Vol XLVI
No. 2

APRIL-
JUNE
1991

ISSN 0019-5014

INDIAN JOURNAL OF AGRICULTURAL ECONOMICS

INDIAN SOCIETY OF
AGRICULTURAL ECONOMICS,
BOMBAY

Ind. Jn. of Agri. Econ.
Vol. 46, No. 2, April-June 1991

Hydro-Economic Interaction between Tank Storage and Groundwater Recharge

Tank irrigation is one of the oldest sources of irrigation in India and is particularly important in South India, where it accounts for about one-third of the rice irrigated area. In Tamil Nadu State alone, there are about 39,000 tanks of varying sizes and types. These tanks normally help irrigate one rice crop between September and December. Currently, the performance of these tanks is poor due to inadequate operation and maintenance (O&M) since the government, after Independence, gave priority to large scale irrigation and groundwater development projects. The neglect of tank management has meant that most farmers receive inadequate quantities of water from tanks. To offset the resulting decline in tank water supplies, farmers have resorted to supplemental supplies from groundwater to avoid crop losses (Palanisami and Easter, 1987). Since only about 15 per cent of the farmers in the tank command area own wells, and there is a growing demand for well water, the well owners are able to charge high prices for well water.

This paper presents the results from a study of eight tanks (160 farmers) in the undivided Ramanathapuram district, Tamil Nadu during 1984-88. The study examines the current status of groundwater use, returns from well irrigation using 1981-82 prices, the level at which well owners maximise profits and the need to augment groundwater supplies.

Levels of and Returns to Supplementary Irrigation

Tank water supply has been in deficit over 50 per cent of the time due to inadequate rainfall.[1] This problem has been aggravated by both the decline in tank storage capacity and an increased demand for irrigation water in general and for supplementary well irrigation in particular. Given the limited tank water supplies, yields have been reduced significantly and/or the area harvested has declined. Different farmers face different water availabilities. Due to their location, certain farmers cannot obtain well water and must minimise losses (maximise profits) by using only tank water. Farmers who have access to well water maximise profits (minimise losses) based on the amount of well water they can purchase. In a number of cases, farmers are not able to purchase as much water as they need to reach the optimum level of production. Depending upon the stage of crop growth and the availability of water from wells, the average number of supplementary irrigations normally varies from 4 to 12 (Table I).

TABLE I. RETURNS TO SUPPLEMENTARY IRRIGATION, UNDIVIDED RAMANATHAPURM, TAMIL NADU, 1984-88

Level of irrigation (1)	Number of irrigations (2)	Rice yield (qtl./ha) (3)	Gross return (Rs./ha) (4)	Profit (Rs./ha) (5)
Sub-optimal	4	6.98	942.30	-793.54
Threshold	5	15.65	2,112.75	193.30
Current 6	18.78	2,535.30	609.04	-
Optimum 9	23.95	3,233.25	1,189.64	-
Over-use	12	24.04	3,245.40	1,062.79

Note:- 1981-82 prices were used in the analysis.

Once the tank water is exhausted, the rice yield is primarily dependent upon the number of supplementary irrigations received, since the variation in the level of other inputs, such as the quantity of fertiliser applied, labour used and the management level, is minimal (Table II). The optimum number of supplementary irrigations was estimated based on the following function:

$$Y = \underset{(1.986)}{5.071^{**}} + \underset{(1.211)}{3.610NI^{**}} - \underset{(0.062)}{0.191NI^{2**}}$$

$N = 369$; $R^2 = 0.46$

** Significant at 1 per cent level.
Figures in parentheses are standard errors.

where Y = rice yield in quintal/ha; and NI = number of supplementary irrigations/ha.

TABLE II. INPUT USE AND RICE YIELD IN SELECTED TANKS, UNDIVIDED RAMNATHPURAM, TAMIL NADU, 1984-88

Input (1)	Quantity (2)	C.V.(%) (3)
Tank water (cm)	87	31
Well water (cm)	21	109
Nitrogen (kg./ha)	92	26
Labour (days/ha)	153	35
Crop management (index)	38	39
Rice yield (qtl./ha)	24	43

Note:- Based on the survey of 160 farmers in eight tanks.

Given the cost of well irrigation (Rs. 30/irrigation) and price of rice (Rs. 135/quintal at 1981-82 prices),[2] nine supplementary irrigations maximise the farmer's profit. At this level the farmer's profit is Rs. 1,189 per hectare. However, a majority of the farmers under-irrigate their rice crop with well water and apply, on the average, only about six supplemental irrigations due to an inadequate number of wells, limited well capacity and well owners' efforts to maximise returns from water sales. Even with water shortages, the farmers' average profits are Rs. 609 per hectare. The critical threshold is to provide, at least, five supplemental irrigations. At levels below the threshold, there will be low rice yields and most of the production expenses incurred in the rice cultivation will be lost. Small profits are obtained with five supplemental irrigations but profits continue to grow until nine irrigations have been applied (Table I).

Hydro-Economic Interaction

Normally, tanks begin filling as soon as the rains start and wells will be simultaneously recharged depending upon tank and groundwater storage conditions. The water available for pumping is greater early in the season and pumping costs are low. But the farmers in the tank command area use the well water only after the tank water is exhausted. By the time farmers want well water, recharge rates are lower and the pumping cost, along with the price of well water, are higher (Table III). This inter-relationship between tank storage, well yield, quantity pumped, well water price and pumping costs can be analysed with a system of simultaneous equations.

TABLE III. RELATIONSHIP BETWEEN TANK STORAGE, WELL YIELD AND PRICE OF WATER, UNDIVIDED RAMANATHAPURAM, TAMIL NADU, 1984-88

Month (1)	Tank storage (metres) (2)	Well yield (metres) (3)	Quantity pumped (hrs) (4)	Price (Rs./hr) (5)
October	5.3	4.6	12	6
November	1.5	1.7	6	8
December	0.5	0.3	4	8
January	0	0.3	4	10

Simultaneous Equations System:

$$TS = f(RF)$$
$$WY = f(TS)$$
$$Qp = f(WY)$$
$$Pp = f(Qp)$$
$$AC = f(Qp)$$

where TS = tank water storage in metres,
RF = rainfall in metres,[3]
WY = well yield in metres,[4]
Qp = quantity of water available for pumping in hours,
Pp = price of well water in rupees per hour,
AC = average cost of pumping well water in rupees per hour, which was calculated taking into account the total annual cost (annualised cost plus operation and maintenance cost) and the total number of hours pumped.

The results indicate that for every hour reduction in the quantity of water available for pumping, there is an increase in the price of water by about one rupee per hour (Table IV). Consequently, for every additional irrigation demanded by the farmers, the well owners normally increase the charge by about Rs. 4 per irrigation compared to the marginal cost of one additional irrigation of only Re. 0.80 (assuming one irrigation takes about four hours of pumping). The higher charge is mainly due to the increased demand for well water and the uncertainty concerning the groundwater stock due to inadequate recharge and the gradual decline in the water table.[5]

TABLE IV. RESULTS OF THE SIMULTANEOUS EQUATION SYSTEM, UNDIVIDED RAMNATHAPURAM, TAMIL NADU, 1984-88

Dependent variable (1)	Model (2)	Coefficient (3)	t-ratio (4)
TS	Independent variable RF	0.023	25.61
	Intercept	-0.671	-3.67
WY	Independent variable TS	0.891	18.45
	Intercept	-0.577	-2.12
Qp	Independent variable WY	2.420	26.16
	Intercept	-0.273	-2.90
Pp	Independent variable Qp	-1.021	-9.62
	Intercept	16.526	3.67
AC	Independent variable Qp	-0.202	-15.25
	Intercept	5.821	3.67

System R^2 = 0.59; N = 43. The model was estimated via three-stage least squares (3SLS) method.

Behaviour Model for Water Extraction

The well owners act like monopolists, where each well owner is the only supplier of groundwater, at least to the group of farmers located near the well. The dispersed nature of wells and their limited number in most areas allow each well owner to become a 'local' monopolist. The high cost of well installation, Rs. 45,000 to Rs. 60,000, is a serious barrier to entry, particularly for small and marginal farmers. However, the real barrier may be the difficulties involved in obtaining institutional finance. The procedures required to obtain such finance are so tedious that many farmers do not even attempt to use it. As pointed out above, only about 15 per cent of the farmers have installed wells.

The effect of pumping on well water levels is reflected in the water supplied and price.[6] Well owners cannot set the quantity pumped and price independently, since price is uniquely determined by water demand once the level of pumping is selected, based on past experience and well recharge behaviour. Reductions in pumping can increase the water price, resulting in higher profit for well owners as long as price elasticity of demand for water is greater than one.[7]

Given the high water prices and varying pumping hours, it is important to know at what level of pumping and water price well owners maximise their profit. Using the (inverse) demand, output and cost functions from the simultaneous equations systems, we obtain the following:

Inverse demand function for well water:

$$
\begin{array}{lll} Pp = & 16.526^{**} & -1.021Qp^{**} \\ & (3.433) & (0.325) \end{array}
$$

Output function for well water:

$$
\begin{array}{lll} Qp = & -0.273 & +2.421WY^{**} \\ & (0.176) & (0.097) \end{array}
$$

Cost function for pumping:

$$
\begin{array}{lll} AC = & 5.821 & -0.202Qp^{**} \\ & (3.421) & (0.0871) \end{array}
$$

** Significant at 1 per cent level.
Figures in parentheses are standard errors.

After solving the equations for well yield (WY), the profit maximising levels of WY, Qp and Pp are:[8] WY = 2.82 metres, Pp = Rs. 9.40 per hour and Qp = 6.57 hours.

Thus well owners maximise profits from water sales by pumping less than 7 hours and charging on an average Rs. 9.40 per hour. Pumping longer than this will reduce well owner profits even though their average cost of pumping is only Rs. 5 per hour.

Conclusions

The results indicated that the well owners charge about two times more than their average cost of pumping. The well onwer's share of irrigation benefits are as high as 50 per cent with the threshold number of irrigations (five), but this share drops to only 15 per cent, when farmers apply the optimum number of irrigations (nine) (Table V). Thus the more limited the groundwater supplied, the higher will be the well owner's share of farmers' returns from well irrigation. To prevent well owners from capturing a large share of the irrigation benefits will require a two-pointed strategy: first, groundwater supplies must be augmented so that well numbers and well irrigation can be increased without significantly lowering groundwater tables, and second, farmers should be encouraged to obtain additional supplementary irrigation and move closer to an optimal level of water use.

TABLE V. WELL OWNER'S SHARE IN IRRIGATION BENEFITS, UNDIVIDED RAMNATHAPURAM, TAMIL NADU, 1984-88

Level of irrigation	Number of irrigations	Total cost		Well owner's share	
		AC	WPP	Rs.	Per cent
(1)	(2)	(3)	(4)	(5)	(6)
Threshold	5	88.20	187.60	99.40	51.4
Current	6	105.84	225.12	119.28	19.5
Optimum	9	158.76	337.68	178.92	15.0
Over-use	12	211.68	450.24	238.56	22.4

Note:- Total cost is based on AC and WPP, where AC is the average cost; WPP is the well owner's selling price times the hours pumped. Well owner's share of irrigation benefits is the difference between AC and WPP.

K. Palanisami and K. William Easter*

Received August 1990. Accepted May 1991.

NOTES

1. Based on 46-year rainfall data, the probability of having a wet season rainfall between 300 and 450 mm that will result in deficit storage was 0.41, and the probability of wet season rainfall below 300 mm that will cause tank failure was 0.16 (Palanisami and Flinn, 1989). For the period 1984-88, the wet season rainfall was deficit every year. The rainfall was between 300 and 450 mm in 1984, 1985 and 1987, and it was below 300 mm in 1986 and 1988.
2. The price of rice during 1981-82 to 1984-88 increased by about 64 per cent and between 1984-85 and 1987-88 increased by 24 per cent. The fertiliser price has been almost constant while the wage rate increased by about 50 per cent between 1981-82 and 1984-88 and by 37 per cent between 1984-85 and 1987-88.
3. The rainfall and groundwater conditions vary between different regions. The model is applicable to regions where the rainfall and groundwater hydrology are similar to the study area.
4. The well yield is expressed in length, as it refers to the water column of an open well. Most of the wells are open wells with their depth ranging from 10 to 20 metres. The groundwater division of the Public Works Department keeps recordings of water level fluctuations in selected wells called observation wells. Hence the water yield of the wells was measured by the water column.

* Associate Professor, Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore and Professor, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota, U.S.A., respectively.

5. This would be a social optimum allocation of groundwater only if the user cost of groundwater is Rs. 3.20 per irrigation, *i.e.*, the present value of all future sacrifices associated with another irrigation is Rs. 3.20.

6. Due to horizontal percolation of water from the tanks to the wells, in most cases, the draw down in one well has had little direct impact on the water level in other wells, *i.e.*, the cones of depression usually do not overlap.

7. Given the profit equation for well owners' sale of water (Henderson and Quandt, 1971),

$$\begin{aligned} \pi &= (Pp * Qp) - (AC * Qp) - FC \\ &= g\,(Qp)\,.\,Qp - h\,(Qp).Qp - FC \\ d\pi/dQp &= g'\,.\,Qp + g - h'\,.\,Qp - h = 0, \end{aligned}$$

and by substituting Qp in the equation, the value of WY can be derived; where π = profit from sale of water, Pp = price of pump water, Qp = water quantity available for pumping, AC = average cost of pump water, FC = fixed cost.

8. WY is assumed to be controllable, since with proper tank management the well water level can be manipulated by well owners (Palanisami and Easter, 1983).

REFERENCES

Henderson, J.M. and R.E. Quandt (1971). Micro-Economic Theory: A Mathematical Approach, McGraw-Hill Inc., London.

Palanisami, K. (1987). "A Simulation of Tank Irrigation Systems - Modernization Strategies and System Performance", Department of Agricultural Economics, International Rice Research Institute, Los Banos, Philippines (unpublished report).

Palanisami, K. and K. William Easter (1983). "The Management, Production and Rehabilitation in South Indian Irrigation Tanks", Staff Paper P. 83-21, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota, U.S.A.

Palanisami, K. and K. William Easter (1987). "Small-Scale Surface (Tank) Irrigation in Asia", *Water Resources Research*, Vol. 23, No. 5, pp. 774-780.

Palanisami, K. and J.C. Flinn (1988). "Evaluating the Performance of Tank Irrigation Systems,", *Agricultural Systems*, Vol. 28, No. 3, pp. 161-177.

Palanisami, K. and J.C. Flinn (1989). "Impact of Varying Water Supply of Input Use and Yield of Tank-Irrigated Rice", *Agricultural Water Management*, Vol. 15, pp. 347-359.

Palanisami, K. and R.K. Sivanappan (1985). "Economics of Groundwater Supplementation in Tank Command Areas - A Case of Ramanathapuram District, Tamil Nadu", Paper presented at the Seminar on Groundwater Development and Management, held at Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore, September 30.