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TANK IRRIGATION IN SEMI-ARID TROPICAL INDIA
PART II: TECHNICAL FEATURES AND ECONOMIC PERFORMANCE

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I. INTRODUCTION

Small water reservoirs behind earthen dams are called tanks in India. Tanks supply many villages with drinking water, but their primary purpose is to provide water for irrigation. Tank irrigation is an old, established practice in most of the semi-arid tropical parts of India. Here the monsoon rains fall erratically during a few months in the year, and irrigation tanks serve to store and regulate the flow of water for agricultural use. In the southern states of India this water is used primarily for the production of rice.

The present study was undertaken to gain a better understanding of the historical and institutional influences, the economic forces, and the technical conditions that have interacted to bring about tank irrigation in India as it is practised today. An understanding of these forces will be valuable to ICRISAT in its efforts to improve the water/soil management systems in the semi-arid tropics of the world, which is one of its mandates.

The study is presented in three parts. The first part gives a brief review of historical records documenting the development of tank irrigation over time, and discusses the relationship of population density and physical factors to the development of tank irrigation (see von Oppen and Subba Rao 1980a). The second part (presented here) is an attempt to determine the economic performance of irrigation tanks. The third part (von Oppen and

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Subba Rao 1980a) discusses the drawbacks in terms of instability and low water use efficiency of tank irrigation as it is practised today. Suggestions are made for improvements through better water control and reorganization of tank management. An approach for judging the possibilities and limitations of transferring India's tank technology to other places in the SAT is proposed.

II. TECHNICAL FEATURES DETERMINING ECONOMIC PERFORMANCE OF IRRIGATION TANKS

The analysis presented in Part I of this study of the regional distribution of tank density in India documents the importance of environmental conditions and population density in determining the existence or absence of irrigation tanks in different regions over time. Similarly, individual irrigation tanks differ in their economic performance because local environmental conditions favor one site over another and thereby predetermine the technical details of a tank's construction. An understanding of some of the technical aspects of tank construction is required for understanding the approach of the economic analysis; this is necessary because some gaps in the data base on some aspects compel us to generate synthetically some of the required information. Table 1 gives a summary of the various data sets available on individual tanks and the type of analysis for which they were used.

The largest set (No. 1) with 45 tanks provides information to show the relationship between tank sizes measured in different ways to settled command area and bund length.

Another set (No. 4) of 16 tanks contains data on the costs of construction together with settled command area and length of bund.

Finally, two sets (Nos. 2 and 3) of 32 tanks together have been

Table 1. Information available from different 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	*	-	-	-
Storage capacity	*	-	-	-
Length of bund	*	*	*	*
Settled command area	*	*	*	*
Rainfall & command area utilization	-	*	-	-
Costs	-	-	-	*
Benefits	-	*	*	-
Size distribution	-	*	*	-
Cropping patterns	-	*	*	-
Source of information	PWD[a], IDC[b]	ICRISAT survey	ICRISAT survey	ICRISAT survey

*Indicates information available

-Indicates information not available

a. Public Works Department
b. Irrigation Development Corporation

compiled from own surveys to assess farmers' benefits due to irrigation from tanks, for which again settled command area and length of bund are the only technical data known.

Thus the three data sets are overlapping in the information on two variables, i.e., "settled command area" and "length of bund" for each tank.

Fortunately, as shall be shown below, these two variables contain sufficient information because of their measurable relationships to other variables. Most importantly, they are significantly related to various types of construction costs so that on the basis of "length of bund" and "settled command area" an estimate of the cost of an irrigation tank can be synthesized.

It is the objective of this chapter to explore the relationships between length of bund and settled command area; tank size and utilization of rainfall; and other variables. With the help of these relationships the three sets of data on irrigation tanks can be used for economic analysis.

A Length of Bund and Size of Command Area

An irrigation tank is a water reservoir behind an earthen dam constructed across the slope of a valley to catch and store running rainwater for the purpose of irrigating agricultural land.

The dam or bund that holds the water varies in size and shape according to the topography of the valley. As the bund constitutes a major part of the costs of an irrigation tank system, it is important that the bund be built in a location and with a shape such as to safely hold a maximum of water with a minimum of earthworks required.

The steeper a valley, the cheaper can bunds be built. Across a narrow gorge between two rocks or hillocks a relatively short and tall bund can be

built in a straight line, or if very tall a convex line, to hold a certain amount of water; this type of tank could be called a gorge-valley tank.[1] On the other hand, where the topography is such that elevations are low and slopes are less steep, a long and not very high bund would be built in a concave line to hold the same amount of water; this type of tank could be called a flood-plain tank.[1]

Thus the same amount of water to irrigate the same command area can be stored either behind a short (and tall) bund or behind a long (and low) bund. Since length of bund and command area are the only two technical variables on which we have information for all tanks (including those for which we want to derive the benefit/cost analysis) it is important that we examine the nature (and costs) of tanks in view of their relationship to length of bund and command area. As Figure 1 shows, the length of bund per unit of settled command area decreases as tank size increases, i.e., larger tanks generally have taller bunds.

Figure 1 was plotted using data of all three sets of tanks; as statistical analysis confirms, all three sets show the same relationships, thus indicating that the data sets are homogeneous in this respect.

This provides the basis for us to assume that certain relationships observed between specified variables within one data set would also hold true for these variables within another data set. These relationships are presented in the following section.

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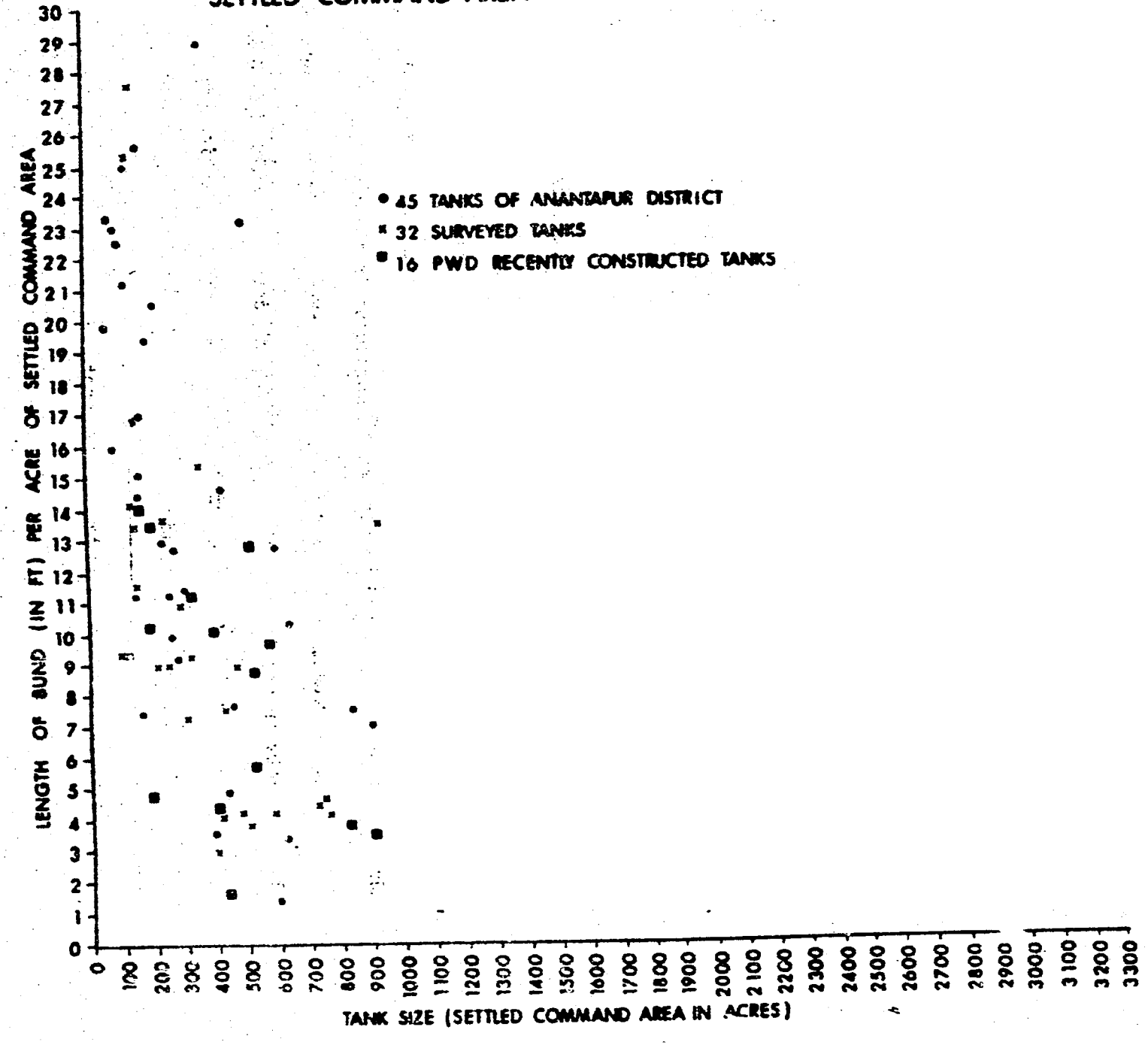
1. Nomenclature suggested by Mr. T. Hanumantha Rao

Figure 1. RELATIONSHIP BETWEEN TANK SIZE AND LENGTH OF BUND PER UNIT OF SETTLED COMMAND AREA



B Other Measures of Tank Size

The amount of water stored and the number of fillings a tank generally gets during the rainy season are the major determinants of the area that can be irrigated from it. The size of a tank is generally expressed by its irrigated area, the so-called "command area." At the time of construction (or rehabilitation) engineers determine the command area on the basis of expected runoff and storage capacity of the tank. This "settled command area" is generally reported and it serves as a measure in official statistics to classify tanks according to size.

The storage capacity of a tank per unit of "settled" command area is more or less constant across averages of different sizes (see Table 2, column 8) and on an average it amounts to 1.5 meters of water. However, within size groups this measure varies between .35 to 2.9 meters according to the variations in number of fillings, amount of runoff, etc.

If for a paddy crop, 1.5 meters of water are required for one crop the average tank requires just about one filling, plus the amount of inflow required to off-set losses of percolation and (negligible) losses of evaporation during the rainy season. For a second crop, a second filling preferably towards the end of the rainy season is needed. After the rains are over no additional inflows can be expected to off-set the considerable losses of percolation and especially evaporation. Therefore, even a full tank at the end of the rainy season will not be sufficient to irrigate the full comand area but only a portion corresponding to the amount not lost.

For instance, losses of an average of 5 mm^2 a day over 120 days of rowing season would imply that approximately about 60 cm or 40% of the tored water would be lost so that the remaining quantity would be just ufficient to irrigate a little more than half the command area in the econd season. This, in fact, is the assumption made by the Public Works epartment in the design of small-scale irrigation works. As we shall see n the following section, the utilization of the command area varies but s generally considerably below 150%.

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

As can be seen from Table 2, column 5, the ratio of settled command area per unit of submerged area increases with increases in tank size. This shows that larger tanks with taller bunds are generally storing more water per unit of submerged area. For our sample in the group of small tanks (below 100 acres) this ratio is .9; for large tanks above 1000 acres it is 1.5; the average ratio for all tanks studied is 1.2. In the larger tanks the command area may go up to three or four times the submerged area but in smaller tanks the ratio rarely exceeds two. On the other hand, in the sample for all size groups the command area may fall as low as half the submerged area, but not below that.

C Utilization of Tank Command Area

The settled command area is determined on the basis of engineering data;

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2. Assuming a command area of about one to two times the submerged area.

Table 2. Technical relationships of different tank sizes (averages for tanks)

Size of Tanks (in Acres)	No.of Tanks	Settled Command Area (SCA) in acres	Submerged Area (SMA) in acres	Storage capacity (STC) in million cubic feet	Length of bund in feet	SCA/SMA	STC/SMA	LB/SCA	STC/SCA
Above 1000	9	1964	1545	413	11330	1.46	0.244	6.8	0.204
Between 500-1000	8	710	786	144	6177	1.29	0.221	9.2	0.201
Between 200-500	13	318	316	55.5	3906	1.29	0.181	12.8	0.185
Between 100-200	9	150	197	32.5	2593	0.95	0.162	17.7	0.209
Below 100	6	73	85	12.5	1908	0.90	0.144	29.1	0.173
All Tanks	45	651	591	132.4	5266	1.2	0.192	14.1	0.195

thus it reflects the judgment of the engineers at the time of completion of the work about water inflows, storage capacities, losses, etc. However, in cases where it later turns out that the runoff from the catchment is more than anticipated, that the water losses are less than estimated, and that the pattern of water use is more efficient than originally assumed, the "settled command area" will be less than the "area actually irrigated." In that case either a larger area can be irrigated by expanding the canal system or the area under a second crop will be larger than assumed, or both.

In the opposite case of an over-estimated settled command area, the reverse will be true. Where siltation fills up the tank bed and thus reduces the storage capacity of the tank, the area actually irrigated may gradually drop even below the settled command area.

For the economic analysis the area actually irrigated -- the degree to which the settled command area is being used -- is the relevant measure upon which we must base our calculations of economic performance rather than the settled command area.

Consequently, it is important to investigate factors affecting the utilization of the command area, particularly rainfall, local conditions, and tank-specific information.

For many tanks the information on area actually irrigated from a particular tank is not available for every year, especially not for years earlier than 10 years ago, because in many taluka headquarters such records normally are not kept for more than 10 years.

For an economic evaluation, a time series of the area actually irrigated for about 20 years without gaps is preferable. This estimate can be

established with the help of an explanatory model, expressing utilization as a function of rainfall, local conditions (soils, slopes, topography) and tank-specific information. By inserting data on rainfall an estimate can be made of the approximately irrigated area.

The data for this analysis comprise 10 years of rainfall observations. They were collected as part of the survey of 28 tanks (set 2 in Table 1). The estimation model used was as follows:

$$AI/SC = a + b_1 RN - b_2 RN^2 + c_i D_i$$

where AI/SC = the utilization ratio of area actually irrigated over settled command area, RN = annual rainfall, D_i = are dummy variables to represent local and tank specific conditions at tank i and a, b_1, b_2 and c_i are estimation coefficients. The estimation was done separately on data from:

a. two sets of five tanks each in Medak and Mahbubnagar districts,

b. five tanks in Anantapur/Kurnool districts,

c. three tanks in Sholapur district,

d. eighteen tanks from all the above districts.

The estimated coefficients are tabulated in Table 3. The results show that in Medak/Mahbubnagar and also in Sholapur districts rainfall significantly determines the percentage utilization of the command area. The higher the rainfall, the higher the percentage of settled command area actually irrigated; however the increase is non-linear and follows a decreasing rate (see also Fig. 2). The high t-values on most of the dummy variables in all equations show the significance of the impact of local and tank-specific conditions on utilization of settled command area.

Table 3. Parameters explaining utilization of settled command area as a function of rainfall in different districts

Variables	Medak & Mahbubnagar		Anantapur & Kurnool		Sholapur		Combined	
	Regression Coefficients	t-value	Regression Coefficients	t-value	Regression Coefficients	t-value	Regression Coefficients	t-value
Rainfall (b_1)	0.173	2.14	0.102	1.0	0.041	1.4	0.115	1.0
Rainfall square (b_2)	-0.00007	1.4	-0.00002	0.25	-0.00002	1.1	-0.00004	1.9
Tank Specific Dummies								
C_1	25.8	1.9	161.6	17.7	19.9	2.7	74.6	6.1
C_2	43.4	3.4	43.8	4.6	-13.4	1.7	89.0	7.2
C_3	55.5	3.8	31.5	3.0			105.0	7.7
C_4	-27.9	2.2	-3.7	0.4			19.0	1.5
C_5	-20.0	1.5					27.9	2.2
C_6	8.9	0.6					56.5	4.2
C_7	-6.0	0.5					37.1	3.0
C_8	13.7	1.0					60.3	4.5
C_9	-54.1	3.8					-6.1	0.4
C_{10}							44.7	3.5
C_{11}							171.5	13.7
C_{12}							54.2	4.0
C_{13}							41.8	2.8
C_{14}							10.6	0.8
C_{15}							14.3	1.1
C_{16}							26.9	2.1
C_{17}							-14.4	1.0
Intercept		-5.8		-19.1		11.7		-26.7
R^2		0.65		0.93		0.58		0.80

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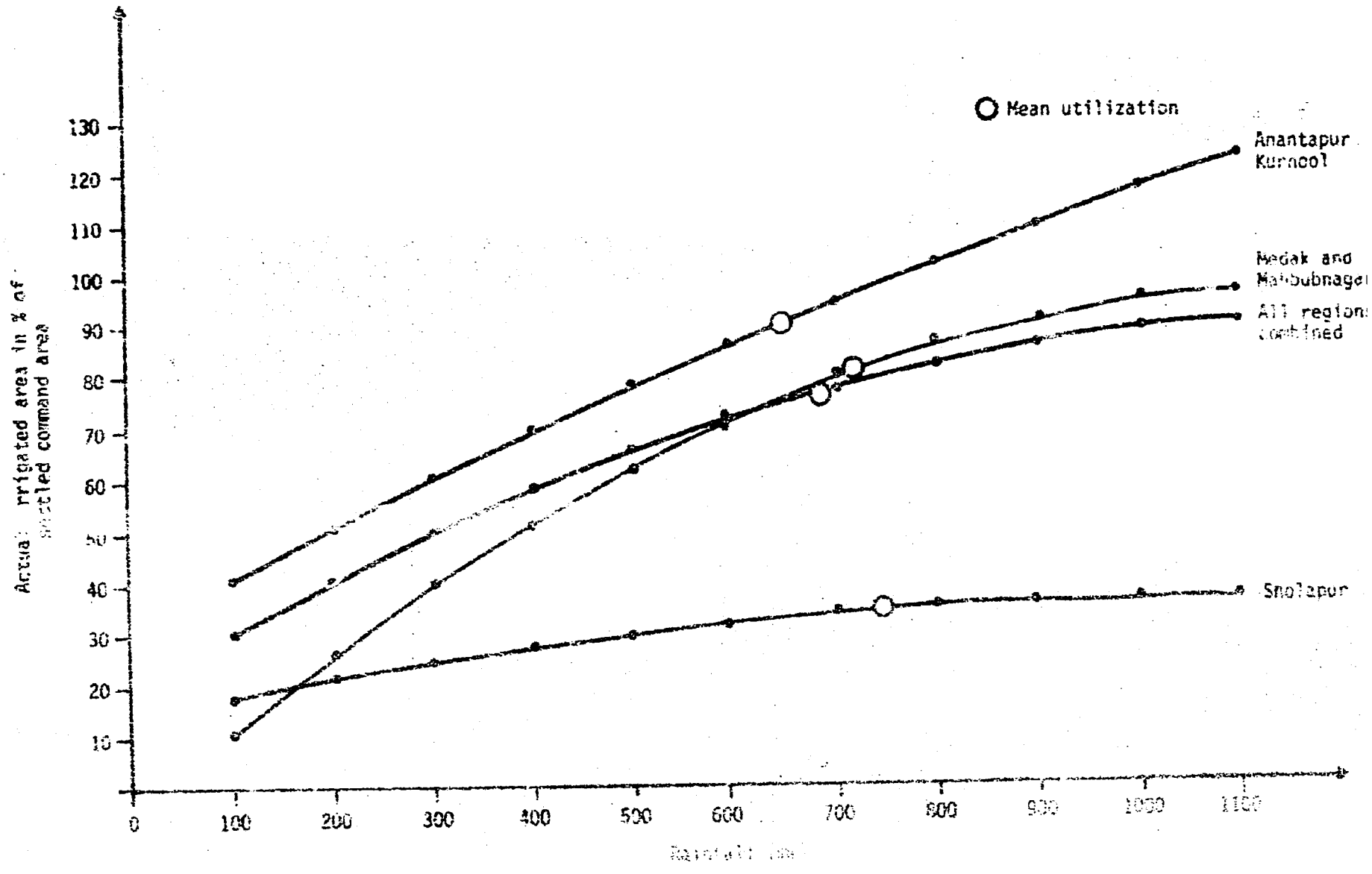
Figure 2. Utilization of settled command area and annual rainfall for selected districts



The coefficient of the dummy variable on a particular tank gives the amount by which the utilization of this tank deviates from the average (i.e., from the intercept plus the coefficient of the leftout dummy). In order to extrapolate, with the help of these coefficients, the settled command area utilization for those years for which data on rainfall only are available, the following procedure was used:

Insert values of mean rainfall into the estimated equation and compute unadjusted percent utilization. Then for every individual tank take difference between "actual mean utilization" for past 10 years and "unadjusted percent utilization" over past 10 years to establish adjustment coefficient for this tank. This adjustment coefficient is then used to adjust annual estimates of utilization percentage for those years for which the data are not available.

In this way, from time series data of 10 years of actual areas irrigated another 10 years of estimated areas irrigated could be created for all 28 tanks. These 20 years time series are needed to derive the benefit streams of tank irrigation. We are now in a position to prepare a comparison of benefits and costs of tank irrigation.

III. ECONOMICS OF TANK IRRIGATION

A Methodology and Data Sources

As shown in Table 1 and explained above, the data for establishing the benefit/cost analysis of tank irrigation systems had to be gathered from different sources.

Information on present construction costs of tanks in Andhra Pradesh was available from the Public Works Department (PWD), Minor Irrigation in

Hyderabad.[3] These cost figures on a total of 16 tanks constructed during 1974-76 could be used to derive estimates on the relationships between length of bund, command area and different types of costs. By measuring these relationships, a basis was provided for synthesizing the costs of construction of 32 tanks surveyed to measure irrigation benefits; this approach is presented below in subsection C.

The choice of the 16 tanks was precluded by their availability; we have to assume that they are representative of tanks elsewhere. As shown in Figure 3, they are located in generally the same areas as most of the 28 tanks surveyed in Medak, Mahbubnagar, Anantapur, and Kurnool districts. However, it is possible that a tank built now will be located at a less favorable site than another tank built, say, 70 years ago when far fewer tanks existed, because the better sites are likely to have been taken first. To the extent that this is true, our cost estimates derived from tanks located in relatively unfavorable places would tend to over-estimate the cost component of tank irrigation and thus provide a conservative benefit/cost ratio.

To obtain information on utilization of irrigation tanks and benefits of tank irrigation, a survey was carried out in 32 tanks (for their location, see Fig. 3). These tanks were purposely selected in order to have: (1) one or two tanks within a 15 km radius of a taluka raingauge; (2) technical data and revenue records available at taluka headquarters; (3) tanks that supplied water at least one season during the study year; (4) tanks outside the immediate vicinity of a large township, so that the environment is represen-

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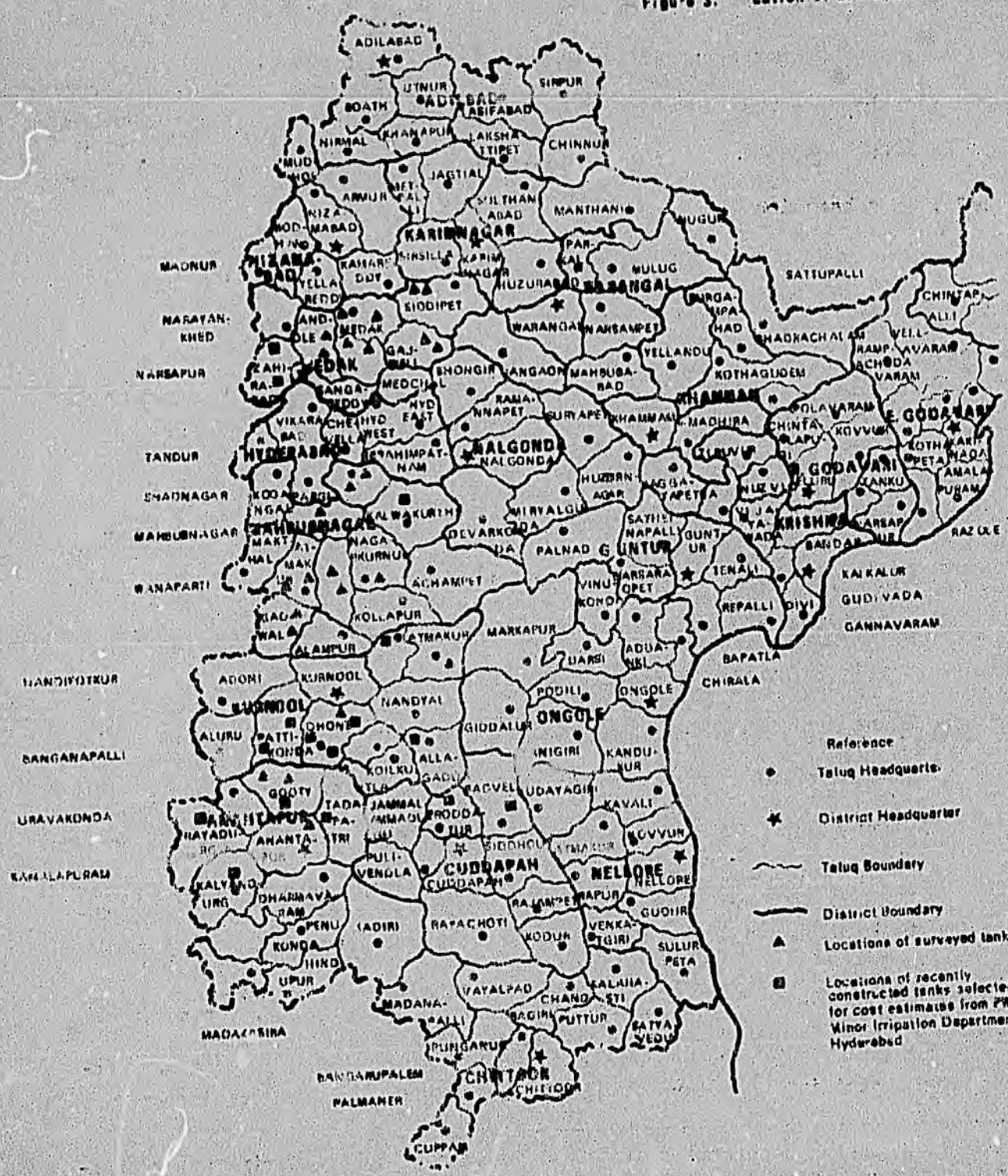
3. Through kind cooperation of Mr. T. Hanumantha Rao, Superintending Engineer, Andhra Pradesh State Irrigation Development Corporation (APSIDC), 7-1-46, Begumpet, Hyderabad 500 016, A.P., India.

Figure 3. cation of surveyed tanks



tative for rural conditions, i.e., limited market access, village wage rates, etc.

The approach taken (as described in subsections B to D) is: (1) to compute benefit data for the 32 tanks for which primary farm survey data have been obtained; (2) to synthesize the cost data for those tanks; (3) to calculate internal rates of return and benefit/cost ratios for the 32 tanks.

The comparison of costs and benefits of tank irrigation follows a scheme presented in Table 4. Thus, an attempt will be made to estimate the financial returns to farmers, financial returns to the "project authority", and economic returns to the nation. Table 4 also shows the data availability.

To the degree that there are data gaps, the analyses remain incomplete; however, these gaps are only of minor order and can be compensated for by suitably qualifying the results.

The "project authority" is a hypothetical body introduced here in order to assess what would be the benefits and costs in case a private corporation undertook tank irrigation on a commercial basis. As shall be seen later, there may be a case for actually creating such a body. However, at this stage, this is not our concern.

Benefits of tank irrigation were calculated on the basis of information collected from farmers on returns from crops with tank irrigation versus returns from crops without irrigation (rainfed crops). In addition, secondary information was collected on water charges, command area utilization, rainfall, etc.

1. Selection of farmers

A list of beneficiaries under the command area of the selected tank with

Table 4. Comparisons of benefits and costs of irrigation tanks accruing to different participants

Participants	Benefits	Costs	Comparison Criteria
I. Farmer	1.Private net returns at villages prices due to irrigation** 2.Increase in land value** 3.Reduction in Risk*	1.Irrigation charges** 2.Obligations to contribute labor# 3.Uncertainty of water availability*	Financial cost/benefit ratio
II. Project Authority	1.Irrigation fees** 2.Income from fisheries, brick making#	1.Land acquisition** 2.Construction** 3.Maintenance** 4.Water fee collection#	Financial cost/benefit ratio
III. Nation	1.Additional production at average prices** 2.Additional employment** 3.Safety in food production* 4.Higher water table# 5.Less soil erosion#	1.Opportunity cost of capital invested (Interest)* 2.Submerged land*	Economic internal rate of return

*indicates information from other sources is available
**indicates survey data are available
#indicates data or information are not available

their respective holding 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 1974-75 was prepared. Those farmers who owned less than 1 acre of land were omitted; if somebody owns a very small irrigated area, it often is the only land that person may possess.[4] Our study aimed at comparing the returns from irrigated versus unirrigated land cultivated by the same farmers, so that the sample was drawn from farmers with irrigated areas above 1 acre; 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.

2. Method of data collection

Primary data from the respondents on cropping activities, land utilization, input-outputs, etc., were collected on a recall basis through personal interview with the help of a pretested structured schedule. Secondary data on rainfall, command area utilization, etc., were obtained from the irrigation and revenue departments.

The data obtained from farmers included: land utilization, cropping pattern, input-output information on crops, prices, wages and land values. These data were used for calculating farmer net income from tank-irrigated, well-irrigated and rainfed crops.

The data obtained from secondary sources included: daily rainfall for last 10 years for the selected taluks, water levels and actual area irrigated from tanks, cropping pattern of the village, land revenue rates

4. For information on size distribution of farms in our selected tanks, see Appendix II.

and irrigation charges collected and details on the practices of the water distribution system. These data together with farmer benefits were used in tank benefit calculations. Unfortunately, we could not get for the Akola tanks all the data required since neither patwari nor the officials at PWD there had kept the necessary records. All the selected tanks are PWD surface storage tanks above 100 acres of command area under gravity flow irrigation.

Appendix I gives the list of villages in which tanks were surveyed.

B Benefits of Tank Irrigation

The benefits of tank irrigation will be elaborated at the levels of (1) farmers, (2) project authority and (3) state and nation.

1. Benefits to farmers

a) Financial benefits due to irrigation

In computing the financial benefits to farmers, the net returns due to irrigation were derived by computing differences between net returns from tank irrigated land and weighted average net returns from all rainfed crops. This method allows minimizing the "differences-in-farmer-effect" as the same farmers were reporting on their irrigated as well as rainfed land. The procedure requires the following steps:

- Collect input-output data on all crops, for 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 labor, bullock labor for all operations, seed, chemical fertilizers and farm yard manure, insecticides and pesticides, custom 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.
- Following steps 2 to 5 for all rainfed plots, the weighted average net returns from unirrigated land are computed.
- Farmers' net benefits due to tank irrigation are obtained as the difference between weighted net returns from tank irrigated crops and weighted net returns from unirrigated 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 5, columns 13 and 14. It is seen that at village prices, tank irrigation produced average net benefits of Rs. 330 per acre for ten tanks studied in Medak district, of Rs. 380 per acre for ten tanks studied in Mahbubnagar district, and Rs. 265 per acre for five tanks studied in Anantapur/Kurnool districts. For three out of 4 tanks in Akola district, there were no benefits due to tank irrigation, while in Sholapur district the three tanks studied averaged a benefit of Rs. 290 per acre. Thus at village prices, tanks in Telengana and Rayalseema are highly beneficial to farmers and benefits there are more than in tanks in Anantapur/Kurnool.

However, the Sholapur tanks 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 the farmers' benefits. In that case the average tanks in Telengana and Rayalseema

Table 5. Farmer's private/direct benefits, costs and benefit-cost ratios (Rs/acre) in selected tanks of selected districts in India

Tank code	Settled command area (Acres)	Net Returns: At village prices: Tank irrig.	Net Returns: At village prices: Rain-fed	Net Returns: At village prices: (3)/(4)	Net Returns: At average prices: Tank irrig.	Net Returns: At average prices: Rain-fed	Net Returns: At average prices: (6)/(7)	Increase in Land Value: Land value (Rs./acre): Tank irrig.	Increase in Land Value: Land value (Rs./acre): Rain-fed	Increase in Land Value: Ratio (9)/(10)	Benefits: Net benefit due to tank irrig. at vill.prices (Rs)	Benefits: Net benefit due to tank irrig. at av. prices (Rs)	Costs: One season irrig. fee per acre excl. dry assessment	Benefit-Cost Ratio: At village prices	Benefit-Cost Ratio: At average prices
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
AA	363	241	-19	241	409	-42	409	5400	1188	4.55	260	451	16.5	15.8	27.3
AB	719	206	186	1.11	394	186	2.12	6175	2010	3.07	20	208	12.5	1.6	16.6
BA	465	309	225	1.37	559	264	2.12	5340	1500	3.56	84	295	14.5	5.8	20.3
BB	161	546	61	8.95	794	113	7.03	5720	1670	3.43	485	681	14.1	34.4	48.3
CA	499	328	62	5.29	527	60	8.78	4200	1320	3.20	266	467	16.0	16.6	29.2
CB	257	650	1	650	824	9	91.5	8600	1750	4.90	649	816	14.0	46.3	58.3
DA	307	496	189	2.62	590	212	2.78	4750	1400	3.40	307	378	13.3	23.1	28.4
DB	242	840	207	4.06	922	228	4.04	4375	1350	3.20	633	694	15.8	40.1	43.9
EA	223	329	325	1.01	412	332	1.24	5000	2040	2.45	4	80	14.4	0.3	5.6
EB	163	774	170	4.55	832	160	5.20	5250	2050	2.56	604	672	13.0	46.5	51.7
MEDAK	340	472	141	3.35	626	142	4.40	5481	1628	3.37	331	474	14.4	23.0	32.0
FA	102	721	273	2.64	737	224	3.29	4417	1667	2.65	448	513	14.9	30.1	34.4
GA	290	960	329	2.92	953	276	3.45	5215	2125	2.45	631	677	14.7	42.9	46.0
GB	398	657	134	4.90	598	110	5.44	5500	2050	2.68	523	487	16.3	32.1	29.9
HA	736	531	140	3.79	609	55	11.7	4330	1820	2.38	391	554	12.2	32.0	45.4
HB	107	550	103	5.34	567	79	7.18	3833	1714	2.24	447	488	13.0	34.4	37.5
JA	103	705	52	13.6	884	57	1.55	5125	2025	2.53	653	826	13.9	47.0	63.5
KA	140	208	141	1.48	285	165	1.73	4165	1670	2.49	67	119	11.5	5.8	10.3
KB	161	380	102	3.73	506	103	4.91	4420	1870	2.36	[illegible]	403	14.5	19.2	27.8
LA	141	324	80	4.05	454	99	4.59	4000	1875	2.13	244	355	11.8	20.7	30.1
LB	147	325	174	1.87	620	183	3.39	4060	1720	2.36	151	437	10.9	14.8	40.1
MAHBUBNAGAR	233	536	153	3.50	621	135	4.60	4506	1854	2.43	383	486	13.4	28.6	36.3
MA	1112	587	307	1.91	691	336	2.06	9500	2000	4.75	280	355	16.8	16.7	21.1
NA	927	409	163	2.51	622	193	3.22	5000	1500	3.33	244	428	16.0	15.3	26.8
NB	442	402	202	1.99	669	191	3.50	5500	1610	3.42	200	479	16.5	12.1	29.0
ANANTAPUR	327	466	224	2.08	661	240	2.75	6667	1703	3.91	241	421	16.4	14.7	25.6

contd...

Table 5 continued ...

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
PA	319	439	141	3.11	650	146	4.45	5000	1450	3.45	298	504	13.5	22.1	37.3
QA	1067	665	389	1.71	812	435	1.87	6600	2100	3.14	276	377	13.5	20.4	27.9
KURNOOL	693	552	265	2.08	731	291	2.52	5800	1775	3.27	287	441	13.5	21.2	32.6
RA	1001	103	88	1.17	134	93	1.44	1000	1000	1.00	15	41	21.3	0.7	19.2
RB	1100	88	149	0.59	76	116	0.66	1063	na	na	-61	-40	25.2	0	0
SA	759	331	425	0.78	354	361	0.98	2500	2500	1.00	-94	-7	24.5	0	0
TA	425	348	348	1.00	353	348	1.01	5000	na	na	0	5	21.3	0	0.2
AKOLA	821	217	253	0.86	229	230	1.00	2390	1750	1.37	-35	0	23.1	0	0
UA	593	446	95	4.69	339	79	4.29	na	na	na	351	260	34.1	10.3	7.6
VA	484	53	-114	0.53	8	-114	8.00	na	na	na	53	8	13.5	3.9	0.6
VB	1779	517	59	8.80	531	46	11.5	na	na	na	458	485	18.8	24.4	25.8
SHOLAPUR	952	339	14	24	293	4	73	na	na	na	287.3	251	22.1	14.7	11.4

[na] Not available

produce benefits of around Rs. 430 per acre while in Sholapur only Rs. 250 per acre are reached, and in Akola there are no benefits.

b) Increase in land value

The increase in land value due to irrigation was measured by averaging values reported of irrigated and non-irrigated land. Such data could be collected only in Medak, Mahbubnagar, and Anantapur districts. These figures are also presented in Table 5. They show that on the average irrigated land is valued from 2.5 times (in Mahbubnagar) to 3.4 times (in Medak district) the value of dry land. In three tanks, two in Medak district, one in Anantapur, the value of irrigated land was reported to be more than 4 times that of unirrigated land. The lowest ratio of irrigated land value over unirrigated was 2.1 reported for one Mahbubnagar tank. There is not much difference in land values of tank-irrigated and nonirrigated land in districts of Maharashtra.

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

c) Reduction in yield risk

Tank irrigation generally reduces the yield risk in comparison to rainfed cropping, but this implies an increase in the uncertainty of the areas irrigated: the irrigated area is adjusted to the water available and thus yield stability is achieved at the cost of area instability. The farmer benefits from the lower variability of yields in tank-irrigated paddy in the sense that his inputs are more likely to return a profit. This is the

reason why tank-irrigated paddy is given more inputs than rainfed crops. Table 6 shows the average levels of yield, area, and production and their variability for two rainfed crops -- sorghum and pigeonpea -- and the major tank-irrigated crop, paddy, in three districts where tank irrigation is the major source of irrigation. It is seen that the coefficient of yield variations for rainfed sorghum, and especially for pigeonpeas, are far higher than for paddy, while for variability of area the opposite is true, i.e., rainfed areas are more stable than tank-irrigated areas. An exception is found in the case of paddy yields in Medak district, which shows an unusually high coefficient of variation. Upon verifying the data to explain this phenomenon it was found that in fact in 1972-73 very low paddy yields (about 300 kg/ha) were reported for this district while in all other years and all other districts yield did not deviate much from an average of about 1000 kg/ha.

In this particular case, the low yields must have been caused by an unusual rainfall distribution; 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, and most of the paddy crop was spoiled. In this particular year in Medak district, the uncertainty of rainfall had not 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.

Table 6. Variability in area, production and yields in selected districts of Andhra Pradesh

District	Crop	Area ('000 ha.)		Production ('000 tons)		Yield/ha. in kilograms	
		Mean	%CV	Mean	%CV	Mean	%CV
Medak	Sorghum	152.3	15.4	79.6	19.9	532	22.0
	P. pea	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
	P. pea	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
	P. pea	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
	P. pea	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, Government of India, Period: 1965-66 to 1974-75.

The net effect on production is often a higher variability of tank-irrigated rice in comparison to rainfed crops; but this varies from region to region and also over time, with an apparent trend towards increasing instability of tank irrigation (for more details see von Oppen and Subba Rao 1980b).

2. Benefits to Project Authority

In India, at present, tanks are being planned and built by the Public Works Department (PWD), operated by the Panchayat; irrigation charges are collected by the revenue department. There is no Tank Irrigation Authority as yet. If there was 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.

Information was available from the Patwari's tank records about the revenue collected over the last 10 years. This information is presented in Table 7, column 9. The revenue collected per irrigated acre in Andhra Pradesh was 14 Rs on average, varying slightly from tank to tank between 11 Rs and 16 Rs. In Maharashtra, a system prevails of rates scaled according to water consumption of the different crops. On average a rate of Rs. 23 per irrigated acre was found to be charged.

3. Benefits to the State and National Economy

a) Additional food production

The major benefit of tank irrigation -- as well as any irrigation project -- is the additional production of food grains it generates. The computation of farmers' net benefits at average prices (see Table 5) reflects

Table 7. Costs and benefits to the project authority

Tank Code	SCA (Acres)	Cost: Total Cost of bund (Rs)	Cost: All other costs (Rs)	Cost: Total cost of the project (Rs)	Cost: Cost/ Acre of SCA (Rs)	Cost: Present value per acre cost assuming 22 years life at 10% interest rate	Cost: Total cost/ acre incl. Rs.10/acre maint. and repairs (Rs)	Benefit: Revenue collected per acre (Rs)	Benefit: Benefit Cost Ratio (9)/(8)
1	2	3	4	5	6	7	8	9	10
AA	363	1244320	574992	1819312	5012	615.7	625.7	16.5	0.026
AB	719	1243520	800786	2044306	2843	349.3	359.3	12.5	0.035
BA	465	1127776	640270	1768046	3802	467	477	14.5	0.030
BB	161	453499	285706	739205	4591	564	574	14.1	0.025
CA	499	813200	666913	1480113	2966	364	374	16	0.043
CB	257	623300	421082	1044382	4063	499	509	14	0.028
DA	307	659780	482742	1142522	3721	457	467	13.3	0.028
DB	242	762300	401296	1163596	4808	591	601	15.8	0.026
EA	223	540086	375861	915947	4107	504	514	14.4	0.028
EB	163	865800	288852	1154652	7083	870	880	13	0.015
MEDAK	340	833358	493849	1327208	4300	528	538	14.4	0.027
FA	102	253764	190347	444111	4354	535	545	14.9	0.027
GA	290	792000	461752	1253752	4323	531	541	14.7	0.027
GB	398	724000	579866	1303866	3276	402	412	16.3	0.039
HA	736	1297811	806362	2104173	2859	351	361	12.2	0.034
HB	107	266266	198972	465238	4348	534	544	13	0.024
JA	103	256254	191958	448212	4352	535	545	13.9	0.025
KA	140	694111	252905	947016	6765	831	841	11.5	0.014
KB	161	585360	285574	870934	5409	664	674	14.5	0.022
LA	141	456200	254402	710602	5040	619	629	11.8	0.019
LB	147	457792	264379	722171	4913	603	613	10.9	0.018
MAHBUBNAGAR	232.5	578555	348452	927007	4564	560	570	13.4	0.024
MA	1112	2258060	888960	3147020	2830	348	358	16.8	0.047
NA	927	2904454	865725	3770179	4067	500	510	16	0.031
NB	442	983242	619905	1603147	3627	446	456	16.5	0.036
ANANTAPUR	827	2048585	791530	2840115	3508	431	441	16.4	0.037
PA	319	790024	496685	1286109	4031	495	505	13.5	0.027
QA	1067	1791614	887317	2678931	2511	308	318	13.5	0.042
KURNOOL	693	1290819	691701	1982520	3271	401.5	411.5	13.5	0.033

Table 7 continued ...

1	2	3	4	5	6	7	8	9	10
RA	1001	1237330	881981	2119311	2117	260	270	21.3	0.079
RB	1100	1324865	888442	2213307	2012	247	257	25.2	0.098
SA	759	1274724	817784	2092508	2757	339	349	24.5	0.070
TA	425	713471	604828	1318299	3102	381	391	21.3	0.054
AKOLA	821	1137597	798259	1935856	2497	307	317	23.1	0.073
UA	593	1004000	732859	1736859	2929	360	370	34.1	0.092
UB	484	822558	655251	1477809	3053	375	385	13.5	0.035
VB	1779	2263168	820430	3083558	1733	213	223	18.8	0.084
SHOLAPUR	952	1363242	736180	2099422	2572	316	326	22.1	0.068

this benefit. In 1975, the year of the survey, a hectare under tanks produced about three times as much in terms of value of food grains as did an unirrigated hectare.

b) Additional employment

Another important national or social benefit of tank irrigation accrues from the employment it generates. Table 8 gives a comparison of the number of hours of labor per acre spent in the various tanks. It shows that the tanks in Rayalseema and Telengana employ an additional 300 to 400 labor hours per acre or about four to five times the amount used on nonirrigated land. Interestingly, this is not true for the tanks surveyed in Akola and Sholapur districts, where there was found to be hardly any difference between the amounts of labor used on tank-irrigated in comparison to nonirrigated land. In these two black soil districts of Maharashtra, the absolute amount of labor used on rainfed land is more and the absolute amount of labor used on tank irrigated land is less than is the case in the red soil districts of Medak, Mahbubnagar, Kurnool, and Anantapur, where rainfed land requires less but irrigated land employs more labor.

c) Safety in food production

Irrigation is generally associated with safety in food production. However, as will be shown in the last part (von Oppen and Subba Rao 1980b) of this study, not all tanks have been equally safe in irrigating the same command area over the past ten years. In fact, it appears for some regions as if there is a general increase in the instability in tank-irrigated food production, at least over the past 10 to 15 years.

Table 8. Social benefit-cost analysis of tank irrigation projects to the nation

Tank Code	At Village Prices		At Average Prices		Employment (Hrs/acre)		Addl. Employment due to tank irrign. (Hrs/acre)	Proportion of Tank Irrigated Employment over rainfed (6) / (7)	Net Present Worth (in '000 Rs)	
	BCR	IRR (%)	BCR	IRR (%)	Tank Irrig.	Rainfed			Village Prices	Average Prices
1	2	3	4	5	6	7	8	9	10	11
AA	0.42	0.9	0.71	5.5	527	187	340	2.8	-1077	-537
AB	..	..	0.68	5	570	146	424	3.9	.	-663
BA	0.27	..	0.9	8.4	488	64	424	7.6	-1344	-189
BB	1.1	11.5 (17)	1.54	17.7 (8)	487	241	246	2	77	409
CA	0.96	9.4	1.68	19.6 (8)	841	326	515	2.6	-59	1041
CB	1.91	22.8 (6)	2.36	29.2 (5)	750	230	520	3.3	974	1446
DA	0.21	..	0.31	..	626	126	500	5	-915	-815
DB	0.55	2.5	0.59	2.9	601	142	459	4.2	-532	-487
EA	..	..	0.14	..	402	139	263	2.9	.	-799
EB	0.46	0.8	0.52	1.8	729	140	589	5.2	-627	-567
MEDAK					602	174	428	3.9		
FA	0.81	6.9	0.9	8.4	411	160	251	2.6	-28	-45
GA	1.03	10.44 (20)	1.1	11.6 (16)	381	162	219	2.4	36	132
GB	1.2	13.4 (11)	1.12	12 (14)	386	124	262	3.1	268	158
HA	0.95	9.21	1.34	15.3 (10)	326	81	245	4	-111	744
HB	0.91	8.5	0.99	9.8	447	115	332	3.9	-44	-6
JA	0.88	8.1	1.12	11.5 (17)	473	73	400	6.5	-56	436
KA	0.04	..	0.08	..	492	67	425	7.3	-918	-885
KB	0.1	..	0.15	..	395	55	340	7.2	-795	-755
LA	0.34	..	0.49	1.26	313	77	236	4.1	-479	-367
LB	0.19	..	0.54	2.3	487	64	423	7.6	-595	-341
MAHBUBNAGAR					411	98	313	4.8		
MA	1.57	18.3 (8)	2.04	24 (6)	506	159	347	3.2	1957	3359
NA	0.42	..	0.7	5.3	329	96	233	3.4	-2221	-1097
NB	0.32	..	0.77	6.2	354	90	264	3.9	-1112	-379
ANANTAPUR					396	115	281	3.5		
PA	0.21	..	0.35	..	620	112	508	5.5	-1043	-854
QA	0.5	0.9	0.68	4.5	497	139	358	3.6	-1388	-879
KURNOOL					558	125	433	4.5		

Table 8 continued

1	2	3	4	5	6	7	8	9	10	11
RA	.	.	.	.	267	276	-9	0.97	.	.
RB	.	.	.	.	230	344	-114	0.67	.	.
SA	.	.	.	.	423	368	55	1.2	.	.
TA	.	.	.	.	271	337	-66	0.8	.	.
AKOLA	.	.	.	.	298	332	-34	0.9	.	.
UA	0.43	0.43	0.32	..	2	197	48	1.2	-1005	-1212
VA	..	..	..	..	230	260	-30	0.9	.	.
VB	0.68	4.9	0.67	4.7	242	175	67	1.4	.	.
SHOLAPUR					239	211	28	1.2	-1046	-1079

Note: Social rate of discount = 10%
Life period = 22 years
Figures in parentheses denote the pay-back period.
'.' = Data not available
'..' = Negligible.

d) Environmental effects

In addition to the economic aspects discussed above, there would be beneficial effects such as increase in water tables, and reduction in soil erosion associated with tank irrigation. Unfortunately, the measurement of these more technically relevant variables could not be included in this study. (However, the need for research in this direction was recognized in the course of this study and measurement is underway on six tanks).

C. Costs of Tank Irrigation

As in the previous section on benefits, we shall also summarize the costs of tank irrigation in the same sequence of 1. costs to farmers, 2. costs to the "Project Authority" and 3. costs to the State and Nation (see Table 4).

1. Costs to farmers

a) Water rates

Farmer water fees for tank-irrigated land are presented in Table 9. In Andhra Pradesh, the amount for the first season is around 11 to 16 Rs/acre while for the second season, half that amount is charged, i.e. on double cropped land the annual revenue charge is between 17 to 26 Rs/acre. In comparison the fee for nonirrigated land is between 1 and 3 Rs/acre. The net amount charged for water only would be the difference between revenue for irrigated minus nonirrigated land, i.e. about 11 to 16 Rs/acre for one season, and 17 to 26 Rs/acre for two seasons. The water fees have the character of a tax to the farmer who pays them together with his other land revenue tax to the same department.

Table 9. Water rates/acre of tank irrigation

Tank Code	Settled Command Area (Acres)	Actual Tank Irrig. Area 1974-75 (Acres)	Total revenue recd. during 1974-75	Water fee paid by the farmers per acre	Average Irrig. charges paid by the farmers		Unirrig. land revenue/acre	Water Fee Irrigated minus Unirrigated	
					One season	Two seasons		One season	Two seasons
AA	363	381.5	6461	16.94	18	27	1.5	16.5	25.5
AB	719	817.5	10908	13.34	14	21	1.5	12.5	19.5
BA	405	571.9	9148	16	16	24	1.5	14.5	22.5
BB	161	191.6	2946	15.37	16	24	1.9	14.1	22.1
CA	499	600.8	10529	17.52	18	27	2	16	25
CB	257	365.9	5994	16.38	16	24	2	14	22
DA	307	121.3	1613	13.3	15	22.5	1.7	13.3	20.8
DB	242	141	2228	15.8	18	27	2.2	15.8	24.8
EA	223	164	2362	14.4	17	25	2.6	14.4	22.4
EB	163	97.5	1267.5	13	1	24	3	13	21
MEDAK									
FA	102	90.3	1345.5	14.9	16	24	1.1	14.9	22.9
GA	290	208.5	3065	14.7	16	24	1.3	14.7	22.7
GB	398	237	3863	16.3	18	24	1.7	16.3	22.3
HA	736	490.2	5980	12.2	13	19.5	0.8	12.2	18.7
HB	107	96.5	1255	13	14	21	1	13	20
JA	103	65.6	912	13.9	15	22.5	1.1	13.9	21.4
LA	140	72.7	836	11.5	14	21	2.5	11.5	18.5
KB	161	38	551	14.5	16	24	1.5	14.5	22.5
LA	141	117.5	1387	11.8	13	19	1.2	11.8	17.8
LB	147	101.9	1111	10.9	12	18	1.1	10.9	16.9
MAHBUBNAGAR									
MA	1112	2191	41059	18.7	18	27	1.2	16.8	25.8
NA	927	751	12016	16	18	27	2	16	25
NB	442	345	5520	16	18	27	1.5	16.5	25.5
ANANTAPUR									
PA	319	131	1965	15	16	24	1.5	13.5	22.5
QA	1067	501.5	7523	15	16	24.	1.5	13.5	22.5
KURNOOL									
UA	593	284.5	7112	25	35.6	..	1.5	34.1	..
VA	484	72.6	1815	25	15	..	1.5	13.5	..
VB	1779	533.7	13342	25	20.3	..	1.5	18.8	..
SHOLAPUR									

'..' = data not available.

In Maharashtra, a different system is being followed. Here the water charges are fixed for different irrigated crops to represent the water consumption of these crops. The rates reported to have been charged during the survey are given in Table 10.

b) Uncertainty of water availability

Even though the farmer has the benefit of reduced yield risks he faces the uncertainty about the amount of water available for tank irrigation. The prevailing water management systems are aiming to adjust the areas irrigated to the actual or expected quantity of water available at a particular time; consequently, from year to year the area irrigated varies considerably. This was already shown in Table 6 and in subsection B.1.C for three districts in Telengana where tank irrigation is the major source of irrigation. The combined effect is probably a higher variability of paddy production than for rainfed crops.

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

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

Table 10. Water rates/acre in Maharashtra State

Crop	Water rate (Rs/acre)
Rice	30
Sugarcane	200
Groundnut	25
Wheat	30
Cotton	45
Pulses	15
Sorghum	15

irrigated by tanks varies between 48 800 ha and 70 300 ha with a CV of 24.6. During the 70 years under this type of management, the tank ran dry during the season 31 times.

As soon as limited water control was introduced, opening the outlet only at the moment the tank was filled, the tank ran dry only 11 times.

2. Costs to the Project Authority

a) Construction costs

As explained above, data on costs of construction of tanks were made available on 16 tanks recently constructed by the PWD. For these data, cost estimates and technical relationships had to be derived with the help of which it was possible to synthesize the costs of construction of the 32 tanks for which farm surveys had been made; so that costs and benefits could be compared. The following describes the steps taken to arrive at the synthetic estimates of costs, to the tank building authority.

Details of the construction costs 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 average, the costs of the bund constitutes 57% of the total cost of construction.

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

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

Village	District	Settled Command Area (Wet Acres)	Cost of Bund	Cost of Sluices	Cost of Weirs	Cost of Canals	Cost of Land Acquisition and Misc.	Total Costs
Lanjabunda	Kurnool	435	4.61	0.2	0.53	1.47	0.44	7.25
Madanantapuram	Kurnool	414	14.42	0.01	3.99	5.61	2.08	27.02
Penumadi	Kurnool	508	16.8	0.3	2.66	3.26	1.28	24.3
Vengaladoddi	Kurnool	525	10.2	0.26	4.07	5.05	2.72	22.3
Khambalampadu	Kurnool	525	11.62	0.63	8.31	3	3.0	26.56
Dantharvanipenta	Kurnool	1125	7.01	0.58	10.71	1.77	1.08	21.15
Jalvanur	Kurnool	1650	20.88	0.32	2.3	6.41	0.53	30.44
Jeedipalli	Anantapur	195	2.35	0.2	1.03	0.91	0.88	5.37
Pinnepalli	Anantapur	165	5.06	0.13	1.41	1.36	0.	8.75
Bagiyakinapalli	Anantapur	195	4.45	0.19	2.2	1.3	1.2	9.38
Chitraseedu	Anantapur	390	9.36	0.51	2.27	1.0	2.68	15.82
Nandyalampeta	Cuddapah	573	13.25	0.29	7.75	3.06	0.03	24.48
Kotulabanda	Cuddapah	900	24.84	0.64	2.5	1.5	0.5	29.98
Gangaveru	Medak	200	2.56	0.65	0.43	0.68	0.86	5.18
Edakulapally	Medak	825	9.97	0.91	2.01	4.21	3.95	20.96
Chinnamadula	Mahbubnagar	320	11.8	0.29	3.43	1.02	4.0	20.54

Source: Mr. T. Hanumantha Rao, APSIDC, and Public Works Department (PWD) Minor Irrigation Branch, Hyderabad.

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:

$$Y_1 = 154.7 + \underset{(3.5)}{1040.7}\, X_1^{-1}$$ where Y_1 is cost of bund per length of bund (rupees per foot) and X_1 = length of bund/settled command area (foot/acre). The R^2 is 0.46 and with the t-value of 3.5 this relationship is statistically highly significant. This relationship is plotted in Figure 4. Based on this result it is possible to derive the costs of bund for all those tanks in the same region, for which information on length of bund and command area exists. These derived costs of bunds are presented in Table 7.

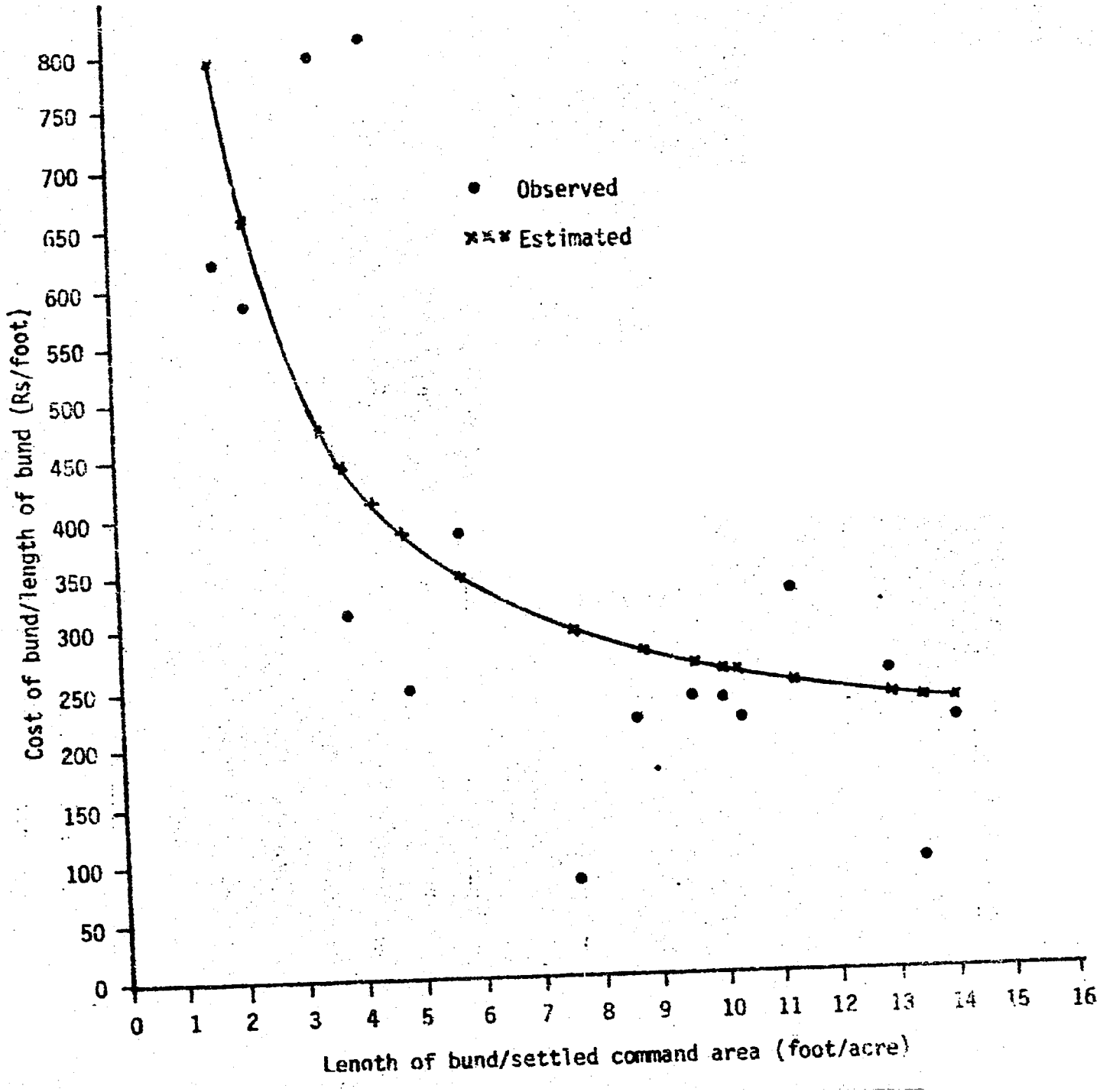
The remaining cost items if expressed per unit settled command area were found to fit a semi-log function of settled command area:

$$\log Y_2 = 7.8 - \underset{(2.8)}{.000839}\, X_2,$$ where Y_2 is the remaining cost per settled command area (log (rupees/acre)) and X_2 is settled command area (acres). With an R^2 of 0.36 and a t-value of 2.8 this relationship is statistically significant.

With the help of this relationship it is possible to derive the non-bund costs of all those tanks in the same region for which information on settled command area is available. These costs are presented in Table 7.

By adding the two cost components, an estimate of total costs of construction is computed (see Table 7). These estimated costs vary between 1700 and 7000 rupees per acre, with an average of 3856 rupees/acre. In

Figure 4. Relationship between length of bund per settled command area and cost of bund per foot length



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.

b) Maintenance costs

Information on maintenance costs was not available per tank; however, from PWD records on expenditures incurred for maintenance and repairs we find the following: in selected districts on average over the years 1973-77 total expenditure for repairs varied between 7 and 11 Rs/acre in the different districts (see Table 12). While expenditures on ordinary repairs were between 5 and 7 Rs/acre, flood repairs ranged from less than 2 Rs/acre in some districts (Mahbubnagar, Medak) to nearly 3 to 5 Rs/acre in others (Anantapur, Chittoor, Cuddapah). These are direct expenditures made on the tanks. The costs of overheads, engineering, etc. are not included.

c) Costs of water control and tank management

The way in which the water management is presently practised by the village community does not involve any direct costs. Farmers are organizing the water control among themselves. In some tanks a water controller (nairudi) was operating. He was being paid for his services in the form of paddy produced. The water charges are collected by the Patwari, i.e. the village record keeper who is collecting the water fees within the land revenue.

3. Costs to the State and Nation

a) Opportunity cost of the capital invested

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

Table 12. Average annual expenditures by the Minor Irrigation Department on tank repairs in selected districts of Andhra Pradesh from 1973 to 1977 (in Rs/acre command area)

District	All repairs	Ordinary repairs	Flood repairs
Nalgonda	7.5	7.0	0.5
Mahbubnagar	7.1	6.0	1.1
Karimnagar	7.5	6.0	1.6
Medak	7.2	5.7	1.6
Kurnool	7.4	5.4	2.0
Anantapur	8.0	5.1	2.9
Chittoor	9.8	5.4	4.4
Cuddapah	11.2	6.2	5.0
All Districts	7.9	5.9	2.0

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

b) Submerged land

The value of land submerged by an irrigation tank varies. Generally tanks are being located such as to minimize their loss, i.e. preferably low value barren land is being used for water storage; nevertheless per one unit of command area requires about .8 unit of land is being submerged, and under conditions of increasing population and rising land values, even this low value has a rising opportunity value; moreover silt deposits in the tank bed lead to a continuous increase in the natural fertility and therefore the value of this land.

D) Benefit-cost comparisons

In comparing costs and benefits we compute cost-benefit ratios at the farmers' level and at the Project Authority level. At the state level both the cost benefit ratio and the internal rate of return are calculated.

1. Farmer level

a) Financial benefit-cost ratio due to tank irrigation

The farmer's net benefits due to tank irrigation vary between 240 to 380 Rs/acre in red soil areas and between zero and 290 in the black soil areas. The costs he incurs are the water fees of about 11 to 16 Rs/acre. Consequently, in red soils, farmers' benefits are about 15 to 25 times the water costs in a normal year. Thus for the farmer in a normal year, tank irrigation is a highly profitable proposition.

b) Farmers reduced yield risks versus uncertainty of water availability

It does not have to be stressed that hardly ever is a year "normal" regarding 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 availability and thus at the cost of area stability. In fact, the resulting productivity of tank-irrigated areas in Telengana is in fact becoming more and more variable than that of rainfed crops. For instance, during 1977 the following phenomenon could be observed: in some tanks in Telengana no crops were being grown, because the well-distributed rainfall never generated any runoff, so that farmers waited in vain during the entire season to plant paddy; at the same time rainfed land had been planted as usual with sorghum and pigeonpeas and yielded an excellent crop. Thus while the yield risk of the tank-irrigated land is less, the uncertainty of water availability -- especially for tail-enders -- makes tank irrigation in Telengana a well-paying but also relatively risky proposition.

c) 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 tax collected once on the presumed increase in land value. This levy generally runs between 50 and 120 Rs/acre. However, for the surveyed tanks no records had been kept on the betterment levy charged at the time of construction.

If a levy of 100 Rs/acre is assumed, then the increase in land value (see Table 5) is 26 to 38 times the levy in the Medak and Mahbubnagar tanks, while in Anantapur it is even 40 to 50 times higher.

2. Project authority level

The benefits accruing to the Project Authority are the revenue collected annually and the betterment levy, charged only once as a tax on the presumed

increase in land value due to tank irrigation. This betterment levy can be accounted against the cost of construction before discounting it to its present value: assuming a 22-year[5] life period (t) and an interest rate (i) of 10 percent[6] on capital invested, the present value (P) of the cost per acre of tank-irrigated land (C can be computed as follows:

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

If an amount of P was put into the bank at interest rate i it would grow to the value of C after t years (see Table 7, column 7). To this annual cost we add the cost of maintenance of Rs 10/acre. The ratio of irrigation fees over present value of tank costs (plus maintenance cost) per acre is the benefit cost ratio which the project authority is facing (Table 7, column 10).

Its 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 being subsidized.

3. State level

In comparing benefits and costs at the State level their cash flows over 20 years were analyzed. It was assumed that the net benefits due to irrigation found for 1974-75 would be the same for all previous 20 years. Information was available on area irrigated for 10 years, up to 1964-65. A relationship estimated between area irrigated and rainfall permitted

5. The period of 22 years is chosen because longer periods would decrease P only marginally.
6. The rate of 10% is chosen as it represents the average rate at which capital might be invested elsewhere.

estimating of the area annually irrigated for another 10 years prior to 1964-65, so that a total of 20 years' data on area irrigated was made available. Multiplication of the area in acres by the net benefits per acre gave the flow of annual total net benefits.

The cost flow for each tank contains the total cost of construction in the first year and the annual costs of maintenance in the following 20 years. The ratio of the summations of the discounted annual values of benefits (B) and costs (C) is computed according to the following formula (Price and Gittinger 1972):

$$BCR = \frac{\sum_{t=1}^{n} B/(1+i)^n}{\sum_{t=1}^{n} C/(1+i)^n}, \quad \text{where } n = 21 \text{ and } i = 10\%.$$

BCR is the benefit-cost ratio.

Tanks with a BCR > 1 are supposed to be economically acceptable. As Table 8 shows, there are only eight tanks out of 28 for which this is the case.

Another approach of comparing benefits and costs is to compute the internal rate of return -- that interest rate at which the benefit cost ratio would be just 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%, would be acceptable to the decision makers as the criterion for economic acceptability then a total of 15 out of 28 tanks would qualify.

This analysis shows in general that among the existing irrigation tanks probably fewer than half are economically viable as they are. 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 one of the tanks would be highly profitable in terms of benefit-costs as well as internal rate of returns. Suggestions of how to achieve a better utilization of the irrigation facility will be put forward in detail in the last part of this study (von Oppen and Subba Rao 1980b).

It might be argued that despite the low economic returns from tank irrigation, there are social benefits such as employment and food production which are sufficient to justify tank irrigation even where it may not be economically justifiable. In addition, it should also be considered that the poor performance for most tanks is not at all an unavoidable necessity. It is quite possible to increase the utilization rates in most tanks through better tank management and control. This effort would at the same time further increase all of the social benefits and to some extent increase stability of agricultural production under tank irrigation.

IV. SUMMARY AND CONCLUSIONS

The data to evaluate the benefits of tank irrigation were collected in surveys of 32 tanks. The data on costs of tank construction were available for 16 recently constructed tanks. Length of bund and settled command area were the variables that allowed us to provide the link between the two data sets and to synthesize cost data for the 32 surveyed tanks. A further set of

15 tanks provided additional information on the storage capacity and submerged area of tanks. Analysis of this technical information in the first section of this paper facilitates the economic analysis of tank irrigation in the second section.

For irrigation tanks of the type studied in Telengana and Rayalseema, the length of bund per irrigated area decreases at a decreasing rate as irrigated area increases (see Fig 5). Tank capacities are normally designed to hold about 1.5 meters of water for the command area; this measure varies somewhat from tank to tank but not with tank size. The irrigated area per unit of area submerged by the tank is around 1.2, smaller tanks having a ratio of .9 or less and larger ones (>1000 acres) a ratio of 1.5 or more. The utilization of the "settled command" area is a non-linear function of rainfall and tank specific information.

The benefits due to tank irrigation accruing to farmers at village prices were found to be around 240 to 380 Rs/acre in Andhra Pradesh and -35 to 290 in Maharashtra (Table 13). However, on aggregate, tank irrigation was found to be a relatively risky activity because of unreliable water availability. Employment in tank-irrigated land in red soil areas of Telengana and Rayalseema is about 3.5 to 4.8 times that on rainfed land while in the black soil areas of Maharashtra there is no difference (Table 13). The costs of tank construction lie between 2500 Rs/acre in Maharashtra and 3300 to 4600 in Andhra Pradesh (Table 13). Among the 28 tanks studied only 15 tanks were found to have economic internal rates of return of at least 5%.

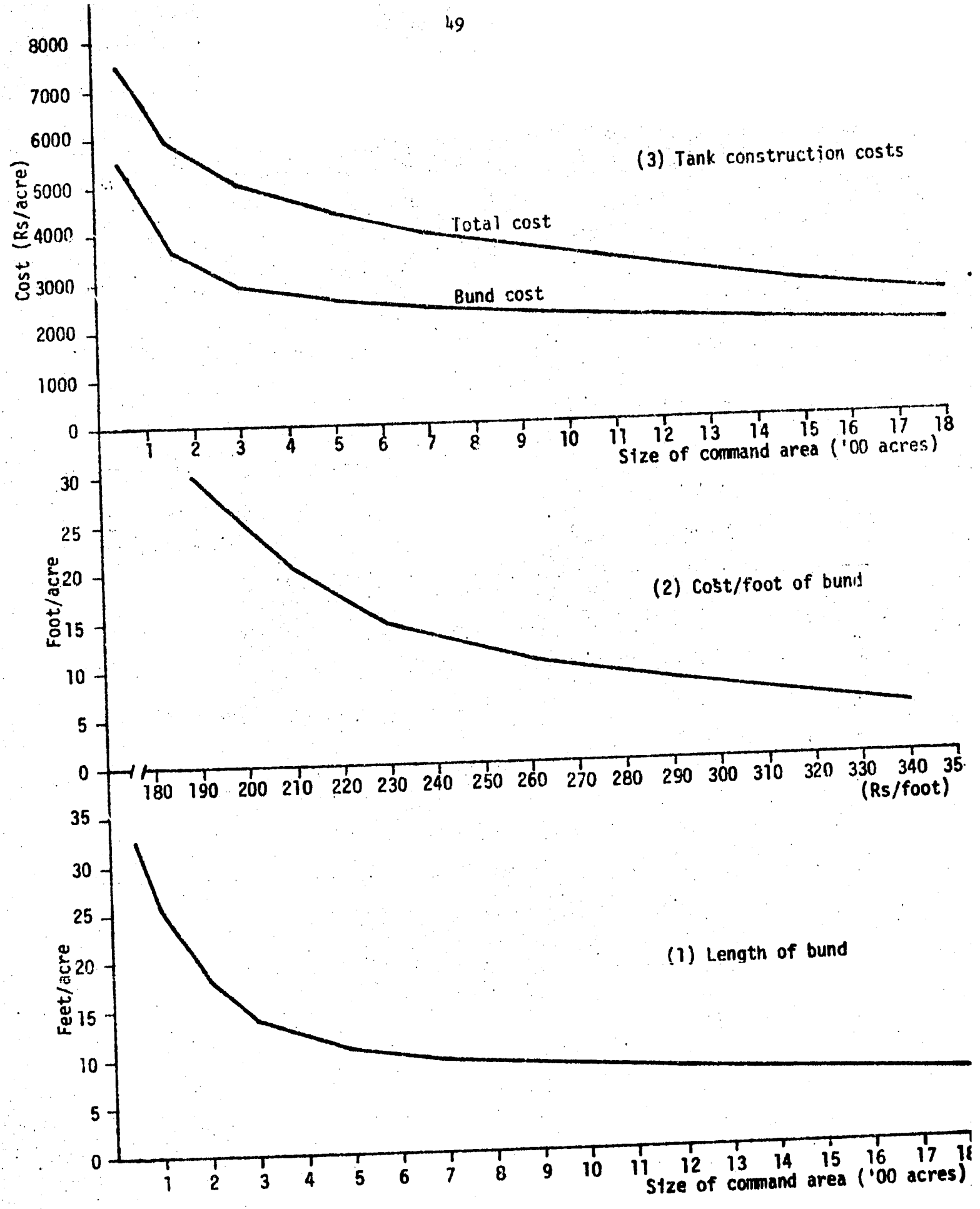


Figure 5. Derivation of tank construction costs

Table 13. Farmers' benefits and cost of construction of tank irrigation in selected districts, 1975

District	No.of tanks surveyed	Farmers' Benefits (Rs/acre)		Cost/acre of SCA	Employment in tank irrigated areas over rainfed
		Village prices	Average prices		
Medak	10	330	470	4300	3.9
Mahbubnagar	10	380	490	4560	4.8
Kurnool	2	290	440	3270	4.5
Anantapur	3	240	420	3510	3.5
Akola	4	-35	-1	2500	0.9
Sholapur	3	287	251	2570	1.2

The economic performance of irrigation tanks depends largely upon the degree of command area utilization. The average rate of utilization was found to be only 80 to 90% in Andhra Pradesh tanks and 30% in Maharashtra tanks. The low utilization rates are largely caused by inefficient water control and lack of appropriate maintenance and repairs of tanks. There is need for an investigation into the possibilities of an institutional framework for increasing the efficiency of water control in order to capitalize on the existing tank irrigation facilities. The aim should be to not only arrest continuing decay but to expand tank irrigation as a socially desirable proposition of high internal rates of return if placed within a proper institutional framework of water control and maintenance works.

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Appendix I. Codes used for selected talukas and villages

Sl. No.	District	Taluk code	Taluk name	Village 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		Gadwal	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	Mangalwada	UA	Talsangi
31.	Sholapur	V	Sangola	VA	Achakandi
32.	Sholapur		Sangola	VB	Chincholi

Villages AA to QA fall under Andhra Pradesh State and RA to VB belong to Maharashtra

Appendix 2. Percentage size distribution of land holdings in command areas of selected tanks (Area in acres)

District	Av. settled command area	Av. No. of farmers	Percentage Distribution						Mean Area
			Upto 0.5	0.51-1	1.01-1.5	1.51-2	2.01-2.5	Above 2.5	
Medak	340	241	32.9	23	15.6	9.3	5.6	13.6	1.36
Mahbubnagar	232.5	85	15.3	14.9	11.6	13.2	9.4	35.6	2.84
Anantapur	827	539	14.1	20.6	23.2	13.5	9	19.6	1.71
Kurnool	693	619	14.1	19.8	31	9.4	11.8	13.9	1.62
Akola	821	61	1.4	11.4	21.2	7.5	21	37.5	2.35
Sholapur	952	127	1.4	10.9	23.6	14.5	16.5	33.1	2.11

Source: Sample Survey