearing completion. This pressure has resulted in some improvement since the mid-1970s, but more is needed. The basic conceptual design of projects needs to be improved to provide for reliable, efficient and equitable water supply while laying the groundwork for much more flexible, demand-based systems which will be needed in the future.
Estimates of Productivity Differentials on Irrigated and Rainfed Land

1. As noted on page 13 of the text, there are serious methodological problems in estimating the benefits arising from irrigation. With these difficulties in mind equations were estimated to measure the effects which differences in the amount of irrigated area and rainfed area had on the net value added from agriculture in the various States of India. Ordinary least squares regressions were run using cross-sectional State level data for 19 States. Appendix Table 1 presents the data set. Separate equations were estimated for a number of years, but since the results were strikingly similar for each year, only the equations estimated for 1977/78, the most recent year for which State level agricultural net value added data are available, are presented here. Cross-sectional data were used instead of time series to avoid attributing to irrigation all the other changes which have occurred in technology in complementary input use etc. and which, like irrigation are highly correlated with time. Net value added was selected as a dependent variable, because its comprehensive character includes variations in both levels of output and shifts to a higher value cropping pattern. It also nets out the costs of seeds, fertilizers and other farm operating expenses.

2. The equations were of a simple linear form:

\[ Y = a + b_1 (IA) + b_2 (RA) + b_3 (R) \]

where \( Y \) is agricultural net value added in rupees, IA and RA are, respectively irrigated and rainfed area in hectares, and R is the rainfall level in millimeters. The difference between the estimated coefficients \( b_1 \) and \( b_2 \) can be broadly interpreted as the difference in net value added in rupees between production on irrigated land and production in rainfed land and this difference gives an indication of the incremental value added to be obtained from irrigating a formerly rainfed hectare of land. The following table summarizes the results of estimating these equations using two different concepts, gross and net, to measure area. The estimated equations are statistically robust, with high t statistics and correlation coefficients, indicating that the equations explain over 90% of the variations in agricultural net value added among the States.
ESTIMATED PRODUCTIVITY DIFFERENCES ON RAINFED AND IRRIGATED LAND

(in 1977/78 - Rs/ha)

<table>
<thead>
<tr>
<th>Land Concept</th>
<th>Gross</th>
<th>Net</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3,544</td>
<td>4,796</td>
</tr>
<tr>
<td></td>
<td>(7.54)</td>
<td>(8.37)</td>
</tr>
<tr>
<td></td>
<td>978</td>
<td>895</td>
</tr>
<tr>
<td></td>
<td>(5.73)</td>
<td>(4.59)</td>
</tr>
<tr>
<td></td>
<td>2,566</td>
<td>3,901</td>
</tr>
<tr>
<td></td>
<td>.91</td>
<td>.90</td>
</tr>
</tbody>
</table>

Note: Figures in parentheses are t statistics. The estimated coefficients are statistically significant at the 99% level.

The much greater difference between irrigated and rainfed land productivity which appears in the equation which uses net area arises from the greater cropping intensity associated with irrigated land. The use of net area captures this important aspect of irrigation and thus this estimate is more effective in capturing the wide range of benefits mentioned on page 13 of the text as arising from irrigation. A separate indication of the importance of irrigation in increasing cropping intensity is given by the equation:

\[
CI = 86.6 + .70 \text{(PNSAI)} + .014(R); \quad R^2 = .99
\]

where CI is cropping intensity (i.e., gross area divided by net area), PNSAI is percent of net sown area irrigated and R is rainfall. The equation was estimated using 1978 cross sectional State-level data, weighted by total net sown area, using generalized least squares estimation techniques.

3. To convert the estimated productivity differentials to 1979/80 (Plan base year) prices the percentage increase in the GDP deflator for agriculture between 1977/78 and 1979/80 (14.8%) was applied to the productivity differentials presented in the above table to yield Rs 2,946 and Rs 4,478 per gross and net hectare respectively.

4. The limitations of these estimates, discussed on page 14 of the text should be kept in mind in interpreting them.
### Appendix Table I

**AGRICULTURAL VALUE ADDED AND IRRIGATION DATA BY STATE, 1977/78**

<table>
<thead>
<tr>
<th>STATE DOMESTIC PRODUCT IN AGRICULTURE (Rs millions)</th>
<th>NET IRRIGATED AREA</th>
<th>NET RAINFOED AREA</th>
<th>GROSS IRRIGATED AREA</th>
<th>GROSS RAINFOED AREA</th>
<th>RAINFALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>23780</td>
<td>3359</td>
<td>7547</td>
<td>4380</td>
<td>8160</td>
</tr>
<tr>
<td>Assam</td>
<td>8240</td>
<td>572</td>
<td>2101</td>
<td>580</td>
<td>2730</td>
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<tr>
<td>Bihar</td>
<td>22070</td>
<td>2913</td>
<td>5655</td>
<td>3780</td>
<td>7790</td>
</tr>
<tr>
<td>Gujarat</td>
<td>15090</td>
<td>1617</td>
<td>7895</td>
<td>1810</td>
<td>8540</td>
</tr>
<tr>
<td>Haryana</td>
<td>10280</td>
<td>1874</td>
<td>1772</td>
<td>2780</td>
<td>2660</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>1920</td>
<td>90</td>
<td>469</td>
<td>160</td>
<td>780</td>
</tr>
<tr>
<td>Jammu &amp; Kashmir</td>
<td>2510</td>
<td>305</td>
<td>409</td>
<td>400</td>
<td>570</td>
</tr>
<tr>
<td>Karnataka</td>
<td>18350</td>
<td>1388</td>
<td>8818</td>
<td>1700</td>
<td>9340</td>
</tr>
<tr>
<td>Kerala</td>
<td>9690</td>
<td>228</td>
<td>1964</td>
<td>350</td>
<td>2570</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>23400</td>
<td>2153</td>
<td>16569</td>
<td>2240</td>
<td>19270</td>
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<td>Maharashtra</td>
<td>27490</td>
<td>1896</td>
<td>16335</td>
<td>2310</td>
<td>17550</td>
</tr>
<tr>
<td>Manipur</td>
<td>590</td>
<td>65</td>
<td>75</td>
<td>80</td>
<td>130</td>
</tr>
<tr>
<td>Orissa</td>
<td>12480</td>
<td>1071</td>
<td>4912</td>
<td>1450</td>
<td>6480</td>
</tr>
<tr>
<td>Punjab</td>
<td>16690</td>
<td>3286</td>
<td>884</td>
<td>5200</td>
<td>1190</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>15830</td>
<td>2765</td>
<td>12427</td>
<td>3170</td>
<td>13750</td>
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<tr>
<td>Tamil Nadu</td>
<td>13970</td>
<td>2836</td>
<td>3452</td>
<td>3720</td>
<td>4050</td>
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<tr>
<td>Tripura</td>
<td>1000</td>
<td>29</td>
<td>217</td>
<td>30</td>
<td>360</td>
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<tr>
<td>Uttar Pradesh</td>
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<td>843</td>
<td>8911</td>
<td>10010</td>
<td>13340</td>
</tr>
<tr>
<td>West Bengal</td>
<td>25060</td>
<td>1489</td>
<td>4689</td>
<td>1540</td>
<td>6340</td>
</tr>
</tbody>
</table>

Sources:  
Area and rainfall data: Directorate of Economics & Statistics, Ministry of Agriculture, Government of India.
Adoption of Agricultural Innovations in Developing Countries: A Survey
Gershon Feder, Richard Just, and David Silberman
Reviews various studies that have provided a description of and possible explanations for farmers' responses to the adoption of technological improvements in the agricultural sector in developing countries and finds that uniform acceptance of technological change is rare and that responses differ across socioeconomic groups and over time. Explores new directions for research in this area.

World Bank Staff Working Paper No. 444. February 1981. 67 pages
Stock No. WP-0444. $3.00.

The Agricultural Economy of Northeast Brazil
Gary P. Kutch and Pasquale L. Scandizzo
This study, based on an agricultural survey of 8,000 farms, assesses the extent and root causes of pervasive rural poverty in northeast Brazil. The authors review a number of policy and project options; they conclude that courageous land reform is the only effective means of dealing with the problem.
LC 81-47615. ISBN 0-8018-2581-4, $25.00 ($17.50) hardcover.

Agricultural Price Policies and the Developing Countries
George Tolley, Vinod Thomas, and Chung Ming Wong
This book first considers price policies in Korea, Bangladesh, Thailand, and Venezuela, bringing out the consequences for government cost and revenue, farm income, and producer and consumer welfare. Other effects, including those on agricultural diversification, inflation, economic growth, and the balance of payments are also discussed. The second part of the book provides a methodology for estimating these effects in any country. Operational tools for measuring the effects on producers, consumers, and government are developed and applied.
LC 81-15585. ISBN 0-8018-2704-3, $25.00 (£17.50) hardcover.

Agricultural Research
(See Publications of Particular Interest, page 1.)

Agroindustrial Project Analysis
James E. Austin
Provides and illustrates a framework for analyzing and designing agroindustrial projects.


The Book of CHAC: Programming Studies for Mexican Agricultural Policy
Edited by Roger D. Norton and Leopoldo Solis M.
The principal tool of analysis is the sector model CHAC, named after the Mayan rain god. This model can be used throughout the sector to cover short-cycle crops, their inputs, and their markets. It can also be broken down into submodels for particular localities if more detailed analysis is required. The model helps planners weigh the costs among policy goals, which can vary from region to region. This volume reports the experience of using the CHAC model and also presents purely methodological material.

Cooperatives and the Poor: A Comparative Perspective
Uma Lele

Land Tenure Systems and Social Implications of Forestry Development Programs
Michael M. Cernea
Discusses some social correlates of the design and the implementation of forestry projects. Analyzes the Hill Farming Technical Development Project, undertaken in 1978 in Pakistan with assistance from the World Bank, with respect to the role of land tenure systems and their sociological implications. Suggests alternative development strategies with particular sociological consideration of the potential roles of farmers' self-help strategies, institutional issues, and forestry cooperatives.
Stock No. WP-0452. $5.00.

Nutritional Consequences of Agricultural Projects: Conceptual Relationships and Assessment Approaches
Per Pinstrup-Andersen
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Stock No. WP-0456. $5.00.

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Malcolm D. Bale and Ernst Lutz

Sociocultural Aspects of Developing Small-Scale Fisheries: Delivering Services to the Poor
Richard B. Pollinac
Pre/SENTS A framework for assessing the sociocultural feasibility of small-scale fisheries projects.
Stock No. WP-0490. $5.00.

Agrarian Reform as Unfinished Business—The Selected Papers of Wolf Ladejinsky
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Agricultural Reforms in Developing Rural Economies Characterized by Interlinked Credit and Tenancy Markets
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Agricultural Extension: The Training and Visit System
Daniel Benor and James Q. Harrison
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Examines the role of scientific research and technological change in increasing agricultural productivity.
LC 74-15210. ISBN 0-300-01815-0. $15.00 hardcover; ISBN 0-300-01877-0, $3.95 paperback.

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Lucio G. Reca
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Hans P. Binswanger

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Uma Lele

Analyzes new ways of designing rural development projects to reach large numbers of low-income subsistence populations. The paperback reprinting in 1979 contains a new chapter by the author updating her findings.

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Spatial mathematical programming is used to develop comprehensive and quantitative methods to suggest development strategies in Portugal’s agriculture sector.
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Paul S. Zuckerman


An Econometric Application of the Theory of the Farm Household
Howard M. Barnum and Lyn Squire


Economic Analysis of Agricultural Projects
J. Price Gittinger

A practical method for comparing alternative investment projects in agriculture in relation to each other and to investments in other parts of the economy to ensure the most economical and efficient use of scarce resources.

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