Vol XXX
No. 3

ISSN 0019-5014

CONFERENCE NUMBER

JULY-SEPTEMBER 1975

# INDIAN JOURNAL OF AGRICULTURAL ECONOMICS

INDIAN SOCIETY OF AGRICULTURAL ECONOMICS, BOMBAY

and a pair of bullock. Clearly, the 'minimum farm family requirement' approach to viability is much more sound than the physical approach, but it requires a greater degree of competence. It will, therefore, be sophisticated if the farm business income figures are translated into physical figures and used to identify the small farmers.

The results of the present study indicated that the acreage requirement for viability varied from situation to situation. The village or stratum which was less progressive and developed in all aspects needed higher acreages to become viable than other villages or strata which were in a better situation. Thus, it can be concluded that if the villages were consolidated, irrigation facilities were provided and infrastructural situations were developed, the income of the small farmers would have increased and a lesser acreage would be needed to make them viable.

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# EXTERNALITIES OF NEW GROUNDWATER TECHNOLOGY ON SMALL FARMERS

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*Introduction*

Modern groundwater technology, based on power pumps, has diffused rapidly (about 17 per cent per annum) in the Indian farm sector. It is estimated that modern groundwater devices lifted about 60 per cent of the total 65 million acre-feet of groundwater lifted by all types of groundwater appliances in 1971.[1] In point of fact, the regions experiencing successful diffusion of the new bio-chemical technology also exhibit high rate of penetration of the new groundwater technology, especially tubewell technology. For example, in the States of Haryana and Punjab the traditional groundwater lifts contributed about 5 and 12 per cent, respectively, to the States' total volume of groundwater raised for irrigation in 1971, and these percentages may be even lower today.

The cost-effectiveness of the new groundwater technology vis-a-vis the traditional one has been highlighted in a number of research studies. It is not our intention to undertake a critical review of this literature. The significant aspect, to which we wish to draw attention here in the particular context of the topic of discussion in this Conference, is the exclusive concern of the researchers with demonstrating the superiority of the new technology purely from the private or individual viewpoint, without due regard to macro angle and long-term social implications. High social cost of the infrastruc-

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1. Government of India: Report of the Task Force on Groundwater Resources, Planning Commission, New Delhi, 1972, Annexure X (mimeo.).

tural capital required by the modern groundwater technology has not attracted appropriate attention in the benefit-cost exercises relating to the new technology.[2] More importantly, the accentuation of external diseconomies, that are invariably encountered in the unregulated exploitation of an "ill-defined-ownership" resource like groundwater, has been totally neglected while appraising the superiority of the new over the traditional technology. The likely impact of these adverse externalities on the well-being of the small and marginal farmers is the main subject of focus in this paper.

*Depth of Water Table*

In the economics of groundwater utilization the depth (D) of water table below the groundwater surface is of crucial economic significance. The operational or variable cost of lifting a unit volume of water (v) with a given technique is an increasing function of water depth, such that $\frac{dv}{dD} > 0$ and $\frac{d^2v}{d^2D} \geqslant 0$. Likewise, the unit capital cost (k) of lifting water is an increasing function of depth of water table, *i.e.*, $\frac{dk}{dD} > 0$ and $\frac{d^2k}{d^2D} \geqslant 0$. Evidently, a change in the depth of water table implies significant economic implications for an irrigator. For example, a rise in the water table would lower the marginal operational cost of groundwater, whereas a decline in the water table may not only raise the marginal operational cost but also give rise to a situation of diminished water availability, resulting in loss of farm output of the irrigator.

Fluctuations in the depth of water table occur almost continually under the complex interplay of a number of factors, of which following four are noteworthy: (1) amount of rainfall (R); (2) volume of groundwater withdrawn (W); (3) rate of recharge of ground aquifer from nearby canals, surface reservoirs and subterranean groundwater stream (I); and (4) rate of groundwater outflow into streams and drains (0).

Of central interest here is the positive relation between groundwater withdrawals and the depth of water table, *i.e.*, for any given area $\frac{dw}{dt}$ and $\frac{dD}{dt}$ are *ceteris paribus* positively correlated.[3] By taking both a very short and a very long view of time factor 't' one can analyse the externalities of new groundwater technology both in the short run and long run.

2. In this connection, see this author's "Economics of Groundwater Utilisation: Public versus Private Tubewell," *Economic and Political Weekly*, Vol. IX, No. 39, September 28, 1974.

3. For a given area $\frac{dD}{dt}$ is negatively associated both with $\frac{dR}{dt}$ and $\frac{dI}{dt}$ but has positive association with $\frac{d0}{dt}$.

*Long-term Externalities*

The hydrologists/hydrogeologists have indeed done a singal service to the nation by alerting the policy-makers to the grave long run consequences of excessive groundwater withdrawal with the rapid but unregulated introduction of tubewell technology Their warnings with regard to groundwater 'mining'[4] in certain tracts experiencing rapid diffusion of the tubewell technology have not, however, been appropriately heeded in the State Legislatures.[5] One important economic explanation why these warnings have failed to register themselves on the legislators as well as the users of the new groundwater technology is the extremely low value of unit operational cost (v) of the new technology compared to the corresponding value for the traditional groundwater technology.[6] Consequently, the lowering of water table does not give rise to serious cost implications for a farmer owning a modern waterlift. For him, the real cause for concern arises when the lowered water table diminishes his water yield. This eventuality too, the adopters of new groundwater technology have, by and large, averted by measures designed to maintain intact their groundwater output.

Because of a number of relieving circumstances the pinch of the much-talked about declining water table is not being felt acutely. Firstly, the sharp outward shift in the demand curve for irrigation water (especially for a source over which a farmer has complete control in regard to the time of application) as a result of the new bio-chemical farm technology has helped in cushioning the additional expenditure entailed by the decline in the water table. Secondly, the lowering of water table in the canal-irrigated tracts has come as a welcome relief to the policy-makers working under the shadow of waterlogging. Thirdly, massive extension of rural electrification network not only reduced a farmer's capital need for powering his tubewell/pumpset but also reduced his unit operational cost wherever he managed to effect a switch-over from a more costly oil-driven to less expensive electric power pump. Fourthly, continued expansion in institutional finance for farm equipment at liberal terms has softened the pinch of extra captital outlay

4. 'Mining' of groundwater resource is deemed to occur when the quantum of water withdrawal over the entire rain cycle of good and bad years exceeds the groundwater recharge over the rain cycle period.

5. Water being a State subject, the Centre has been urging the State Governments to enact suitable groundwater legislation to prevent excessive withdrawal of groundwater by the tubewells. In this connection a model bill, titled "The Ground Water (Control and Regulation) Bill 1970" was prepared by the Centre to guide the State legislatures. So far, no State has adopted any legislative measure for groundwater regulation.

6. For the sake of illustrating the dimension of costs involved, below are set out the comparative values of 'v' :

| | Cost per 1000 cubic meters (Rs.) |
|---|---|
| State tubewell | 1.4 |
| Private tubewell | 1.2 |
| Persian wheel | 44.6 |
| Rope and Bucket lifts (*charsa*) | 93.0 |

*Source :* Based on data in T. V. Moorti : A Comparative Study of Well Irrigation in Aligarh District, India, Cornell International Agricultural Development Bulletin 19, Cornell University Ithaca, 1970, pp. 61-64.

that would have otherwise to be raised from the village capital market bearing exorbitant interest rate.

It is true that in the matter of access to liberal finance, the small and marginal farmers have not been as fortunate as the large farmers backed with bureaucratic-cum-political influence. But, then, the small farmers have been relatively late comers to the new groundwater technology. It is, after all, the small and marginal farmers, having surplus bullock/family labour of low opportunity cost on the one hand or/and lack of access to the liberal segment of the capital finance market on the other hand, who still find using traditional groundwater lifts a worthwhile, if not a paying proposition. Those among them, who opted for the new groundwater technology, may have been hurt badly by the decline in the water table, especially if they failed to raise additional finance required for maintaining intact water yield of their wells.

It is primarily the users of high cost (high variable cost though low capital cost) traditional waterlifts who experience sizable external diseconomies due to permanent lowering of water table by the introduction of new groundwater technology in their vicinity. In case the depth of water table recedes to a level which is still within the *technical capability* of their waterlifts, the externality shows up either as enhanced cost of lifting water or diminished water output, or both. Given that (*a*) technical capability of human-operated counterpoise waterlifts (*Dhenkali, Lot, Tera, Shadoof,* etc.) is almost half that of animal-operated waterlifts (*Rahat, Mhote, Charsa, Kapila* and *Pun*) and (*b*) animal-operated waterlifts are usually less costly than the other traditional lifts, the magnitude of external diseconomies consequent upon a certain recession in the water table would be far greater for the owners of counterpoise appliances than for the owners of animal-driven appliances. In point of fact, the counterpoise lifts practically become inoperative when the depth of water table crosses the 15-feet limit. The corresponding limiting value of 'D' for animal-driven devices is about 30 feet. Beyond these critical limits of 'D', permanent lowering of water table threatens to throw out of farming activity the users of traditional modes of groundwater lifting unless they can effect a change-over in their techniques of tapping groundwater.

How disastrous may be the consequences of the long run externalities on the owners of traditional waterlifts would depend upon both on the magnitude of decline in the water table and the ability of these owners to effect appropriate capital changes in their wells. In the event the water table is lowered just below the technical limits of a human waterlift, the scope for a switch-over to animal-driven devices may be exploited by deepening the dugwell. In case the water table has receded below the lifting capacity of farm animals, one may not be able to carry on farm activity without changing over to new groundwater technology. In either case, additional capital outlays are needed. It is here that the small and marginal farmers may find themselves at a great disadvantage. To begin with, their lack of access to the liberal segment of the rural capital market may stand in their way. Secondly, even if they can manage to raise additional capital required for a switch-over in techniques, their size and fragmentation disabilities may be substantial enough to make the additional investment look unattractive uneconomically. Unless they see a prospect of surmounting these disabilities in some indirect manner (say, either by selling surplus water to the neighbours, or buying water from the neighbours using new groundwater technology), they are doomed as peasant farmers.

*Short-term Externalities*

Adverse short run externalities of the tubewell technology on the users of traditional waterlifts and open wells fitted with power pumps—to be distinguished from short run externalities which the tubewell owners impose on one another due to lack of proper spacing among the tubewells—are not so well realised in the literature as are the long-term externalities of the unregulated introduction of the tubewell technology. In order to bring out these externalities it is necessary to dwell here on induced changes in the water table brought by pumping in the vicinity of a tubewell. As water is pumped out, water held in the formations surrounding the tubewell begins to infiltrate into the tubewell. The surrounding formations so affected are in the shape of a solid cone whose base is on the surface of the static water level and the apex touches the surface of the pumping level of groundwater. The radius of the circular base of this inverted cone is known as the 'radius of influence' ('r') of the well, and as the pumping level recedes in the well 'r' becomes larger.[7]

The value of 'r' is vitally dependent on two factors : groundwater withdrawal rate $\left(\frac{dw}{dt}\right)$ and the physical characteristics of the water-bearing strata $\left(\frac{dw}{dt}\right)$ is of high magnitude for modern groundwater technology compared to the traditional technology, with the result that the area of influence of the former technology is several times that of the latter technology. Thus, compared to 5 to 8 acre-feet of water withdrawn annually through a traditional open well, 12-20 acre-feet is raised by an open well fitted with a power pumpset; 15-40 acre-feet by a shallow tubewell and 200-300 acre-feet by a deep State-owned tubewell.[8] Likewise, the comparatively high speed of the modern groundwater technology may be gauged from the fact that a power pump can almost empty an open well in just 2 to 3 hours of opera-

7. The determining formula for changing value of 'r' when the pumping level is receding is $r = 3000\ d\ (P)^{1/2}$, where 'P' is the permeability coefficient and 'd' is 'drawdown' (extent of decline in water table while pumping).

*Sources :* V.I. Aravin and S. N. Numerov: Theory of Fluid Flow in Underformable Porus Media, 1965, p. 105.

8. *Source :* Reference to footnote 1.

tion whereas a traditional waterlift might take 10 to 12 hours of operation for emptying the same well.

Within the radius of influence of a well the extent of adverse externality —as reflected in lowering of water table—experienced by another groundwater exploiter is in inverse proportion to his distance from the well in question. How the water table is lowered in open wells at various distances from a tubewell has not been empirically and thoroughly investigated in India.[9] More importantly, we do not have studies indicating the lowering of water table at various distances as a result of *simultaneous* operation of a few tubewells with radii of influence overlapping. In order to illustrate the potential short run hydraulic spillover-effects on users of groundwater resource at different distances from the site of a *single tubewell*, we present in Table I some data based on pumping tests for two tubewells of West Pakistan. It

TABLE I—EXTENT OF LOWERING OF WATER TABLE AT VARIOUS DISTANCES FROM A TUBEWELL

| Tubewell No. | Observed decline in water table (in feet) at a distance (in feet) of | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | 2 | 50 | 100 | 250 | 500 | 1000 | 2000 | |
| I .. .. | 7.0 | 6.5 | 5.8 | 4.5 | 3.3 | 2.0 | 1.0 | This tubewell of 3.8 cusec discharge rate was operated for 30 days. |
| II .. .. | 3.2 | 2.5 | 1.8 | 1.2 | 0.7 | 0.8 | — | This tubewell of 2.9 cusec discharge was operated for 10 days. |

*Source:* Nazir Ahmed, "Hydraulics of Tubewells," *Engineering News*, Vol. 12, No. 4, December, 1966.

is clear from such data that the small and marginal farmers operating the traditional waterlifts in an area having tubewells may be experiencing external diseconomies when tubewells depress the water table in the very short run. Such temporary depressions in the water table, which are likely to occur at the peak time of agricultural season when tubewells have a high probability of working simultaneously, may have deleterious impact on crops under the command of traditional waterlifts. The prospects for such an eventuality is all the more when the expected rains fail. Thus, the very reliability of tubewell water in drought time can be a source of undoing of farmers using traditional lifts (unless the former agree to supply water to their doubly-stricken brethren).

9. The author is aware of only few empirical studies conducted by the U.P. Irrigation Research Institute, Roorkee. However, these are based on just one observation well in the vicinity of a State tubewell.