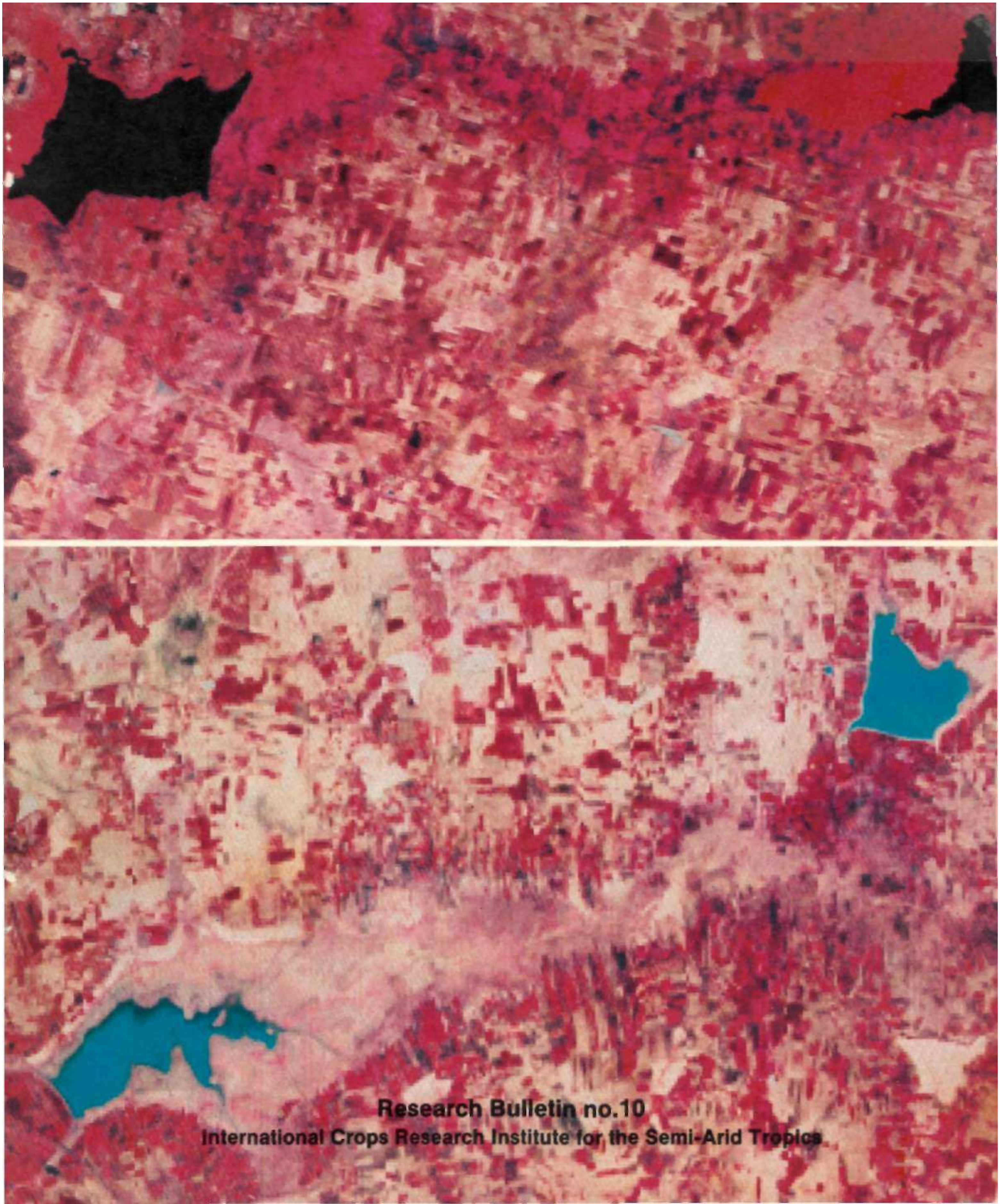
Tank Irrigation in Semi-Arid Tropical India

Economic Evaluation and Alternatives for Improvement



Abstract

von Oppen, M., and Subba Rao, K.V. 1987. Tank Irrigation in Semi-Arid Tropical India: Economic Evaluation and Alternatives for Improvement. Research Bulletin no. 10. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid tropics.

A survey of 32 tanks and farm data from Andhra Pradesh and Maharashtra states was used to assess the economic performance of irrigation tanks in SAT India. District data on climatic and Institutional variables were used to analyze the factors affecting tank-irrigation density.

Results indicate that the spatial distribution of irrigation tanks is determined primarily by physical factors—hard rock substratum, postmonsoon rains, low moisture-holding capacity of soils—and by population density.

Tank irrigation, formerly a source of relative stability, has become a source of instability for agricultural production in many parts of India. Important factors for the decline in tank irrigtion are: environmental degradation such as deforestation, soil erosion, siltation, tankbed cultivation, and lack of administrative setup to provide timely repair and maintenance of tanks, and to ensure proper water control and tank management.

Simulation results show that with improved water control and by keeping sluices closed on rainy days, a 20% larger command area can be irrigated. A Tank Irrigation Authority is proposed for better water control and management. Another concept proposed is Composite Watershed Management on Alfisols involving a system of runoff- and erosion-controlling land management for enhanced groundwater recharge and sustained well irrigation. This concept, analyzed at ICRISAT Center in a modeling exercise, has considerable economic potential.

Resume

von Oppen, M. et Subba Rao, K.V. 1987. (Reseaux d'irrigation a petits reservoirs dans les zones tropicales semi-arides de l'Inde. Evaluation economique et possibilites d'amelioration). Tank Irrigation in Semi-Arid Tropical India: Economic Evaluation and Alternatives for Improvement. Research Bulletin no. 10, Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

L'etude de 32 reservoirs se trouvant dans les Stats d'Andhra Pradesh et de Maharashtra ainsi que l'analyse des donn6es agricoles provenant de ces regions ont permis d'evaluer la performance economique de petits reservoirs d'irrigation dans les zones tropicales semi-arides de l'Inde. La repartition regionale de ces reseaux d'irrigation dans ces zones a ete expliquee a l'aide de donnees sur les variances g6ographiques, climatiques et institutionnelles obtenues au niveau des districts.

Les resultats montrent que l'existence des reservoirs d'irrigation est determinee essentiellement par des facteurs physiques (substrats en roche dure, les pluies apres la saison pluviale, une capacite maximum pour l'eau peu elevee) et par la densite demographique.

Le systeme d'irrigation avec petits reservoirs, source de stabilite relative dans le temps, est devenu maintenant une source d'instabilite" notable pour la production agricole dans plusieurs parties de ITnde. Les facteurs importants qui influencent le declin de ce systeme sont : la degradation de l'environnement telle que la deforestation, l'erosion des sols, l'envasement, ['exploitation au fond des reservoirs et enfin, le manque d'une infrastructure administrative susceptible de garantir l'entretien et la reparation des reservoirs en temps utile et d'assurer l'exploitation efficace des reservoirs visant a la bonne conduite des eaux.

Les resultats de la simulation montrent que la conduite amelioree des eaux et la fermeture des vannes les jours de pluies permettent d'augmenter de 20% la superficie asservie. On pourrait envisager la creation d'un Service d'irrigation a petits reservoirs dans le but d'assurer une rneilleure conduite des eaux et une meilleure exploitation des reservoirs actuels. Cependant, il est peu certain que ce Service d'irrigation soil a meme de retourner la tendance des reservoirs qui cedent a la pression demographique sur la terre. Un autre concept est egalement propose : amenagement des bassins versants composites sur les Alfisols. Ils'agit d'un systeme d'amenagement des terres comprenant le controle du ruissellement et de l'erosion permettant ainsi l'alimentation arnelioree de la nappe d'eau et l'irrigation par puits continue. Analyse au Centre ICRISAT dans un essai de moderation, ce concept s'avere tres prometteur sur le plan economique.

Cover: Satellite views of tank-irrigated areas in southern India. Shallow, sedimented tanks arc shown in blue, and deep, clear-water tanks are black. Cropland appears in dark and light red. (Courtesy of the National Remote Sensing Agency, Hyderabad, India.)

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Contents

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This research bulletin summarizes the results of eight years' research on different aspects of tank irrigation in the Indian Semi-Arid Tropics (SAT). Most of the material presented here is taken from our earlier reports listed below:

- von Oppen, M., and Binswanger, H.P. 1977. Institutional and physical factors affecting tank irrigation density in India. Presented at the 17th Annual Conference of the Indian Econometric Society, 19 -21 Dec 1977, Trivandrum, Kerala, India.
- von Oppen, M. 1978, Instability of area and production under tank irrigation in selected districts of Andhra Pradesh and Tamil Nadu. Economics Program Discussion Paper no. 9. Patancheru, A.P. 502 324, India; International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)
- von Oppen, M., and Subba Rao, K.V. 1980. Tank irrigation in semi-arid tropical India. Part I. Historical development and spatial distribution. Economics Program Progress Report no.5. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)
- von Oppen, M., and Subba Rao, K.V. 1980. Tank irrigation in semi-arid tropical India. Part II. Technical features and economic performance. Economics Program Progress Report no. 8. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)
- von Oppen, M., and Subba Rao, K.V. 1982. History and economics of tank irrigation in semi-arid tropical India. Pages 54-75 *in* Proceedings of the Symposium on Rain Water and Dryland Agriculture, 3 Oct 1980, New Delhi, India. New Delhi, India: Indian National Science Academy.
- Venkatram, B.R. 1985. Administrative feasibility of a Tank Irrigation Authority. Economics Program Consultant's Report. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)
- von Oppen, M., Subba Rao, K.V., and Engelhardt, T. 1983. Alternatives for improving small scale irrigation systems in Alfisols watersheds in India - a position paper. Presented at the University of Minnesota/Colorado University/ USAID Workshop on Water Management and Policy, 13-15 Sep 1983, Khon Kaen, Thailand. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)

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M. von Oppen
K.V. Subba Rao

1. Introduction

Irrigation in India

Irrigation is vital to the Indian economy as it helps to relieve agriculture from its dependence on the monsoon rains. Farmers with access to irrigation can stabilize and increase farm production; risks of crop failure can be reduced and opportunities increased for making full use of improved seed and fertilizer. At present about 28% of India's cultivated land is under irrigation.

Irrigation systems in India are categorized for administrative purposes into major, medium, and minor irrigation works. Major irrigation works are generally built on perennial rivers, and constitute large dams and canals that irrigate areas of many thousand hectares. Medium irrigation works constitute reservoirs of run-off water, or the so called "large" tanks. Minor irrigation works include all surface and groundwater sources which cost below Rs 2.5 million per project. Table 1 presents the area in India irrigated by major and medium irrigation sources in comparison to minor irrigation from surface and groundwater sources.

Each of these three types of irrigation sources evolved at different times in history to meet man's changing requirements for irrigated land and as technologies developed for storing, transporting, and lifting water. While irrigation from tanks and dug wells is a comparatively old technology, canal and borewell irrigation with electric- or diesel-powered pumps are relatively recent innovations. Figure 1 shows the area irrigated by different sources in India. These irrigation sources vary in importance in different regions, depending upon factors such as topography, technology, local administration, and altitude.

Decline of Tank Irrigation

Small water reservoirs behind earthen dams are called tanks in India (Sharma 1981). Tanks supply many, villages with drinking water, but their primary purpose is irrigation. Tank irrigation is an established practice in most of the semi-arid tropics (SAT) of India and of some other countries. In India, the monsoon rains fall erratically during a few months of the year, and irrigation tanks serve to store and regulate waterflow for agricultural use. In southern India tanks are used primarily for rice cultivation. Thus tank irrigation is a water- management technology that is ideally suited to the SAT, where provision of a continuous flow of water with low mineral content permits uninterrupted rice cultivation year after year, without ever exhausting or salinifying the soil.

However, despite these advantages the tank-irrigated area in India over the past two decades has tended to stagnate and fall. From a source of relative stability, tank irrigation has become more and more unreliable; in many areas tank irrigation now is a source of increasing instability in agricultural production.

Objectives of this Report

These observations prompted us to study the factors contributing to this development and to draw inferences that would point to future action. The study is based on a survey of 32 surface irrigation tanks spread across the states of Andhra Pradesh and Maharashtra (Appendix 1).

Table 1. Gross area irrigated by major and medium and minor irrigation sources in India, 1950-51 to 1977-78.

	Gross area irrigated ('000000 ha)				
Source	1950-51	1960-61	1968-69	1973-74	1977-78
Major and medium irrigation	9.7	14.3	18.1	20.7	25.0
	(42.9)[1]	(49.3)	(48.1)	(45.8)	(46.5)
Minor irrigation					
Surface	6.4	6.4	6.5	7.0	7.8
	(28.3)	(22.1)	(17.3)	(15.5)	(14.5)
Groundwater	6.5	8.3	13.0	17.5	21.0
	(28.8)	(28.6)	(34.6)	(38.7)	(39.0)
Total	22.6	29.0	37.6	45.2	53.8
	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)

1. Figures in parentheses indicate percentage area irrigated by different sources.
Source: 37th All India Agricultural Economics Conference—Presidential Address by M.S. Swaminathan, 1977.

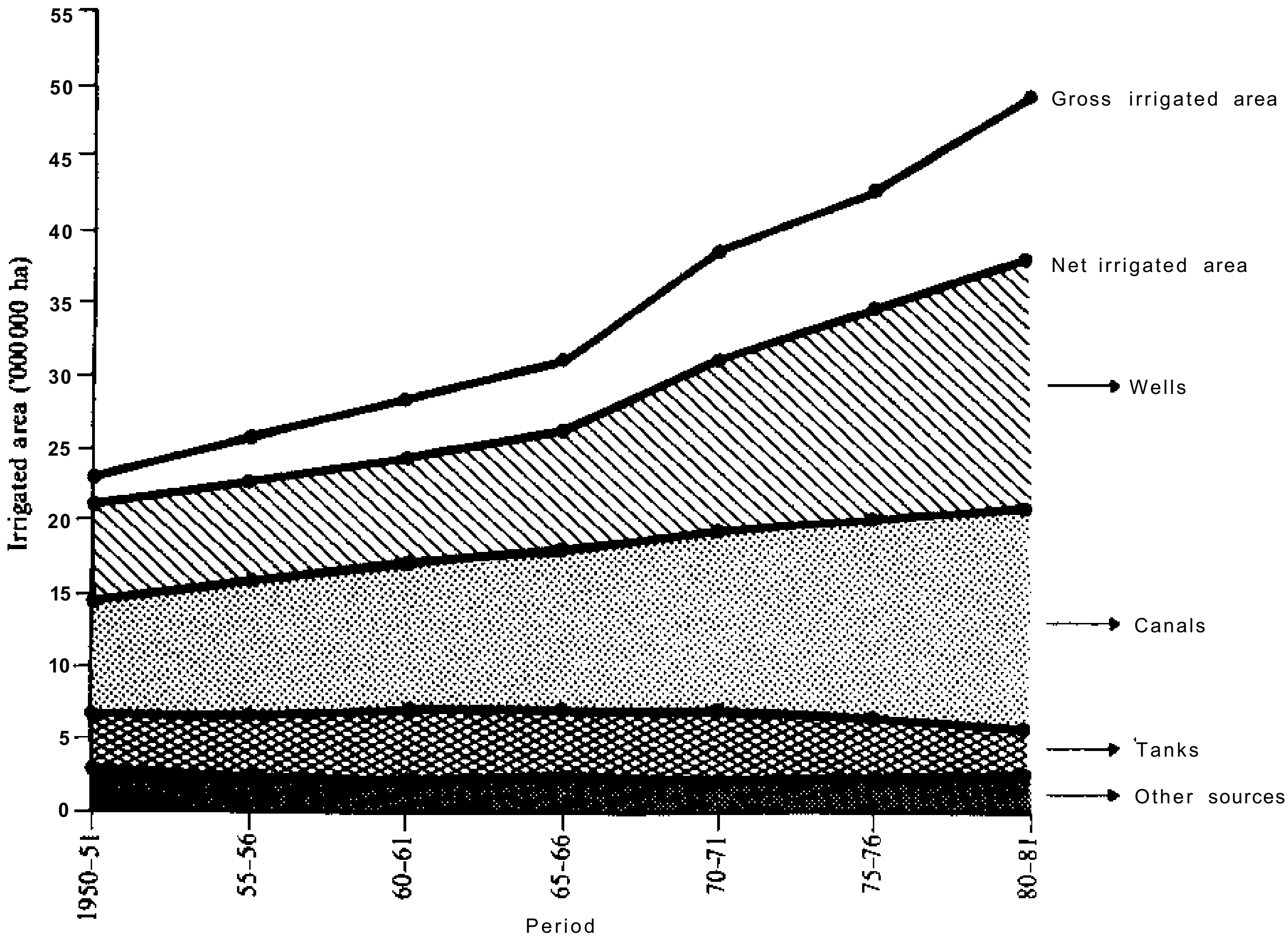

Figure 1. Area irrigated by different sources in India.

The report has four objectives.

1. To explain the geographical distribution of tank irrigation in India.
2. To measure the economics of tank irrigation.
3. To explore the physical and administrative factors affecting the performance of irrigation tanks.
4. To propose ways to improve tank irrigation or alternative watershed-management systems in India.

The second chapter presents a brief account of the historical development of tank irrigation and summarizes the factors which determine the regional distribution of irrigation tanks in India. In the third chapter the economics of tank irrigation is analyzed. The fourth chapter shows how at the all India level, tank irrigation expanded until the early 1960s, subsequently became stagnant, and presently declined at a rapid rate. The reasons for this decline are examined. We present in the fifth chapter two viable concepts for improving tank-water management on Alfisols. The final chapter summarizes the findings and conclusions emerging from the previous chapters.

2. History and Development of Tank Irrigation

Historical Records on Tank Irrigation

In the southern states of SAT India, tank irrigation systems have existed since Vedic times. Two tanks are mentioned in the Ramayana: the Lake of Five Nymphs (Panchapsarotataka), associated with Mandkarni or Satkarni; and the Pampasaras, which is apparently the same as Pampasagar, a tank in Huvimothadagalli taluk, Bellary district, on the Tungabhadra river (Yazdani 1960). There are references to tank-irrigation practices in early Indian records dating back to many centuries before the Christian Era. Many of the tanks found in southern India have been in existence for several generations — two in Chingleput District are referred to in inscriptions of the 8th and 9th centuries (Harris 1923).

In the Telengana region of Andhra Pradesh, known for rice cultivation, tank irrigation developed extensively since ancient times. The districts of Warangal and Karimnagar have several old irrigation tanks; the lakes of Pakhal, Ramappa, Laknavaram, and Sanigaram were constructed in the 12th and 13th centuries by kings of the period (All India Economic Conference 1937). There is a system of tanks at Kattagiri referred to in inscriptions dated 1096 AD. These accounts describe the practice of constructing tanks in a series at different levels of a watershed. In 1188 AD, a merchant named Dasi-Setti renovated and increased the size of a tank at Banavur. In 1201/02 AD, after a famine in Tiruvannamalai village, two persons built a tank in memory of their mother (Appadorai 1936). A Somavaram inscription dated 1213 AD states that one Racherla Beti Reddi constructed two tanks. A number of inscriptions dated around the 11th and 12th centuries describe tank-construction activities *in* Warangal (Gopal Reddy 1973).

Several southern rulers took an interest in tank construction. The Kesari-Tatakam Tank was built by Prola I of the Kakatiyas. Beta II constructed two tanks, Setti-Kere and Kesari-Samundra. Another Kakatiya ruler, Prola II, built two tanks. The Pratapa-Charitra states that the ruler Ganapatideva built tanks at Nellore, Gangapuram, Ellore, Ganapapuram, and Ekasilanagaram (Yazdani 1960).

A rock inscription dated 1030 AD praises the local ruler Kota Gonka for the many tanks built by him (Vaidehi Krishnamurty 1970). An inscription from the Sorali taluk in Shimoga district, dated 1071 AD mentions that fresh land was brought under cultivation by the construction of a new tank called Setti-kere (Department of Information and Public Relations, Hyderabad, 1953). Often tanks were donated to temples, and tank income was used for temple maintenance.

While studying the cultural economy of irrigation in southern Tamil Nadu, Ludden (1978) observed that tank construction in the past played a key role in the ritual-based system of entitlement to control land resources. Through the construction of a tank the local chief generated resources for donations to temples, which in turn brought him the support of the Brahmins. "The irrigation system as a whole grew in a cellular segmented manner: similar, allied but staunchly independent units were merely added on as population and irrigated area increased. It was this system—within which irrigation facilities were constructed, maintained, and regulated by the same organizational units that controlled cultivation processes as a whole—that confronted British administrators in the nineteenth century" (Ludden 1978).

The British were highly impressed by the extent of tank irrigation in the country. In 1853, R. Baird Smith observed that "The extent to which tank irrigation has been carried throughout all the irrigated region of the Madras Presidency is truly extraordinary. An imperfect record of the number of tanks in the 14 districts shows them to amount to not less than 43,000 in repair and 10,000 out of repair or 53,000 in all" (Smith 1856).

Some 30 years later, tank-irrigation statistics were assembled, and a list of tank-irrigated areas (Manual of Administration of the Madras Presidency, 1885) in the districts of the Madras Presidency from 1882 to 1883 gave a figure of 32000 non-private tanks. When comparing the net areas irrigated by these tanks in 1882-83 with areas irrigated by all tanks (i.e., including the formerly private tanks) in 1969-72 (Table 2) we find that in the entire area for which this information is available, the extent of tank irrigation today is about the same as it was a century ago. Tank-irrigated area has decreased in two regions including the districts of (1) Anantapur, Kurnool, Cuddapah, and Bellary, and (2) Salem, Coimbatore, and Madurai. On the other hand, tank irrigation has increased in two other regions, i.e., (1) Vizag, Krishna, and Nellore, and (2) Chingleput, North Arcot, South Arcot, Thanjavur, Tirunelveli, and Tiruchirapalli.

The overall area under non-private tanks was reported to be 785 000 ha in 1882-83, while the area irrigated from all tanks in 1969-72 was 930 000 ha. This difference is not very large and if the private tanks, excluded from the earlier figures, could be accounted for (the present figures include all tanks), it can be concluded that in the former Madras Presidency there has hardly been any change in the overall extent of tank irrigation during the last 100 years.

In contrast to the marginal change in tank-irrigated area in the former Madras Presidency, the total cropped

District	1882-83 Total cropped area ('000 ha) (1)	1882-83 Net area irrigated by tanks ('000 ha) (2)	Average for 1969-72 Total cropped area ('000 ha) (3)	Average for 1969-72 Net area irrigated by tanks ('000 ha) (4)	(3)/(1) (5)	(4)/(2) (6)
Anantapur	46	36	910	32	19.8	0.9
Cuddapah	97	76	462	17	4.7	0.2
Kurnool	29	16	1303	13	44.5	0.8
Bellary	29	21	610	8	21.0	0.4
Krishna	116	16	672	36	5.8	2.3
Nellore	91	61	666	92	7.3	1.5
Vishakapatnarn	19	12	529	89	27.4	7.3
Salem	75	39	924	32	12.3	0.8
Coimbatore	57	18	837	5	14.6	0.3
Madurai	94	64	648	53	6.9	0.8
Chingleput	174	127	433	164	2.5	1.3
North Arcot	137	81	643	105	4.7	1.3
South Arcot	161	86	723	108	4.5	1.3
Thanjavur	42	18	875	30	20.8	1.6
Tirunelveli	152	59	557	76	3.6	1.3
Tiruchirapalli	100	53	822	79	8.2	1.5
Total	1421	785	11614	939	8.2	1.2

Table 2. Area irrigated by tanks, and total cropped area in the region of the old Madras Presidency, 1882-83 and 1969-72.

Source: Tamil Nadu Season and Crop Reports, 1969-72.

area in the region increased about eight times during the last century. Thus, while tank irrigation was available for over 50% of the total cropped area in the past, it is available now to less than 10% of the total cropped area. Even though other sources of irrigation have become available- now canals and wells, for instance, irrigate approximately another 10% each in this area—the overall cropped area under irrigation has fallen from 50% to about 30%.

In contrast to the situation in the old Madras Presidency, there is evidence that tank irrigation in the old Hyderabad State is of more recent origin. The area irrigated from tanks increased considerably only during the latter part of the 19th century, under the Nizams of Hyderabad. From 4000 ha in 1895-96, records of the Public Works Department (PWD) of the Hyderabad State show around 40000 ha of tank-irrigated area around the turn of the century, and around 350000 ha some 40 years later. No estimate is made in the sources of these statistics about the number of private tanks that must have existed. The fact that the PWD of Hyderabad State expanded the tank-irrigated area during the turn of the century, while the British Government in the Madras Presidency did not do so, indicates that tank-irrigation intensity in different areas was to some extent influenced by the governments in those areas and their emphasis on certain types of capital-development programs. However, as is shown below, in the long run it is not only institutional factors but also population-density factors that influence tank development. Differences in development of tank irrigation over time can be largely explained by these variables.

Development of Tank Irrigation over Time

There is evidence that this method of utilizing runoff water is deeply rooted in Indian culture and some tanks have inscriptions dating back a millenium or more. Historians and anthropologists have pointed out that there is a dialectic relationship between population and tank irrigation, one reinforcing the other (Ludden 1978).

However, the relationship between population density and the intensity of tank irrigation is not necessarily linear, i.e., at different levels of population density the growth of tank-irrigated area may vary. Initially, where physically feasible and economically attractive, tank irrigation systems are expanded till the population density crosses a threshold level. Beyond this level further population pressure may tend to adversely affect the existing tank-irrigation systems and special measures may be required to preserve the capital invested in irrigation tanks.

The historical data on tank development in different states over the years indicate that the threshold density to begin intensive tank construction lies between 50 and 60 persons km^{-2}. The upper limit is not clearly discernible -- it seems to vary from one region to another — but there is clearly a decline in tank irrigation at very high levels of population density. For instance, in India as a whole, the absolute area irrigated by tanks increased from about 3.5 million ha in 1945-50 to over 4.5 million ha in 1960-70; it fell to less than 4 million ha from 1973 onwards (Table 3), when the rural population density in India increased to more than 135 persons km^{-2} from 100 persons km^{-2} in 1960. The three southern states of Andhra Pradesh, Tamil Nadu, and Karnataka contribute more than 60% of the tank-irrigated area in SAT India. The tank-irrigated area forms around 30% of the net irrigated area. The proportion of tank-irrigated area as a percentage of net irrigated area in India declined from 17% in 1950-51 to 10% in 1978-79, whereas the well-irrigated area increased from 28% to 43% of net irrigated area during the same period. Tank irrigation decreases with an increase in population; at the same time canal and well irrigation expand rapidly.

The development of tank irrigation in India after independence was also influenced by other factors that are related, though perhaps not directly attributable to, population density. Abolition of ownership rights for private tanks stopped private investment in tank irrigation soon after independence. This also decreased the efficiency of water control and tank management. On the other hand, public campaigns were launched to increase food production; and tank building was one of the activities vigor-

Table 3. Growth of tank irrigation in India.

Year	Total cropped area	Net irrigated area	Well-irrigated area	Tank-irrigated area	Tank-irrigated area to total cropped area (%)	Tank-irrigated area to net irrigated area (%)	Well-irrigated area to net irrigated area (%)
	............('000 000 ha).............						
1950-51	131.9	20.9	5.9	3.6	2.7	17.2	28.2
1951-52	133.4	21.0	6.5	3.4	2.5	16.2	30.9
1952-53	137.5	21.2	6.6	3.2	2.3	15.1	31.1
1953-54	142.3	21.7	6.7	4.1	2.9	18.9	30.9
1954-55	144.0	21.9	6.7	4.0	2.8	18.3	30.6
1955-56	146.7	22.8	6.7	4.4	3.0	19.3	29.4
1956-57	149.1	22.5	6.2	4.5	3.0	20.0	27.6
1957-58	145.4	23.2	6.8	4.5	3.1	19.4	29.3
1958-59	150.8	23.4	6.7	4.8	3.2	20.5	28.6
1959-60	152.1	23.8	6.9	4.7	3.1	19.7	29.0
1960-61	152.3	24.6	7.3	4.6	3.0	18.7	29.7
1961-62	156.2	24.9	7.3	4.6	2.9	18.5	29.3
1962-63	156.8	25.7	7.6	4.8	3.1	18.7	29.6
1963-64	157.0	25.9	7.8	4.6	2.9	17.8	30.1
1964-65	159.3	26.6	8.1	4.8	3.0	18.0	30.4
1965-66	155.3	26.7	8.7	4.4	2.8	16.5	32.6
1966-67	156.8	27.1	9.2	4.6	2.9	17.0	33.9
1967-68	163.0	27.5	9.3	4.6	2.8	16.7	33.8
1968-69	159.7	29.0	10.8	4.0	2.5	13.8	37.2
1969-70	163.9	30.3	11.1	4.4	2.7	14.5	36.6
1970-71	167.4	31.4	11.9	4.5	2.7	14.3	37.9
1971-72	164.2	31.9	12.2	4.1	2.5	12.3	38.2
1972-73	161.5	32.0	13.0	3.6	2.2	11.2	40.6
1973-74	169.5	32.5	13.2	3.9	2.3	12.0	40.8
1974-75	163.9	33.7	14.2	3.5	2.2	10.5	42.1
1975-76	171.0	34.5	14.3	4.0	2.3	11.6	41.5
1976-77	167.1	34.8	14.8	3.9	2.3	11.2	42.5
1977-78	172.3	36.7	15.7	3.9	2.3	10.6	42.8
1978-79	175.2	38.0	16.4	3.9	2.2	10.3	43.2

Source: Indian Agriculture in Brief, Government of India, Ministry of Agriculture.

ously pursued in such campaigns until the late 1950s. Subsequently, the availability of diesel- and electric-powered pumps made well water more attractive as an alternative, privately controlled source for irrigation. Resources were shifted from the development of tanks towards wells, leading to a massive expansion of well irrigation. Further, reluctance of the policy makers to raise the water rates made it more and more difficult for the PWD to acquire funds to cover the increasing costs of maintenance and repair. Tank irrigation, formerly considered an economically productive and profitable undertaking, began to be neglected and was only half-heartedly supported by policy makers and planners. The resulting decrease in efficiency and reliability of the performance of irrigation tanks tended to create the impression that tank irrigation was inferior to other types of irrigation.

Factors Affecting Regional Distribution of Irrigation Tanks

Although runoff-collection tanks exist in nearly every Indian district, tank-irrigation density varies considerably from district to district. Presently, in the Indian SAT (Figure 2), tanks are concentrated in the southern and central regions, i.e., in the coastal districts of Tamil Nadu, in Telengana, the coastal districts of Andhra Pradesh, in south-central Karnataka, and in eastern Vidarbha. In northern India, there are two pockets that show a high density of tank irrigation: northeastern Uttar Pradesh, in the area of the former kingdom of Oudh, and Rajasthan, east of the Aravalli mountain range. Apart from physical factors and population density, it appears that institutional factors have also played a role in determining tank distribution. A map showing the territory under British and princely rule in 1890 indicates that tank irrigation was promoted more under princely rule than under British rule (Figure 3).

We evaluated the factors affecting regional distribution of irrigation tanks using data from 165 districts in SAT India in a regression analysis (von Oppen and Subba Rao 1980).

This analysis showed that both in the former princely and British areas, physical factors such as hard rock substratum, annual average humidity, postmonsoon rainfall, total rainfall, and low soil moisture-holding capacity encouraged tank irrigation. Such factors explain about 50% of the variation in tank-irrigated area. Furthermore, the study showed that in the former princely areas (but not in the former British areas) the influence of population on tank irrigation was measurable, explaining another 20% of the variation in tank density. Keeping all other variables constant, the follow-

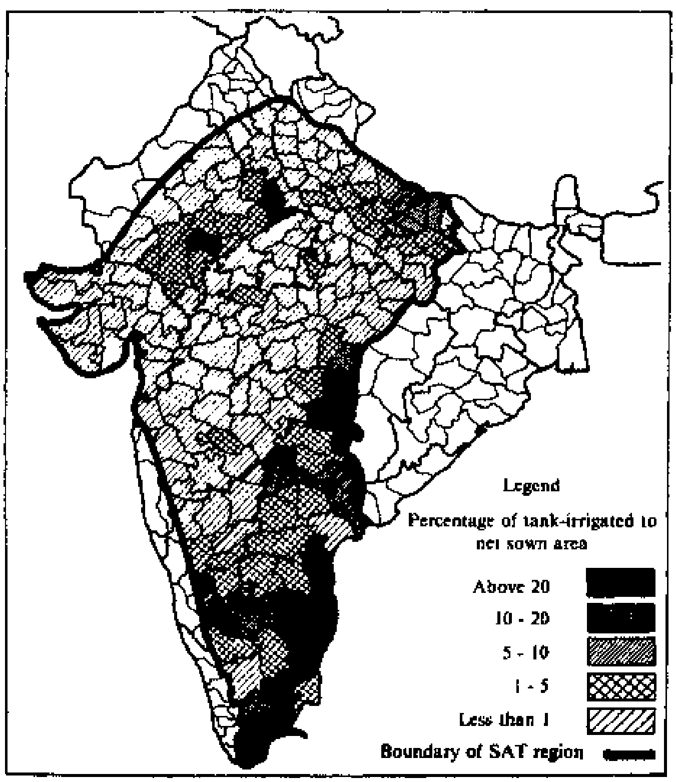

Figure 2. Tank-irrigation density in SAT India.

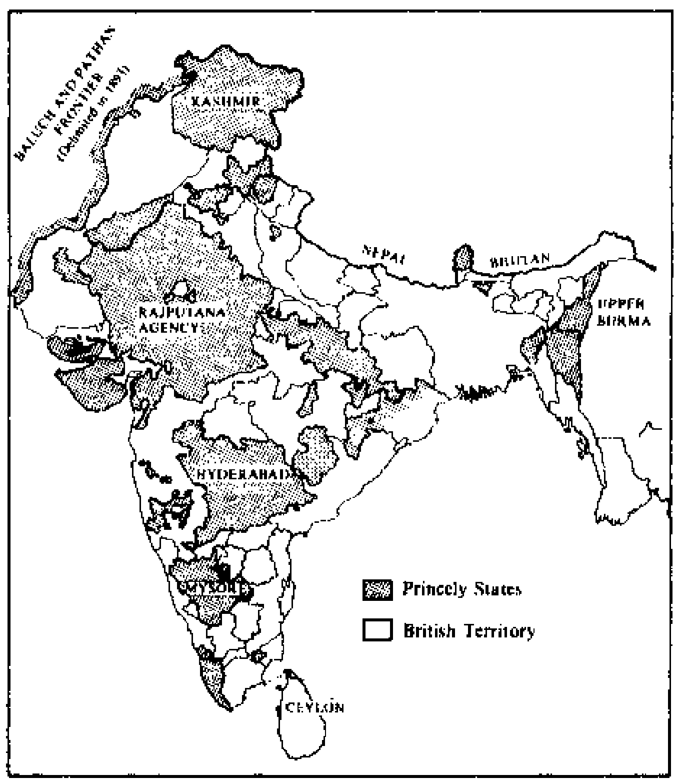

Figure 3. British and princely territories in 1890.

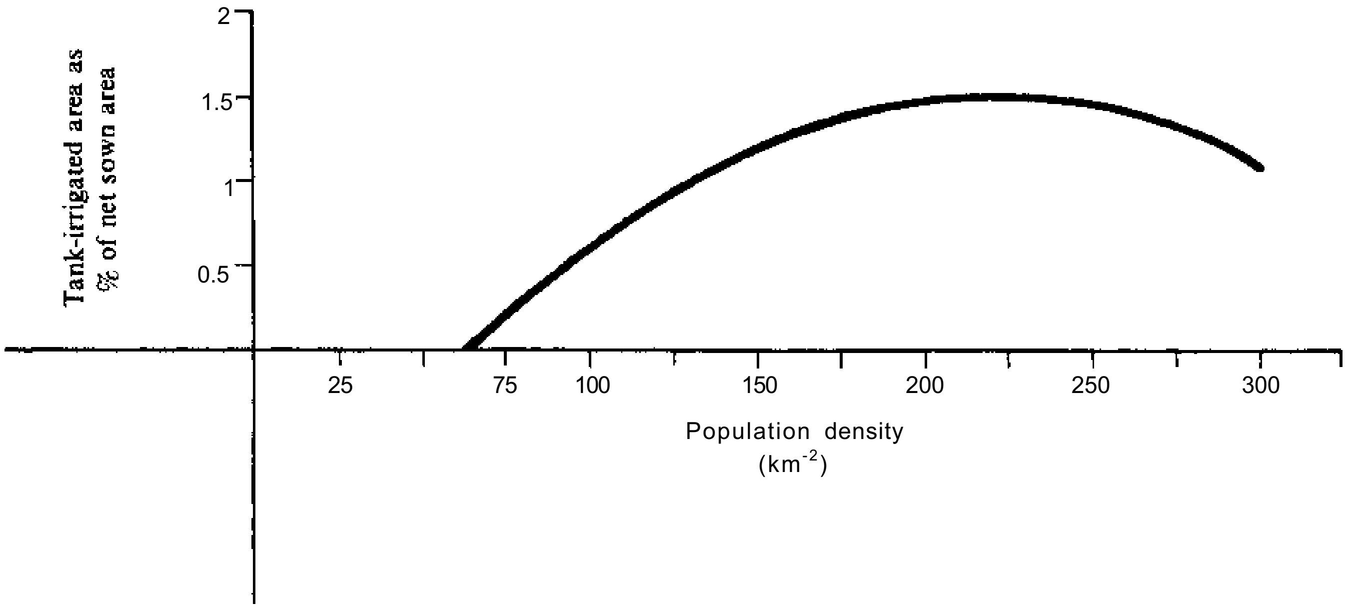

Figure 4. Tank irrigation as a function of population density in districts formerly under princely rule (physical factors remaining constant).

ing observations were made: as population density in the former princely states crossed the level of about 60 persons km^{-2}, density of tank-irrigated areas began to increase, reaching a maximum at population density of around 220 persons $krrr^2$ (Figure 4), and dropping with further increase in population density. For the former British districts, there was no statistically significant relationship between population and tank density. These results imply that the institutional environment, to the extent that it differed between British and princely rule, had an influence on construction and maintenance of irrigation tanks. In fact, this influence may still continue in the prevailing local customs of water control, tank management, and maintenance.

Summary

- Historical records give ample evidence of tank irrigation having been practiced for centuries in many parts of India.
- About 60% of the area irrigated by tanks is concentrated in Tamil Nadu, Andhra Pradesh, and Karnataka.
- Statistical analysis of district data shows that spatial distribution of tank irrigation is determined primarily by physical conditions such as hard rock substratum, average humidity, postmonsoon rainfall, total rainfall, and low soil moisture-holding capacity. However, further study shows that in the former princely areas the influence of population density on tank irrigation is measurable, explaining another 20% of the variation in tank density. It reveals that tank density increases when the population density crosses 60 persons km^{-2} and reaches the maximum with a population density of around 220 persons km^{-2} in princely districts. Since administration, organization, legal conditions, and land tenure differed between British and princely rule, tank irrigation as a manifestation of the economic interests of both public authority and private farmers was certainly affected and may still continue to be so. Generally, with the abolition of fuedal land-tenure systems the small irrigation tanks became common property and suffered the typical fate of inefficient management.
- The percentage of tank-irrigated area to net irrigated area in India fell from 17% in 1950-51 to 10% in 1978-79. Some of the reasons are: abolition of ownership rights on private tanks after independence, poor tank-water management, and the increased convenience of well irrigation with the availability of electric- and diesel-powered pumps.

3. Economics of Existing Tank Irrigation

To assess the economics of tank irrigation we require information on benefits from tank irrigation and on costs of construction and operation of irrigation tanks. In this chapter we describe the technical features determining the economic performance of irrigation tanks and provide estimates of benefits, costs, and benefit-cost comparisons. Quantitative estimates are derived from the analysis of data collected in special surveys or from secondary sources.

Tanks Selected for Farm Surveys

A total of 32 tanks were surveyed. These were selected from the states of Andhra Pradesh, an area with high tank density, and Maharashtra, an area with low tank density. In Andhra Pradesh the following districts were chosen: Medak and Mahbubnagar representing the Telengana area which had been under princely rule (Nizams of Hyderabad) and was characterized by medium rainfall, red soils, and high tank density; and Anantapur and Kurnool representing the Rayalaseema area with low rainfall, red soils, and relatively low tank density. This area formerly belonged to the Vijayanagara Kingdom, and later to the Nizams, but was ceded to become part of the British-ruled Madras Presidency. In Maharashtra state the districts of Akola and Sholapur were chosen, both with low tank-irrigation intensity, with medium and low rainfall, and deep and medium-deep black soils. Akola belonged to Berar, a British territory after 1853, while Sholapur became a British collectorate in 1838. The selection of villages within the districts was purposive; two tanks per taluk were selected on the basis of availability of data from irrigation and revenue departments at the taluk headquarter; tanks supplied water for at least one season in the year under study. Appendix I gives the list of villages in which tanks were selected. In each tank area eight farmers were surveyed.

Farmer Selection

A list of beneficiaries (with their respective holdings) under the command area of the selected tank was obtained from the patwari (village record keeper). In some cases where the command area had not been regularly cultivated, a list of cultivators who got water during 1975-76 was prepared. Our study aimed at comparing the returns from irrigated versus nonirrigated land cultivated by the same farmer, so that the sample was drawn from farmers with irrigated areas above 0.5 ha. Those farmers who owned less than 0.5 ha were not included.

Eight farmers were selected at random from the remaining list for detailed investigation. If a farmer was not available, the next farmer on the list was selected. Benefits of tank irrigation were calculated on the basis of returns from tank-irrigated crops compared with returns from crops without irrigation (rainfed crops).

Data Collection

Primary data on cropping activities, land utilization, input-output, etc., were collected on a recall basis through personal interviews using a pretested structured schedule.

The data obtained from secondary sources (irrigation and revenue departments) included *10* years' daily rainfall for the selected taluks, water levels and actual area irrigated from tanks, cropping patterns in the village, land revenue rates and irrigation charges collected, and details of the water-distribution system. These data together with farmer benefits were used in calculating benefits of tank irrigation. For the Akola tanks we could not get all the data required, since neither the patwari nor the officials at the district PWD had kept the necessary records. Therefore, the Akola data were analyzed and interpreted separately. All the tanks selected in this region are PWD surface-storage tanks of above 40 ha command area under gravity-flow irrigation.

Technical Features Determining Costs and Performance of Irrigation Tanks

The analysis presented in the previous chapter on the regional distribution of tank density in India documents the importance of environmental characteristics and population density in determining tank-irrigation intensity in different regions overtime. Consequently, individual irrigation tanks also differ in their economic performance because local environmental conditions favor one site over another. These factors influence the technical design of an irrigation tank.

An understanding of some of the technical aspects of tank construction is required to appreciate the approach we have taken in the economic analysis; gaps in the data base on some aspects made it necessary to approximate some of the required information. Table 4 gives a summary of various data sets available on individual tanks

Table 4. Information available from selected data sets on irrigation tanks.

Information	Data sets 1	2	3	4
Number of tanks	45	28	4	16
Location (District, State)	Anantapur, AP	Medak, AP Mahbubnagar, AP Anantapur, AP Kurnool, AP Sholapur, Maharashtra	Akola, Maharashtra	Cuddapah, AP Anantapur, AP Kurnool, AP Medak, AP Mahbubnagar, AP
Variables				
Submerged area	*[1]	_[2]	-	-
Storage capacity	*	-	-	-
Bund length	*	*	*	*
Settled command area	*	*	*	*
Rainfall and command-area utilization	-	*	-	-
Costs	-	-	-	*
Benefits	-	*	*	-
Size distribution	-	*	*	-
Cropping patterns	-	*	*	-
Data source	PWD3,IDC4	ICR1SAT survey	ICRISAT survey	PWD

1. * indicates information available.
2. - indicates information not available.
3. Public Works Department.
4. Irrigation Development Corporation.

and the type of analysis for which they were used. Since information on the costs of tank construction together with information on bund length and settled command area was available only for 16 tanks (column 4), we used this information to estimate the costs for the other tanks for which only bund length and settled command area were known.

Bund Length

The bund of a tank varies in size and shape according to topography, and constitutes a major component of the costs of an irrigation tank. Therefore bunds have been designed for particular locations so as to optimize water-storage capacity and minimize the earthwork requirement. Bunds found in undulating terrain—between two hills, for instance—are generally much higher and less wide than those found in fairly flat areas.

Tank Size

The amount of water stored and the inflow during the rainy season are the major determinants of the area that a tank can irrigate. The size of a tank is generally expressed by its irrigated area, the so-called "settled command area". During construction, engineers determine the command area on the basis of expected runoff from the catchment area and storage capacity of the tank. This settled command area is generally recorded in official statistics to classify tanks according to size.

Submerged Area

Another economically important measure related to tank size is the submerged area, that is the area covered with water when the tank is full. The submerged land is a determining factor in the costs of tank construction.

Technical Relationships

Table 5 presents information on technical relationships of 45 tanks from Anantapur district as averages for different size groups. It shows that the ratio of settled command area per unit of submerged area increases with increase in tank size. This means that larger tanks with taller bunds generally store more water per unit of submerged area. For small tanks (below 40 ha settled command area) this ratio is 0.9, while for large tanks (above 400 ha command area) it is 1.5. The average ratio of

Table 5. Technical relationships for 45 tanks of different sizes in Anantapur district.

Tank size (ha)	No. of tanks	Settled command area (SCA, ha)	Submerged area (SMA, ha)	Storage capacity (STC, million m^3)	Length of bund (LB, m)	SCA/ SMA	LB/ SCA	STC/ SCA
Above 400	9	795	625	11.70	3453	1.46	5.1	0.014
Between 200-400	8	287	318	4.08	2883	1.29	6.9	0.014
Between 80-200	13	129	128	1.57	1190	1.29	9.6	0.013
Between 40-80	9	61	80	0.92	790	0.95	13.3	0.015
Below 40	6	29	34	0.35	582	0.90	21.9	0.012
All tanks	45	263	239	3.75	1605	1.20	10.6	0.014

settled command area to submerged area for all tanks studied is 1.2. The bund length per hectare of settled command area is 5.1 m in large tanks and increases to 21.9 m in small tanks with an average of 10.6 m for all tanks observed. The average storage capacity of a tank per unit of command area, which is more or less constant across averages of different sizes, amounts to 1.4 m of water.

Command-Area Utilization

The settled command area, conceived as the optimum area a particular tank would irrigate, is almost always underutilized. The area actually irrigated by a tank depends on the water availability at different periods of time. The factors affecting command-area utilization are rainfall, local conditions, and tank-specific information. This relationship was established using 10 years' data on rainfall and tank-irrigated area for the 28 surveyed tanks. The utilization ratio of area actually irrigated over settled command area was expressed as a function of annual rainfall, rainfall squared, and tank dummies to reflect local conditions (von Oppen and Subba Rao 1980, Part II). The results show that in Medak, Mahbubnagar, as well as in Sholapur districts rainfall significantly determines command-area utilization (Figure 5). The higher the rainfall, the higher is the utilization of the command area actually irrigated. However, command-area utilization increases with increasing rainfall at a decreasing rate.

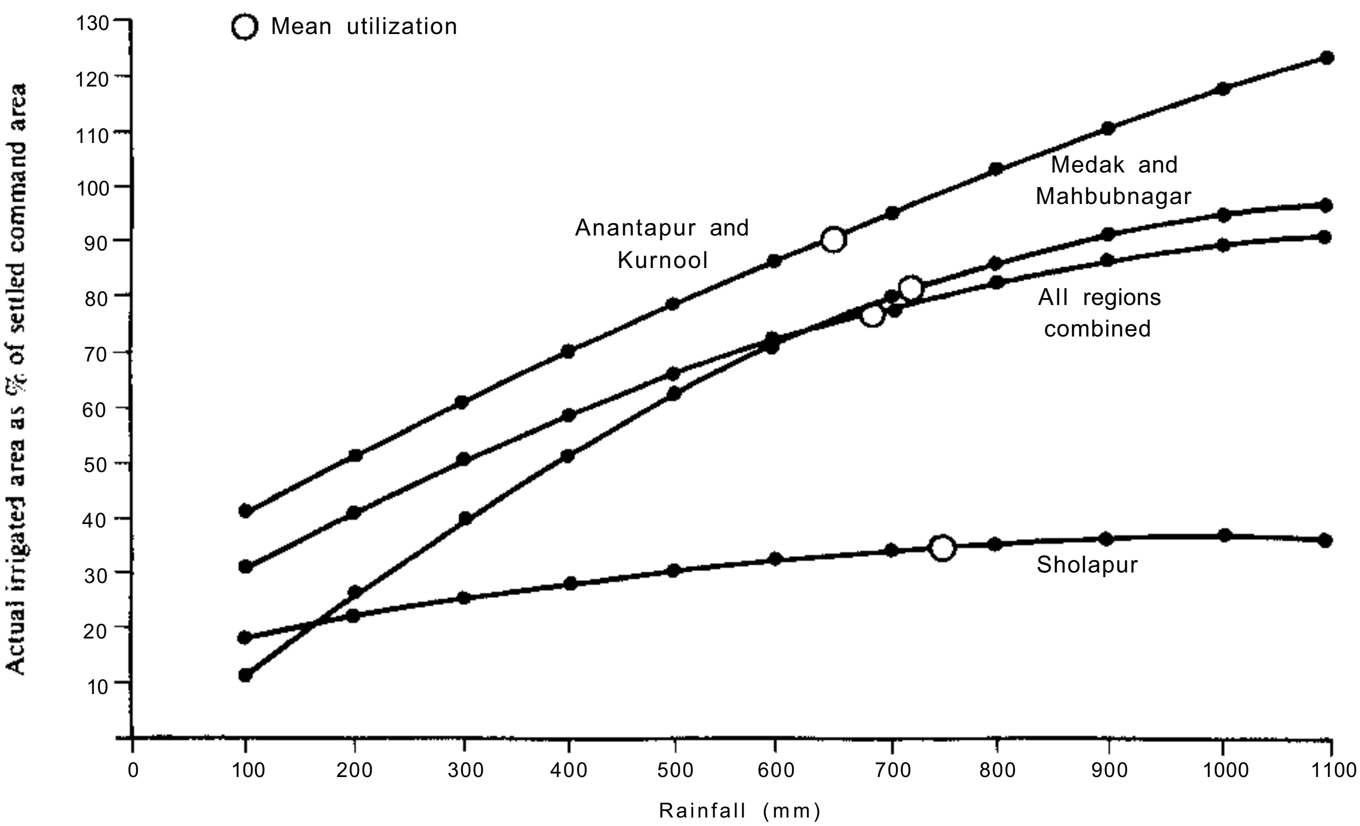

Figure 5. Utilization of settled command area and annual rainfall for selected districts.

Benefits, Costs, and Benefit-Cost Comparisons of Existing Tank Irrigation

The benefits and costs of tank irrigation can be measured at three levels: (1) at the farmer's level, (2) at the level of the "Project Authority" responsible for tank construction and operation, and (3) at the state and national levels.

Table 6 indicates the factors constituting the costs and benefits at each of these levels and the source of this data.

Benefits of Tank Irrigation

Benefits to Farmers

Financial benefits. In computing the financial benefits to farmers, the net benefits owing to irrigation were derived by computing differences between net returns from tank-irrigated crops and weighted average net returns from all rainfed crops. This method minimizes the "differences-in-farmer" effect, as the same farmers provided data on irrigated as well as rainfed land.

The procedure involves the following steps:

- Collect input-output data on all tank-irrigated and rainfed crops.
- Compute gross returns from all tank-irrigated plots by adding main product value plus by-product value at village prices.
- Compute variable costs of cultivation per plot including costs of human and bullock labor, seed, chemical fertilizers and farmyard manure, insecticides and pesticides, contract charges, and irrigation fees.
- Compute net returns for plots by subtracting total variable costs from gross returns for all plots.
- The sum of all returns on all irrigated plots, divided by the sum of all irrigated plot sizes, gives the weighted average net returns from tank irrigation per tank per ha.
- Following the same steps for all rainfed plots, the weighted average net returns from nonirrigated land are computed.
- Farmers' net benefits due to tank irrigation are calculated as the difference between weighted net returns from tank-irrigated crops and weighted net returns from nonirrigated crops.
- The same procedure can be repeated for a comparison of the economics of tanks across regions within a country, but average prices and costs should be used instead of village prices and costs.

The results of these calculations are presented in Table 7, columns 12 and 13. It is seen that at village prices, tank irrigation produced average net benefits of Rs 818 ha^{-1} for 10 tanks studied in Medak district, Rs 946 ha^{-1} for 10 tanks studied in Mahbubnagar district, and Rs 650 ha^{-1}

Table 6. Comparisons **of** costs **and benefits** of **irrigation tanks accruing to different participants.**

Participants	Benefits	Costs	Comparison criteria
Farmer	Private net returns at village prices due to irrigation[1] Increase in land value[1] Reduction in risk[2]	Irrigation charges[1] Obligation to contribute labor[3] Uncertainty of water availability[2]	Financial cost-benefit ratio
Project authority	Irrigation fees[1] Income from fisheries, brick making[3]	Land acquisition[1] Construction[1] Maintenance[1] Water fee collection[3]	Financial cost-benefit ratio
Nation	Additional production at average prices[1] Additional employment[1] Safety in food production[2] Increased groundwater[3] Less soil erosion[3]	Opportunity cost of capital invested (Interest)[2] Submerged land[2] Higher water table (Increased salinity)[3]	Economic internal rate of return

1. Indicates survey data available.
2. Indicates information from other sources available.
3. Indicates data or information not available.

Table 7. Farmers' benefits, costs, and benefit-cost ratios for tanks in selected Indian districts, Andhra Pradesh and Maharashtra states.

Tank code and district[1]	Settled command area (ha)	Net returns (Rs ha⁻¹) At village prices Tank irrig.	Rain-fed	(3)/(4)	At average prices Tank irrig.	Rain-fed	(6)/(7)	Increase in land value (Rs ha⁻¹) Tank irrig.	Rain-fed	Ratio (9)/(10)	Benefits: Net benefit due to tank irrig. at vill. prices (Rs)	Net benefit due to tank irrig. at av. prices (Rs)	Costs: One season irrig. fee ha⁻¹ excl.dry assessment	Benefit-Cost Ratio At village prices	At average prices
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Medak															
AA	147	596	-47	-	1011	-104	-	13344	2936	4.55	642	1114	40.8	15.8	27.3
AB	291	509	460	1.11	974	460	2.12	15259	4967	3.07	49	514	30.9	1.6	16.6
BA	188	764	556	1.37	1381	652	2.12	13195	3707	3.56	208	729	35.8	5.8	20.3
BB	65	1349	151	8.95	1962	279	7.03	14134	4127	3.43	1198	1683	34.8	34.4	48.3
CA	202	810	153	5.29	1302	148	8.78	10378	3262	3.20	657	1154	39.5	16.6	29.2
CB	104	1606	2	6.50	2036	22	91.5	21251	4324	4.90	1604	2016	34.6	46.3	58.3
DA	124	1226	467	2.62	1458	524	2.78	11737	3459	3.40	759	934	32.9	23.1	28.4
DB	98	2076	511	4.06	2278	563	4.04	10811	3336	3.20	1564	1715	39.0	40.1	43.9
EA	90	813	803	1.01	1018	820	1.24	12355	5041	2.45	10	198	35.6	0.3	5.6
EB	66	1913	420	4.55	2056	395	5.20	12973	5066	2.56	1493	1661	32.1	46.5	51.7
Average	138	1166	348	3.35	1547	376	4.11	13544	4023	3.37	818	1171	35.6	23.0	32.0
Mahbubnagar															
FA	41	1782	675	2.64	1821	554	3.29	10915	4119	2.65	1107	1268	36.8	30.1	34.4
GA	117	2372	813	2.92	2355	682	3.45	12887	5251	2.45	1559	1673	36.3	42.9	46.0
GB	161	162	331	4.90	1478	272	5.44	13591	5066	2.68	1292	1203	40.3	32.1	29.9
HA	298	1312	346	3.79	1505	136	11.70	10700	4497	2.38	966	1369	30.1	32.0	45.4
HB	43	1359	255	5.34	1401	195	7.18	9472	4235	2.24	1105	1206	32.1	34.4	37.5
JA	42	1742	128	13.60	2184	141	15.50	12664	5004	2.53	1614	2041	34.3	47.0	63.5
KA	57	514	348	1.48	704	408	1.73	10292	4127	2.49	166	294	28.4	5.8	10.3
KB	65	939	252	3.73	1250	255	4.91	10922	4621	2.36	687	996	35.8	19.2	27.8
LA	57	801	198	4.05	1122	245	4.59	9884	4633	2.13	603	877	29.2	20.7	30.1
LB	59	803	430	1.87	1532	452	3.39	10032	4250	2.36	373	1080	26.9	14.8	40.1
Average	94	1324	378	3.50	1535	334	4.60	11134	4581	2.43	946	1201	33.1	28.6	36.3
Anantapur															
MA	450	1450	759	1.91	1707	830	2.06	23475	4942	4.75	692	877	41.5	16.7	21.1
NA	375	1011	403	2.51	1537	477	3.22	12355	3707	3.33	603	1058	39.5	15.3	26.8
NB	179	993	499	1.99	1653	472	3.50	13591	3978	3.42	494	1184	40.8	12.1	29.0
Average	355	1151	554	2.08	1633	593	2.75	16474	4208	3.91	596	1040	40.5	14.7	25.6
Kurnool															
PA	129	1085	348	3.11	1606	361	4.45	12355	3583	3.45	736	1245	33.4	22.1	37.3
QA	432	1643	961	1.71	2006	1075	1.87	16309	5189	3.14	682	932	33.4	20.4	27.9
Average	280	1364	655	2.08	1806	719	2.52	14332	4386	3.27	709	1090	33.4	21.2	32.6
Akola															
RA	405	255	217	1.17	331	230	1.44	2471	2471	1.00	37	101	52.6	0.7	19.2
RB	445	217	368	0.59	188	287	0.66	2627	na	na	-151	-99	62.3	0	0
SA	307	818	1050	0.78	875	892	0.98	6178	6178	1.00	-232	-17	60.5	0	0
TA	172	860	860	1.00	872	860	1.01	12355	na	na	0	12	52.6	0	0.2
Average	332	536	625	0.86	566	568	1.00	5906	4324	1.37	-86	0	57.1	0	0
Sholapur															
UA	240	1102	235	4.69	835	195	4.29	na[2]	na	na	867	642	84.3	10.3	7.6
VA	196	131	-282	-	20	-282	-	na	na	na	131	20	33.4	3.9	0.6
VB	720	1278	146	8.80	1312	114	11.50	na	na	na	1132	1198	46.5	24.4	25.8
Average	385	838	35	24	724	10	72	na	na	na	710	620	54.6	14.7	11.4

1. Villages AA to QA belong to Andhra Pradesh state, and RA to VB belong to Maharashtra state. 2. na = data not available.

for 5 tanks studied in Anantapur and Kurnool districts. For 3 out of 4 tanks in Akola district, there were no benefits due to tank irrigation, while in Sholapur district the 3 tanks studied averaged a benefit of Rs 710 ha^{-1}. Thus at village prices, tanks in Telengana are highly beneficial to farmers, more so than in Anantapur and Kurnool.

The Sholapur tanks too produced higher benefits at village prices than did the Anantapur/Kurnool tanks. The picture changes somewhat if average prices instead of village prices are used to compute farmers' benefits. In that case the average tanks in Telengana and Rayalaseema produce benefits of approximately Rs 1100 ha^{1}, in Sholapur only Rs 625 ha ', and negligible in Akola.

Increase in land value. The increase in land value due to irrigation was measured by averaging the reported values for irrigated and nonirrigated land. Such data could be collected only in Medak, Mahbubnagar, and Anantapur districts. These figures are also presented in Table 7. They show that on an average, irrigated land is valued 2.5 times (in Mahbubnagar) to 3.4 times (in Medak district) over dryland. In 3 tanks, 2 in Medak district and I in Anantapur, the value of irrigated land was reported to be more than 4 times that of nonirrigated land. The lowest ratio of irrigated land value over nonirrigated was 2.1, reported for one Mahbubnagar tank.

We tried to compare the ratios of irrigated over nonirrigated land value with net benefits. A correlation analysis did not show any relationship, possibly because benefits measured by us reflect only one year's observations while land values take into account the long-term productivity and yield risks of the land.

Reduction *in yield* risk. Tank irrigation generally reduces yield risk in comparison to rainfed cropping, but often brings with it an uncertainty about the area irrigated. The irrigated area is adjusted to the water available, and thus the advantage of yield stability is achieved at the disadvantage of area instability. The farmers benefit from a lower variability of yields in tank-irrigated paddy since their inputs are more likely to return a profit. This is why tank-irrigated paddy receives higher inputs than rainfed crops.

Table 8 shows the average levels of area, production, and yields and their variability for two rainfed crops sorghum and pigeonpea - and the major tank-irrigated crop, paddy, in three districts where tanks are the major source of irrigation. It is seen that the coefficient of yield variations for rainfed sorghum, and especially for pigeonpea, are far higher than for paddy. For variability of area the opposite is true, i.e., rainfed areas are more stable than tank-irrigated areas. An exception is the case of paddy yields in Medak district, which show an unusually high coefficient of variation. While seeking to explain this phenomenon it was found that in 1972-73 very low paddy yields (about 300 kg ha^{-1}) were reported for this district while in all other districts the yield did not deviate much in any year from an average of about 1000 kg ha^{-1}.

Jn this particular year, the low yields must have been caused by unusually low rainfall. The tanks were filled and planting was done at the beginning of the season over areas that later could not be irrigated when the tanks, lacking replenishment from rains, ran dry.As a result most of the paddy crop was damaged. In this particular year in Medak district, the uncertainty of rainfall had not

Table 8. Variability in area, production, and yields in selected districts of Andhra Pradesh.

		Area ('000 ha)		Production ('000 000 kg)		Yiield (kg ha-')	
District	Crop	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
Medak	Sorghum	152.3	15.4	79.6	19.9	532	22.0
	Pigeonpea	9.0	19.3	2.7	26.4	309	34.1
	Paddy	88.1	24.9	111.4	45.7	1195	31.7
Mahbubnagar	Sorghum	333.5	10.1	134.9	25.2	407	26.4
	Pigeonpea	21.9	17.2	6.0	37.1	296	52.5
	Paddy	102.4	17.6	121.7	24.2	1183	13.2
Warangal	Sorghum	186.4	6.9	95.6	23.3	514	23.6
	Pigeonpea	8.9	15.9	2.9	29.1	331	25.5
	Paddy	114.0	27.9	147.3	33.4	1286	13.6
Combined	Sorghum	672.2	8.2	310.0	17.9	462	17.8
	Pigeonpea	39.8	13.6	11.6	29.9	309	38.4
	Paddy	304.6	22.2	380.4	30.8	1223	14.5

Source: Estimates of area and production of]principal crops in India, 1965-66 to 1974-75.

Table 9. Costs and benefits of tank irrigation to the project authority.

Tank code[1] and district	Settled Command Area (SCA, ha)	Cost: Total cost of bund ('000 Rs)	Cost: All other costs ('000 Rs)	Cost: Total cost of project ('000 Rs)	Cost: Cost ha^{-1} of SCA (Rs)	Cost: Present value ha^{-1} assuming 22-year life period at 10% interest	Cost: Total cost ha^{-1} including Rs 25 ha^{-1} for maintenance and repairs	Benefit: Revenue collected (Rs ha^{-1})	Benefit: Benefit-cost ratio (9)/(8)
(J)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	00)
Medak									
AA	147	1244	575	1829	12385	1521	1546	40.8	0.026
AB	291	1244	801	2044	7025	863	888	30.9	0.035
BA	188	1128	640	1768	9395	1154	1179	35.8	0.030
BB	65	453	286	739	11345	1394	1418	34.8	0.025
CA	202	813	667	1480	7329	899	924	39.5	0.043
CB	104	623	421	1044	10040	1233	1258	34.6	0.028
DA	124	660	483	1143	9195	1129	1154	32.9	0.028
DB	98	762	401	1164	11881	1460	1485	39.0	0.026
EA	90	540	376	916	10149	1245	1270	35.6	0.028
EB	66	866	289	1155	17502	2150	2175	32.1	0.015
Average	138	833	494	1327	10625	1305	1329	35.6	0.027
Mahbubnagar									
FA	41	254	190	444	10759	1322	1347	36.8	0.027
GA	117	792	462	1254	10682	1312	1337	36.3	0.027
GB	161	724	580	1309	8095	993	1018	40.3	0.039
HA	298	1298	806	2104	7065	867	892	30.1	0.034
HB	43	266	199	465	10744	1319	1344	32.1	0.024
JA	42	256	192	448	10754	1322	1347	34.3	0.025
KA	57	694	253	947	16717	2053	2078	28.4	0.014
KB	65	585	286	871	13366	1641	1666	35.8	0.022
LA	57	456	254	711	12454	1530	1554	29.2	0.019
LB	59	458	264	722	12140	1490	1515	26.9	0.018
Average	94	579	348	927	11278	1384	1409	33.1	0.024
Anantapur									
MA	450	2258	889	3147	6993	860	885	41.5	0.047
NA	375	2904	866	3770	10050	1236	1260	39.5	0.031
NB	179	983	620	1603	8962	1102	1127	40.8	0.036
Average	355	2049	792	2840	8668	1065	1090	40.5	0.037
Kurnool									
PA	129	790	491	1286	9961	1223	1248	33.4	0.027
QA	432	1792	887	2679	6205	761	786	33.4	0.042
Average	280	1291	692	1983	8083	992	1017	33.4	0.033
Akola									
RA	405	1237	882	2119	5231	643	667	52.6	0.079
RB	445	1325	888	2213	4972	610	635	62.3	0.098
SA	307	1275	818	2092	6813	838	862	60.5	0.070
TA	172	713	605	1318	7665	942	966	52.6	0.054
Average	332	1138	798	1936	6170	759	783	57.1	0.071
Sholapur									
UA	240	1004	733	1737	7238	890	914	84.3	0.092
VA	196	823	655	1478	7544	927	951	33.4	0.035
VB	720	2263	820	3084	4282	526	551	46.5	0.084
Average	385	1363	736	2099	6356	781	806	54.6	0.068

1. For details see Appendix Table 1.

only affected the variability in area irrigated (as is usually the case) but it also drastically reduced yields.

Normally, however, as seen for the other districts individually and for the three districts combined, tank irrigation reduces yield risks while it involves a high degree of area variability.

The net effect is often a higher variability of tank-irrigated rice production than that of rainfed crops. However, this varies from region to region and also from year to year, with an apparent trend towards increasing instability of tank irrigation, as shown in the next chapter.

Benefits to Project Authority

In India, at present, tank construction is planned and executed by the PWD, and tanks are operated by the Panchayat. Irrigation charges are collected by the Revenue Department. There is no Tank Irrigation Authority as yet. If there were such an Authority it would have to operate on the basis of irrigation fees as major-income, but it might be able to generate some additional income by renting the tank for fish production or by selling the silt for brickmaking.

The patwari's records provided the last 10 years' revenue information for 28 tanks (Table 9, column 9). The revenue collected per irrigated hectare in Andhra Pradesh was Rs 35 on average, varying slightly from tank to tank between Rs 27 and Rs 40. In Maharashtra, the rates are scaled according to water consumption of the different crops. On an average, a rate of Rs 56 per irrigated hectare was charged.

Benefits to the State and National Economy

Additional food production. The major benefit from tank irrigation — as from any irrigation project — is the additional production of food grain it generates. The computation of farmers' net benefits at average prices (Table 7) reflects this benefit. In 1975, the year of the survey, a hectare under tank irrigation produced about three times more (in terms of value) than a nonirrigated hectare.

Additional employment. Another important social benefit from tank irrigation is the employment it generates. Table 10 gives a comparison of the number of labor hours per hectare for the various tank command areas. It shows that the tanks in Rayalaseema and Telengana employ an additional 750 to 1050 labor hours ha^{-1}, or about four to five times more than on nonirrigated land. Interestingly, this is not true for the tanks surveyed in Akola and Sholapur districts, where there was a negligible difference between the number of labor hours employed on tank-irrigated land in comparison with nonirrigated land.

Security in food production. Irrigation is generally associated with security in food production. Not all tanks have been equally reliable over the past 10 years. In fact, there appears for some regions a general increase in the instability of tank-irrigated food production, as discussed in the next chapter.

Environmental effects. In addition to the economic aspects discussed above, there would be beneficial environmental effects such as increase in groundwater levels, and soil retention and accumulation in the tank beds, thus making it possible to reclaim the eroded top soils. Unfortunately, the complexities of these more technically relevant variables could not be considered in this study for lack of measurements and data.

Tank Irrigation Costs

As in the previous section on benefits, we shall summarize the costs of tank irrigation in the same sequence, i.e., (1) costs to farmers, (2) costs to the Project Authority, and (3) costs to the State and Nation (Table 6).

Costs to Farmers

Irrigation charges. Farmers' water fees for tank-irrigated land are presented in Table 7 (column 14). In Andhra Pradesh, the amount for the first season is around Rs 27 to Rs 40 ha^{-1} while for the second season, half that amount is charged, i.e., on double-cropped land the annual revenue charged is between Rs 42 to Rs 65 ha^{-1}. The net amount charged for water only would be the difference between revenue for irrigated minus nonirrigated land, i.e., about Rs 27 to Rs 40 ha^{-1} for one season, and Rs 42 to Rs 65 ha^{-1} for two seasons. The water fees are in the form of a tax which the farmer pays together with his other land revenue taxes to the same Revenue Department.

In Maharashtra, a different system prevails. Here the water charges are fixed in proportion to the water consumed by the irrigated crops.

Uncertainty of water availability. Even though the farmer has the benefit of reduced yield risks, he still faces an uncertainty about the amount of water available for tank irrigation. Prevailing water-management practices are aimed at adjusting the area irrigated to the actual or expected quantity of water at a particular time. Consequently, the area irrigated varies considerably from year to year. The combined effect is probably a higher variability of paddy production than of rainfed crops.

Table 10. Social benefit-cost analysis of tank-irrigation projects to the nation.

Tank code[1]	At village prices		At average prices		Employment (h ha^{-1})		Additional employment due to tank irrigation (h ha^{-1})	Proportion of tank irrigated employment over rainfed (6):(7)	Net present value ('000 Rs)	
	BCR[2]	IRR[2] (%)	BCR	IRR (%)	Tank irrigated	Rainfed			Village prices	Average prices
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Medak										
AA	0.42	0.9	0.71	5.5	1302	462	840	2.8	-1077	-537
AB	n[3]	n	0.68	5.0	1408	361	1048	3.9	na	-663
BA	0.27	n	0.9	8.4	1206	158	1048	7.6	-1344	-189
BB	1.10	11.5 (17)[4]	1.54	17.7 (8)	1203	596	608	2	77	409
CA	0.96	9.4	1.68	19.6 (8)	2078	806	1273	2.6	-59	1041
CB	1.91	22.8 (6)	2.36	29.2 (5)	1853	568	1285	3.3	974	1446
DA	0.21	n	0.31	n	1547	311	1236	5	-915	-815
DB	0.55	2.5	0.59	2.9	1485	351	1134	4.2	-532	-487
EA	n	n	0.14	n	993	343	650	2.9	na	-567
EB	0.46	0.8	0.52	1.8	1801	346	1455	5.2	-627	-567
Average	0.54	2.1	0.93	9.8	1448	430	1058	3.9	-5679	-924
Mahbubnagar										
FA	0.81	6.9	0.90	8.4	1016	395	620	2.6	-88	-45
GA	1.03	10.44 (20)	1.10	11.6 (16)	941	400	541	2.4	36	132
GB	1.2	13.4 (11)	1.12	12 (14)	954	306	647	3.1	268	158
HA	0.95	9.21	1.34	15.3 (10)	806	200	605	4	-111	744
HB	0.91	8.5	0.99	9.8	1105	284	820	3.9	-44	-6
JA	0.88	8.1	1.12	11.5 (17)	1169	180	988	6.5	-56	436
KA	0.04	n	0.08	n	121	166	105	7.3	-918	-885
KB	0.1	n	0.15	n	976	136	840	7.2	-795	-755
LA	0.34	n	0.49	1.26	773	190	583	4.1	-479	-367
LB	0.19	n	0.54	2.3	1203	158	1045	7.6	-598	-341
Average	0.72	5.8	1.08	11.10	1016	242	773	4.8	-2528	676
Anantapur										
MA	1.57	18.3 (8)	2.04	24 (6)	1250	393	857	3.2	1957	3359
NA	0.42	n	0.70	5.3	813	237	576	3.4	-2221	-1097
NB	0.32	n	0.77	6.2	875	222	652	3.9	-1112	-379
Average	0.84	8.0	1.23	13.6	979	284	694	3.5	-1252	-1799
Kurnool										
PA	0.21	n	0.35	n	1532	277	1255	5.5	-1043	-854
QA	0.5	0.9	0.68	4.5	1228	343	885	3.6	-1388	-879
Average	0.4	n	0.58	4.3	1379	309	1070	4.5	-2210	-1599
Akola										
RA	na[5]	na	na	na	660	682	-22	0.97	na	na
RB	na	na	na	na	568	850	-282	0.67	na	na
SA	na	na	na	na	1045	909	136	1.2	na	na
TA	na	na	na	na	670	833	-163	0.8	na	na
Average	na	na	na	na	736	820	-84	0.9	na	na
Sholapur										
UA	0.43	0.43	0.32	n	5	487	119	1.2	-1005	-1212
VA	n	n	n	n	568	642	-74	0.9	na	na
VB	0.68	4.9	0.67	4.7	598	432	166	1.4	na	na
Average	0.43	n	0.42	n	591	521	69	1.2	-3369	-3454

1. For details see Appendix Table 1.
2. In computing the benefit-cost ratio (BCR) and the internal rate of return (IRR) the following were assumed: social rate of discount = 10%, and life period = 22 years.
3. n = negligible. 4. Figures in parentheses denote the pay-back period. 5. na = data not available.

Our tank survey provides ten years' data on the area irrigated by individual tanks. The coefficients of variation (CV) computed from these data show how this variability differs across tanks, depending upon the local climate, topography, layout of the catchment and the command areas, water management, and tank maintenance.

We have attempted to understand better the impact of these variables with the help of a simulation model. This exercise shows that at given rainfall distribution (Hyderabad, 1901-1970) in the case of tanks operated without water control — i.e., the outlet is open throughout the year as is, in fact, frequently the case for tanks north of Hyderabad — the tank-irrigated area does vary considerably, with a CV of 25%.

Costs to the Project Authority

Land acquisition. Table 11 gives the cost of land acquisition for recently constructed tanks. On an average, land acquisition cost per hectare of command area amounts to Rs 720. This varies between 1-20% of the total cost of construction, depending upon land quality and ownership.

Construction costs. Data on tank-construction costs for 16 tanks recently constructed by the PWD were collected. In order to compare costs and benefits, cost estimates and technical relationships were considered to arrive at construction costs of the 32 tanks for which farm surveys had been made. The steps taken to arrive at the estimated costs to the tank building authority are described below.

Construction cost details of 16 tanks are presented in Table 11. The total costs of construction were reported separately for five components — bunds, sluices, weirs, canals, and land acquisition. On an average, the bund constitutes 57% of the total cost of construction.

Since all tanks are located in more or less similar topographic environments, there would be little variation in the distance of earth transportation required, so that the bund cost largely depends upon shape and height of the bund. The shape and height of the bund are approximately determined by the length of bund per unit of settled command area. Therefore, it was hypothesized that the cost per unit length of bund would be related to length of bund per unit of settled command area.

In a test of this hypothesis the following functional form was found to fit:

$$Y_1 = 503.6 + 2598.4 \, X_1^{-1}, \quad R^2 = 0.46 \qquad (3.5)$$

where

Y_1 = cost per length of bund (Rs m^{-1}), and

X_1 = length of bund per settled command area (m ha^{-1}).

Table 11. Breakdown of tank-construction costs ('00 000 Rs) for selected districts, 1974-75.

Village	District	Settled command area (ha)	Cost of bund	Cost of sluices	Cost of weirs	Cost of canals	Cost of land acquisition and misc.	Total cost
Lanjabunda	Kurnool	176	4.61	0.20	0.53	1.47	0.44	7.25
Madanantapuram	Kurnool	167	14.42	0.01	3.99	5.61	2.08	27.02
Penumadi	Kurnool	206	16.80	0.30	2.66	3.26	1.28	24.30
Vengaladoddi	Kurnool	212	10.20	0.26	4.07	5.05	2.72	22.30
Khambalampadu	Kurnool	212	11.62	0.63	8.31	3.00	3.00	26.56
Dantharvanipenta	Kurnool	455	7.01	0.58	10.71	1.77	1.08	21.15
Jalvanur	Kurnool	668	20.88	0.32	2.30	6.41	0.53	30.44
Jeedipalli	Anantapur	79	2.35	0.20	1.03	0.91	0.88	5.37
Pinnepalli	Anantapur	67	5.06	0.13	1.41	1.36	0.79	8.75
Bagiyakinapalli	Anantapur	79	4.45	0.19	2.20	1.30	1.20	9.38
Chitraseedu	Anantapur	158	9.36	0.51	2.27	1.00	2.68	15.82
Nandyalampeta	Cuddapah	232	13.25	0.29	7.75	3.06	0.03	24.48
Kotulabanda	Cuddapah	364	24.84	0.64	2.50	1.50	0.50	29.98
Gangaveru	Medak	81'	2.56	0.65	0.43	0.68	0.86	5.18
Edakulapally	Medak	334	9.97	0.91	2.01	4.21	3.95	20.96
Chinnamadula	Mahbubnagar	129	11.80	0.29	3.43	1.02	4.00	20.54

Source: T. Hanumantha Rao, Andhra Pradesh State Irrigation Development Corporation, and Public Works Department, Minor Irrigation Department, Hyderabad.

The relationship explains 46% of the variation in costs. The t-value of 3.5 indicates that it is statistically highly significant. This relationship is plotted in Figure 6.

Based on this result it is possible to derive the bund costs for all tanks in the same region for which information on bund length and command area exists. These derived costs are presented in Table 9.

The remaining cost components (canals, sluice, overflow weir, etc.) depend on the size of the settled command area. The relationship was found to fit a semi-log function as follows:

$$Y_2 = 8.714 - 0.00208\ X_2,\ R^2 = 0.36$$
$$(2.8)$$

where

Y_2 = the remaining cost per settled command area (log Rs ha^{-1}), and

X_2 = settled command area (ha).

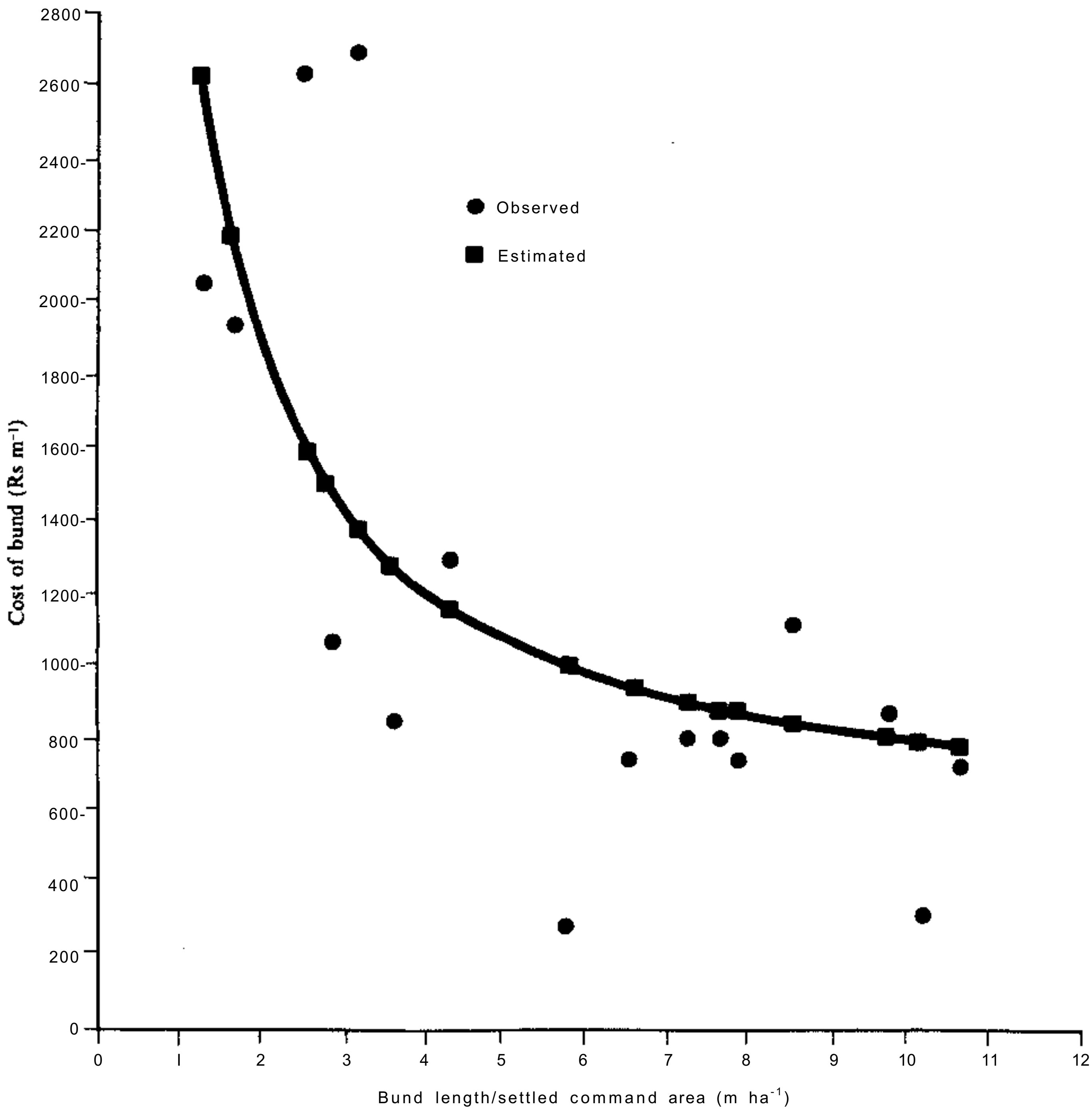

Figure 6. Relationship between bund length per settled command area and cost of bund.

With an R^2 (the coefficient of multiple determination) of 0,36 and a t-value of 2.8, this relationship is statistically significant.

Using this relationship, it is possible to derive the nonbund costs of all those tanks in the same region for which information on settled command area is available (Table 9).

By adding the two cost components, an estimate of total construction costs is computed. These estimated costs vary between Rs 4300 and Rs 16 700 ha"[1] with an average of Rs 9000 ha^{-1}. In comparison the actual data on total costs vary more (note that the above estimated relationships explain only about 50% of the variation). Our estimations look quite feasible within the context of the actual cost data available.

Maintenance costs. Information on maintenance costs per tank was not available. However, from PWD records on expenditures incurred on maintenance and repairs we find the following: in selected districts on an average, over the years 1973-77 total expenditure on repairs varied between Rs 18 and Rs 27 ha^{-1} (Table 12). While expenditures on ordinary repairs were between Rs 12 and Rs 17 ha', flood repairs ranged from less than Rs5 ha^{-1} in some districts (Mahbubnagar, Medak, Nalgonda) to nearly Rs 7 to Rs 12 ha^{-1} in others (Anantapur, Chittoor, Cuddapah). These are direct expenditures made on the tanks. The costs of overheads, engineering, etc., are not included.

Costs of water control and tank management. Water management, as presently practiced by the village community, does not involve any direct costs. Farmers organize the water control among themselves. In some tanks there was a water controller (nairudi) who was paid for his services with paddy produced. The water charges are collected by the Patwari, along with the land revenue.

Table 12. Average annual expenditure (Rs ha^{-1} command area) by the Minor Irrigation Department on tank repairs in selected districts of Andhra Pradesh, 1973 to 1977.

District	All repairs	Ordinary repairs	Flood repairs
Nalgonda	18	17	1
Mahbubnagar	18	15	3
Karimnagar	19	15	4
Medak	18	14	4
Kurnool	18	13	5
Anantapur	19	12	7
Chittoor	24	13	11
Cuddapah	27	15	12
All districts	20	15	5

Source: Government of Andhra Pradesh, Public Works Department, Minor Irrigation, through personal communication of T. Hanumantha Rao.

Costs to the State and Nation

Opportunity cost of the capital invested. For simplicity the opportunity cost of capital invested was assumed to be 10%.

Submerged land. The value of land submerged by an irrigation tank varies. Generally tanks are located so as to minimize their cost, i.e., low-value barren land is preferred for water storage. One unit of command area requires about 0.8 units of land to be submerged, and under conditions of growing population and rising land values, the cost of submerged land has increasing opportunity value. Moreover, silt deposits in the tank bed lead to a continuous increase in natural fertility, thereby increasing the value of this land.

Level of water table. Lowering the water table by well irrigation can lead to groundwater depletion. It is desirable to maintain the water table at a higher level for pumping groundwater from wells. For a detailed explanation of benefits from groundwater recharge, see the discussion on Composite Watershed Management in Chapter five.

Benefit-cost comparisons

To compare costs and benefits we compute cost-benefit ratios at the farmers' level and at the Project Authority level. At the state level two performance parameters—the cost-benefit ratio and the internal rate of return—are calculated.

Farmer Level

Financial benefit-cost ratio. The farmers' net benefits due to tank irrigation vary between Rs 650 to Rs 950 ha^{-1} in red-soil areas and between zero and 700 in black-soil areas. The costs incurred are the water fees, of about Rs 27 to Rs 40 ha^{-1}. Consequently, in red soils, farmers' benefits are about 15 to 25 times the water costs in a normal year. Thus in a normal year, tank irrigation is a highly profitable proposition for the farmer.

Farmers' reduced yield risks versus uncertainty of water availability. It need not be stressed that hardly ever is a year "normal" with regard to rainfall distribution. While the yields of tank-irrigated crops (paddy) are less variable than the yields of rainfed crops, this yield stability is achieved by adjusting the irrigated area to the water available, thus affecting area stability. In fact, the resulting productivity of tank-irrigated areas in Telengana is becoming more and more variable than that of rainfed areas.

For instance, during 1977 no crops were grown in some tank command areas in Telengana because rainfall was so well distributed that it did not generate any runoff, and farmers waited in vain throughout the season to plant paddy. At the same time rainfed land had been planted as usual with sorghum and pigeonpea and yielded an excellent crop. Thus while the yield risk of tank-irrigated land is less, the uncertainty of water availability — especially for tailenders — makes tank irrigation in Telengana a relatively risky proposition.

Betterment levy and increase in land value. With the establishment of an irrigation scheme, those who own land within the prospective command area are charged a so-called "betterment levy", a one-time tax collected on the presumed increase in land value. This levy generally ranges between Rs 125 and Rs 300 ha^{-1}. However, for the surveyed tanks no records had been kept on the betterment levy charged at the time of construction.

If a levy of Rs 250 ha^{-1} is assumed, then the increase in land value (see Table 7) is 26 to 38 times the levy in the Medak and Mahbubnagar tanks, while in Anantapur it is even 40 to 50 times higher.

Project Authority Level

The benefits accruing to the Project Authority are the annual revenue and the one -time betterment levy. This betterment levy can be accounted against the cost of construction before discounting it to its present value: assuming a 22-year life period (t) and a 10% interest rate (i) on capital invested, the present value (P) of the cost per hectare of tank-irrigated land (C) can be computed as follows:

$$P = \frac{C}{(1+i)^t}$$

A life-period of 22 years is chosen because longer periods would decrease P only marginally. An interest rate of 10% is chosen as it represents the average rate at which capital might be invested elsewhere.

If an amount P was deposited in the bank at interest rate i it would grow to the value of C after t years (see Table 9, column 7). To this annual cost we add the maintenance cost of Rs 25 ha^{-1}. The ratio of irrigation fees over present value of tank costs plus maintenance cost per hectare is the benefit-cost ratio which the project authority faces (Table 9, column 10).

The low average levels of about 0.03 in all districts indicate the high degree of subsidization in tank irrigation. At the project authority *level* about 97% of the costs of tanks are subsidized.

State Level *

For comparing benefits and costs at the State level, their cash flows over 20 years were analyzed. It was assumed that the net benefits from irrigation for 1974-75 would be the same for each of the previous 21 years. Information was available on area irrigated for 10 years, from 1964 to 1974. A relationship estimated between area irrigated and rainfall permitted an estimation of the area annually irrigated for another 11 years prior to 1964-65, so that a total of 21 years' data on area irrigated was generated. The flow of annual net benefits was obtained by multiplying the area (ha) by the net benefits per hectare.

The cost flow for each tank consists of the total construction cost (in the first year) and the annual maintenance costs (in the following 21 years). The ratio of the summations of the discounted annual values of benefits (B) and costs (C) is computed according to the following formula (Gittinger 1972):

$$BCR = \frac{\sum_{t=1}^{n} B_t/(1+i)^t}{\sum_{t=1}^{n} C_t/(1+i)^t}$$

where
t = 1.........22 years and
i - 10% rate of interest.
BCR is the benefit-cost ratio.

Tanks with a BCR of 1 or more are supposed to be economically viable. As Table 10, coloumn 4, shows, there are only 8 tanks out of 28 for which this is the case.

Another measure of comparing benefits and costs is to compute the internal rate of return — that interest rate at which the BCR would bejust one. This approach does, of course, present the same fact, i.e., eight tanks would have internal rates of return greater than 10%. If a lower rate of return, say 5%, was acceptable to the decision makers as the criterion for economic viability, then a total of 15 out of 28 tanks would qualify. This analysis shows that fewer than half of the existing irrigation tanks are economically viable.

Sensitivity analysis has shown that the area actually irrigated plays a major role in determining the economic performance of irrigation tanks. If a higher utilization of the command area—at the rate of about 150%—could be achieved in most years, every tank would be highly profitable in terms of benefit-costs as well as internal rates of return. Detailed suggestions to achieve a better utilization of the irrigation facility will be put forward in chapter five of this study.

It might be argued that the low economic returns from tank irrigation are offset by social benefits such as employment and food production which justify tank irrigation even where it may not be economically viable. In addition, it should also be considered that the poor performance of most tanks can be avoided. It is possible to increase the utilization rates in most tanks through better tank management and control. This effort would at the same time augment the social benefits and to some extent increase the stability of agricultural production under tank irrigation.

Summary

- The ratio of settled command area per unit of submerged area increases with increase in tank size. On an average the ratio is 0.9 for small tanks of up to 40 ha command area and 1.5 for tanks of above 400 ha command area.
- In Medak, Mahbubnagar and Sholapur districts rainfall significantly determines the percentage utilization of command area actually irrigated; as rainfall increases the utilization increases at a decreasing rate.
- Farmers' net benefits from tank irrigation at village prices in the districts studied are Rs 880 ha^{-1} in Telengana, Rs 650 ha^{-1} in Rayalaseema, and Rs700 ha^{-1} in Sholapur. In Akola district tank irrigation has negligible net benefits. At average prices, Telengana and Rayalaseema regions have higher net benefits. Tanks generally generate higher profits in Alfisol areas than in Vertisol areas.
- Land values under tank irrigation are about 2.5 to 4 times those of drylands in the Alfisol districts of Andhra Pradesh. There is not much difference in values of dry and tank-irrigated land in the Vertisol districts of Maharashtra state.
- Tank irrigation reduces yield risks but involves a higher level of area variability.
- For the project authority, the benefits are in terms of irrigation fees collected, which are Rs 35 ha^{-1} on an average in the Andhra Pradesh districts.
- At the project authority level, about 97% of the costs of tank irrigation are being subsidized.
- The direct benefits of tank irrigation for the nation are additional food production and employment. There are also environmental benefits such as rise in groundwater table. The tanks in Rayalaseema and Telengana regions employ an additional 750 to 1050 labor hours ha^{-1}, which is about 4 to 5 times the labor used on nonirrigated land. The tanks surveyed in Akola and Sholapur districts have only a marginal employment effect.
- The cost of the bund constitutes around 60% of the total cost of construction and there are economies of scale in construction.
- The area actually irrigated plays a vital role in determining the economic performance of irrigation tanks. Only 8 tanks out of 28 have an internal rate of return greater than 10%, and 15 with *5%* and above. With higher utilization rates tank irrigation can become an economically and socially profitable technology.

4. Deterioration of Tank Irrigation and Need for Remedial Action

Tank Irrigation as a Source of Instability

Using statewise data from 1956 to 1962 on proportion of irrigated area and of area irrigated by tanks and wells to the total irrigated area, Hanumantha Rao (1968) found that variability of agricultural production was affected significantly by tank and well irrigation: the higher the proportion of irrigated area the lower the variability, but the larger the share of irrigation from tanks and wells the higher is the variability in productivity. At the all India level, tank irrigation expanded till the early 1960s; subsequently the area irrigated from tanks has been stagnant and has even decreased in many regions (see Table 3).

The observed decrease in tank irrigation with population increase from a certain "optimum" point of population density in the former non-British districts of India seems to be related to another phenomenon: the increasing instability in tank-irrigated areas (and therefore production) in certain regions of India. District analysis of the variability of tank-irrigated areas, using a moving coefficient of variation (MCV) over 8 years (moving from 1958-65 up to 1968-75), shows the following: in the districts of Telengana, e.g., in Warangal, the variability of tank-irrigated area had earlier been well below the variability of ramfall which remained at about the same level throughout the entire period, while variability of tank-irrigated area during the second half of the period went up considerably (Figure 7). This observation is true also for districts in Rayalaseema, e.g., in Cuddapah (Figure 8), but not (or not yet) for districts in Tamil Nadu (Figure 9) (von Oppen 1978).

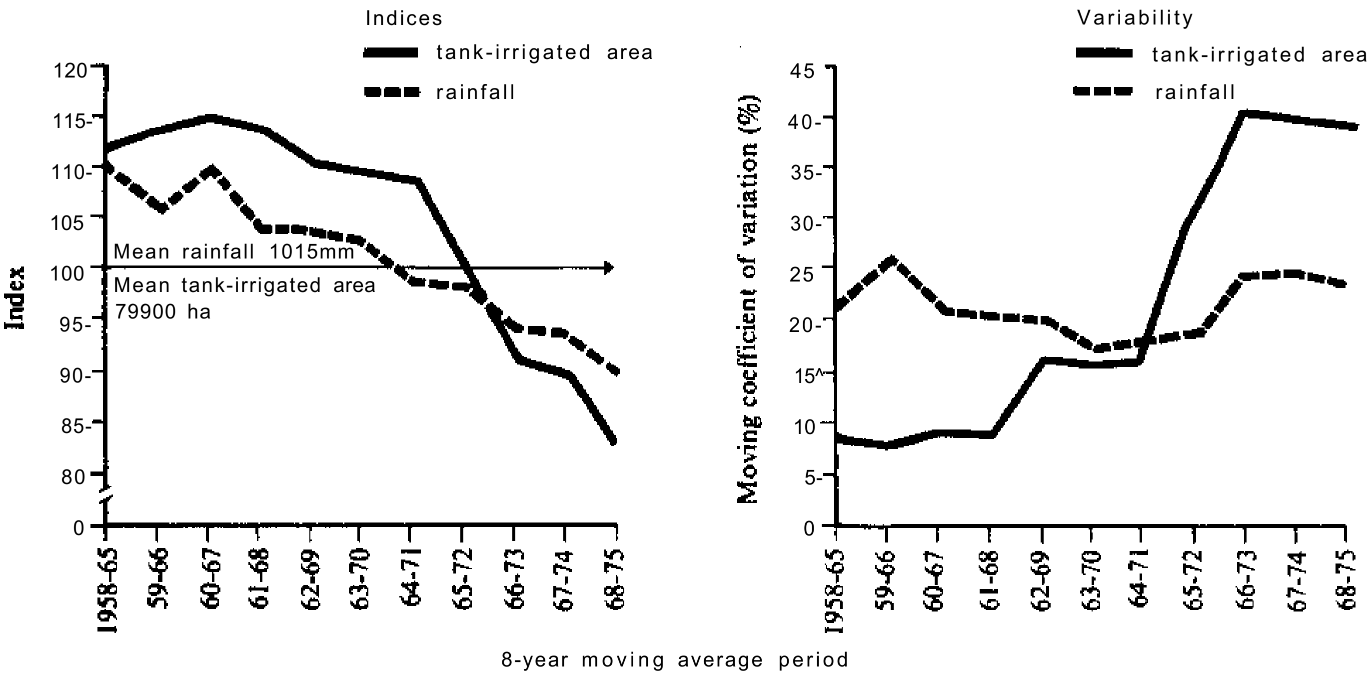

Figure 7. Indices (mean area and rainfall =. 100) and variability ofrainfall and tank-irrigated area, Warangal district, Andhra Pradesh, India.

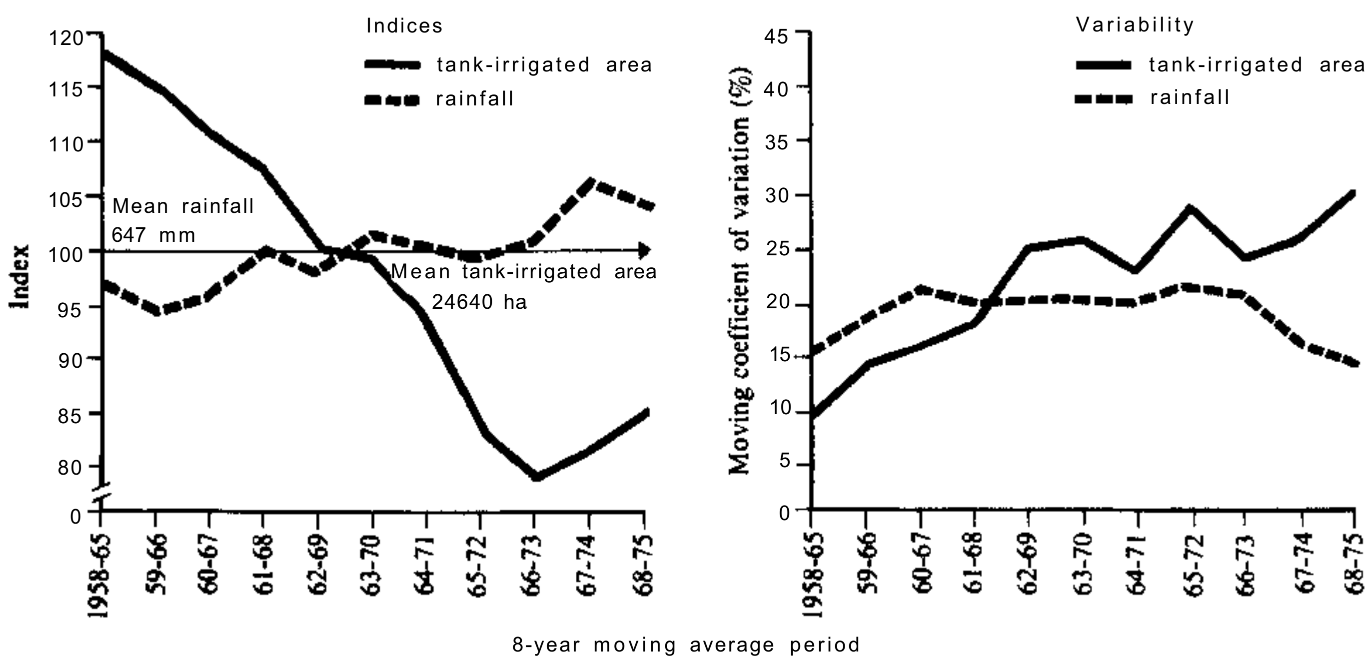

Figure 8. Indices (mean area and rainfall = 100) and variability ofrainfall and tank-irrigated area, Cuddapah district, Andhra Pradesh, India.

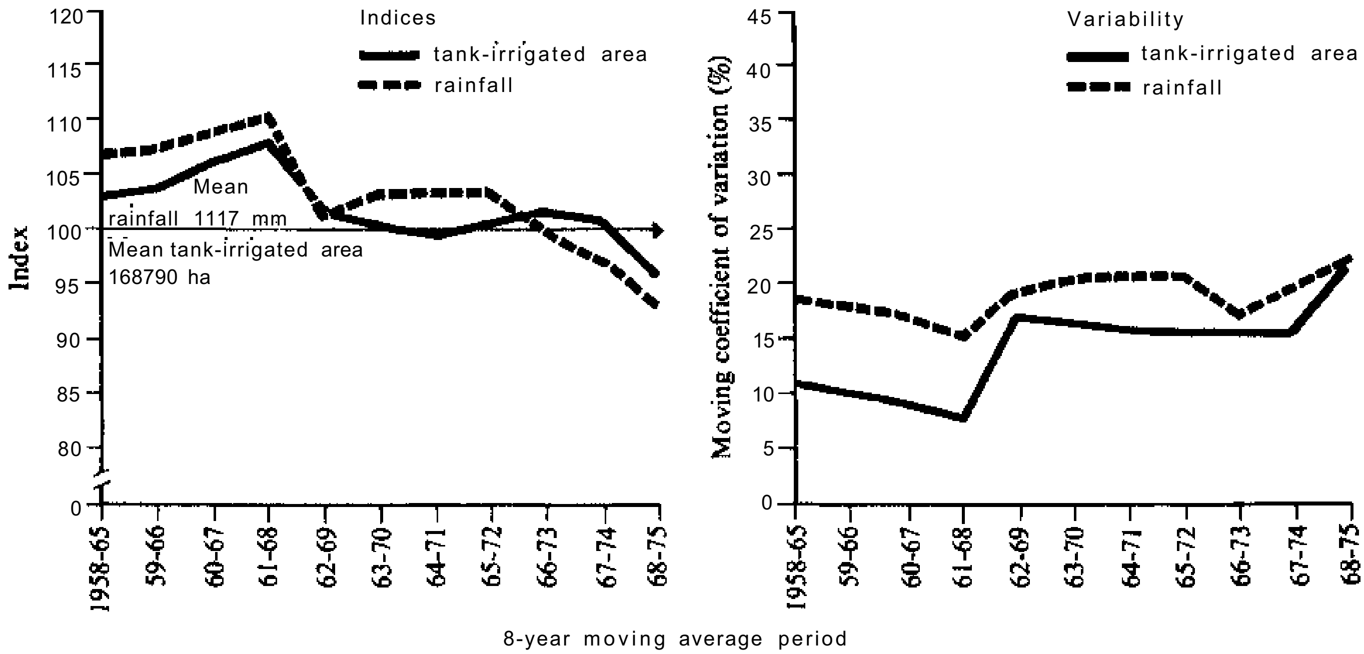

Figure 9. Indices (mean area and rainfall - 100) and variability of rainfall and tank-irrigated area, Chingleput district, Tamil Nadu, India.

The increase in the variability of tank-irrigated area is probably a function of physical as well as institutional variables, which are directly and indirectly related to population pressure (erosion, encroachment), and also attributable to changes in the institutional environment. After the abolition of the zamindari system, tank management, organization, maintenance, repair, water control, etc., ceased in most cases to be under private control and became the responsibility of different bodies of public administration.

Reasons for Decline in Tank Irrigation

The important reasons for the decline in extent and reliability of tank irrigation in the southern states of SAT India are:

- Lack of soil conservation and afforestation in the catchment areas leading to flash runoff and increase in tank-bed siltation.
- Inadequate maintenance of bunds, waste weirs, and draft channels;
- Decline in the effectiveness of tank- and tank-water management (Meinzen-Dick 1984);
- Unauthorized cultivation, tank- bed cultivation, and foreshore encroachments;
- Secular shift in the seasonal distribution of rainfall (Bandara 1977);
- Increase in population densities (von Oppen and Subba Rao 1980, Part I).

Remedial Action for the Improvement of Tank Irrigation

Tank irrigation in parts of India is decreasing in extent and reliability although it has the potential to be socially and economically beneficial. The concern is to ensure that the existing capital of irrigation tanks is preserved, better utilized, and possibly expanded.

In the light of the information presented, it is clear that the performance of tank-irrigation technology depends not only upon the farmers on whose land the runoff to fill the tank is being generated and on those whose land is being irrigated, but also upon the government agencies which are largely responsible for the administration of tanks. This includes water distribution, maintenance, and collection of water fees. Generally, the smaller tanks are governed by individual farmers' decisions while larger tanks depend upon government agencies operating the system.

The improvement of tank-irrigation efficiency for all tank sizes would require a more balanced integration of farmers' involvement, and government commitment and participation in activities such as control of water distribution, maintenance and repair, revenue collection, and management of the tank and tank bed as well as of the catchment areas.

Control of Water Distribution

The water-use efficiency (WUE) of a tank depends largely upon water management. Judicious water use and distribution during the two growing seasons would result in larger areas being served from a particular tank. Even a high water consumptive crop such as paddy covering the entire tank command area does not require the same amount of water every day. Instead, the water required varies with the crop-growth stage and with weather and wind conditions. Theoretical calculations (see following chapter) show that tank command area can increase significantly when a 'tank controller' allocates water optimally by taking these variables into account.

Naturally, if crops that require less water are grown — groundnut, sorghum, cotton, etc. — the WUE can be further increased. However, such a step to increase WUE entails considerably higher costs of organizing a more sophisticated water-allocation system; for instance, to provide supplementary irrigation for irrigated dry crops the entire canal system of a tank would have to be laid out so as to allow flooding of the entire command area within a few days when a dry spell occurs. Because of the larger and wider command area, longer channels would be required which will have to be lined and provided with adjustable outlets. Staff would have to be provided during those days to supervise the flushing operation.

It is not likely that radical shifts away from paddy can be achieved easily, because of these relatively high physical and institutional investments. Instead, water allocation by a tank controller, and a system of fixing water charges according to actual water use might allow less extreme and therefore more feasible solutions, i.e., a change in land-use patterns, where perhaps the outer fringes of a command area would be planted to irrigated dry crops while the areas near the tank are cultivated to paddy. Depending upon water availability from year to year, farmers could be induced to shift towards irrigated dry crops so as to achieve better water and land use.

A cost-efficient solution has to be found for maximizing productivity through improved water management. However, an optimal point, where marginal costs of improved water management are equal to *its* marginal benefits, is difficult to determine as it varies from year to year.

Model calculations using 70 years' daily rainfall data to simulate a water-storage system have shown that for an average tank, a simple rule of keeping the sluice closed on rainy days would permit a 20% increase in the irrigated area and reduce by about half the number of years that the tank runs dry during the cropping season (von Oppen, Subba Rao, and Engelhardt, 1983). It should be possible to implement this type of a simple control function by a public authority at relatively low cost.

Regular Maintenance and Repair

Any tank constitutes an artificial obstacle to a natural waterway and is permanently subject to destructive forces which would eventually lead to its breaching and washing away, unless it is continuously repaired and well maintained. Thus tanks, as old as some of them may be, cannot be regarded as permanent and stable features per se.

The amount of money available to the PWD for tank repairs has always been claimed to be insufficient for proper maintenance. Considering the Revenue Department's water rates (calculated as the difference between land revenue from dry vs wet land) are only around Rs 35 ha^{-1} of command area, the level of maintenance expenditures probably can not be expected to increase unless the water rate is increased. On the other hand, as the capital cost of one hectare of command area is about Rs 5000 to Rs 10000 (average of Rs 7500) and maintenance rates range between Rs 17 to Rs 27 ha"[1] (average of Rs21 ha^{-1}) this amounts to only about one-third of 1% of the capital value, which, judging from all practical experience, is not likely to be enough.

Direct investigations do not indicate how the situation in Tamil Nadu differs from that in Andhra Pradesh. However, from other accounts (Chambers 1977) it would seem that in Tamil Nadu the village tank has often been regarded as common property with maintenance based on community action. "Kudi Maramath (cooperative repair work) is older than the British Administration. When the British began to administer Madras Province, they found that it was customary for village communities in many districts to contribute labor towards repairs of minor irrigation sources." (Baliga 1960).

A gradual erosion of the capital of irrigation tanks is the consequence of inadequate maintenance. Tank construction today is regarded as a welfare activity, and in the field of minor irrigation, public decision makers as well as farmers and private entrepreneurs often pay more attention to the expansion of pump irrigation than to maintenance (not to mention expansion) of irrigation tanks.

Maintenance of irrigation tanks requires annual inspection and regular repair work. The amounts spent for repair have to be kept at levels sufficiently high to preserve the capital value of a newly constructed tank, which now costs about Rs 6000 to Rs 10000 ha'[1] of command area.

Revenue Collection and Tank Management

Water rates levied in the tanks under study amount to about Rs 35 ha^{-1}. These water charges are collected by the Revenue Department as a tax on people who own irrigated land. Repair work by the PWD (in five-year cycles) is financed out of the water charges previously collected.

In the past zamindars, who collected up to 50% of the production under tanks, are likely to have spent a much higher amount on construction as well as on maintenance and repairs than is spent now by government agencies. Also, the provision that the same person, i.e., the zamindar or his equivalent, was responsible for maintenance as well as revenue collection allowed for more direct attention to urgently needed repairs than is possible in the present system in which two separate Government departments are responsible for revenue collection and maintenance.

Avoiding Tank-bed Cultivation

Tank beds should be kept free from cultivation so that desiltation is not inhibited; they could be used for grazing or to grow trees in the upper fringes. Tank-bed cultivation and the subsequent acquisition of ownership rights by individuals is likely to reduce storage levels of tanks.

Desiltation of Tank Beds

Though controlled erosion minimizes tank-bed siltation, it does not entirely eliminate it, and over time, the accumulated silt will reduce the effective storage capacity of the tank. Regular desiltation of existing tanks should be the responsibility of a public body. The fertile silt can be dug up and redistributed on the uplands from where it originated, thereby upgrading the value of these uplands. At the same time, the storage capacity of the tank would be restored.

Lining of Irrigation Channels and Farmer Cooperation

A study often tanks of varying sizes in Ramanathapuram district in Tamil Nadu clearly indicates the importance of farmer cooperation for efficient management of tank irrigation. The government departments should encourage such organizations and help in identifying a strong local leadership. Studies have shown that investments in lining irrigation channels and the installation of community wells below the tank outlets lead to a good internal rate of return (Palanisami and Easter 1984).

Measures for rehabilitating irrigation tanks are required. Wherever irrigation tanks are operative under good management, they show high levels of productivity and considerable economic benefits. It is worth while to maintain this capital, with relatively small investments for rehabilitation (Palanisami 1981).

Summary

- Tank irrigation, formerly a source of relative stability, has become more and more unreliable. It is now a source of instability for agricultural production in many parts of India.
- Major factors causing the deterioration of tank irrigation include: environmental degradation such as deforestation, over grazing, soil erosion, siltation, etc., all of which are related to increases in population density; lack of administrative structures for tank maintenance and repair, and to provide proper water control and general tank management.
- Remedial measures for improvement of existing tanks include: increase in efficiency of water use by control of water distribution and management, regular and timely maintenance and repair, regular desiltation of tank beds (beneficiaries should share the responsibility), avoidance of tank-bed cultivation, creation of an agency responsible for revenue collection and tank management, soil conservation and afforestation measures to control erosion, lining of field channels to avoid transit losses, and farmers* cooperatives at the tank level for efficient water management.

5. Alternatives for Improving Tank Irrigation

Water management holds one of the most important keys to improved productivity of agricultural land use in the SAT. As has been shown above, tank irrigation is a water-management technology which can produce considerable economic and social benefits. Its present decline in India under the influence of growing population pressures and in competition with alternative technologies (such as well irrigation) is a fact which calls for remedial measures. Some measures, many of which have also been suggested by other authors, are presented in the previous chapter. These represent "soft" measures for remedial action. Information on such remedial measures is relevant not only to preserve the "capital" of irrigation tanks in India which is in danger of being fast depleted. Lessons learned from the Indian experience will also be of use to areas where tank irrigation is becoming feasible now, i.e., where population densities have reached threshold levels of 50 to 100 persons km^2 and where geographical conditions are conducive to the more intensive land-use system of tank irrigation. Such regions exist in West Africa (northern Nigeria, Mossi Plateau in Burkina Faso, etc.) and in north-eastern Thailand.

However, it appears that in many cases and under particular conditions such "soft" measures are not sufficient to cope with the situation. Often more decisive action is required, demanding somewhat more far-reaching decisions than merely the advice to do more or Jess of one or another type of activity. In those cases "soft" measures may have to be replaced by "hard" action.

We present below two alternative concepts for improved water management.

(1) The concept of tank management through a Tank Irrigation Authority (TIA). This concept is still aiming at the preservation of tanks through better management of tank water, but by way of a definitive administrative infrastructure.

(2) The concept of Composite Watershed Management (CWM) on Alfisols. This concept is more radical in the sense that it accepts the fact that traditional irrigation tanks will become technically obsolete in the wake of new technologies for water lifting and water management.

The Concept of a Tank Irrigation Authority

The concept of a Tank Irrigation Authority (TIA) was explored at the state level. The existing conditions of tank irrigation and the present organization of tank management were studied in the states of Andhra Pradesh, Maharashtra, Karnataka, and Tamil Nadu. The expected costs and returns of a TIA were assessed to assure administrative as well as economic feasibility (Venkatram 1985).

Present Situation

The organization and management of tank irrigation differs across states. However, generally for small tanks the responsibility for maintenance and repairs and water regulation rests with village authorities, while for larger tanks the Minor Irrigation Division of the Public Works Department (PWD) is responsible. Revenue collection for all tanks is in the hands of the Revenue Department, except in Maharashtra (Table 13). This division of responsibilities leads to a diffusion of activity. Better linkage between decision makers and coordination of decisions regarding operation and maintenance of irrigation tanks could bring about more effective tank management and water control. At present in most of the tanks, particularly the smaller ones, the water flow is either controlled very crudely or not at all by keeping the outlet continuously open. In such cases, once it is opened there is hardly any intermediate adjustment of the flow according to water requirements.

The rates charged for tank water vary considerably from state to state and within states from region to region, owing to historical developments and past practices. Generally, the rates charged for tank water are only about one third to one fifth of what they ought to be if they are to cover the discounted costs of tank construction and maintenance. However, drastic increases in water rates would be politically difficult to enforce; therefore, instead of charging higher water rates, increased participation of farmers in tank maintenance and organization should be envisaged.

The state governments continue to invest in physical maintenance and even expansion of tank irrigation. Government expenditures recorded during 1951 to 1980 for minor irrigation (gravity flow) show that in the states for which information was available, Rs 3000 to Rs 3500 was spent per hectare of new area under irrigation, amounting to about 1 million hectares in the three states of Andhra Pradesh, Karnataka, and Tamil Nadu (Table 14). However, such physical investments are not likely to produce returns if they are not supplemented with appropriate organizational structures for efficient operation of tank-irrigation systems. Also, a comparison of

Table 13. Responsibilities for irrigation-tank management in four Indian states.

State	Tank command area	Public Works Department	Revenue Department	Village
Andhra Pradesh	< 40 ha in Telengana < 80 ha in Andhra	na[1]	Revenue collection	Maintenance and repair Water regulation
	40-400 ha in Telengana 80-400 ha in Andhra	Maintenance and repair	Revenue collection Water regulation	na
	> 400 ha	Maintenance and repair Water regulation	Revenue collection	na
Karnataka	< 4 ha	na	Revenue collection	Maintenance and repair Water regulation
	4-80 ha	Maintenance and repair Supervision of water regulation	Revenue collection	Water regulation under supervision
	> 80 ha	Maintenance and repair Water regulation	Revenue collection	na
Maharashtra	< 100 ha	na	Revenue collection	Maintenance and repair Water regulation
	> 100 ha	Maintenance and repair Water regulation Revenue collection	na	na
Tamil Nadu	< 40 ha	na	Revenue collection	Maintenance and repair Water regulation
	> 40 ha	Maintenance and repair	Revenue collection Water regulation	na

I. na = not applicable.

different sources of statistical information shows that in most states accurate and consistent data on minor irrigation are not always available; for e.g., the Revenue Departments report tank-irrigated areas to be considerably lower than what the Public Works Departments show.

Table 14. Total government expenditure on minor irrigation, 1951 to 1980.

State	Expenditure per unit area (Rs tor')	New area under irrigation (X)00 ha)	Total expenditure ('000 000 Rs)
Andhra Pradesh	3382	346	1170
Karnataka	3331	437	1455
Tamil Nadu	3049	218	665

The Organization of a Tank Irrigation Authority

In order to achieve better tank management with more intensive farmers' participation, a Tank Irrigation Authority (TIA) is proposed. Essentially the TIA would integrate the village-level tank-irrigation committees along with the water regulators and/or supervisory staff into the existing hierarchy of the minor irrigation administration (Table 15). The administrative structure that evolves by establishing close links between the existing organization and the new village-level irrigation committee may bring about a greater degree of agreement among farmers, both on water-management practices and their enforcement. Farmers would more easily accept a village-

Table 15. Organizational pattern of the Tank Irrigation Authority (TIA) at different administrative levels.

1. Tank level	Tank Irrigation Committee or Village Irrigation Committee employing Tank Water Regulator (TWR)
2. Taluk level	Junior Engineer, Minor Irrigation, and Assistant Agricultural Officer
3. Divisional level	Assistant Engineer, Minor Irrigation, and District Agricultural Officer
4. District level	Executive Engineer, Minor Irrigation, and Deputy Director of Agriculture
5. Regional level	Superintending Engineer, Minor Irrigation, and Joint Director of Agriculture
6. State level	Chief Engineer, Minor Irrigation, and Director of Agriculture
7. Government level	Secretary, Public Works Department

level authority to assure improved water-management practices if it was apparent that the ensuing benefits would be higher.

Improvement of Water Control in Existing Tanks

Research on irrigation tanks in southern India has shown that tank irrigation can be profitable (von Oppen and Subba Rao 1980). In actuality, however, most irrigation tanks perform poorly. This is reflected in the overall decline of tank-irrigated area and the growing instability.

Water distribution in some tanks may be managed in a rudimentary manner by controlling the date on which the sluice is opened, but once this is done, the water is generally let out continuously. Water controllers who were once in charge of operating the sluice have now almost completely vanished. Better water management could be achieved by very simple measures, such as: (1) controlling the outflow at night, thereby reducing evaporation overnight, (2) keeping the sluice closed on rainy days (assuming that rainfall will be sufficient to supply the requirement on a rainy day), and (3) a combination of these two.

None of these measures would require any physical change for the tank as such. The structures of the water outlet would remain as they are since outlets in most tanks are traditionally fitted with a round hole into which a conical wooden plug can be pushed from the top of the bund. There would be no need for improved distribution channels nor for new cropping systems; paddy irrigation and field-to-field flow would continue.

A simulation model was built (von Oppen et al. 1983) to compute the amount of water which could be saved if the sluice remains closed on rainy days. Based on 70 years' daily rainfall data at Hyderabad, the model computes the effect of different water-control rules. It calculates (1) the chances for successfully growing a crop in the rainy season (there is still water in the tank in the 43rd week) and (2) the amount of water available for growing a second crop (at the end of the 43rd week). The 43rd week is assumed to be the end of the first season for a rice crop which takes about 120 days to mature.

The results are presented in Table 16. They show that in a command area of 10 ha, a water-control rule of closing sluices on rainy days would reduce the number of years during which the tank runs dry before harvest from 50 years to 40 years, i.e., the probability of crop failure for this particular tank would fall from 0.69 to 0.56. These probabilities of crop failure are relatively high because of the small tank size assumed. Larger tanks have relatively lower evaporation losses and therefore would benefit even more from water-control methods that help water storage over longer periods. Assuming a 20% increase in the command area, water control would decrease risk of crop failure from 0.73 to 0.59.

In summary, water control of the kind described would permit irrigation of a 20% larger command area at a 17% lower risk of crop failure (from 0.69 to 0.59), and the water left in the tank at the end of the first season would be 24% more than the amount stored with no water control.

The increased irrigated area would generate additional revenue to the government, as higher rates would be collected from the larger areas. This would be sufficient

Table 16. Results of the Simulation Model of Tank Operation with Irrigation on Alfisols (Basis: 1901 to 1970 daily rainfall data for Hyderabad).

Command Area	10 ha		12 ha	
Water requirement	1000 $m^3 d^{-1}$ outlet		1200 m^3 d^{-1} outlet	
Control	Daily outlet	No outlet on rainy days	Daily outlet	No outlet on rainy days
Case	(1)[1]	(2)[2]	(3)[1]	(4)[2]
No. of years with empty tank at the end of the 43rd week (end October)	48	39	51	41
Probability of empty tank (%)	69	56	73	59
Average volume of water remaining in tank after 43rd week (m^3)	23800	33000	22200	29600
Relative water saving (%)	100	139	100	133
	100	139	93	124

1. Without water control.
2. With water control.

Table 17. Expected returns and expenditure (000 000 Rs) from improved water-management alternatives in tank-irrigated areas of selected Indian states.

	Expected returns		Alternative expected expenditure				
			Grant for water regulator		Supervision and water regulation		
						Government[6]	
	Farmers[1]	Govern-ment[2]	Farmers[3]	Govern-ment[4]	Farmers[5]	Inspectors and supervisors	Super-visors
Andhra Pradesh	140.0	6.8	24.0	6.0	30.0	6.24	4.80
Karnataka	65.6	5.2	19.2	4.8	24.0	3.12	2.40
Maharashtra	19.3	6.2	NA[7]	NA	NA	NA	NA
Tamil Nadu	**129.7**	**9.4**	**9.9**	6.6	16.5	4.78	3.67

1. From 20% additional irrigated area at average farmers' net returns.
2. From 20% additional irrigated area at present water rates.
3. Farmers pay 80% of salary (Rs 100 $month^{-1}$) for water regulators.
4. Government pays 20% of salary (Rs 25 $month^{-1}$) for water regulators.
5. Farmers pay full salary (Rs 125 $month^{-1}$) for water regulator.
6. Government pays for special supervisory staff, either a) inspectors (one per 50 tanks) and supervisors (one per 20 inspectors), or b) supervisors (one per 100 tanks).
7. NA = data not available.

Source: BR. Venkatram (1985).

to employ the tank managers required. Substantial extra income will also accrue to those cultivators who would bring additional land under irrigation (Table 17). Moreover, farmers will derive benefits during those years when the tank does not run dry prematurely (as would have happened without water control). These benefits are less visible but amount to another 5% of total irrigated area. That is, if a water regulator controls the flow, and instead of running dry every 10 years without water control the tank runs dry only every 20 years, then instead of 10% the loss is only 5% which implies a gain of 5% in the annual net returns from the irrigated area. This stability gain would provide the major argument to convince all farmers that they would have to contribute to support such a water regulator. In addition, the general argument holds that water rates are not being increased even though costs have increased. Water control will, of course, not be free of cost. An organization to employ and supervise tank controllers has to be set up. This organization has to be planned for individual states in India in such a way that it fits into the existing structure of the department responsible for tank irrigation.

Expected Costs of Water Regulation

The government and farmers, with their investments pooled, should be able to achieve through the TIA much more than could be effected by either party separately.

Tank-irrigation committees would have to be formed at the village level according to certain statutory rules; these committees would employ a water regulator for every tank. Conditions in the states of Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu were studied to propose the most feasible organization. The costs of the water-control systems projected for each state were compared with the expected returns from a 20% larger tank-irrigated area. These comparisons are presented in Table 17. It shows for each of the states included in the study the expected total returns to farmers and to the state governments from a water-control system. The returns to farmers of course exceed those to the state governments by a multiple of over 15, as the farmers' average net returns from tank-irrigated agriculture exceed the presently paid water rates by the same multiple.

The two alternatives envisaged for financing the schemes in the different states, and expenditures required are also presented in Table 17. One, a state government grant would cover 20% of the water regulator's salary, while the remainder will be paid by the farmers, who will also provide supervision. Two, the farmers would be entirely responsible for the salary while the government will provide supervisors and/or inspectors. The expenditure for farmers would in all cases be only a fraction of their returns from a 20% additional command area; the expenditure for the government would in no case exceed their returns from increased income from water charges on the 20% additional irrigated area.

This exercise is indicative of the feasibility of the scheme at the aggregate level; the scheme is feasible and economically highly profitable to farmers while also moderately remunerative to governments (Venkatram 1985).

The implementation of the scheme at the village level may initially pose some problems, as those who now have access to sufficient water might have fears about its availability when the command area is extended. Their experience, however, of better stability of water supplies for the first season and having 24% more water for the second season (which has not been accounted for in terms of additional irrigated area) should convince the reluctant ones to collaborate.

This concept of establishing a TIA would fall into the category of indirect investment approaches, which Coward (1985) favors as a measure for inducing farmers' participation and mobilization of local resources.

Nevertheless, further study and experimental research in villages is required to decide how best and where to implement this concept. A proposal for such experimental research on tank control was submitted to and accepted by the Government of Andhra Pradesh, Council for Scientific Research, in 1984.

Composite Watershed Management (CWM) on Alfisols

Historically one can observe a nonlinear relationship between population density and tank irrigation in large parts of India; tanks tend to be established at population densities of 50 to 60 persons knr^2 and higher population densities bring about more tanks up to a maximum of about 220 persons $km"^2$, beyond which tanks tend to decrease (von Oppen and Subba Rao 1980, Part I). This observation is based on the simple truth that with increasing population pressure the value of the land which a tank occupies increases. Consequently, the rationale of the use and maintenance of the tank as a common property resource is increasingly being questioned by farmers and landless people. Private claims on the fertile tank land are followed by encroachments, which in turn lead to lower water levels and decreased irrigation efficiencies.

At the same time, wells in the tank command area do provide water for irrigation. If tapped and recharged efficiently, this groundwater reservoir can irrigate all or more of the land formerly served by the tank, assuming favorable hydro-geologic characteristics.

The approach proposed here aims at incorporating the entire watershed, i.e., the traditional catchment of a tank plus its submerged and command areas. For such an area a management system is envisaged which combines erosion- and runoff-controlling land management (i.e., through vegetative cover, bunds, check dams, small percolation tanks, etc.) with irrigation wells for lifting groundwater. The well water is being lifted on a sustained basis to the extent of annual recharge of groundwater replacing the amount withdrawn.

Research at ICRISAT Center was initiated in 1981 to assess the potential of this concept, keeping in view the cost factors listed above and comparing these with the expected advantages in an optimization framework (for details see Engelhardt 1984).

This research was based on field surveys and a discrete stochastic linear programming model. The model allows the user to assess the impact of CWM on SAT agriculture, which is constrained by the stochastic nature of its water supply. Parametric changes and sensitivity analysis of critical technical and economic parameters such as well density, factor cost, and product prices permits identification of a promising natural and socioeconomic environment for implementation of the new concept.

Results from the model runs have been summarized in Figure 10. The benefits from water management were calculated in terms of net returns (Rs ha^{-1}) and employment (man-days ha^{-1}). For comparison, the benefits of five different systems were calculated, ranging from a situation of rainfed agriculture without any wells to systems with wells (at three levels of well densities), but with little or no groundwater recharge.

Rainfed agriculture without wells produces net returns of Rs 200 ha^{-1} and provides employment of about 30 man-days ha^{-1}. In contrast, well irrigation drastically increases benefits to twice (at 5 wells per 100 ha) or more than thrice (at 15 wells per 100 ha) the levels of rainfed agriculture. However, especially at higher densities, well irrigation is restricted by limited groundwater recharge. Substantial increases in net returns can be generated at high well densities through artificial groundwater recharge. At optimum levels of groundwater recharge the increase in productivity would be about 30% at low well densities of 5 wells per 100 ha but 70% at densities of 15 wells per 100 ha.

This concept of CWM attains additional significance if we look at it in the context of developments in water-lifting technology. Groundwater-exploitation technologies such as locating groundwater, drilling deep wells, and energized pumping have become increasingly accessible to farmers. Credit institutes too are encouraging use of groundwater for irrigation.

New technologies such as solar-powered pumps are likely to be available in the near future. A study by Sir William Halcrow (1983) states that: "Solar pump costs have declined appreciably and will probably continue to do so. At the cost levels which it is predicted will apply by 1987, the Specific Capital Cost of systems designed to pump through static lifts of 7m and 20m are estimated to be in the band \$0.9 to \$ 1.5 $kJ^{-1}d^{-1}$, compared with around \$2.8 $kJ^{-1}d^{-1}$ for well designed systems at prices current in Phase I. As the price of photovoltaic arrays continues to fall and systems become more efficient and manufactured

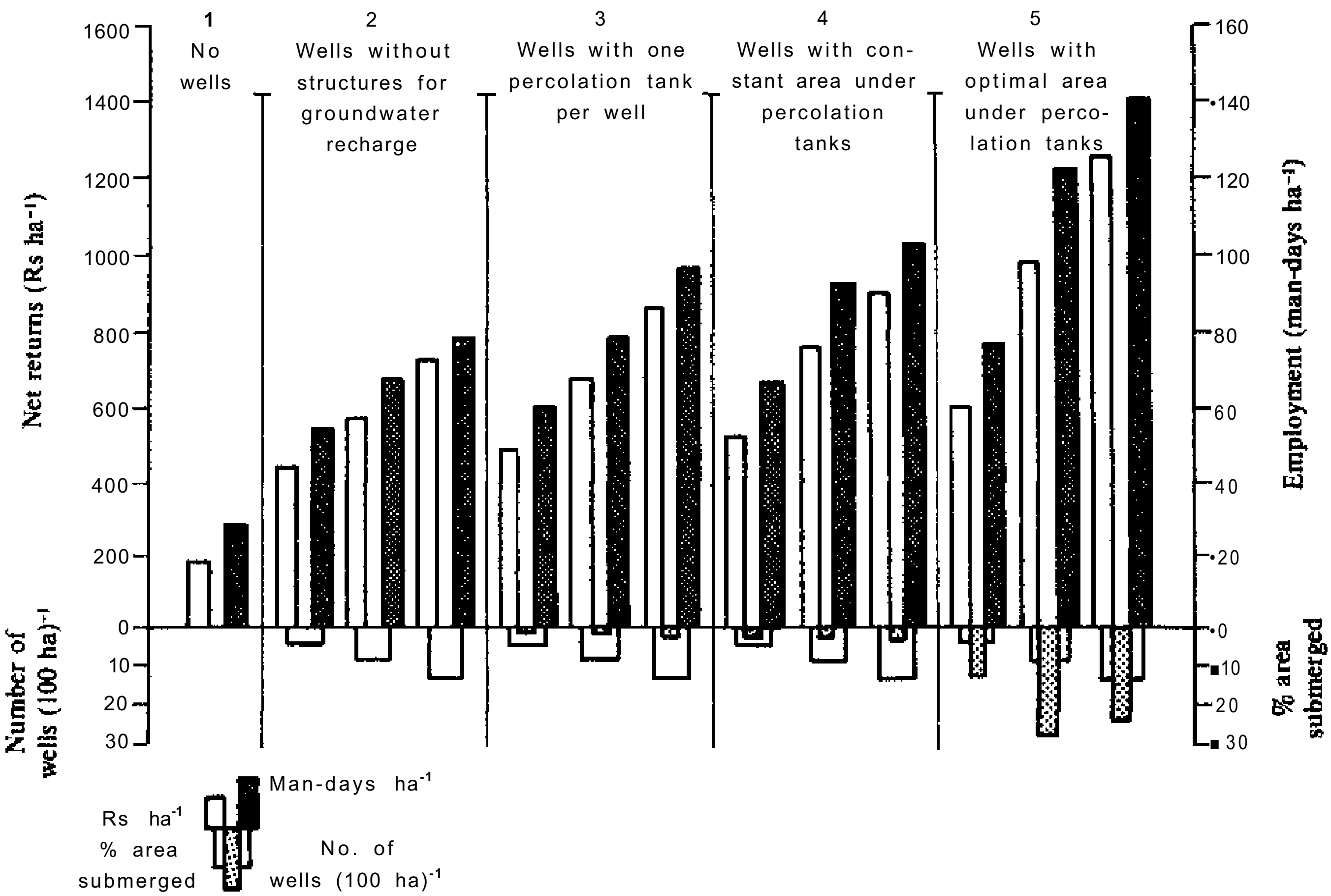

Figure 10. Net returns and employment on an Alfisol watershed under alternative water-management systems (results based on a model).

in greater volume, the specific capital costs should fall to around \$0.5 $kJ^{-1}d^{-1}$ by 1993." The specific capital cost is the capital cost of the system per unit of hydraulic energy output over a standard solar day of 5 KWH m^{-2}.

Solar pumps require relatively shallow water tables from which to lift water; CWM will be of help to ensure sustained irrigation by means of solar energy from water tables maintained at reasonably shallow levels. This will yield not only economic benefits but also a socially desirable effect of equitable access to water, since falling groundwater levels call for deeper wells and larger capacity pumps which only the richer farmers can afford. A solar-powered groundwater-managed system of well irrigation would provide more even access to well irrigation for all farmers.

Summary

- Tank-water controllers could be reintroduced at the village level to increase the water-use efficiency.

Simulation results show that with the improvement of water control, e.g., by closing sluices on rainy days, a 20% larger command area can be irrigated. Accordingly, creation of a Tank Irrigation Authority (TIA) is proposed for training and supervising the water controllers and for being responsible for revenue collection as well as repair and overall tank management. Investment required to set up and operate the TIA is justified by the expected returns from increased and more stable production in the tank command areas. Two concepts are being explored, one being conservation of tanks and the other, more radical, aiming at CWM. These concepts should be tested empirically in field experiments.

The concept of CWM on Alfisols involves a system of runoff- and erosion-controlling land management for enhanced groundwater recharge and sustained well irrigation. This concept was analyzed at ICRISAT Center and was found to generate considerable gains in net returns and employment. Further research on CWM is presently underway at two locations, Aurepalle and Anantapur, to substantiate these findings.

6. Summary and Conclusions

Tank-irrigation technology has had a deep influence on the cultural development in many regions of India. Spatial distribution of tank irrigation has been determined primarily by physical factors such as hard rock substratum, vapor pressure, postmonsoon rains, low moisture-holding capacity of soils, and by population density. Tank irrigation, especially in southern India, is very closely interwoven with settlement pattern and village organization. Nevertheless, in many parts of the country, especially in areas of high population density, irrigation tanks are in decay and the area irrigated by tanks is declining.

There are three reasons for this decline in tank irrigation. (1) The human pressure on land transforms the environment and affects the performance of irrigation tanks; vegetation in the catchment areas decreases because of over-utilization; subsequent erosion and flash run-off cause siltation of the tank beds and breaches of tanks. (2) Alternative sources for irrigation water have been developed, especially well water lifted by mechanical devices. Public as well as private investments tend to favour these options over the traditional tank-irrigation schemes. (3) The administration of irrigation tanks is neglected, leading to increasingly inefficient water use which in turn accelerates the redirection of private investments. Irrigation tanks are increasingly being treated as common property resources, exploited without proper management, and degraded.

Nevertheless, a survey of 32 tanks in Andhra Pradesh and Maharashtra shows that there is potential for economically beneficial tank irrigation. There are tanks which generate internal rates of return of 23%. High water-use efficiency and command-area utilization are the major factors associated with high rates of return from tank irrigation.

Since tank irrigation has potentially high economic payoffs, means to rehabilitate irrigation tanks should be found. In order to increase water-use efficiency, tank-water controllers should be reintroduced at the village level, and authorized to operate the water sluices for better water control. Formation of a Tank Irrigation Authority (TIA) at the state level is recommended. The TIA would train and supervise the water controllers and be responsible for improved tank management. Cost calculations show that the investment required to set up and operate a TIA in the three southern states of Andhra Pradesh, Karnataka, and Tamil Nadu is justified by the expected returns from increased stability and increased area under tanks.

The concept of composite watershed management (CWM) on Alfisols proposes a system of runoff- and erosion-controlling land management for enhanced groundwater recharge and sustained well irrigation. This concept was analyzed at 1CRISAT Center in a modeling exercise, and it was found to have considerable economic potential. Further research on CWM is underway.

In addition to its economic potential, CWM will have the socially desirable effect of providing more equitable access to water. It will also be beneficial to use the anticipated technology of solar- powered water lifting by ensuring relatively shallow water tables for effective exploitation.

7. References

All India Economic Conference. 1937. Economic life of Hyderabad. Hyderabad, India: Government Central Press. pp 117.

Andhra Pradesh: Department of Information and Public Relations. 1953. History and legend in Hyderabad (Dn). Hyderabad, A.P. Department of Information and Public Relations.

Appadorai, A. 1936. Economic conditions in southern India (1000-1500 AD). University of Madras pp.202-203.

Baliga, B.S. 1960. Studies in Madras administration. Vol.11. Madras, India: Government of Madras.

Bandara, C.M. 1977. Hydrological consequences of agrarian change. Pages 323-339 *in* Green revolution? (Farmer, B.H., ed.), London, UK: The MacMillan Press.

Chambers, R. 1977. Men and water: the organisation and operation of irrigation. Pages 340-363 *in* Green revolution? (Farmer, B.H., ed.), London, UK: The MacMillan Press.

Coward, E. W., Jr. 1985. Traditional irrigation systems and government assistance: current research findings from Southeast Asia. Pages 1-30 *in* Traditional irrigation schemes and potential for their improvement. Proceedings of Irrigation Symposium, 1985, Deutscher Verband fur Wasserwirtschaft und Kulturbau vcrlagpaul parey (Mock, J.F., ed.), Hamburg, Berlin Bulletin 9.

Davies, C.C. 1976. An historical atlas of the Indian peninsula. 2nd edn. Madras, India: Oxford University Press. 73 pp.

Engelhardt, T. 1984. Economics of traditional small-holder irrigation systems in the SAT of South India. Ph.D. thesis, University of Stuttgart-Hohenheim, Federal Republic of Germany. 173 pp.

Gittinger, J.P. 1982. Economic analysis of agricultural projects. 2nd ed. Baltimore, USA: John Hopkins University Press. 505 pp.

Gopal Reddy, Y. 1973. Agriculture under Kakatiyas of Warangal. Itihas, Journal of Andhra Pradesh Archives. 1: 56-65.

Halcrow, Sir William. 1983. Small-scale solar-powered pumping systems: the technology, its economics and management. World Bank, UNDP Project GLO/80/003.

Hanumantha Rao, C.H. 1968. Fluctuations in agricultural growth. Economic and Political Weekly 3(I-2):87-94.

Harris, D.G. 1923. Irrigation in India. London, UK: Oxford University Press.

Ludden, D. 1978. Ecological zones in the cultural economy of irrigation in southern Tamil Nadu. South Asia 1(NS): 1-13.

Madras Presidency Report. 1885. Manual of administration of the Madras Presidency. Vol. 1(A). pp. 319-406.

Meinzen-Dick, R.S. 1984. Local management of tank irrigation in South India: organization and operation. Cornell Studies in Irrigation no. 3. Ithaca, New York, USA: Cornell University.

Palanisami, K. 1981. Irrigation tank rehabilitation. New Irrigation Era 19(3):36-37.

Palanisami, K., and Easter William, K. 1984. Irrigation tanks of South India: management strategies and investment alternatives. Indian Journal of Agricultural Economics 34 (2):214-223.

Sharma, P.N. 1981. Optimization of small reservoir irrigation system for semi-arid tropics. Ph.D. thesis, University of California, Davis, California, USA.

Smith, B.R. 1856. Irrigation in southern India. London, U.K: Elder and Co.

Vaidehi Krishna Murty, A. 1970. Social and economic conditions in eastern Deccan (1000-1250 AD). Madras, India: Kabeer Printing Press.

Venkatram, B.R. 1985. Administrative feasibility of a tank irrigation authority. Economics Program Consultancy Report. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution).

von Oppen, M. 1978. Instability of area and production under tank irrigation in selected districts of Andhra Pradesh and Tamil Nadu. Economics Program Discussion Paper no. 9. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics (Limited distribution).

von Oppen, M., and Subba Rao, K.V. 1980. Tank irrigation in semi-arid tropical India. Part I. Historical development and spatial distribution. Economics Program Progress Report no.5. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics (Limited distribution).

von Oppen, M., and Subba Rao, K.V. 1980. Tank irrigation in semi-arid tropical India. Part II. Technical features and economic performance. Economics Program Progress Report no.8. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics (Limited distribution).

von Oppen, M., Subba Rao, K.V., and Engelhardt, T. 1983. Alternatives for improving small scale irrigation systems in alfisols watersheds in India: a position paper. Presented at the University of Minnesota/Colorado University/USAID Workshop on Water Management and Policy, 13-15 Sept 1983, Khon Kaen, Thailand. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution).

Yazdani, G. (ed.). 1960. The early history of the Deccan. London, UK: Oxford University Press, Parts 1-4, pp. 8-9.

Yazdani, G. (ed) 1960. The early history of the Deccan. London, UK: Oxford University Press, Parts 7-11, pp.667-680.

8. Appendix

Appendix 1. Codes used for selected taluks and villages in Andhra Pradesh and Maharashtra where tanks were surveyed.

Sl. no.	District	Taluk code	Taluk name	Village[1] code	Village name
1.	Medak	A	Medak	AA	Borugpally
2.	Medak		Medak	AB	Rayanpally
3.	Medak	B	Narsapur	BA	Narsapur
4.	Medak		Narsapur	BB	Rustumpet
5.	Medak	C	Andole	CA	Andole
6.	Medak		Andole	CB	Annasagar
7.	Medak	D	Siddipet	DA	Raghavapur
8.	Medak		Siddipet	DB	Rajakapet
9.	Medak	E	Gajwel	EA	Gajwel
10.	Medak		Gajwel	EB	Pregnapur
11.	Mahbubnagar	F	Mahbubnagar	FA	Tankara
12.	Mahbubnagar	G	Wanaparthy	GA	Rajanagar
13.	Mahbubnagar		Wanaparthy	GB	Wanaparthy
14.	Mahbubnagar	H	Gadwal	HA	Sangal
15.	Mahbubnagar		Gadwai	HB	Parmal
16.	Mahbubnagar	J	Nagarkurnool	JA	Chirikipally
17.	Mahbubnagar	K	Shadnagar	KA	Motighanapur
18.	Mahbubnagar		Shadnagar	KB	Raikal
19.	Mahbubnagar	L	Atmakur	LA	Madepalli
20.	Mahbubnagar		Atmakur	LB	Erladinne
21.	Anantapur	M	Anantapur	MA	Singanamalla
22.	Anantapur	N	Gooty	NA	Gooty
23.	Anantapur		Gooty	NB	Pathakotacheru
24.	Kurnool	P	Dronachalam	PA	Veldurty
25.	Kurnool	Q	Atmakur	QA	Siddapuram
26.	Akola	R	Washmi	RA	Borala
27.	Akola		Washmi	RB	Shirupati
28.	Akola	S	Mangrolpur	SA	Wathod
29.	Akola	T	Murtizapur	TA	Karanza
30.	Sholapur	U	Mangalwade	UA	Talsangi
31.	Sholapur	V	Sangola	VA	Achakandi
32.	Sholapur		Sangola	VB	Chincholi

1. Villages AA to QA belong to Andhra Pradesh state, and RA to VB belong to Maharashtra state.

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