

Comanagement of Power and Groundwater Resources: Issues in Sustainability and Equity in Groundwater Scarce Areas

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Executive Summary

1. **Groundwater** resources are showing increasing signs of overdevelopment in many arid and semi-arid regions in India. Groundwater is a very valuable resource in India since it accounts for 75-80 percent of the value of irrigated crop produced in India. Roughly 35 million hectares can be irrigated by groundwater - a figure which exceeds the 33 million hectares of irrigation potential created through all major and medium irrigations projects in India. If current trends continue, overdevelopment could pose a major threat to the sustainability of irrigated agriculture in these areas.

2. In the North-Western state of Gujarat, groundwater accounts for over 76 percent of the total area irrigated in the state. In the southern state of Karnataka, groundwater accounts for 26 percent of the gross area irrigated. Many districts in these states are facing acute groundwater overdevelopment problems. In Mehsana district in Northern Gujarat, groundwater accounts for 85 percent of the districts irrigation needs. In Kolar district of Karnataka, it accounts for 59 percent of the areas irrigation needs.

3. Water tables have been rapidly falling in Mehsana. The decline has been nearly three meters per year since 1981. Majority of wells in Mehsana are drawing water from depths of nearly 400 feet. In the hard rock region of Kolar in Karnataka, there is a high borewell failure rate (nearly 50 percent) and decreasing probability of striking water.

4. Dramatic increases in the number of electrified pumpsets is one of the major reasons for overdevelopment of groundwater. The provision of electricity based on the horse power of irrigation pumpsets and not on actual electricity consumption at highly subsidised rates is also seen as a factor responsible for overdevelopment.

5. The provision of subsidised electricity to the agricultural sector is mainly responsible for the poor financial performance of the monopolistic electricity utilities called State Electricity Boards (SEB's). Gujarat sells over 40 percent of its electricity production to agriculture, while the corresponding figure for Karnataka is 36 percent. While the average cost of electricity production in Gujarat and Karnataka is 150.89 paisa/kwh and 110.64 paisa/kwh, farmers in these states are charged only 23 paisa/kwh and 11 paisa/kwh as electricity tariff respectively. The SEB's in these states have incurred huge commercial losses due to the unremunerative tariff structure in these two states. In Karnataka, 95 percent of the irrigation pumpsets owners do not pay any tariffs since tariff is levied only on farmers operating pumps over 10 HP.

6. The poor state of the financial health of SEB's is reflected in the demand supply gaps, frequent power cuts, poor quality of power supply to the agriculture sector. Gujarat and Karnataka have a flat rate HP (horse power) based tariff system for the agricultural sector. In a HP based system, farmers are charged on the basis of their pump HP and not according the actual electricity consumed. Both Gujarat and Karnataka are unable to meet the minimum rate of return of 3 percent as enacted by the 1948 ESA (Electricity Supply Act).

7. Charging higher electricity tariffs based on a metered (consumption) system to the agricultural sector is frequently recommended by many policy makers to improve the financial health of SEB's and also arrest the overdevelopment of scarce groundwater resources. The implicit assumption being that in a HP based system, farmers have no incentive to save on both power and groundwater.

8. Three separate case studies were undertaken in the state of Gujarat and Karnataka to study the role of energy (electricity) pricing in mitigating groundwater overdevelopment. These studies were conducted in Mehsana a alluvial region of the state and Junagadh a hard rock region. In Karnataka the study was conducted at Kolar a hard rock region. All these areas face acute groundwater scarcity. The equity implications of using a consumption based energy pricing policy was also studied. These case studies are very site and assumption specific and relevant to the specific groundwater scarce region only. Moreover, the study only looked at prices that are within a politically feasible range i.e., the average cost of electricity production in the state concerned.

9. In the case of Mehsana, Gujarat a region where the institution of groundwater markets is pervasive it was seen that switching over to a consumption based tariff will not have any effect on the rate of groundwater extraction. In Mehsana, the price of groundwater currently reflects its scarcity value and not the cost of extraction.

10. Given the wide disparity between current extraction and recharge rates in Mehsana and low groundwater demand elasticities, it is doubtful if electricity prices can play more than a supplementary role in the sustainable use of groundwater. The more productive means could be through technological intervention on the demand side and improving storage structures to conserve groundwater.

11. Simulations showed that tariffs above 60 paisa/kwh (less than the current average cost of supply which is 150 P/kwh) could have adverse equity implications on non-bhagidars by transferring their incomes to the bhagidars since there elasticity of groundwater demand is less than one.

12. If current rates of recharge and extraction continues in Mehsana, the prohibitive costs of investing in new wells could have major negative equity implications on small and marginal farmers. Energy consumption could also rise if higher HP pumps are installed to pump out groundwater from lower depths. This could again worsen the financial position of the SEB in Gujarat.

13. In Maliya taluka of Junagadh district, Gujarat, a hard rock region, water tables have been falling over the past ten years. The cropping pattern has not changed in this area with most farmers growing groundnut and wheat, the major kharif and rabi season crops. Most farmers operate 5 HP electric pumpsets in Maliya taluka while a substantial number of farmers also irrigate there farms with 5 HP diesel pumpsets. Electricity is available in the region for only 10-12 hours a day.

14. Farmers who operate 5 HP electric pumps pay approximately 20 paisa/kwh (in energy terms) while diesel pump operators pay approximately 200 paisa/kwh. Despite the wide disparity in energy costs between these two sets of farmers, a marginal productivity analysis showed that neither of them are using their groundwater input inefficiently in an economic sense. Efficiency here is defined as the point where the value of the marginal product is equal to the marginal cost of the input.

15. Despite paying higher energy costs, diesel pump owners did not resort to any water and/or energy conservation measures.

16. There was widespread technological dualism in maliya taluka with implications for equity. Diesel pump owners complained that during times of drought they were forced to irrigate less because water tables decline sharply and get beyond the reach of diesel pumps. They also said that continuous pumping by electricity pump owners in a bad rainfall year depleted there wells. Diesel pump owners are therefore very vulnerable as a group during times of water stress.

17. A related aspect of equity is the inherent inequity associated with the state (wittingly or unwittingly) continuing to subsidise electricity pump owners and not diesel pump owners, when both get the same price for there crops.

18. In Kolar, Karnataka, farmers use 6 HP submersible pumps to extract groundwater from a depth of 160 feet. The main crops grown in the region are ragi and paddy (mainly for self consumption) and tomato in the kharif season. Potato, carrots and cabbage are grown during the rabi season while mulberry and grapes are perennial crops.

19. The analysis for optimum water application at various electricity tariff rates showed that consumption based tariffs over a large range would not have any impact on water demand.

20. Over a large range of tariffs, water application intensity would be much larger than the present average application rate (which is sub-optimum). This implies that switching over to a consumption based electricity tariff structure would have no impact on water application intensity. Water application intensity is low because of the overall scarcity of water in Kolar.

21. Crop-switching to lower water intensive crops as a means to save water is also ruled out because of the overall scarcity of water. Even if crop switching did take place, water saved due to crop switching is likely to be used to either increase water application intensity and/or irrigate additional land.

22. The quality of power supplied to the region needs improvement. The poor quality of power supplied has led farmers to store water in tanks constructed near their fields. Groundwater is pumped into these tanks (at night when power is available for 8- 10 hours) used to irrigate the land the following day. This leads to a 25 percent loss in water stored in tanks due to seepage, percolation, and transpiration. The implied energy losses at some tariff rate may become prohibitive enough to compel farmers to invest in tank improvement measures. Our analysis showed that despite high (simulated) tariff rates, farmers may not invest in tank improvement measures. This is because of the lack of sufficient funds available with farmers and/or their risk averse behaviour.

23. Given the scarcity of groundwater resources in Kolar, there is a need to strengthen surface irrigation systems and also build efficient water harvesting structures to conserve groundwater. Given the cropping pattern in Kolar, modern irrigation like drip or sprinkler can also play a major role in conservation of groundwater.

Chapter 1

1.0 Introduction: Nature and Scope of Study

Groundwater resources are showing increasing signs of overdevelopment in many arid regions of India. As a source of irrigation, groundwater is probably India's most valuable and perhaps its most vulnerable water resource. Groundwater irrigation accounts for 75-80 % of the value of irrigated crop production in India (Daines and Pawar, 1987,p.5). Agricultural development in India since the late 1960's has come to be identified more with rapid growth of private wells than with canal or tank irrigation because the crop yields on groundwater-irrigated lands are higher than those on canal or tank-irrigated lands (Dhawan, 1988). Roughly 35 million hectares (Mha) can be irrigated from groundwater - a figure which exceeds the 33 Mha of irrigation potential created through all major and medium irrigation works (Dhawan,1990). Over the past four decades groundwater development in India has grown exponentially. Long viewed as an unlimited "renewable" resource, threats to groundwater supplies are becoming increasingly evident. Long-term declines in water tables, high well failure rates and sea-water intrusion into fresh-water inland aquifers are emerging in many areas.

Dramatic increases in the number of wells and energized pumpsets to extract groundwater are probably the most important factors responsible for overdevelopment. Diesel and electric pumpsets numbered over 12.5 million in 1990 and have increased at a continuous growth rate of over 12 % since 1950 (Dadlani, 1990). The provision of electricity for pumping under an annual horsepower based tariff structure and at highly subsidized rates is also seen as a contributing factor.

The financial health of the State Electricity Boards (SEB's) is adversely affected by the subsidised agricultural tariffs in most parts of the country. The subsidies inherent in agricultural power tariffs and the increasing use of irrigation pumping using electricity are of great concern to decision makers in the power sector. It is not merely the financial effects of current tariffs which need to be considered in sensitizing decision makers for taking a fresh look at agriculture tariffs, but also the impact these would have on a vital natural resource such as groundwater. In this context, the present study undertakes a review and analysis of the power pricing structure for the agricultural sector and its implications on groundwater resources in water scarce regions of India.

This study arises from the concerns about the magnitude and persistence of groundwater depletion in a region where depletion of scarce groundwater resources could threaten the long term sustainability of irrigated agriculture.

The main objectives of this report are as follows:

- to study the role of energy pricing on sustainable utilization of groundwater resources for irrigation
- understand the equity and efficiency effects of energy pricing on groundwater management regimes

An associated objective of this study is to identify, on the basis of existing knowledge, feasible policy options for managing fast depleting groundwater resources. The method of enquiry consists of a literature survey and one colloquium where researchers and the TERI study-team debated the issues in an informal setting. Field work in the state of Gujarat and Karnataka was specifically undertaken for this study to enable team members to gain invaluable experience into field realities and apply their experience into policy and research implications. To keep the report concise and directed, some important and complex issues are excluded from in-depth investigation, i.e., salinity, conjunctive water management, the availability of complementary input subsidies other than electricity subsidies in the two states.

For ease of exposition, the report is divided into five chapters. Chapter 1-3 deal with the Gujarat section of the report. It presents the nature of the groundwater problem vi-a-vis power management in water scarce areas of the state of Gujarat. This exercise is undertaken in the form of case-studies conducted in two groundwater scarce regions of the state, namely, Mehsana in North Gujarat and Junagadh in Saurashtra.

Chapter one of the Gujarat report, draws the macro linkages between groundwater and energy in the state of Gujarat. We discuss the role of water market in Gujarat and examine the theoretical implications of using energy prices as a tool for groundwater management in water markets which have scarce groundwater resources as pointed out by past and on-going debates in this area. This chapter also highlights the overdevelopment of groundwater resources with respect to deficient rainfall and the rapid rise in number of electrified pumpsets in one groundwater scarce district of Gujarat. Chapter two of the Gujarat report, explores the role of electricity pricing as a tool for managing depleting groundwater tables in the groundwater scarce district of Mehsana which has one of the most well developed water markets in the region. Water price and power price elasticity of demand are estimated for two category of farmers to draw policy implications on using electricity pricing as a groundwater management tool. A simulation exercise with and without power rationing is also carried out to find out the effect of electricity prices on water prices and its effect on equity and sustainability of groundwater resources. Given the wide differences in the structure and rate of prices

among farmers using electric and diesel pumpsets, what is the difference in water use behaviour among farmers within a given region? An attempt is made to answer this question in Chapter three by conducting a case study in another groundwater scarce region of Gujarat i.e. Junagadh, a region where there are no water markets.

Chapters 4-5 presents the findings of the study undertaken in water scarce areas of the state of Karnataka. Since the nature, extent and typologies surrounding groundwater regimes was different in these two states, it was felt necessary to present the results of both studies separately. All chapters are self-contained.

1.1 Energy for Groundwater Pumping

In India as in other countries, the agricultural sector is subsidized by the government. As a result, many of the inputs which go into the agricultural production process are provided to farmers at rates which are lower than their marginal cost of production. For example, electricity tariffs for pumping groundwater in the agricultural sector in India are based on a flat rate system where farmers pay electricity charges based on the pump horsepower and not a pro-rata metered system. This pricing structure, since it is not based on marginal cost pricing principle, many analysts believe, is responsible for wastage of both power and groundwater resources.

Popular concerns about groundwater overdevelopment and power pricing is highlighted by falling groundwater tables in states where a large amount of electricity is sold to the agriculture on a flat-rate basis and at prices that are much below the cost of power produced. This is illustrated by the table below for the year 1993-94;

States	% of power produced in the state that is sold to agriculture sector	Average cost of production in Paisa/kwh	Average tariff at which electricity is sold to agriculture (Paisa/kwh)	Commercial losses suffered by SEB (Rs.crores)	Water table decline reported from various parts of the state (1978-1990) (meters)
Harayana	44.68	166.04	35.0	-377.16	2-3
Gujarat	41.53	150.89	23.0	-598.0	10-20
Karnataka	35.95	110.64	0.11	-33.87	5-10
Punjab	43.26	143.65	12.21	-846.2	5-10
Tamil Nadu	26.03	146.27	0.00	-29.80	5-8

Source: Planning Commission (1994), VIKSAT (1993)

According to Moench (1992b), the current debates on using electricity pricing as a groundwater management lever to control depletion is centered around two assumptions;

- i) That current flat rate electricity pricing is responsible for groundwater depletion.
- ii) That changing energy pricing policies will, by altering the structure of incentives underlying current water use patterns, change the efficiency of water use.

We need to distinguish between economic efficiency (maximizing returns to the scarce resource) and other forms of efficiency like water use efficiency (preventing wastage of water).³

Not only is the pricing structure based on a flat-rate system, it is also highly subsidized. On an all-India basis, while the average cost of production and generation per unit of electricity is Rs 1.49 the average revenue realized from sale of power to the agricultural sector is Rs 0.20 per unit of power (Planning Commission, 1994). The subsidy borne by the SEB's (State Electricity Boards) from 1990-94 in supplying power to the farm sector is estimated to be Rs 26,273.64 crores. This has led to the SEB's losing revenue worth Rs 10, 933.65 crores between 1990-91 - 1993-94 (Planning Commission, 1994)⁴. Since the agriculture sector accounts for an increasing share of the

³ Assume a demand schedule for power that is smooth, continuous and convex to the horizontal axis. Equation (1) below represents the demand curve for power:

$$Q_p = g(C_p) \quad C_p' < 0 \text{ and } C_{pp}'' > 0 \quad (1)$$

In equation (1) above, Q^p is the quantity of power which is a single valued function of the cost of power C_p with the usual first order and second order conditions. Farmers use the power to pump water from their wells given by equation (2) below.

$$W = h(Q_p) \quad h' > 0 \quad (2)$$

Equation (2) implies that water extraction rises with increase in quantity of power used. Substituting equation (1) into (2) we derive the following equation which relates amount of groundwater extracted with the cost of power.

$$W = h(g(C_p)) \quad g' < 0 \quad (3)$$

Equation (3) states that the price of power and groundwater extraction are inversely related. This is the theoretical basis for relating power pricing to groundwater extraction. *Ceteris Paribus*, as the price of power rises farmers use less of groundwater for irrigation. If electricity is charged on an unit rate basis (Rs/kwh) then economic logic suggests that farmers would consume power efficiently i.e the point where the value of marginal product of the crop is equal to the marginal cost of power. This is the economic efficiency criterion referred to above.

⁴ The cumulative loss is lower than the subsidy because of higher tariffs charged to the industrial sector and State governments cover a part of the subsidy borne by the SEB's

total electricity consumption (more than 40 % in Haryana, Gujarat and Punjab) it is not surprising that the losses of the SEB's are rising correspondingly⁵.

1.2 Energy Pricing and Groundwater Extraction in Water Markets

The role of irrigation from groundwater in the growth of agricultural production in India has, it has been recently acknowledged, been crucial, and, it has even more recently been realized, much, if not most of this resource is allocated through groundwater markets. During the mid-1980s many researchers emphasized the extent and role of groundwater markets in the development of agriculture (Shah, 1985; Kolavalli, 1987;). However, pioneering work in this area was conducted at IRMA (Institute of Rural Management, Anand, Gujarat) by Professor Tushar Shah and his colleagues.

Shah (1985, 1987) pointed out the extent of groundwater markets and their significance and analyzed them as "natural oligopolies" which are characteristically inequalitarian and inefficient, and needed to be transformed into powerful instruments of small farmer development. In particular, Shah argued for charging electricity (good quality rationed supply) for pumping using a flat rate (FR), on the grounds that it leads these oligopolies to perform like competitive markets. Based on field work, Shah argued that differences in water prices between regions "is explained not by aquifer conditions but by the degrees of water sellers monopoly power and by incremental pumping costs. He pointed out that these costs are lower in states which have a FR electricity tariffs since these reduce incremental pumping costs to zero⁶. States with flat rate tariffs had experienced rapid tubewell development and this development apparently improved equity in rural areas by making water accessible to the rural poor and also through increased employment. In order to counter the deleterious effects of over-pumping of groundwater, Shah suggested rationing "high quality" electric supplies to limit groundwater drawdown externalities.

⁵ Domestic consumers are also supplied cheap power. According to the Economic Survey of 1993-94 the subsidy involved in supplying power to the household sector amounts to Rs 5000 crores for the years 1991-93. This is however another issue altogether which is beyond the scope of our study.

⁶ The basic propositions advanced by Shah are based on the Lerner index of monopoly, which suggests that the degree of monopoly can be expressed as the ratio of price to marginal cost, which is related to the elasticity of demand. $L = (p-c)/p$, where L is the Lerner index, p is the market price, and c is the marginal production cost of the monopolist. For a monopoly, $L = -1/e$ where e is the price elasticity of demand for the good produced by the monopoly. For a monopolist: $\pi = p(q).q - c.q$, where π is the monopolists profit, $p(q)$ is the monopolists demand inverse demand curve, q is output, and c is the unit variable cost of production. Differentiating and rearranging this yield's the result $(p-c)/p = 1/e$ or alternatively, $p/c = e/(1+e)$.

A number of states have now adopted flat rate electricity tariffs, under political pressure from farmers and in Gujarat following advice from Shah. Unfortunately, the quality of rural electric supplies has not improved and rationing has not been introduced in a planned way due to which socially undesirable overpumping and groundwater drawdown seems to be continuing in many areas which have flat rate electricity tariffs for the agricultural sector, namely, Gujarat, Punjab, Karnataka Tamil Nadu and Uttar Pradesh.

Richard Palmer-Jones (1993) provides an excellent critique of Shah's work on electricity pricing and groundwater markets. We summarise below the main empirical evidence advanced by Shah for promoting flat rate pricing for groundwater pumping and Palmers-Jones's counter arguments.

a) Costs and Mark-ups

Based on data from seven tracts in Tamil Nadu, Punjab, UP, Gujarat and Andhra Pradesh, Shah (1993,p.210) argues that:

"Since the average pumping costs per hp per hour in the case of diesel WEM's (water extraction mechanisms) show remarkable uniformity, it could be inferred that the differences in prices charged by water sellers in different regions reveal variations in monopoly power enjoyed by water sellers in different regions. Indeed, the ratio of price charged to incremental pumping costs is a good indicator of the monopoly power of water sellers in different regions".

However, as Palmer-Jones points out, both hydro-geological and agro-climatic conditions vary greatly between these regions. These climatic differences make for considerable differences in the irrigation requirements of different crops. It is also likely as he suggests, that the average pumping water depth, and total dynamic head - which determines pumping costs- varies between sites. Furthermore, Palmer-Jones contends that important costs such as transactions costs are neglected by Shah in his analysis. Lack of complete information, for example, on seasonal variations in pumping water depths also makes it difficult to believe that diesel powered tubewells should have uniform costs.

b) Electricity Tariffs and Competition in Groundwater markets

Shah (1993a) also argues that a pro-rata price for electricity means that water sellers have high incremental pumping costs, while with flat rates, the marginal costs falls to zero⁷. Under flat rate pricing, monopolists would have to lower prices and which would

⁷ However, according to Chicoine and Kolavalli (1989, p.42) marginal costs of water sales are not zero; there are marginal labour, operation and maintenance costs. In Kheda district in Gujarat for example, where water selling is widespread, not all credit sales were completely recoverable and hence written off.

expand water sales thereby increasing competition. Shah supports this theoretical argument that FR induces competition and PR limits it on the basis of evidence collected from the states of Gujarat, West Bengal, Punjab, Tamil Nadu and Andhra Pradesh. In Gujarat, Shah points out, water prices rose when PR rates increased. Moreover, water prices showed apparent uniformity across regions with different levels of FR.

However, most of Shah's arguments hold for both monopoly and competitive markets. Flat rate pricing may be expected to lower prices and expand sales in a competitive market as well as in a monopolistic one if average costs are lowered (Palmer-Jones, 1993, p.20).

Finally, Shah refers to the fact that "following the rapid increase in pro rata power charge in Gujarat since 1978 the sale prices of groundwater in private water markets have risen rapidly and ... profits from water sales have also increased along with increases in power tariffs ..." (Shah and Raju, 1987, p.37). Figures provided by Shah and Raju (1987) show that between 1974 and 1986 power costs increased by 364 % while water prices increased 417 % and the profit rate (calculated as the difference between the per hour electricity charge - the units per hour* price per unit - the water price per hour) rose by 560 %. Thus, water price increased by a somewhat greater proportion than electricity charge. This information is provided to justify the monopoly hypothesis since a monopoly may pass on more than the increase in input price under some conditions.

However, these facts need not support the monopoly hypothesis. It is equally likely that the rise in costs and output prices over time may be a result of inflation. One should bear in mind that while water and electricity prices rose by 17 % and 16.5 % per annum respectively during the period 1974-1986, the average annual rate of inflation at that time in India was 7.8 % per annum (World Development Report, 1988). Secondly, water sales in Gujarat are usually paid for at harvest, with significant delays and even defaults, while electricity is paid monthly; clearly some charge for interest on the credit advanced, the defaults and transactions costs is part of the marginal cost of sellers. Part of these costs would increase with the electricity charge. Third, the mark-up over marginal costs by the monopolists depends on the shape of the demand curve and the associated elasticity of demand; if demand is linear then only half the increase in cost is passed on, while for a constant elasticity of demand price will rise by more than the increase in price. Hence, without information on elasticity of demand for irrigation water it is hard to give much weight to the evidence of monopoly. Finally, the scarcity value

Accordingly, the marginal cost of credit sales is non-zero even in a flat rate electricity pricing regime.

of water could also be reflected in higher water prices over time due to rationing of power and rise in the density of tubewells in a given aquifer.

1.3 Energy Pricing and Groundwater Development: The Equity Debate

The use of electricity prices for promoting rural equity has consequences for levels of economic activity and welfare within both irrigation and other sectors. Shah (1985) argues that groundwater markets exhibit strong responsiveness to intervention and policies should be designed to work through these markets. Shah, argues that FR has beneficial effects on equity and rural poverty. For areas where groundwater is relatively abundant, he favors flat rate tariffs to lower water prices and expand groundwater sales. This should benefit poorer sections of the community, since they can afford to use more irrigation water on their own land and there will be increased demand for labour due to the adoption of more water intensive crops⁸. Evidence from the states of Andhra Pradesh, UP and Maharashtra is provided by Shah to support this argument.

In areas where groundwater resource is overdeveloped and scarce, equity goals can often be in direct conflict with those of efficiency. While FR may promote competition in groundwater markets by giving access to the poorer sections via relatively equitable water markets, they do not provide any incentive to save power or water⁹. Moreover, Shah suggests that to mitigate the harmful environmental effects of FR, power rationing should be resorted to. This however could lead to higher water prices leading to inequity in access to scarce irrigation water!

It is not clear how well equity goals have been served by FR pricing. While Shah supports FR on the basis of evidence that it promotes equitable groundwater markets which allow the poor access to a scarce resource, others like Bhatia (1992) and Goldman (1989) argue that water markets are highly inequitable. As Moench states, ... *given the pervasive electricity shortages in India, inefficient use reduces overall availability of energy for pumping. It is (therefore) not clear if the poor are better served by more equitable access to a pie who's size has been reduced by inefficiency or if they would be better simply by efficient use patterns that effectively double the size of the pie* (Moench, 1993 p.5).

⁸ Studies on irrigation and labour absorption elasticities have been done at ICRISAT. See ICRISAT (1987).

⁹ Pump owners in Mehsana district of Gujarat, an area of rapidly falling water table, and one which has one of the most well developed groundwater market, often sell water at half dry season rates during the monsoon in order to maximize profits over the fixed electricity charges.

FR may also encourage extraction rates - a factor which is directly in conflict with sustainability in overdeveloped aquifers. Shah promotes FR on the premise that it would have positive equity implications in monopolistic water markets. However, groundwater development via efficient water markets in overdeveloped aquifers has distinct equity implications. Extraction technology is "lumpy". Falling water tables progressively limit the effectiveness of different pumping technologies. Only the resource-rich are able to "chase the water-table"¹⁰.

1.4 Irrigation Development in Gujarat

The state of Gujarat comprises 1,95,984 Sq.km of area in the western semi-arid region of India. About 53,860 Sq. km area is drought prone. Groundwater resources of the state are limited on account of scanty rainfall, frequency of droughts in the state and vast tracts of land coming under saline category. The climate of the state is divided between the summer and winter season briefly interluded by a period of monsoons between mid-June to September. A large part of the state lies within the 35° and 45° summer isotherms.

The role of irrigation from groundwater in the growth of agricultural production in Gujarat, has been crucial since the 1960s. Previously groundwater was widely exploited using traditional irrigation technologies, but since the mid 1960s there has been an explosion in groundwater irrigation (Dhawan, 1990). This was brought about by technical innovations in tubewell irrigation during the middle of this century, but was mainly triggered by the green revolution.

¹⁰ Many believe that water markets may be responsible for depleting aquifers due to competition among farmers to overexploit an open-access resource by selling water. This they feel, has negative equity implications (Bhatia, 1992, Saleth, 1993, Janakrajan, 1993.). Others feel that since equitable water markets expand sale of water, the poor have access to a valuable resource and therefore water markets have positive equity implications (Shah, 1993. Kolavalli and Chicoine 1987). In many hard rock regions which have no groundwater markets (Kolar in Karnataka for example) but have overdeveloped groundwater resources, the emergence of overdevelopment appears to be having a number of effects. First, the costs and risks of failure associated with digging new wells preclude small farmers. As scarcity emerges the wealthy are better positioned to maintain access to water and "capture" the remaining resource (Kolavalli & Athecq, 1993).

The pace of development of irrigation in Gujarat in recent times can be seen from table 1.1 and 1.2 below.

Year	Gross area sown (Sq.km)	Gross area irrigated (Sq.km)	Gross area irrigated as percentage of area sown
1960	96,676	7338	7.5
1970	105,403	14939	14.2
1985	111,457	30,001	27

Source: Statistical Abstract of Gujarat, 1984-85

Source	1960-61	1970-71	1983-84
Govt. canals	652 (9.5)	2358 (17.2)	4892 (21.5)
Private canals	6 (0.1)	6 (0.04)	--
Wells	5677 (83.1)	10831 (79)	17370 (76.5)
Tanks	128 (1.9)	372 (2.7)	407 (1.8)
Others	366 (5.4)	141 (1.0)	40 (0.2)
Total net area irrigated	6829 (100)	13708 (100)	22709 (100)
Gross area irrigated	7338	14939	27974

Source: Statistical Abstract of Gujarat, 1984-85

Between 1960 and 1985, the percentage of gross area irrigated to gross area sown increased nearly four times. Table 1.2 shows that groundwater irrigation accounts for almost 77 percent of the total area irrigated in the state. Within the wells category there has been a dramatic rise in the area irrigated by the number of modern water extraction mechanisms and the stagnation of dug-wells from 1960 to the 1980s.

1.5 Over-Exploitation & Sustainability of Groundwater Resources

Groundwater irrigation accounts for roughly 77% of the total irrigated area in Gujarat. This irrigation is undertaken mainly through variety of wells- tubewells, dug-wells, dug-cum-bore wells and borewells only. With Gujarat achieving 97% rural electrification approximately 50% of the wells are now powered by electricity and 45% by diesel engines (CMIE,1993).

Like surface water, groundwater has its origin in rain and snow. The infiltration of rainfall into the soil beyond the crop root zone is the source of groundwater recharge. The concept of over-exploitation of groundwater is essentially normative in character. Groundwater is said to be overexploited when the extraction for irrigation and non-irrigation exceeds the annual recharge. This normative definition is based on the "safe yield" principle of groundwater hydrology which states that extraction of groundwater should equal recharge so as to keep the stock of groundwater intact. This implies that secular decline in depth to water table is a clear signal of over-exploitation of groundwater or groundwater mining.

The safe yield principle is used by CGWB (Central Groundwater Board) to categorize agricultural blocks (talukas) in India into dark, grey and white areas. According to CGWB, an area is declared dark when groundwater extraction to utilizable recharge ratio is 85 percent or more. A grey area is one where extraction to recharge ratio is between 65 to 85 percent and white when this ratio is below 65 percent¹¹.

Based on the above categorization groundwater resources in the state of Gujarat have been declining alarmingly with 60 out of the 183 talukas in Gujarat falling in the dark and grey categories (34 talukas fall in the dark category and 26 in the grey category). Secular fall in water tables monitored by the Gujarat Water Supply and Sewerage Board, has also shown that water table fell in 87 out of the 96 observation wells between 1981-90, with the decline varying from 7 to 9 metres in the districts of Ahmedabad, Banaskantha, Junagadh, Rajkot and Surendranagar (Bhatia, 1992). Moreover, available data suggest that recharge rates may be very low in the arid region of Gujarat. Probable dates on water samples from deep aquifers in Gujarat are roughly 500 years (Bhattacharya, et al. 1979 cited in Moench, 1993). These aquifers are recharged primarily by leakage from the upper sections (CGWB,1984). Recharge studies

¹¹ According to some researchers the categorization of blocks into such hydrological zones is deceptively simple. While the use of blocks is convenient they do not have any relation to hydrological boundaries and are not a meaningful way of defining the territorial units for measuring rates of recharge and rates of extraction. The problem is compounded because if the aquifer is continuous, like the Indo-gangetic plain, one cannot talk meaningfully about sustainable rates of extraction in any single part of it (Vaidyanathan, 1993).

based on moisture profiles and tritium suggest recharge rates on the order of 5-14 % of rainfall, far lower than the 20-25 % of rainfall generally assumed for similar (alluvial) soils in official groundwater estimates (Gupta & Sharma 1987 cited in Moench,1993).

The districts affected by groundwater depletion in Gujarat are Mehsana, Banaskantha, Sabarkantha and Ahmedabad. Among these districts, Mehsana is the worst affected with all its 12 talukas coming under the dark or overexploited category. The annual rate of decline of water levels had increased from about 1-2 meters from 1970 to to 3-4 meters in the early parts of the 1990s¹². In other parts of North Gujarat, namely Ahmedabad, Banaskantha, Sabarkantha and Kutch the decline in water tables has been exacerbated due to poor rainfall during consecutive drought years of 1985, 1986 and 1987, coupled with increase in groundwater draft brought about by increased pumping. Declining water tables due to failure of rainfall and rise in number of energized pumpsets are two of the most cited reasons in discussions centering around over-exploitation and sustainability of groundwater resources in the state of Gujarat.

1.6 Declining Rainfall & Groundwater Depletion

Official documents attribute the frequency of droughts in Gujarat as one of the major reasons for declining GW tables. In a official document published by Central Groundwater Board (Phadtare, 1988) it was highlighted that there was large scale groundwater mining during the 1970's and 1980's. Phadtare (1988) reports historical data on the basis of hydrographs and long-term trend of groundwater levels and calculates water table levels from 1979 to 1987. For the 8 years examined, there were severe drought years (1979-80, 1985-86 and 1986-87). These maps clearly showed that there was an overall decline in water levels in all regions with water tables having fallen by over 2-4 metres. Phadtare's analysis (table 1.3 below) clearly shows that water tables declined drastically in drought years because recharge was negligible while draft occurred continuously.

¹² Personal communication with John Ambler, (October 28, 1994) citing studies undertaken by the Dutch rural water supply programme in North Gujarat.

Table 1.3 Groundwater resources during drought years

Year	Rainfall (mm)	Ground Water Recharged (mcm)	Ground Water Discharged (mcm)	Average decline between May 1984 and May of the relevant year (metres)
<u>Saurashtra</u> (Average annual rainfall: 550 mm; area: 64,339 Sq.km)				
1984	506	6426	3737	--
1985	291	3400	3830	1.3
1986	398	4650	3925	2.5
1987	140	1635	2757	5.0
<u>Kutch</u> (Average annual rainfall: 350 mm; area 45,652 Sq.km)				
1984	335	803	282	--
1985	222	509	289	1.3
1986	164	422	296	2.5
1987	40	96	148	5.7
<u>North Gujarat</u> (Average annual rainfall: 625 mm; area: 37,870 Sq.km)				
1984	706	4535	2292	--
1985	381	2764	2063	1.5
1986	299	2169	2856	3.3
1987	175	1269	1763	4.5

Source: Phadtare (1988)

Note: mm = milimetres, mcm = million cubic meters

While decline in groundwater due to the failure of the monsoons may have contributed to the fall in water tables, this could however be only a short-term phenomenon. Official claims that declining rainfall is the major cause of groundwater decline is seriously discredited by our time trend study reported below in table 1.4. Table 1.4 shows that there is no long term decline in rainfall in state of Gujarat and also the districts of Sabarkantha and Mehsana for the period 1951-1990.

While this analysis sheds light on the contributory role of rainfall on groundwater table recession in Gujarat, we have to clearly understand the relative contributory role of a transitory phenomenon like drought (caused by bad weather cycles) and overdevelopment of groundwater irrigation in the state due to expansion of energized

pumping for irrigation. This is important because even in the decade of the eighties, districts which had no history of groundwater problems in Gujarat had declining water tables. As the 80's progressed rainfall in Gujarat tended to be markedly below normal-it was nearly normal in 1981, the beginning of the decade under reference.

Table 1.4 Trends in rainfall

Area and period	Time coefficient	t-Ratio
Gujarat, 1951-85	0.73	0.16
Gujarat, 1951-90	-1.87	-0.49
Sabarkantha, 1951-85	-0.30	-0.05
Sabarkantha, 1951-90	-3.11	-0.66
Mehsana, 1951-90	-1.38	-0.27
Mehsana, 1951-85	6.6	1.1

Source: Bhatia (1992), IIM - Ahmedabad (1991)

1.7 Groundwater Depletion & Energized Pumping

The National Water Policy (1987) gives the highest priority to drinking water. Agriculture has second priority followed by industry. On a practical level, the small magnitude of drinking and domestic needs relative to water requirements for agriculture, coupled with India's long-term emphasis on food security has led to an emphasis on groundwater development for agriculture.

Over the past four decades groundwater development has grown exponentially. By 1990, the country had 12.5 million diesel and electric pumpset. It is estimated that 35 million hectares (roughly 42%) of India's irrigation potential can be served by groundwater. Twenty percent of India's electricity production (more in some states) goes towards pumping groundwater (Planning Commission, 1994).

In Gujarat the utilization of groundwater began during the first five year plan in 1951. To encourage agricultural production in the state, the government encouraged rural financial institutions to lend credit to farmers on soft terms to buy and install energized pumpsets. Rapid rural electrification raised the electricity consumption in agriculture and irrigation in Gujarat from 39.63 MKWH (Million Kilowatt hours) in 1960-61 to 5670 MKWH in 1990-91 (GSEB, 1991). While electricity consumption in agriculture grew exponentially, the share of industry in electricity consumption has remained unchanged during the corresponding period. Table 1.5 and 1.6 below illustrate this.

Table 1.5 Rural electrification in Gujarat

Year	Villages electrified	Number of pumpsets electrified	Electricity consumption in agriculture per gross cropped area (kWh/hectare)
1960-61	823 (4%)	5401	395.7
1991-92	17,892 (97%)	503,353	490

Source: CMIE - Current Energy Scene in India, May 1993.

Figures in brackets show the number of villages electrified as a percent of the total number of villages in Gujarat

Table 1.6 Share of electricity consumption in agriculture and industry in Gujarat

Year	Share of agriculture (%)	Share of industry (%)
1960-61	9.4	39
1990-91	35	40

Source: CMIE - Basic Statistics Relating to the Indian Economy, 1993

1.8 Efficiency of Rural Electrification

The economic efficiency of investments in groundwater extraction is an important social objective. Resources allocated to groundwater development through direct financial investments or indirect subsidies, are drawn out of other potentially productive areas in the economy. As Moench points out, "in many cases, approaches taken to achieve maximum sustained yield conflicts directly with efficiency goals" (p.3, 1993). The rapid growth of electrification in the rural sector has been encouraged by selling electricity to agriculture at prices which were much below the cost of generation and distribution. Table 1.7 shows the average cost of electricity generated by GSEB and the average rate at which it is sold to the agricultural sector.

Table 1.7 Electricity subsidy to the agriculture sector in Gujarat.

Year	Average cost of production (paisa/kwh)	Average price at which power is sold to agriculture (paisa/kwh)	Subsidy per unit sold (paisa/kwh)	% of subsidy
1981	46.1	38.1	8.0	17
1985	83.5	53.1	30.4	36
1987	90.4	22.0	68.4	75
1990	105.1	21.5	83.5	80

Source: Planning Commission (1994).

Over 40 percent of Gujarat's electricity production goes towards pumping groundwater for irrigation (Planning Commission, 1994). Farmers pay flat-rate electricity tariffs based on their pump horsepower and not on actual energy consumed¹³. In a flat-rate regime since the marginal cost of power is nearly zero, farmers may have a tendency to consume more power than required¹⁴. This difference between cost of power produced and the rate at which it sold to the farmers has resulted in a revenue loss of nearly Rs 598 crore to the Gujarat State Electricity Board for the financial year 1992-93 (Planning Commission, 1994).

1.9 Growth in Energized Pumping & Overdevelopment of Groundwater Resources

Analysis undertaken earlier and presented in table 1.4 showed that there has been no long term decline in rainfall in Gujarat for the period 1951-1990. However, unpublished statistics provided by the Gujarat Water Supply and Sewerage Board (GWSSB) and reported by Bhatia (1992) showed that there was a secular fall in most observation wells between 1979 and 1987 (Bhatia, 1992).

¹³ The Gujarat State Electricity Board has since revised electricity tariffs for its agricultural consumers. Electric pump owners who use pumps of more than 15 Horse Power are now given the option of paying either Rs 960/HP/annum or Rs 0.50 per unit of energy consumed. However, farmers who own pumps below 7.5 HP continue pay a flat rate of Rs 500/HP/annum and farmers who use pumps above 7.5 HP but below 15 HP pay a flat rate of Rs 800/HP/annum. Informal discussions with farmers and water companies in Mehsana revealed that most would like to continue paying under a flat-rate system and not under a metered system. According to Shah and Ballabh (1993) farmers are extremely apprehensive about dealing with GSEB staff who they allege harass them and demand petty bribes.

¹⁴ This is an empirically testable proposition. See chapter 3 in this report.

To understand the relative contribution of deficient rainfall and rise in energized pumping which are blamed for falling water tables during the period 1981-1990 we resort to the following multiple regression models;

$$Depth_t = a + b \text{ Rain}_t + \text{Time}$$

$$Depth_t = a + b \text{ Rain}_t + c \text{ EP}_t$$

where $Depth_t$ stands for depth to water table from the ground in year t ; $Rain_t$ stands for rainfall in year t ; EP_t are the number of energized electric pumps in year t and also a time trend.

To capture the secular decline in water tables, we have introduced a time trend variable into the model. If the coefficient of time is positive and statistically significant, we can assert that there has been a permanent lowering in groundwater table for the period 1981-1990.

A partial version of the above model has been used by pooling taluka level data for the district of Mehsana in North Gujarat.¹⁵

1.10 Groundwater Situation in Mehsana

Mehsana district is one of the most intensively cropped districts in the state of Gujarat. The net sown area is nearly 65 % of the total geographical area. With no major surface irrigation schemes in Mehsana, nearly 85 % of the irrigation needs are met by groundwater. During the past thirty to forty years, large scale exploitation of groundwater with annual draft from aquifers far exceeding annual recharge from rainfall has led to continuous fall in groundwater tables over most of the district. Average depth of wells in this area is about 400 feet. With falling water tables, farmers now have pumpsets of higher horsepower (mainly 35-50 HP) thereby increasing the energy consumption per unit volume of pumping substantially. The extent of groundwater mining in this district is so acute that all the twelve talukas that comprise Mehsana district are in the dark category of groundwater classification.

For both May-June water table and October water table¹⁶, our regression results shows that rainfall had no role to play in lowering of groundwater tables in Mehsana District

¹⁵ For 5 talukas for the year 1981-1990.

¹⁶ For May-June water table the independent rainfall variable is for the previous year. For October water tables, the rainfall variable is for the same year. We also ran a distributed lag regression model using lag values of the rainfall variable. The results were not conclusive.

(none of the t-ratios are statistically significant). The time trend is positive and statistically significant for all four equations. This implies that water tables declined permanently (and significantly) for the period 1981-1990 in Mehsana district.

Table 1.8 Pooled time series-cross-section regression equations - Mehsana District

Dependent Variable	Intercept	Rain	Rain ²	Time	BUSE-R ²
May-June Water table	46.3 (7.6)	-0.0045 (-2.2)		3.8 (6.3)	0.56
May-June water table	46.3 (7.5)	-0.006 (-1.01)	0.00005 (0.36)	3.9 (6.9)	0.55
October water table	37.87 (6.8)	-0.0003 (-1.07)		3.31 (6.3)	0.51
October water table	40.3 (7.5)	-0.0067 (-1.07)	0.00000 5 (1.07)	3.19 (5.9)	0.52

Source: Water table data (in meters) - unpublished data collected from Central Groundwater Board, Western Region. Mehsana Office.
Rainfall data (in mm) - IIM, Ahmedabad (1991). Sample size = 50

Note : DW- Dumbin Water Statistics

A similar exercise was carried out again for Mehsana district, but this time we have introduced number of electrified pumpsets as an additional explanatory variable. The multiple regression results reported in Table 1.9 below clearly shows that for both the linear and quadratic models lowering of water tables in Mehsana district was because of the rapid electrification of irrigation wells. Once again rain has no effect on the water table (dependent variable).

Table 1.9 Pooled time series - cross-section regression equations - Mehsana District

Dependent Variable	Intercept	Rain	Rain ²	WEM	BUSE R ²	DW
October Water Table	31.18 (6.9)	-0.0004 (-.027)		0.021 (6.9)	0.56	1.56
October Water Table	34.9 (7.2)	-0.001 (-1.6)	0.000005 (1.6)	0.020 (6.6)	0.57	1.53

Source: Water table data (in meters) - unpublished data collected from Central Groundwater Board, Western Region, Mehsana office.
Rainfall data (in mm) - IIM, Ahmedabad (1991). Sample size = 50.

As table 1.8 & 1.9 show, groundwater table in Mehsana now stands permanently lowered. The regression analysis clearly shows that water tables during the period (1981-90) declined 3 meters per annum. This was mainly brought about by the rise in the number of electric water extraction mechanisms.

1.11 Equity Implications of Falling Water Tables in Mehsana

Falling water tables have distinct equity implications. The GWRDC (Gujarat Water Resources Development Corporation) monitors a network of over 80 wells in Mehsana district. In May 1973, none of the wells were dry. By May 1990, nearly 45 % of these 86 wells were dry. This has negative equity implications. For example, data collected by Hariss (1988) showed the dynamic relationship between land and wells and instances of downward mobility which could be attributed to wells going dry. Discussions with farmers in Mehsana and primary data on cost of installing a deep tubewell indicate that most wells are below 600-1000 feet in depth and the cost of installing submersible pumps of 35- 80 HP capacity exceeds Rs 3.5-4 lakh rupees (US \$ 13,000-16000). Given the high cost of developing new wells, less wealthy farmers are at a distinct disadvantage in their ability to gain access to a scarce resource. Most new wells in Mehsana are constructed by partnerships (called bhagidari in the local parlance) consisting upto 125 farmers and water markets are common. Despite this, however, the increasing cost of obtaining access to water places poor farmers under enormous pressure.

1.12 Conclusions

Chapter 1 presented issues and problems related to groundwater management and energy in Gujarat. Persistence of negative groundwater balance may result in further lowering of groundwater tables in the aquifers of North Gujarat. Major strides in the state were made by farmers in increasing irrigation, generously helped by input subsidies on power and other agricultural inputs. However, rapid development of rural electrification has led to two major problems. First, there has been an increase in groundwater draft which could lead to the long term unsustainability of irrigated agriculture and the livelihood of millions who depend on it. Second, subsidies given for promoting rural electrification has led to the state electricity boards incurring huge commercial losses thereby threatening their existence as a financial entity. Clearly, a way has to be found whereby energy could play a proactive role in promoting the twin goals of agricultural development and improving the financial health of SEB's. One major tool propounded by policy makers is to raise energy (electricity) prices which would reflect the true resource cost of a common pool resource like groundwater and thus lead to its rational use over time. Higher electricity prices to the agricultural sector would also improve the state electricity board's financial health.

Could higher electricity prices translate into more efficient and sustainable use of groundwater withdrawal decision by farmers? What would be the equity effect of changing the structure and also raising electricity prices on groundwater withdrawal decision by farmers? These and other related questions are answered in the following chapter.

Chapter 2

2.1 Energy Pricing and Groundwater Depletion in a Water Scarce Region With Water Markets

In this chapter we explore the role of electricity prices on current unsustainable use of groundwater and the role electricity tariffs could play as a tool for arresting groundwater depletion in a groundwater scarce area. The study was undertaken in Mehsana district of Gujarat. The chapter is divided in three parts. In part one we present and implement a methodology to estimate demand for irrigated groundwater. This is done for two major crops and for the main major cropping season as a whole. In part two we undertake a simulation exercise to relate the effect of pro-rata tariff rates on water prices. The third part considers the impact of (pro-rata) tariff rates on water use and water prices under power rationing.

2.2 Area Profile of Mehsana

Mehsana is situated in North West Gujarat and that faces acute groundwater scarcity. Due to extreme arid conditions and erratic rainfall, surface water sources are almost negligible. Groundwater accounts for more than 85 % of the districts irrigation needs. Over the past 2-3 decades, the number of electric water extraction mechanisms in the district has increased manifold leading to very low water depths. The average depth of wells in Mehsana is as high as 400 feet. All 12 talukas in Mehsana are overexploited¹.

The main crops grown are wheat, mustard, bajra, jowar and castor. Wheat and mustard are the principal crops grown during Rabi season. Bajra, jowar, pulses are occasionally grown during Kharif. Irrigation is applied during the Rabi season and well developed water markets operate during this season. Only in case of extremely poor rainfall do farmers apply irrigation to their Kharif crops.

Water tables in Mehsana are very deep due to which openwells are virtually non-existent except in Kheralu taluka which is a hard rock region. Some openwells and dug-cum-borewells are found in Kheralu taluka and parts of Visnagar taluka but the other talukas have a predominance of borewells. Submersible electric pumpsets of capacities ranging from 30-82 HPs are used to extract water from an average depth of 400 feet. Due to the high cost of installation and risk of well failure, a number of farmers get together and install pumps jointly. The system is popularly known as the *bhagidari System* and the participants are called *bhagidars*. The individual's share in the initial investment is

¹ In Mehsana groundwater draft per year is 911.81 mcm while the net utilizable recharge is 470.99 mcm per year i.e., draft exceeds recharge by nearly 200 %.

determined by the financial status of the *bhagidar* as well as the number of bighas (2.5 bighas = 1 acre) he wishes to irrigate from that well. Water is sold to the bhagidars at a fixed price and excess water is sold to non-bhagidars at the same price as bhagidars². Typically, water from a particular pump is divided among 1 to 4 farmers at a time and the price charged to a particular farmer is inversely proportional to the number of farmers receiving water at the same time. The price of water is denoted in rupees per hour of water supplied to the farmer though there are instances of price being in terms of units of crop irrigated and less frequently payment is made as fixed percentage of output.

2.3 Methodology

The exercise of investigating the linkage between electricity price and water usage can be broken down into two components:

- (a) establishing a link between electricity price and water price,
- (b) establishing a link between water price and water use for different crops.

In this part we shall try to establish the second component of the exercise.

Actual water use for any crop per bigha would be a function of many factors. Assume that the water use intensity function is given by the following equation;

$$W_i = f(P_i, R_i, P_c, S_i, L_i)$$

Where;

W_i is watering hours per bigha per crop by the *i*th farmer.

P_i denotes water price per hour

R_i is the rainfall

P_c is the expected price of the crop

S_i is the soil type.

L_i is the land holding of the *i*th farmer.

Since the sample is restricted to a region covering seven taluks of Mehsana district, we assume that variations in rainfall, soil and output price are negligible and consequently these are dropped from the equations. We can regress water use on water price and land holding size to obtain the water demand function. However, we have to bear a caveat in mind while using this functional form to estimate water demand. The table below shows

² Bhagidari (or a water company) is an informal organization with memberships ranging from 5-120, but with average size of 25-30 members. The formation of a bhagidari is signified by the agreement on a Rs 10 non-judicial stamp paper entered into by all promoters partners of the bhagidari. Bhagidaries maintain their own bank accounts about revenue generated from water selling, in the name of the manager of the bhagidari or in the name of the bhagidari itself. All resources for running the bhagidari is internally generated. All the authority needed to ensure the smooth running of the bhagidari is provided by its member partners to the managing committee or the manager (Shah, 1993, p.8).

the price paid by two farmers in buying water from two different tubewells and amount of water being applied per bigha for the same crop.

	Total Hours of watering per bigha	Price of Water/hour
Farmer A	20	14
Farmer B	15	21

This table above seems to suggest that there is a negative relationship between price and quantity of water. However if the actual water discharge per hour received by the Farmer B is also less, then neither price nor quantity are comparable across the two farmers.

We therefore need to make adjustments for the actual flow of water in each farmer's field. In absence of data on actual water discharge, we have resorted to the second best option of using theoretical discharge using our data on water depth and horse power of the pump being used by farmer's. We also assume identical pump efficiencies for all the observations in our data. This is not likely to lead to serious error since given the massive investment cost and the general water scarcity great care is taken in maximizing the yield from the tubewell. Furthermore, the sample is drawn from a hydrogeologically similar region. For all these reasons potential discharge is likely to be close to actual discharge from the tubewells.

We have made the following adjustments before using the data for our econometric exercise. Discharge from wells is given by the following formula:

$$D = \frac{75 \times E \times HP}{Head}$$

Where; D = Discharge, E = Efficiency of pump, HP = Pump horse power

Since we have assumed similar efficiencies for all pumps, given the HPs and head, discharge can be calculated using the above formula. For sake of convenience we have set the discharge per hour from a tube well drawing water from a depth of 300 ft. using a 30 hp pump for an hour equal to 1 and we shall call this as one unit as the Standard unit (SU). The water discharge from all other wells is made relative to this. The water received by a farmer in an hour is then equal to the discharge of his tubewell divided by the number of farmers who share the discharge. For example, if 1 SU water is being discharged from

a well and two people are sharing the water at the same time, then actual water flow into a field is 0.5 SUs.

We now convert the information on total hours of watering per bigha of each crop sown and the price paid for water into comparable units by using the information on discharge from each tubewell. This adjustment takes care of the possibility of spurious relationship referred to above.

2.4 Price Elasticity of Water Demand

We have carried out estimation of water demand for two categories of water users, the bhagidars and the non-bhagidars. There is no price discrimination for these two category of water buyers, water demand has been estimated for both the groups separately. The demand has been estimated for two major crops covered by our sample, namely wheat and mustard. We have also carried out estimation for total water use per bigha of land irrigated in the rabi season. This last estimation will capture the water use differences due to different cropping pattern across farmers. The result for both categories of water users is discussed below.

Dependent variable	Functional form	R ²	Price Elasticity	T-stat
W	Linear	0.44	0.73	-5.01
Log W	Double Log	0.37	0.70	-4.40
Log W	Semi-Log	0.49	0.82	-5.52

Note: Sample size (N) = 32

The interesting points to notice are the relatively high values of r-square and the small differences in the value of elasticities between different functional forms calculated at the mean values wherever relevant.

Dependent variable	Functional form	R ²	Price Elasticity	T-stat
W	Quadratic	0.52	1.24	-3.44
W	Linear	0.46	1.14	-5.48
Log W	Double Log	0.46	0.98	-5.47
Log W	Semilog	0.43	1.07	-5.20

Note: Sample Size (N) = 35

Table 2.3 Price elasticity of water demand for the rabi season for Bhagidars

Dependent variable	Functional form	R ²	Price Elasticity	T-stat
W	Linear	0.43	1.08	-5.44
Log W	Double Log	0.45	0.89	-5.69
Log W	Semi Log	0.48	1.04	-6.06

Note: Sample Size (N) = 39

The price elasticities are higher for mustard than for wheat for comparable functional forms while the elasticities for rabi and total water use lies in between the values of the two crop elasticities. These observations are along the expected lines since mustard is a highly profitable crop relative to wheat.

2.5 Price Elasticity of Water Demand for Non-bhagidars

A similar exercise was carried out for the non-bhagidar farmers. The results are given below.

Table 2.4 Price elasticity of water demand for mustard for Non-Bhagidars

Dependent Variable	Functional form	Price Elasticity	R ²	T-stat
W	Linear	0.50	0.15	-2.31
Log W	Double log	0.48	0.21	-2.39
Log W	Semi log	0.59	0.12	-1.86

Note: Sample Size (N) = 19

Table 2.5 Price elasticity of water demand for wheat for Non-Bhagidars

Dependent Variable	Functional form	R ²	Price Elasticity	T-stat
W	Linear	0.02		-1.30
Log W	Double log	0.029	0.31	-1.29
Log W	Semi-log	0.03		-1.30

Note: Sample Size (N)=23

Table 2.6 Price elasticity of water demand for the rabi season for Non-Bhagidars

Dependent Variable	Functional form	Price Elasticity	R ²	T-stat
W	Linear	0.46	0.21	-7.25
Log W	Double log	0.48	0.22	-2.83
Log W	Semi-log	0.54	0.20	-2.78

Note: Sample Size (N)=26

The interesting observation about the various demand equations is their poor fit compared to those obtained for the bhagidars¹.

2.6 Effect of Electricity Tariff on Water Prices: A Simulation Exercise

Having established in the first part of the exercise the effect of water price on the water use intensity we now need to arrive at the energy price elasticity of water demand and also to quantify the effect of electricity tariffs on the water prices.

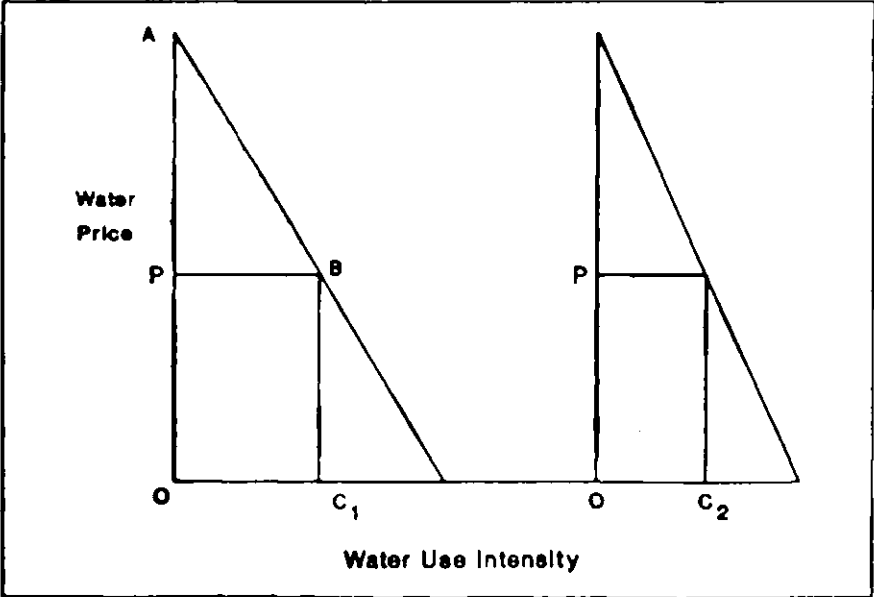
Farmers in Mehsana are charged a flat annual fee based on the horsepower of the pump used implying zero marginal cost of power consumption and therefore water extraction. We have no time series data on electricity tariffs which we can relate to groundwater consumption for irrigation purpose. Absence of such data precludes the possibility of deriving an econometric relationship between electricity pricing and water prices. To circumvent this difficulty we have carried out a modelling exercise that generates a relationship between the two variables. We make the following five assumptions:

- (1) The water company (bhagidari) seeks to maximize the total profits of its members which is the sum of net revenue from farming and water sales to the non-members.
- (2) Power is the only significant variable cost of operating the pumps.
- (3) The area irrigated by the bhagidars is twice that of the non-bhagidars. We have derived this value from our survey data.
- (4) The water company does not discriminate between the members and non-members in setting the prices. This assumption is justified from an analysis of primary survey data.
- (5) The cost of drawing a given volume of water from a given well is assumed to be constant given the tariff rate. This amounts to an assumption of static water levels.

¹ We carried out Breusch Pagan test to check for the presence of heteroskedasticity in the data. This was done only for the case of bhagidars for the total water demand equation in the rabi season using land size as the possible cause of heteroskedasticity. The result failed to provide any ground for rejection of null hypothesis.

It would be useful to consider the first assumption in some detail. The fact that the water company sells water to its members and also non-members makes it difficult to classify it as one of the market forms. However the significant costs involved in distributing water through pipelines endows the water company with considerable monopoly power. Water companies come into existence for the purpose of supplying water to its members. Profits through sale of water to non-members is not the driving motive behind their existence. In fact, maximizing net revenue from water sales would yield lower revenue compared to an objective function that maximizes sum of revenues from water sales and revenue from irrigating own land irrigation water on own land. This argument becomes clearer in the diagram below.

Fig. 1.1



If a given volume of groundwater is used on the farmers own land, the revenue accruing to the farmer would be given by the shaded area under the first diagram on the left above i.e., area of the trapezium OABC₁. Whereas, the sale of the same volume of water would yield only the shaded area on the right hand diagram.

Therefore the objective function that water company has to maximize may be written as follows;

$$Z = 0.5 * (OA + BC_1) * W_1 * 2 + P * W_2 * 1 - K * (2 * W_1 + 1 * W_2) \quad (1)$$

Here K is cost of power for drawing one SU of water ($K = 0.75 \text{ hp/ water discharge per hour (in SU)}$). W_1 is the water use intensity of bhagidars, while W_2 is the water use intensity of non-bhagidars, P is the price (per hour) of water, which is the same for both bhagidars and non-bhagidars. Note that in the diagram above $OC_1 = W_1$ and $OC_2 = W_2$ respectively.

From the non-discriminatory pricing policy, it follows that water use intensity of the two categories of farmers would be related to each other. This relation is obtained by denoting the demand of the bhagidars and the non bhagidars in terms of water quantities and setting them equal. This gives us the following relation.

$$W_2 = 12.26 + 0.32 * W_1 \quad (2)$$

Substituting from equation (2) above for W_2 in equation (1) and differentiating with respect to W_1 we get on consolidation

$$W_1 = 38.42 - 0.85K \quad (3)$$

Substituting for W_1 in equation (1) above we get

$$W_2 = 24.55 - 0.27K \quad (4)$$

Substituting for W_2 in the last equation we get a relation between tariff and water price.

$$P = 10.58 + 0.88 * K \quad (5)$$

From assumption 5 it follows that the elasticity of P with respect to K will be the same as elasticity of P with respect to tariff rate.

Since K will depend on the water table depth and HP (horse-power) of the pump being used given the tariff rate for our calculations we have used the average values of 52HP for pump and 400 feet for water level. From our earlier calculations we know that relative discharge from such a pump would be 1.3 SU. For this 39kwh of power would be used which implies 30kwh would be used for drawing 1 SU of water. This provides the basis for relating tariff rates to water prices and estimating elasticities.

The water price elasticities and power price elasticities and the total elasticity corresponding to various tariff rates have been calculated and shown in the table 2.7 below.

Table 2.7 Water and power price elasticities

Tariff (Rs/kwh)	K (Rs/SU)	P (Rs/SU)	E_{pk}	E_{wp}	E_{wk}
0.1	3.0	13.22	0.20	0.42	0.08
0.2	6.0	15.9	0.33	0.51	0.17
0.3	9.0	18.5	0.43	0.66	0.28
0.4	12.0	21.1	0.50	0.76	0.38
0.5	15.0	23.8	0.56	0.93	0.52
0.6	18.0	26.4	0.60	0.99	0.59
0.7	21.0	29.1	0.64	1.24	0.79
0.8	24.0	31.7	0.67	1.59	1.05
0.9	27.0	34.3	0.69	1.89	1.31
1.0	30.0	36.98	0.71	2.26	1.62
1.1	33.0	39.6	0.73	2.81	2.06
1.2	36.0	42.2	0.75	3.80	2.84
1.3	39.0	45.0	0.76	4.94	3.78
1.4	42.0	47.5	0.78	6.75	5.25
1.5	45.0	50.2	0.80	10.18	8.03

Note: E_{pk} is the elasticity of water price to energy cost of 1 su of water. E_{wp} is the elasticity of water use with water price and $E_{wk} = E_{wp} * E_{pk}$ is the elasticity of water use with respect to energy cost.

2.7 Effect of Power Rationing

The exercise carried out above gives the effect of different levels of electricity tariffs on water prices and water use under the assumption of unlimited supply of electricity and groundwater.

However, to analyze the effect of pro-rata tariff rates we need to take account of factors operating on the supply side. It is doubtful if the current groundwater resources can support unlimited withdrawal of groundwater. Currently supply restriction takes the form of restrictions in the hours of power supply of about 10-12 hours a day. To determine the impact of supply constraint on various important variables we have to modify our water demand equations which are in terms of water use per unit of land to capture the total water demand and set it against the supply. The analysis of our primary survey shows that out of the total area irrigated two thirds belongs to the bhagidars and the rest to the non bhagidar farmers. Further the command area of a 52 HP tubewell is about 84 bighas. We

assume that this command area is allocated between bhagidars and non bhagidars in the ratio of 2:1 as found from our primary data. Furthermore, as water prices vary, this division will not be affected. Lastly to build the supply constraint we have calculated the available supply in the following manner. Our primary data shows that farmers on an average use their pumps for 1309 hours in the rabi season. This translates into 1699 standard units of water. So the problem of water companies can be set up as follows;

Maximize:

$$Z = L_1 \cdot 0.5 \cdot (OA + BC) \cdot W_1 + L_2 \cdot P_2 \cdot W_2 - K \cdot (L_1 \cdot W_1 + L_2 \cdot W_2)$$

Subject to

$$(1) L_1 \cdot W_1 + L_2 \cdot W_2 \leq S$$

$$(2) P_1 - P_2 = 0$$

Where;

$L_1=56, L_2=28, S=1699$ units of water.

This is a simple Kuhn-Tucker problem. Solution of this simple problem yields a relation between tariff rates and total water use, water prices, water use intensity as shown in the following table 2.8 below.

Tariff (Rs/kwh)	unit price of water	W_1	W_2	Total water use	Water Price (Rs/hour)
0.1	28.77	20.87	18.94	1699	37.4
0.2	28.77	20.87	18.94	1699	37.4
0.3	28.77	20.87	18.94	1699	37.4
0.4	28.77	20.87	18.94	1699	37.4
0.5	28.77	20.87	18.94	1699	37.4
0.6	28.77	20.87	18.94	1699	37.4
0.7	29.06	20.81	18.89	1694	37.8
0.8	31.7	18.25	18.07	1528	41.2
0.9	34.34	15.69	17.25	1362	44.6
1.0	36.98	13.13	16.43	1195	48.1
1.1	39.62	10.57	15.6	1029	51.5
1.2	42.26	8.00	14.7	863	54.9
1.3	44.9	5.44	13.98	697	58.4
1.4	47.54	2.89	13.16	530	61.8
1.5	50.18	0.33	12.34	364	65.3

In the following table we juxtapose the effect of tariff rates on total water use, water prices calculated under assumption of unlimited power/water availability and under power rationing.

Tariff (Rs/kwh)	Water prices (Rs/hour)	Water prices under power rationing	Water use without rationing (SU)	Water use with rationing (SU)
0.1	17.12	37.4	2692	1699
0.2	20.62	37.4	2526	1699
0.3	24.05	37.4	2359	1699
0.4	27.48	37.4	2193	1699
0.5	30.91	37.4	2027	1699
0.6	34.35	37.4	1861	1699
0.7	37.79	37.79	1694	1694
0.8	41.21	41.21	1528	1528
0.9	44.64	44.64	1362	1362
1.0	48.07	48.07	1195	1195
1.1	51.51	51.51	1029	1029
1.2	54.94	54.94	863	863
1.3	58.37	58.37	697	697
1.4	61.80	61.80	530	530
1.5	65.23	65.23	364	364

The price predicted by our model incorporating the power supply constraint approximates the observed prices fairly well. The average price is about Rs 35.90 whereas our model predicts a price about Rs 37.40.

It may be noted that the sample used for the demand estimation has average pump and water level values of 44hp and 346 feet respectively whereas for our simulation exercise we have used the values of 52hp and 400 feet.

2.8 Policy Implications

It is clear from a perusal of the table above that if the current level of power rationing continues then switching over to pro-rata system of tariff rates will not have any effect on water prices and therefore rate of extraction of groundwater may be expected to remain unchanged even if tariff rates are hiked up to as high as 60 paise per kwh. The price of water reflects its scarcity price and not the cost of extraction. Therefore if pro rata rates are imposed it will not affect the decisions of the farmers with regard to water use.

Second, The implications for some aspects of equity are also quite strong and follow from the first point. Since water use intensity and total water use remain unaltered there will no negative impact on output, labour demand and even income of the non bhagidar group of farmers if tariff rates are hiked upto 60 paise per kwh. It may be mentioned here that the bhagidars are better endowed compared to non bhagidars. The average land holding size of former is twice that of the latter. So a switch to pro-rata tariff rate may lead to transfer of incomes from richer farmers represented by bhagidars to the electricity boards.

Third, even if we consider tariff rates above 60 paise it is not clear that these rates will necessarily lead to a decline in the rate of extraction of groundwater extraction. This assertion is based on the following logic.

The total area irrigated by the bhagidars as a percentage of their land holding is much higher than that the corresponding figure for the non bhagidars. The implication is that even if tariff rates are fixed above 60 paise per kwh the reduction in water use intensity working through higher water prices may go towards meeting the unmet demand for water of the non bhagidars. Further there may be farmers without access to irrigation water. So a hike in tariff rate to high levels may allow some of these farmers to irrigate part of their land and therefore extraction rates may not go down by less than expected amount. On the negative side rates higher than 60 paise per kwh will transfer income from the non bhagidar farmers since their water demand elasticities is less than one.

Fourth, a proper combination of pro rata rates and flat rate may transfer incomes from water companies without adverse impact on non member farmers. This transfer of incomes may create a situation where at least some farmers may be willing to adopt new water saving technologies.

Finally, given the wide disparity between current recharge and extraction rates and low water demand elasticities, it is doubtful if electricity can play more than a supplementary role in sustainable use of groundwater. The most productive water conservation approaches therefore may be through technological intervention on the demand side and supply augmentation through investment in water harvesting structures.

2.9 Conclusions

In this chapter we carried out the estimation of energy price elasticities of groundwater use. The exercise was broken down in two parts. In the first part we utilized the data on the hours of watering for different crops and the water prices charged per hour of watering and carried out a econometric exercise to investigate the link between the two. Given the variability in the water table depth and horsepower of the pump being used across the sample we made adjustment for different rates of discharge from different tubewells. The resulting price

resulting price coefficients and the relevant price elasticities were found to be significant and were in accord with the economics of the situation.

In the second part of the exercise due to the absence of relevant time series data and other inherent problems instead of relying on a direct econometric exercise we constructed a model in which the water company was seen as maximizing the sum of profits of its members. Using the result from first part of the exercise along with the non-discriminatory nature of their pricing policy we generated a relationship between tariff rates and water prices. In the third part we analyzed the impact of power rationing and derived the strong result that over a politically feasible range of pro rata tariffs it makes no difference between flat rate system and pro rata system of electricity pricing from the view point of water conservation.

Chapter 3

3.0 Energy Pricing and Groundwater Use in a Groundwater Scarce Area with no Water Market

This chapter presents the findings of a survey undertaken in Junagadh district of Gujarat to understand whether subsidized electricity tariffs are responsible for rapid groundwater depletion in Maliya taluka. The survey was conducted in four villages of Maliya taluka of Junagadh district. Junagadh district lies in the Saurashtra region of Gujarat. Agriculture is the main occupation of the region. The major crop grown in this region is groundnut. The region also grows substantial quantities of sugarcane, Jowar and winter wheat and mangoes. During the 1950's water for irrigation was mainly drawn using human or animal power and the number of wells were very small. However, supportive government policies which made input and credit subsidies liberal during the 1960's and 1970's, made it possible for farmers to dig more wells and extract water using modern electric pumps.

The first part of this paper attempts to characterize water use behaviour in the survey villages in order to test the following hypotheses;

- (a) Groundwater for irrigation is used inefficiently by farmers who operate electric irrigation pump sets.
- (b) A large part of this inefficiency is due to flat-rate electricity pricing.

3.1 Sample Selection

Approximately 60 farmers operating 5 HP electric and diesel pumpsets from an average depth to water table of 60-70 feet were interviewed in the months of July and August 1993 in four villages of Maliya Taluka, namely - Amrapur, Katrasa and Jallandhar and Virdhi. These villages were selected for the following reasons:

- i) these villages are in Maliya Taluka which is designated as "dark" by the GWRDC (Gujarat Groundwater Development Corporation)¹
- ii) they are neighbouring villages in Maliya Taluka and thus have similar topography and soil types.
- iii) all the four villages have a significant number of both diesel and electric irrigation pumpsets;
- iv) water quality is not a problem in this agricultural block and is thus not a complicating factor in water usage for agriculture.

¹ A taluka is designated as "dark" when groundwater extraction to utilizable recharge for irrigation is 85 % and above.

3.2 Average Number of Irrigations for Wheat and Groundnut Crop

Approximately sixty farmers provided information on the number of waterings required by wheat in the rabi season and for groundnut in the Kharif season². The results are summarized in Table 3.1 and 3.2 below.

Table 3.1 Average number of irrigations in rabi for wheat

	Pump (HP)	Sample size	Average waterings
Electric	5	35	14.5
Diesel	5	20	12.8

Table 3.2 Average number of irrigations in kharif for groundnut

	Pump (HP)	Sample size	Average waterings
Electric	5	27	5.3
Diesel	5	15	4.1

Note: These figures are for waterings required for groundnut crop if monsoon rains are insufficient.

From the above responses, it appears that electric pump operators are inclined to provide more waterings than diesel pump operators. Nonetheless, there may be some confounding influences. For example, the variation may also be a result of soil depth, as deeper soils may require more water. Or farmers who water more frequently do lighter irrigation applications. One of the respondents explained that land with a thin soil layer loses moisture quickly, and thus needs frequent watering to keep the roots of the crop moist. This necessity for moisture is particularly important during sowing and may necessitate some watering prior to the monsoons. Conversely, land with a thicker soil layer is better able to retain moisture as the deeper reaches are less affected by sunlight penetration. At the same time, such soils benefit from waterings of longer duration since they take longer to reach saturation and retain moisture longer.

According to the respondents it appears that shallow soils benefit from short but frequent waterings, whereas deeper soils benefit from longer but less frequent waterings. The latter method is likely to result in less water lost through evaporation and encourages deeper and thus hardier root growth, whereas the former is more susceptible to greater

² Farmers who operate 5 HP electric pumpsets pay approximately Rs 0.15/kwh while diesel pumpset operators with 5 HP pumps pay approximately Rs 2.20/kwh. Diesel/ Crude oil costs Rs 8 per litre.

water loss and weaker root growth. The adoption of one or the other method, however, seems to be determined by soil depth and not by a concern for minimizing water loss.

It is quite possible that since electricity supply is limited during the day (available for only 10-12 hours a day) electric pump owners choose to water more frequently and for shorter durations than do diesel operators who can run their pumps continuously until soil saturation. A factor that is easily overlooked due to is the possibility that diesel operators may be applying less water to their land. If electric operators are applying more water since their marginal cost of operation is zero, then is it not possible that diesel operators are applying less water to save on costs and in the hopes of rain ? A look at crop yields in both the kharif and rabi seasons provides some insights.

Table 3.3 Productivity for kharif (groundnut) and rabi crop (wheat) for 5 HP electric and diesel pump owners

	Average productivity (groundnut kg/ha)	Average productivity (wheat kg/ha)
Electric, N = 35	1552	2450
Diesel, N = 20	1460	2250

Note: N = number of respondents

The option of waiting for rainfall only exists for the kharif crop as little rain is expected in the rabi season. Thus it is expected that farmers who wait too long for the rains will suffer a loss in yield during the kharif season only, and those who apply less water will suffer a loss in the rabi season. The number of waterings by electric pump owners can serve as a possible indication of water use inefficiency by them and perhaps also as an indicator of underirrigation and over-waiting by diesel operators. The data from table 3.1-3.2 appear to present a case for overirrigation by electric operators.

3.3 Measuring Inefficiency in Input use: Marginal Productivity Analysis

To understand whether farmers were using electricity inefficiently given flat-rate pricing tariffs we undertook a more rigorous analysis with our data set. In the second stage of the survey, detailed information on cost of cultivation of the two major crops groundnut and wheat was collected from farmers in Maliya Taluka. Production function analysis was undertaken to calculate the marginal value productivity (MVP) of irrigation for 5 HP diesel operated tubewell and 5 HP electric operated tubewell. The quadratic production function used for carrying out the regression analysis was as follows:

$$Y = A + bX + cX^2$$

where;

Y = Output of crop per hectare on farm

X = Irrigation hours per hectare

3.4 Estimation of Marginal Value Productivity

The marginal value productivity of diesel operated tubewells and electric operated tubewell irrigation was estimated with the help of the regression analysis of the production function referred to above.³ Marginal value productivity for the irrigation input is calculated as follows;

$$\text{Marginal Productivity of hours of Irrigation per hectare} = \frac{\partial Y}{\partial X} = b + 2cX$$

where;

Y = Average of output of crop per hectare

X = Average number of irrigation hours per hectare (for both diesel and electric pumps separately).

After estimating the regression separately for both wheat and groundnut crop for farmers with 5 HP diesel and electric tubewells, we estimated the marginal productivity of diesel and electric pumpsets for wheat and groundnut crops⁴. The results are presented in the table 3.4 and 3.5 below.

Table 3.4 Marginal value productivity of irrigation in groundnut

	Sample size	Average landholding (ha)	Average area irrigated (ha)	Crop yield kg/ha	Marginal product of water
5 HP Electric Tubewells	N = 18	10.1	7.87	1450	5.36
5 HP Diesel Tubewells	N = 12	6.89	5.50	1410	6.01

³ Fertilizer consumption cost per hectare and labour cost per hectare were also regressed on the dependent variable but was found to be statistically insignificant and therefore were dropped from the final regression estimate.

⁴ Since our sample included small, medium and large farmers we carried out a Breusch-Pagan test to check for heteroskedasticity in our sample. Our test however indicated absence of any heteroskedasticity in the sample.

Table 3.5 Marginal value productivity of irrigation in wheat

	Sample size	Average landholding (ha)	Average area irrigated (ha)	Average productivity (kg/ha)	Marginal Product of water
5 HP Electric Tubewells	N = 20	11.31	8.08	2230	4.66
5 HP Diesel Tubewells	N = 15	6.06	4.84	2145	6.11

Marginal productivity analysis shows that both diesel and electric pump owners use their groundwater inputs efficiently since the marginal products are positive. There is no over watering of crops by either electric pump owners or diesel pump owners.

3.5 Irrigation Practices and the Dependency on Rain

Junagadh district receives upwards of 45 inches of rainfall in a good year. The current year (1993) started off well with a promising rainfall of 10-15 inches. Farmers were encouraged by the rains and the majority planted groundnut on most of their land. The rains subsequently stopped and as of early August the second set of rains had not arrived. The majority of wells in the region range from 60 to 75 feet in depth, extending to perhaps a little over 90 feet where borewells are in place. If it does not rain, most of this water will be used for groundnut, which will require between 3 to 5 waterings, depending on its stage of growth and soil depth. Consequently, little if any water will remain in the wells for watering wheat.

Given these conditions, a number of questions arise that may enable some inferences on water use behaviour:

- 1/ How long is a farmer willing to wait for rain before commencing irrigation? Are there differences between diesel and electric operators?
- 2/ What are the advantages and disadvantages of commencing irrigation before most other farmers do?
- 3/ Once farmers commence irrigation, are there any differences in water use behaviour between diesel and electric operators?

At the time of the survey (July-August, 1993), it was found that most farmers were willing to wait a few days and at the most one week before commencing irrigation. Of all

the diesel operators interviewed only 2 (out of twenty) had started irrigating their farms. Apart from these two diesel pumpset owners, every diesel operator interviewed was hoping for rain so that he would not have to run his equipment and thereby save costs. In contrast, most electric pump operators had already commenced irrigation.

The diesel operator is clearly cost-conscious as his operating expenses are higher. The startup or initial expenses for a diesel pump far exceed those for an electric pump as the machine needs tuning up, parts need replacement, and an investment in crude oil or diesel must be made. According to the respondents, it is common for these initial expenses to range from a few hundred to over one-thousand rupees. For electric pumps the cost of startup is usually zero. Estimates of annual operating expenses for running the diesel pumps (operation, maintenance and fuel) by diesel operators ranged from Rs. 3500-7000 for irrigated land area between 1.2 and 6 Hectares, whereas expenses for electric operators ranged from Rs. 1000-2072, land area being irrelevant. The initial expense factor, in addition to the high cost of crude/diesel, places diesel pump operators at a great disadvantage in comparison to electric operators. Diesel operators are hoping to avoid or delay a major expense by not irrigating until absolutely necessary, whereas electric operators do not face such a dilemma since they pay a flat rate regardless.

Apart from the initial expense issue, early commencement of irrigation plays an important role in groundwater balance. Farmers are clearly aware of the low water availability and also have some idea of aquifer storage and groundwater flow. They are aware that increased extraction by other farmers affects water levels in their wells. When questioned on the possible reasons for the groundwater shortage in the region, almost every single farmer cited the tremendous increase in wells and thus of extraction as being the primary contributor to water scarcity. For example, the village of Amrapur had 243 wells in 1991 as compared to 100 in 1965, and has suffered a drop in its water table from approximately 30 feet to 75 feet⁵. Bromley (1989) claims that excessive pumping results from "the absence of reliable knowledge concerning the state of the aquifer, and the inability of farmers to be secure that water they save for tomorrow will not be extracted today by a neighbour".

3.6 The Role of Electricity Pricing

If water use behaviour can be characterized as in the preceding section, a number of questions on the role of electricity pricing arises:

- i) What is the current electricity pricing strategy?
- ii) How has it affected water use behaviour?

⁵ AKRSP(I) 1993

- iii) Can electricity pricing encourage water conservation?
- iv) If yes, then what sort of strategy/strategies might work?
- v) What sort of response might such strategies elicit from farmers?

The current pricing strategy charges farmers an annual flat rate based on pump size (Rs. 192 per horsepower per annum for pumps up to 7.5 HP). Most of the electric pumps in the region studied have 5 horsepower motors, and thus are associated with an annual fee of Rs. 960 payable to the Gujarat State Electricity Board (GEB). This fee was instituted in 1987 after intense pressure by the farmer lobby to eliminate the pro-rata pricing structure then in place. Part of the farmer lobby's strength came from the fact that most other states in the country had adopted flat-rate tariffs prior to Gujarat state.

Our marginal productivity analysis shows that the structure of energy pricing may not play a role in water use behaviour. Being an open access resource, it is unlikely and unreasonable to expect that groundwater will be extracted in a manner that prioritizes conservation. While the flat-rate pricing strategy eliminates the marginal cost component from water use by bringing the marginal cost of pumping to zero, we have no reason to believe that it encourages excessive use of groundwater in Junagadh.

3.7 Groundwater as a Common Pool Resource

A pricing strategy to encourage water conservation, must introduce a cost-conscious component into water use. An example may be of use here. The village of Samadhiala, also in Maliya Taluka of Junagadh district in Gujarat, organized a cooperative lift irrigation society (LIS) in 1986 with the assistance of a local NGO⁶. The society pumps water out of the Meghal River for irrigation purposes and distributes the water amongst its members for a fee based on the number of acres watered. Since the society is organized around a natural resource that must be carefully managed, it charges proportionately for that resource. The working details of the society are not of interest here, but rather the principle -- the pricing of a common pool resource.

The pricing of groundwater is problematic because there are no institutions or rules governing the use of the resource. Groundwater is invisible and not easily quantifiable. Estimating the quantity of groundwater available in a region is difficult, particularly in unconfined aquifer regions. A decline in the quantity of groundwater is not easily observable, making protection of the resource difficult. In Samadhiala, the society is capable of rationing water depending on river flow and observable storage, but the same is not true for groundwater.

⁶ Shah (1991)

As an common pool resource, groundwater extraction needs to be regulated either through a pricing mechanism that not only makes excessive withdrawal unattractive but also encourages water conservation, or through collective action through a heightened user awareness of aquifer behaviour and the consequences of depletion. Such an awareness, combined with the collection of reliable data on aquifers, can perhaps serve to make the resource more "visible" to its users.

3.8 Strategies for Groundwater Conservation

There appear to be two options available for conserving groundwater resources;

- i) the direct control of water through water pricing or physical regulation;
- ii) the pricing of electricity which is used to extract that water.

3.9 Direct Control of Water

In attempting to control water directly, one has the option of looking at recharge and/or extraction. In the long run increasing recharge through percolation tanks, checkdams may not be an adequate solution. While it may be necessary to implement such recharge schemes, which provide the additional benefits of erosion control, reduction of soil loss etc., sufficient recharge may not be achieved because as recharge increases, so does extraction. An example will clarify this point. Within the Saurashtra region of Gujarat, Junagadh district receives 35-50 inches of rainfall in a good year, and Jamnagar district receives 15-20 inches in a good year. Yet the former district faces groundwater shortages which are at least as acute as the latter. The choice of crop partially explains this problem since Junagadh district grows more water-intensive crops as these fetch a higher price in the market. Moreover, support prices set by the government encourage the growth of such crops thereby encouraging excessive groundwater extraction. Thus, greater the water supply, greater the extraction.

The other option for managing depleting groundwater resources is by regulating extraction, which can be achieved by;

- a/ pricing of water;
- b/ marketable permits to extract
- c/ mandating water conservation

3.10a. Pricing of Water

The pricing of groundwater is inherently problematic for it is the pricing of a common pool resource. Pricing of an common pool resource like groundwater means that one has to assign property rights to the resource. Property rights are sanctioned relations among people that arise from the existence of things and pertain to their use (Furubotn & Pejovich,1972).

A specific property right might be characterized by answering the question: Who can the holder(s) of the right exclude from modifying, transporting, or using a particular resource?

Who can a well owner exclude from using the groundwater? According to the Easements Act and Transfer of Property Act, farmers in India have private groundwater rights. It is not open to non-landowners. The government cannot prevent farmers from pumping groundwater on their fields. There are no public rights to groundwater. Groundwater is a free resource in India, but at the same time it is also a scarce resource. Unless property rights are well defined, pricing of groundwater is not an option for mitigating depletion⁷.

3.10b. Marketable Permits to Extract

In a system of marketable permits, families within the aquifer region would be allocated permits or "rights" to the extraction of a set quantity of water. All permits combined would not exceed the total allowable extraction from that aquifer. Trading of permits would be allowed, thus enabling the emergence of a water market. A marketable permit system however presupposes that a village level aquifer management exists in a village. Bromley (1989) recommends the establishment of village water management association and committees which appoint a village water master to run a groundwater management scheme. He also outlines the data that is necessary to collect on aquifer characteristics and adds, "Only through collective action on the demand side can the village avoid the inevitable slide into uncertain cropping owing to insecure water supplies. This message must constitute the very foundation of our work in the village."

The advantage of marketable permits for groundwater is that the landless would be included in the market as they would be allocated rights which they could sell⁸. This system would require some means of monitoring the quantity of water extracted and may thus require the use of water meters. While there have been problems with tampering of meters in the past, this option need not be ruled out. The development of a system of monitoring and enforcement which minimizes meter tampering may be possible, as meters are widely used in urban centres. A system that employs members of the village in enforcement and maintenance of these water meters may prove more effective than one which is exogenously run.

⁷ Even when property rights to groundwater are clearly defined, and groundwater is priced as in the western U.S, there are still problems of depleting aquifers (Moench, 1991; Smith, 1993; Thomas, 1993).

⁸ For discussions on marketable permits the reader is directed to an excellent paper by Hahn and Hester (1989).

The marketable permits system however attempts to address caste division and inequities by issuing tradable rights to all. But even this approach would require some form of organization or management. It is conceivable that a water management association may come up with approaches to dealing with equity other than those mentioned here.

3.10c. Mandated Conservation

An alternate way of directly controlling water extraction is by requiring the use of water conservation methods. In other words, the government could mandate the use of drip irrigation in all orchards and the use of pipes and lined channels in all irrigated farms. Subsidies could be made available for the adoption of such technologies, perhaps with higher subsidies being offered to the resource poor or low caste. The Government of Gujarat currently offers subsidies of this nature for the construction of biogas plants. Politically, however, the mandating of technology can make a government very unpopular, unless implemented carefully and with large subsidies.

3.11 Control of Water through Electricity

The other option is that of controlling the electricity which is used to extract water.

- a/ Pro-rata tariffs based on electricity usage.
- b/ Charges based on size of irrigated land area.
- c/ A combination of strategies.

3.11a. Pro-Rata Tariff

The pro-rata (PR) system was in place prior to 1987 in Gujarat. The most obvious benefit of this strategy is pricing proportionate to electricity/water use. It discourages excessive electricity consumption thereby reducing groundwater extraction. The pro-rata system has however been criticized in terms of enforceability, as illegal electric connections and meter tampering's abound. Nonetheless, if an institutional framework can be established within which a pro-rata system can be implemented, the benefits would be obvious. It is also noteworthy that, as indicated by current practices of diesel operators, a pro-rata tariff alone may not be sufficient to encourage the adoption of water conservation methods such as channel lining, piping, or drip irrigation. So while a pro-rata tariff will reduce water consumption, it may not result in sufficient conservation to significantly impact groundwater depletion. In addition, as recent history has shown, a pro-rata tariff on its own is not likely to be accepted by the farmer lobby.

3.11b. Land-Based Tariff

A system of charges based on size of land area was suggested by a respondent¹⁰. He felt that electricity pricing should be proportionate to land area. "Land area" may be qualified to "irrigated land area" as farmers do not irrigate all of their land.

The Samadhiala Lift Irrigation Society operates on this concept since it charges per acre of watering. While this strategy is particularly appealing for it avoids a need for metering and does not provide special subsidies to the large landowner, it is also highly problematic. The primary failure of this strategy is that it does not discourage excessive groundwater extraction. It essentially amounts to a variable flat rate because a farmer who irrigates 10 acres of land pays a fee that represents the 10 acres and not the actual amount of water used. So although there may be an incentive to irrigate less land, there is no incentive to use less water while irrigating that land. In addition, such a strategy may encourage water-selling by the small farmer who has excess water in his well. He will pay a rate proportionate to his land area, and can sell water to larger landowners who either need more water or who wish to irrigate land which they have declared as "unirrigated".

3.11c. Combination Tariff

Neither a flat-rate strategy based on horsepower, nor a more variable flat-rate based on landholding achieve the objective of groundwater conservation. A metered system is more likely to reduce water extraction, but presents problems in implementation and is also likely to face a strong farmer lobby. But that is not to say that the option of metering should be ignored. Perhaps a form of variable flat-rate that is adjusted by metering and other conservation incentives is possible. The tariff charged to each farmer could consist of a combination expressed as the following:

$$T = A*L + B*E - D(B*E)$$

also written as

$$T = A*L + B*E(1-D)$$

where;

T - tariff

A - a variable flat rate based on irrigated landholding

B - a metered rate based on kilowatt-hours of electricity consumed

D - a reduction in the metered rate based on the adoption of water conservation techniques (a discount rate)

L - land area under irrigation

E - kilowatt-hours of electricity consumed

¹⁰ Badrubhai of Katrasa

The basic charge consists of a variable flat-rate based on land area ($A*L$), which is augmented by a metered charge based on the amount of electricity used for extraction ($B*E$), and is reduced by a discount rate that is intended to encourage the adoption of water conservation techniques, such as drip irrigation, channel lining, piping.

This form of tariff is suggested as an attempt to discourage excessive water use while building in an incentive to reduce further, and aims to be a sufficiently simple calculation for implementation. Since it appears that the reintroduction of metering is unavoidable if groundwater is to be conserved through electricity pricing, the tariff must include means through which the impact of a pro-rata component can be minimized. The discount component attempts to fulfil this role.

Such a tariff may be able to encourage the widespread use of practices such as drip irrigation, channel lining, piping, etc.. For example, a tariff that offers a high discount rate to orchard owners with drip irrigation may provide sufficient incentive to encourage wider use and awareness of drip and other technologies. The financial incentive from the discount is two-fold since the adoption of the technology not only provides a discounted rate, but also reduces water usage thereby reducing the volume charged pro-rata. A farmer who drip irrigates all of his land could increase his discount and reduce his pro-rata component to such a degree that he essentially only pays the variable flat rate based on acreage. These savings would, over the course of a few years, pay for the capital expenditure on drip equipment, and could reduce his water consumption.

Within the combined tariff there lies the obvious difficulties of calculating the discount rate D , which can vary for different water conservation technologies and for different soil and crop conditions. For example, since drip irrigation is likely to be more appropriate for a coconut grove than for a groundnut field, the rate D could be designed so as to be more likely to encourage drip irrigation in orchards and perhaps channel lining in groundnut fields.

While the above equation may be only a rudimentary form of a viable tariff, it is intended to illustrate the advantages of a combined tariff and also the inherent complexities. If electricity pricing is to be used as a groundwater conservation tool, then some form of a combined tariff is necessary since pro-rata, land-based, or horsepower-based tariffs in isolation do not seem capable of meeting conservation objectives.

3.12 Institutional Options

Whichever strategy is adopted, its implementation will demand meticulous attention. While it is not in the scope of this paper to provide a detailed outline of institutional options for implementation, a few thoughts are briefly noted. Within Gujarat, there appear

to be three organizational structures potentially capable of implementing and monitoring a strategy:

- i) Gujarat Electricity Board (GEB) or other such agency
- ii) Panchayats
- iii) Village level organizations/NGOs

The Gujarat Electricity Board is currently responsible for keeping track of electric water extraction mechanisms so that owners can be charged the appropriate flat rate. Obviously a structure is already in place for collecting this revenue. A metered system would require the installation of meters in addition to the monitoring of meters. The land-based component of a tariff would require additional information on irrigated landholdings, and occasional visits to fields to check on the data. Whether or not the GEB would be interested in the additional fieldwork is uncertain, but the prospect of increased revenues may serve as an incentive.

Alternatively, the responsibility of tariff collection or groundwater management could be placed with a more localized village level institution such as the Panchayat. Panchayat executives would need to ensure that the revenues are collected and handed over to the GEB. The GEB would need to develop relatively accurate incoming revenue estimates, so as to cross-check these with actual collections.

Within villages there are often existing organizations intended to carry out particular tasks. For example, in villages where the Aga Khan Rural Support Programme operates, village institutions have been formed to administer and implement programmes, such as the Samadhiala Lift Irrigation Society. In villages connected to the National Dairy Development Board's milk grid, both local and regional milk producer cooperatives exist. Basically, a number of local organizations are in existence in many regions, which may be able to assist in the implementation of a strategy. Perhaps some of the most vital links can be established through networking with NGOs. As mentioned earlier, aquifer level management could possibly be achieved through village organizations supported by NGOs.

The institutional options mentioned can be divided into two broad categories -- exogenous or endogenous. In the former category fall all of the options that are imposed from above. All of the electricity pricing strategies and some of the water control strategies fall into this category. The endogenous options include those, such as Bromley's proposal, that seek grassroots or village level solutions to groundwater problems. As experience has shown, farmers are not likely to respond well to forced change, and certainly not to ad hoc increases in electricity tariffs.

Implementation from above is likely to aggravate the farmer lobby, which was able to succeed in 1987 to introduce the present flat-rate to Gujarat, and is currently agitating against a proposed 300% tariff increase. There is no reason to believe that any imposed

tariff strategy will be more favourably received. Conversely, a strategy that seeks to involve farming communities through a process of education on the need for water conservation and which also seeks to involve these communities in decision-making may be more acceptable. An inclusive approach that seeks farmer opinion and involvement on possible tariff or management structures and alternatives may be more likely to succeed.

3.13 Equity in Groundwater Use

The objective of ensuring equity in groundwater access may be answered by posing the following question. Are the proposed strategies discussed above capable of providing groundwater access to both the resource-rich and resource-poor? Under the current flat-rate tariff all farmers with electric pumps of same horsepower pay the same tariff rate regardless of their wealth. Tariffs that charge more to resource-rich farmers are intended to charge more to those who can afford more, without disadvantaging the poor. The proposed strategies, though skeletal, are more likely to make water extraction affordable for the small farmer provided that the overall tariff for the small farmer is not beyond his means.

In our survey in Maliya we interviewed many small and marginal farmers who do not have wells and depend entirely on rainfed agriculture. Many Harijan and lower caste families in these villages have no wells and claim to have a yearly income of about Rs.2000-3000 (US \$ 75-100), obtained primarily from working as labourers. Many landless farmers or labourers share a well for their drinking water needs, and depend on rainfall for agriculture. Access to groundwater necessarily implies access to wells and water extraction mechanisms. Tariffs on electricity or water exclude this group of farmers, and are only capable of addressing equity issues amongst those that already have wells, and who are consequently not the poorest in the farming communities.

Another aspect of equity in Maliya taluka relates to technological dualism. Many diesel pump owners complained of well interference. As water tables declined, resource rich farmers installed expensive submersible technology which has affected the technical efficiency of diesel pumps in the area because of the overlapping "radius of the influence" of the two. Generally, owners of diesel pumpsets will face problems when more submersible pumps with higher HP operate in the area. First, farmers with diesel will be subjected to a decline in their well yields, and may be forced to switch to submersible technologies, or abandon irrigation if they cannot afford to make the initial high capital cost of installing a submersible. Second, installation of submersible by all farmers would increased groundwater draft, lowering water tables and imposing financial penalties through higher pumping costs. A related but no less important aspect of the equity debate the state (wittingly or unwittingly) favouring one set of farmers over others i.e., subsidizing a set of farmers (electricity pump

owners) by providing cheap energy and not other farmers (diesel pump owners) when both get the same prices for their crops ? This seems to be inherently inequitable in itself.¹⁰

The marketable permit and endogenous aquifer management strategies have the potential to include those that do not have wells. From an equity perspective, it appears that a endogenously developed conservation strategies may be better suited to meeting the objective of access to all. Imposed strategies are inherently incapable of being equitable.

3.14 Conclusions

The survey in Maliya Taluka of Junagadh district indicates, that the structure of energy pricing may not play a role in groundwater management. However, while it may be true that altering the energy pricing strategy will change the efficiency of water use, a focus on this assumption can misdirect the search for groundwater management alternatives by restricting it to pricing possibilities only. There are two distinct issues of concern here -- the management of groundwater and the management of power -- and they need not necessarily be considered in combination. What higher electricity tariffs via flat rate, or prorata, or a combination of both could however do is to improve the finances of the Gujarat State Electricity Board. It may, therefore, be useful to present comanagement of groundwater and power resources separately rather than together.

The possible groundwater management strategies outlined in this chapter have been presented in isolation from the larger issues of agricultural systems and population pressures. This study, like most others has not looked at groundwater within the context of an input to agriculture. Conventional agriculture is input intensive, with high-yielding crop varieties being responsive to large quantities of fertilizers and water. Increasing populations places ever increasing demands on land to improve yields. Given these conditions, it is quite possible that aquifers carefully managed by conservation-conscious farmers will be unable to meet the demands of intensive agriculture. Basic crop water requirements may far exceed sustainable supply. The question of groundwater management, then, is not simply one of conservation, but one of an entire system of agricultural practice. Consequently, a sustainable and equitable groundwater management strategy is only one component of a sustainable and equitable agricultural system.

¹⁰ This point was raised by Dr John Ambler, December 12 1994 (Personal communication).

Chapter 4

In the first part of the report we investigated the potential of using power tariff policy in management of groundwater resources through case studies carried out in the state of Gujarat. Our main conclusions there were that in the politically feasible range of power tariffs electricity pricing would not alter the groundwater withdrawals. It was also argued that switch to reasonable high consumption based power tariffs would not affect the less well off farmers adversely. In this part of report we shall examine the same issues with respect to a water scarce hard rock region in the state of Karnataka.

4.1 Irrigation development in Karnataka¹

Karnataka is the 6th largest state in the country with a total geographical area of 1,92,00,000 ha. It has a cultivable area of about 1,07,00,000 ha, of which only 20% is under irrigation. The state receives an average rain of 1138 mm which is highly erratic in space and time. More than 2/3rd of the total geographical area of the state receives an annual rainfall of about 750 mm or less. The irrigated agriculture in Karnataka is mainly supported by tank and groundwater resources. Table 1 below shows how the relative contribution of different sources of irrigation have changed over the years. It can be seen from table 1 and figure given below that agriculture in Karnataka has become increasingly dependent on groundwater resources.

	1970-71	1975-76	1981-82	1985-86	1992-93
CANAL IRRIGATED	-	487,626	580,329	734,756	903,383
TANK IRRIGATED	364,849	410,311	321,333	241,964	257,107
WELL IRRIGATED	458,453	335,909	401,275	439,067	476,588
TUBEWELL IRRIGATED	1111	64	794	41,758	243,191
OTHER SOURCES	92,442	130,687	135,555	121,892	187,084
GROSS IRRIGATED	1,583,885	1,706,791	1,801,124	2,012,291	2,787,977
NET IRRIGATED	1,365,543	1,364,597	1,470,687	1674996	2,188.843

¹ The chief sources of information for this section is Reddy et al (1992)

Fig. 4.1

4.2 Overdevelopment of groundwater resources²

This dependence on groundwater is due to at least two factors. Firstly, major surface irrigation projects cover only parts of Gulbarga, Raichur, Belgaum, Bellary, Hassan, Mandya and Mysore districts. In the remaining parts of northern and southern regions availability of surface water is limited. These areas mostly depend on minor irrigation tanks or on groundwater for agriculture, industry and drinking water needs. Even the assured rainfall regions of the State like Dakshina Kannada, Uttara Kannada and Kodagu districts, experience drought in some years. In addition to this, the districts of Bangalore, Kolar, Tumkur, Chitradurga, Bellary, Raichur, Gulbarga, Bidar, Belgaum, Bijapur and Dharwad are chronically drought prone. Secondly the irrigation technology developed traditionally by farmers in the hard rock areas of Deccan Peninsula was dominated by tanks till the middle of the present century. The Deccan plateau has the largest number of irrigation tanks. After the recognition of states in 1956 the total number of tanks in the state was 34,523 which irrigated 343639 hectares contributing 49 percent to the total irrigated area. In 1970 the area irrigated by tanks was 27% amounting to 364849 hectares. It fell to 22% in 1980 with 321332 hectares under tank irrigation. With more than 38,000 irrigation tanks, the area under tank irrigation was 257106 hectares constituting only 11 percent in 1992. The importance of tank irrigation declined and its management suffered with the shift in ownership of tanks to the State Government. Encroachment and siltation of tank beds drastically reduced the irrigation capacity of these structures. Most of the tanks are in need of desilting.

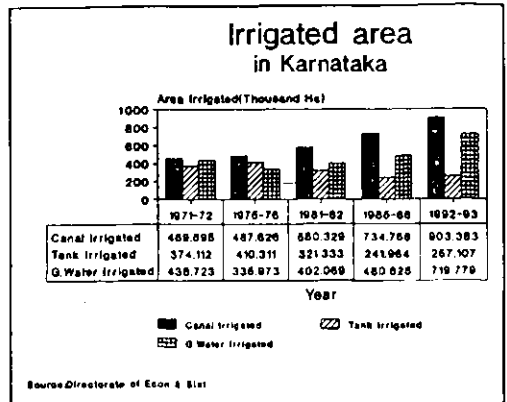
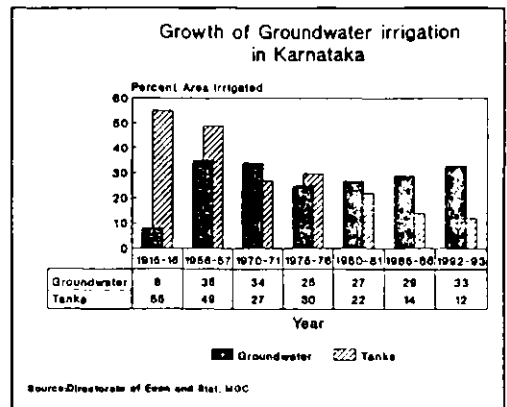


Fig. 4.2



² This section is largely based on Rao(1993)

strengthening of bunds and modernisation of conveyance and distribution channels. The State Government is unable to raise the resources needed to rehabilitate them. As a result, tanks which recharged groundwater and provided irrigation are now languishing. In a short period of 25 years since 1950-51, the proportion of tank irrigated area to net irrigated area has declined from 49 to 11.6 per cent in the state.

With serious constraints on restoring tank irrigation and expanding canal irrigation, the attention shifted to ground water irrigation since the 1960s. Farmers were drawn to well irrigation because of the private ownership it offered. Planners were attracted to it because of the vast potential, speedy implementation without gestation and relatively lower cost of construction. Various government sponsored programmes subsidizing well construction, easy availability of institutional credit and rapid rural electrification have given fillip to well irrigation here as in many parts of the country during the last three decades.

In 1960-61 Karnataka state had only 1.35 lakh dug wells, most of them operated by bullocks , each yielding meagre discharge, sufficient to irrigate about 0.4 ha of light irrigated crops. Thus the low potential of hard rocks matched the low yield of the dug wells. Under those conditions ground water levels were high and construction of dug wells was cost effective because their depth was less than 10 meters. Well failure was uncommon because the dug wells tapped mostly the weathered zone which is a reliable aquifer, as compared to the underlying fractured zone.

Since the 1960s, centrifugal pumpsets became exceedingly popular because of their low cost, high efficiency and easy maintenance. In a span of 30 years since 1960-61, the number of electric pumpsets steadily increased from 16,819 to 8,57,513 by March 1993. Correspondingly the acreage under groundwater irrigation increased from 12,23,910 acres in 1970 to 18,00,197.5 acres in 1992. While well owners were switching over to pump irrigation, new wells were also mushrooming simultaneously in large numbers. Karnataka witnessed three fold increase in wells, from 1.35 lakhs in 1960-61 to 5.10 lakhs in 1984-85, an annual growth rate of 11 per cent.

Groundwater draft in Karnataka increased almost ninefold from about 64,800 hectare metres (ham) in 1960-61 to 5,31,360 hectare meters by 1984-85(unit draft per dug well,

Fig. 4.3

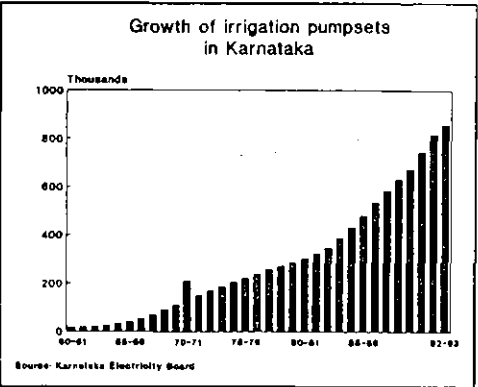
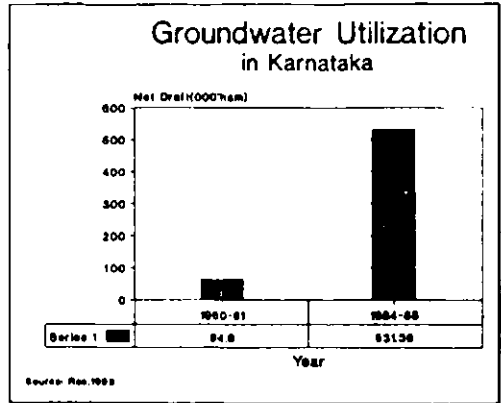


Fig. 4.4

operated by bullock power is taken as 0.3 ham and by pumpset as 1.2 ham as per the norms of the state Ground Water Department). Such steep increase disturbed the balance between ground water recharge and withdrawals and resulted in decline in water levels such as in the southeastern districts(see charts/appendix). The decline in water levels necessitated the need for deeper penetration of well. Soon even the dug



cum borewells which used the centrifugal pumpsets became unattractive as water receded from its suction zone. Farmers began to switch over to deeper surface bore wells, for whose operation costly submersible pumpsets had to be installed. This process commenced in the early 1980s, marking an important phase of ground water development in the state.

Several advantages associated with bore wells, such as ease of construction and possibility of continuous withdrawal of water encouraged Karnataka farmers to construct more and more borewells. Ironically, bore wells, constructed as a solution to declining water levels, actually caused further decline because these structures are capable of pumping more water. More ver, with the onset of bore wells, farmers could not revert to dug wells because the declining water levels made dug wells vulnerable to failure.

The proliferation of the bore wells in the 1980s was encouraged by Government policies. Government of Karnataka extended liberal subsidy schemes and also introduced insurance coverage against failures to protect the farmers financed under Government sponsored schemes (the insurance scheme has been withdrawn since May 1991 as the Insurance Agency found it uneconomical due to high failure rate of bore wells).

Groundwater resource in hard rock area like Karnataka is limited unlike in alluvial terrain. Though groundwater is replenishable resource, if the exploitation exceeds the limit of dynamic recharge, it will cause irreversible damages. Groundwater resources are showing increasing signs of overdevelopment in this region. The table 2 below shows the extent of average recharge and utilisation for three southeastern districts of Karnataka as on 1991. These three districts account for more than 30% of energised pumps in the state and are among the worst affected from groundwater exploitation. From the table it is clear that the rate of groundwater exploitation is very high.

Table 4.2 Groundwater recharge and draft of some districts of Karnataka in 1990

District	Net recharge (ham)	Net discharge (ham)	Stage of development(%)
Bidar	34013	8891	26
Gulbarga	98096	11025	11
Raichur	88981	11957	13
Belgaum	100642	36554	36
Bijapur	93572	35186	38
Dharwad	80360	14888	19
Bellary	73776	14612	20
Chitradurga	59831	22256	37
Chikkamagalur	65289	4317	07
Hassan	65505	5512	08
Tumkur	95393	39152	41
Bangalore	79532	36257	46
Kolar	51111	36130	71
Mandya	63741	9623	15
Mysore	102116	14762	14
Shimoga	61736	4020	07
Coorg	30304	1014	03

Source: Dept. Mines and Geology

Table 4.3 Net recharge and draft according to Drought Monitoring Cell

District	Net recharge (ham)	Net draft (ham)	Stage of development
Kolar	72993	69289	95
Bangalore	76460	64174	84
Tumkur	84278	55689	66

4.3 Implications of power tariff policy for agriculture

Since 1981 the Govt of Karnataka has adopted the policy of supplying power at low and flat rates which were fixed based on the HP of the pumpsets (Rs.50/BHP/YR). It is contended that this flat tariff has been a strong incentive for prolonged pumping and cultivation of water intensive crops. In

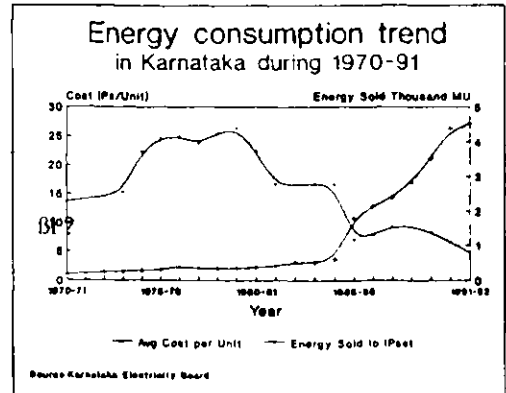
the absence of metered power supply farmers pump indifferently, least caring for conveyance distribution and application efficiencies (Rao 1993). He also observed in his study that even while irrigating water intensive crops farmers are not making any efforts to improve irrigation efficiency. Because of the uncertainties in power supply during day time farmers have constructed unlined earthen ponds for storing the water which would add to the storage losses. It was

also observed that many farmers pump the borewells throughout night and store water in the dry dug wells. Water thus stored is pumped by centrifugal pumpsets during day time. Farmers already having open wells (dry) avoid further expenditure on surface ponds. This has resulted in substantial power wastage. The decision of the state government to provide power free of charge up to and inclusive of 10 HP has from 1992 may have further aggravated the situation as almost all pumpsets are having less than or equal to 10 HP. This step has deprived Karnataka Electricity Board (KEB) of the little revenue it used to earn. Free supply of such a large quantum of power has jeopardised the financial position of the KEB and prevented it from investing on power generation to meet the ever increasing demand for power. Increasing gap between supply and demand has resulted in poor power quality, voltage fluctuation and frequent burning of motors.

Conclusion

The groundwater resources of Karnataka have come under tremendous pressure. The main factors which have precipitated this condition are scanty surface water availability, the neglect of tank irrigation system and Government policies which encouraged proliferation of high water yielding borewells. The net result has been a high rate of borewell failure in recent times. This may have had important equity implications as less well off farmers

Fig. 4.5



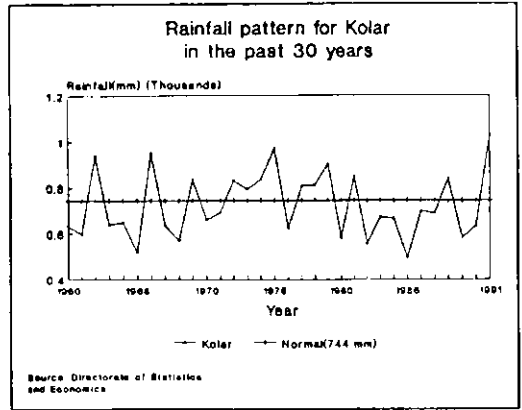
are relatively disadvantaged in their ability to invest in borewell when probability of failure is high.

The precarious condition of groundwater resources raises the issue of management options. Among the management options energy pricing is among the most readily accessible tools. In the following chapter we examine the utility of this instrument as potential management lever through a case study. Since Kolar is among the worst affected region, we shall examine these issues in context of Kolar.

Chapter 5

5.1 General features of Kolar District
 Climate is generally dry in Kolar district. April and May are the hot months and maximum temperature during this period is about 40°C. Minimum temperature is about 10°C. Annual normal rainfall in Kolar district is 744 mm, out of which 70% is received during South-West monsoon period. The district Kolar form part of South-interior Karnataka. In the above district, there are no perennial rivers and hence the availability of surface water for irrigation, domestic and industrial purposes is limited.

Fig. 5.1



The major source of surface irrigation is only through irrigation tanks (See table 3). But in the past 20 years the area under tank irrigation has reduced from 35 Percent in 1970 to about 18 percent in 1992. Over the years, the use of groundwater resources has increased by manifolds. The area under groundwater irrigation increased from 64 percent in 1970 to 76 percent in 1990. As a result, groundwater levels are declining from year to year.

Fig. 5.2

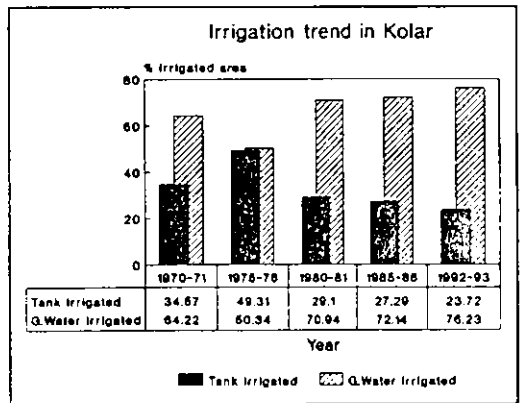


Table 5.1

	1970-71	1975-76	1981-82	1985-86	1992-93
CANAL IRRIGATED	-	-	-	-	-
TANK IRRIGATED	36,275	34,920	29,014	21,209	17,081
WELL IRRIGATED	67,391	35,653	45,571	48,117	23,410
TUBEWELL IRRIGATED	-	2	-	7,946	31,535
OTHER SOURCES	1,268	248	52	446	-
GROSS IRRIGATED	118,075	96,730	81,564	88,379	94,321
NET IRRIGATED	104,934	70,823	74,637	77,718	72,026

The shift towards groundwater resources has been brought about by a large increase in energised pumpsets.

As table 4 indicates the number of energised pumpsets in Kolar district has increased from 4423 in 1961 to 99240 in 1993 registering a 50 fold increase in the last three decades with an annual exponential growth rate of 9.8 percent. However its share in the total pumps in the state has declined.

Fig. 5.3

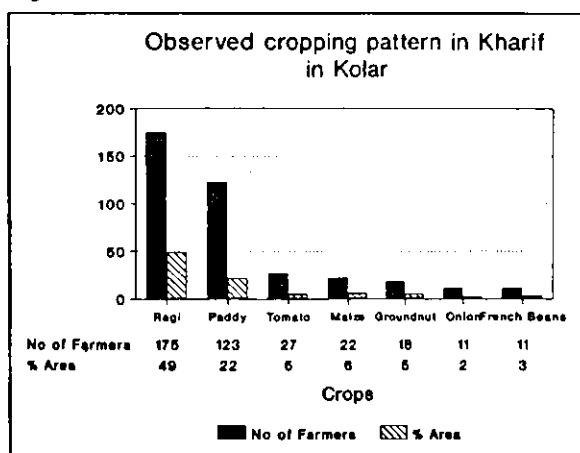


Table 5.2	
YEAR	PUMPS
60-61	4423
65-66	9585
70-71	21444
75-76	34532
80-81	45123
85-86	66243
92-93	96240

Fig. 5.4

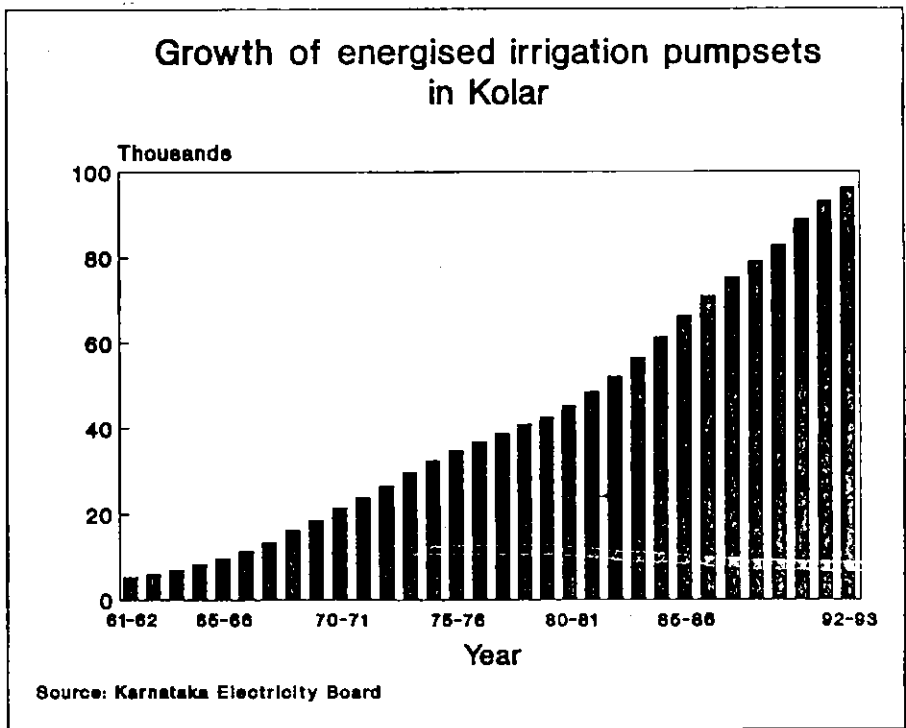
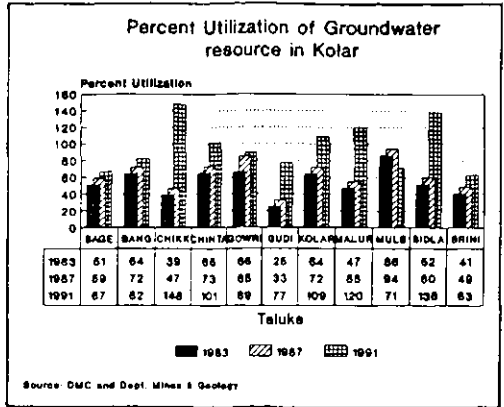


Fig. 5.5

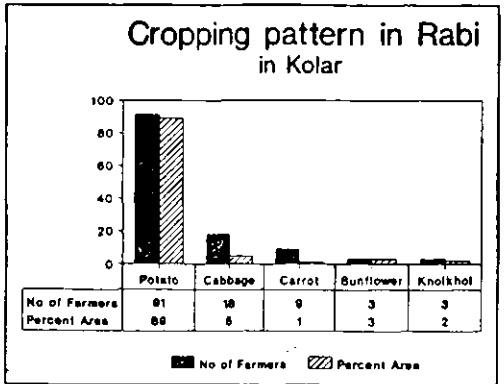
Consequently the utilization of groundwater resources in different taluks of Kolar over period of time has increased. The figure shows that out of eleven taluks six are dark, four are categorised as grey and only one taluk ie srinivasapura is considered to be white.



5.2 Some results of Kolar field survey

A survey was carried out covering about 250 farmers over more than 70 villages of the district. Information on agriculture related features such as crops grown, area allocated among different crops, output prices, number of bore wells owned by each farmer, the total land holdings, output of different crops was collected. Some of these are discussed here and others at more appropriate part of the report.

Fig 5.6



Main crops

Among the main crops paddy, tomato and ragi are grown in the Kharif; Potato , carrot and cabbage are grown in the rabi season ; Tomato ,paddy and onion in summer while mulberry and grapes are the perennial. Besides this a number of other vegetable crops are grown. The table below show the number of farmers growing each crop and area allocated to some major crops.

Crop	Number of farmers growing each crop	Area (acres)
Potato	91	168
Cabbage	18	21
Carrot	9	10
Ragi	174	362
Paddy	37	55
Tomato	74	86
Onion	30	41
Watermelon	21	35
Groundnut	14	26
Mulberry	135	232

It can be seen from the above table that mulberry, tomato, potato, ragi and paddy are the most important crops. Ragi and Paddy are grown mainly for self-consumption.

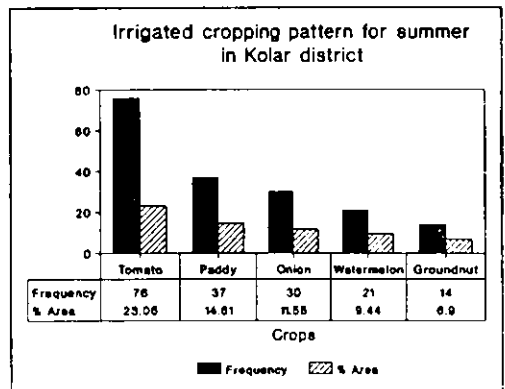
Power supply

Power is available for an average of 10 hours per day though there is considerable uncertainty in actual timing and voltage fluctuation is common feature of the power situation here. The farmers incur a significant amount of expenditure averaging Rs3000 for repair of pumps. The poor quality of power supply has led farmers to construct small tanks in which water is first pumped and stored overnight. In no instance water was conveyed through any kind of pipeline.

Source of irrigation

The main source of irrigation is groundwater which is extracted from an average depth of 160 feet. The main water extraction mechanism is the borewell fitted with submersible

Fig. 5.7



farmers. Most of these borewells are owned by larger farmers. It may be noted that in the total sample only 21 marginal farmers were found to own one or more borewell. Further the tank command area¹ increases with the size of farm holding. This seems to indicate the possibility that the larger farmers spread the water more thinly. Water markets are non-existent here. Only one instance of water transaction was observed in the study area.

Table 5.4

	Class I	Class II	Class III	Class IV
BORENO.	1.19	1.15	1.33	1.82
SAMPLE SIZE	21	76	85	55
TNKCOMM	0.95	1.21	1.18	2.02
Class I	denotes farmers owning land less than 2.5 acres.			
ClassII	denotes farmers with land less than 5 acres and more than 2.5 acres.			
Class III	denotes farmers with land less than 10 acres and more than 5 acres.			
Class IV	refers to farmers owning more than 10 acres of land.			

5.3 Role of energy pricing² as a groundwater management tool

The chief objective of this study is to examine the impact of electricity pricing on groundwater extraction for agricultural purposes. In principle they can influence (1) the water application intensity for different crops. (2) allocation of water among different crop choices.(3) investment in water conservation measures which has clearly defined private benefits. Shifting electricity prices to a consumption based structure is widely seen as a necessary step to remove incentives for inefficiency and to bring extraction more in line with recharge, that is bring about a more sustainable use of groundwater resources . This step however may have significant equity implications.(Moench 1992b) We now turn to an examination of these effects of a consumption based tariff structure.

5.3.1 The impact of power tariffs on water use intensity

¹ Tank command area is here defined as the average area irrigated by a farmer's tank.

² Since diesel pumps cannot be operated in the region, the term energy prices is used interchangeably with electricity prices throughout this report.

5.3.1 The impact of power tariffs on water use intensity

The methodology

We need to establish how changes in unit tariff rates will affect withdrawal of groundwater. In principle this could be done by relating tariff rates for different years with the rate of groundwater extraction for the corresponding periods. However since 1981 pricing system is based on the horsepower of the irrigation pumps. The implication of this pricing system is that the marginal cost of pumping water is zero. Hence the data on tariff rates needed to establish the link with groundwater extraction is non-existent. There is however another approach to analyze the link between tariff rates and groundwater usage. This method is based on the estimation of water production function.

The impact of energy prices on water use can be broken down in two steps. The energy prices(t) will first affect the cost of water extraction(C)³. The change in the cost of extraction will alter the profitability of irrigation water on the margin and hence alter the level of water application(W). Since E_{wt} , the elasticity of water application intensity with respect to power tariff(t) is mathematically defined as

$$E_{wt} = \frac{dW * t}{dt * W}$$

Using the above chain relation we can rewrite the above as

$$E_{wt} = \frac{dW * t}{dt * W} = \left(\frac{dW * C}{dC * W} \right) \times \left(\frac{dC * t}{dt * C} \right)$$

But the terms in the brackets are E_{wc} and E_{ct} respectively. This implies that

$$E_{wt} = E_{wc} * E_{ct}$$

It can be easily seen that last elasticity term will be unity in the following situations (1) where water markets exist and are perfectly competitive so that any increase in cost will be passed on as proportionate increase in water prices. (2) where farmer irrigates his land from own tubewell. This implies that any change in power tariff will translate in to a

³ We assume that no investment will be taken to improve pump efficiency as a result of switch over to pro-rata tariff structure and changes in the PR levels. This assumption is shown to be irrelevant elsewhere in this report.

proportionate change in water extraction cost. Thus the elasticity of irrigation intensity with respect to power tariff will simply be equal to water cost(price) elasticity of water demand. The estimate of the power elasticity can be obtained after estimating the demand for irrigation for different crops.

Estimation of water demand

In situations where water markets exist the demand for irrigation may be estimated since data on water prices exist. However in case of non existent water markets the demand for water may be estimated from the production function . It is a well known result in economic theory that the demand for a factor of production (for example, water) is defined by its value of marginal product curve⁴. The marginal product curve for an input in turn can be derived from the production function.

To illustrate let q be the output of a particular crop per acre of land, w be the amount of water applied per acre of crop sown, f be the amount of fertilizer applied. Assuming these two are critical inputs we can write the yield function (production function) as

$$q = h (w, f)$$

Differentiating the above equation with respect to each of the inputs will yield the respective marginal product equations . The VMP equation for water is simply $P \cdot h'_w (w,f)$ where P is the per unit price of the produce and $h'_w(w,f)$ is marginal product of water. The first step in estimating energy price elasticity is the estimation of the water production function .

Estimation of water production function: The yield of a particular crop will depend on a number of factors such as water,fertilizer , seeds and labour to mention a few inputs. However in what follows we shall consider water as the only explanatory. The bias resulting from excluding other explanatory variables should be borne in mind.⁵

⁴ Value of marginal product (VMP) of an input is the value of additional output obtained from the last(marginal) unit of that input when other input application levels are held constant.

⁵ If however, water is uncorrelated with other relevant explanatory the estimates will be unbiased.

A second observation regarding the yield function concerns its shape. The most commonly used yield response functions display a inverted -U shape. This is because with increasing application of input to a fixed factor(land in this case) the yield after reaching a maximum begins to decline if the input is applied above a certain level . This kind of yield response excludes the use of better known functions such as Cobb-Douglas production function since the latter has the undesirable property that the marginal product of any input is always positive.i.e. the output always increases with input application. A commonly used yield function is the quadratic form written as

$$Y=a + bw + cw^2$$

where w is the water applied and Y is yield of any particular crop.This functional form satisfies the above mentioned characteristic of production functions. Our estimation of water demand elasticities will make use of this functional form.

Because of sample size limitation and complicating impact of rains in Kharif season we have carried out the estimation of the yield function and water demand for only two crops: Potato, a rabi crop and Tomato, a summer crop, though it is also grown in Kharif. Mulberry though widely grown had to be excluded because its output is in the form of cocoons which is not entirely a function of agricultural operations.

Measurement of water and yield: As mentioned earlier farmers pump water into a tank and use it to irrigate their lands. The method we employed to measure the quantum of water applied to various crops is as follows: We obtained the measurements of the tank volume for all the farmers, the number of irrigations applied to different crops and the average tank command area. This last observation was obtained for about 60 farmers. Tank command area was regressed on the tank volume This yielded the following equation.

$$TNKCOMM=0.52+0.000238 \times TNKVOL$$

$$R^2=0.64$$

where TNKCOMM is the tank command area measured in acres and TNKVOL is the volume of the tank measured in cubic feet. This equation was used along with the information on each farmers' tank volume to estimate the tank command area for each farmer.

The volume of water(W) applied per acre of a crop is simply

$$W = \frac{TNKVOL}{TNKCOMM} \times \text{NUMBER OF IRRIGATIONS PER CROP}$$

This volume was converted into depth of irrigation per acre(cms per acre) by dividing the water volume by the area of an acre of land. Yield was obtained from production and area data for the respective crops.

RESULTS:

Potato: The yield function: (See Fig. 5.8)

$$y = 3.8 + 0.225W_n - 0.002W_n^2$$

$$R^2=20, \text{ Sample size}= 69$$

where y = yield per acre in tonnes and W_n is water application per acre in terms of height (cms)

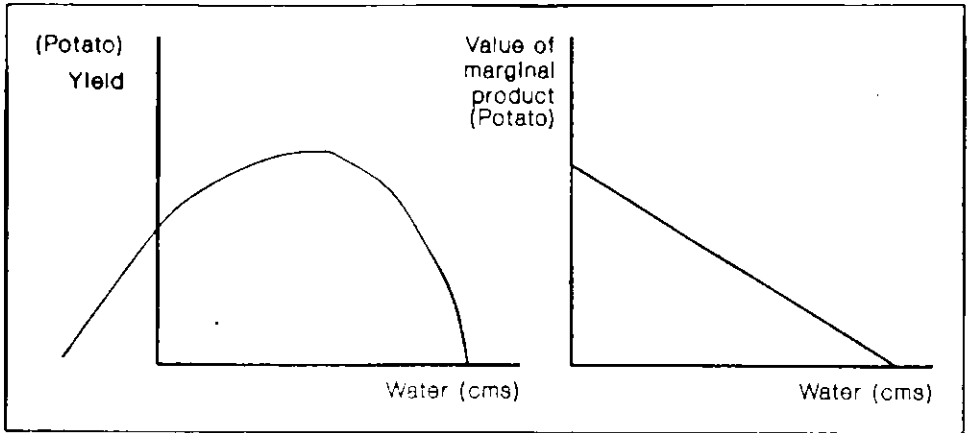
The marginal product (MP) of water therefore is

$$MP_w = 0.225 - 0.004W_n$$

The demand for water per acre of potato is obtained by multiplying the above equation by the average price of potato which in our sample was Rs.2170/- per tonne. This yields

$$D_{wp} = 488.25 - 8.68W_n$$

Fig. 5.8



Similarly for Tomato crop: the yield function is (See Fig. 5.9)

$$y = -7.665 + 0.794W_n - 0.00475W_n^2$$

$$R^2 = 28, \text{ Sample size} = 42$$

The marginal product in the case is

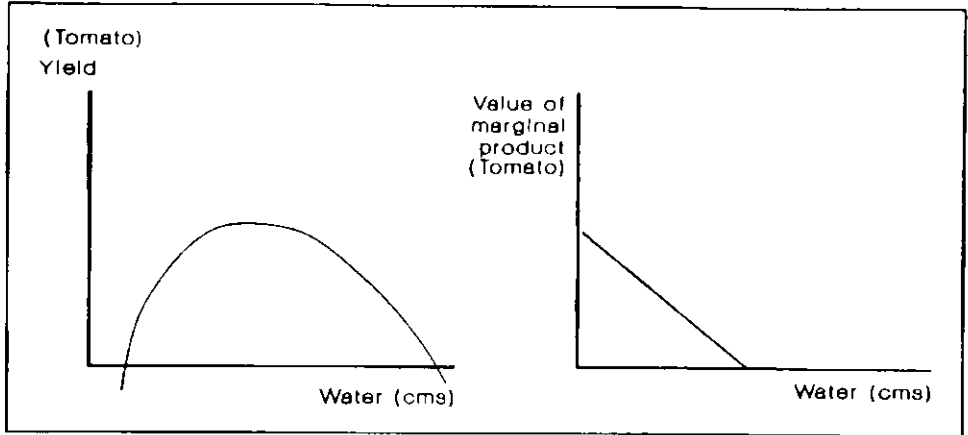
$$MP_{w_c} = 0.749 - 0.00950W_n$$

Based on our survey we use the average price for tomato of Rs.3200/- and multiplying the above we obtain

$$VMP_{w_c} = 2397 - 30.4W_n$$

Estimation of unit cost of water : How much water will a farmer apply at any particular tariff rate?. The VMP equations estimated above help us to answer this question . Since the VMP equation tells us the marginal value of water, a profit maximizing farmer will apply water till its marginal value is equal to its marginal cost. However before we can find out

Fig. 5.9



the optimal requirement of water at different tariff rates we require the estimate of cost of extracting a unit volume of water (C). Solving $C(t) = VMP$ we can obtain the optimum application of water at various tariff rates. Since water in our preceding equations has been measured in terms of depth of irrigation over an acre of land, for sake of uniformity we shall measure the cost of extracting an equivalent amount of water.

If 'D' denotes the average discharge in gallons per hour, "t" denotes the tariff rate per kwh of power consumed, "h" denotes the average horsepower of the pump used to extract groundwater.

Then energy cost of 1 cm of water over an acre of land (C)⁶ is simply

$$C = ((6.228 \times 43560) + (d \times 30)) \times 0.75 \times h \times t$$

The terms in the bracket denote hours of pumping required to fill an acre of land to depth of 1 cm.

The following tables give the optimum application of water at different tariff rates, obtained by solving the equation $C(t) = VMP$ for the two crops. A discharge value of 2500 gallons/hour and a pump horsepower of was used. These values correspond to the mean of the relevant variables in our sample. Produced alongside are the energy price elasticities at different tariff rates, estimated by utilizing the formula obtained earlier. It can be seen from the tables that the relevant energy elasticities are very small. What is even more important is that over a large range of electricity tariff, water application intensity would be much larger than the present average application rate for these two crops. This implies

⁶ We assume that cost of extraction is constant. This is justified if change in water levels is insignificant

that switching to a consumption based tariff structure over a wide range of tariff the water application intensity would be virtually unaffected.

tariff (Rs/Kwh)	E_{WT}	OPTIMUM W(cms)
0.1	0.00084	78.78
0.2	0.00167	78.71
0.3	0.00250	78.65
0.4	0.00334	78.59
0.5	0.00418	78.52
0.6	0.00503	78.45
0.7	0.00588	78.39
0.8	0.00672	78.32
0.9	0.00756	78.26
1	0.00841	78.19
1.1	0.00926	78.13
1.2	0.01011	78.06
1.3	0.01097	77.99
1.4	0.01182	77.93
1.5	0.01267	77.86

t (Rs/kWh)	E_{w_t}	optimum W(cms)
0.1	0.00411	56.02
0.2	0.00826	55.79
0.3	0.01244	55.56
0.4	0.01666	55.33
0.5	0.02091	55.10
0.6	0.02520	54.87
0.7	0.02952	54.64
0.8	0.03388	54.41
0.9	0.03828	54.18
1	0.04271	53.95
1.1	0.04719	53.72
1.2	0.05170	53.49
1.3	0.05625	53.25
1.4	0.06084	53.02
1.5	0.06547	52.79

However even these elasticity estimates are irrelevant. The table below gives the current average water application per acre of crop sown in cms.

	Potato	Tomato
Water/acre	47	61

It is obvious that for both these crops the current application intensity is much smaller than the optimum requirement at various tariff rates. Given the importance of these crops in the overall cropping pattern and absence of evidence indicating limited availability of other factors of production it seems that water application intensity is low because of overall scarcity of water. Thus consumption based tariff rates over a wide range will have no impact on water demand. This conclusion stands even if high tariff rates encourage more efficient extraction of water. This is because present application rate is well below the optimum requirement and therefore demand side considerations are irrelevant. This indirectly indicates that farmers would be willing to pay very high tariff rates. This is in sharp contrast to Nagraj's result (Nagraj 1993). He shows using the willingness to pay approach that farmers would be willing to pay 18.48 paise/kwh.

5.3.2 Impact of tariff changes on crop substitution : Even though tariff rates are not likely to have any impact on water application intensity it is possible that tariff changes would by altering the relative profitability of crops affect the cropping pattern and hence the overall extraction of groundwater resources. The proper approach to analyzing this aspect would be to compare the profitability of different competing crops at various tariff rates. However in absence of comprehensive cost data for various crops we merely indicate the possibility of crop switching as a result of tariff changes by considering the significance of energy costs in the total value of output. Table 5.8 below gives the energy required to irrigate an acre of land under different crops. The average volume of water applied to different crops was used along with average values of pump horsepower and discharge to compute these values.

Crop	Water applied/acre (gallons)	Pumping Hours/acre	Energy(Kwh) per acre
Potato	427478	171	770
Cabbage	581770	233	1049
Carrot	369501	148	666
Paddy	1201094	480	2160
Tomato	551075	220	990
Onion	465032	186	837
Watermelon	503247	201	905
Groundnut	269747	108	486
Mulberry	888205	355	1598

Table 5.8 gives the importance of energy costs in total value of output at different tariff rates. In these calculations we assumed the water application rate to be constant across different tariff levels.

tariff ((Rs/kWh)	0.2	0.4	0.6	0.8	1.0	1.5
Potato	0.83	1.66	2.49	3.32	4.15	6.23
Cabbage	0.66	1.32	1.98	2.64	3.3	4.95
Carrot	0.65	1.3	1.95	2.6	3.25	4.86
Paddy	6.1	12.2	18.3	24.4	30.5	45.75
Tomato	0.44	0.88	1.32	1.76	2.2	3.3
Onion	1.1	2.2	3.3	4.4	5.5	6.6
Watermelon	0.87	1.74	2.61	3.48	4.35	5.22
Groundnut	1.37	2.74	4.11	5.48	6.85	10.28
Mulberry	0.92	1.84	2.76	3.68	4.6	6.9

It can be seen from the table above (5.9) that for all crops considered here the proportion of energy costs in total value of output is small and does not differ much across crops. Paddy which is grown for self consumption is the only exception to this generalization. It may be noted that most of the paddy is grown in the Kharif season and hence water application may be overstated. Moreover in many cases it is grown in tanks thus at least partially making use of water which would be lost through percolation and seepage. Furthermore if the proportion of area under different crops is taken as an indicator of its relative profitability then the more profitable crops like tomato have lower energy content as compared to other crops. It may be worth bearing in mind that, for several reasons all crops do not compete with each other for available resources. However the most overwhelming reason why crop switching is unlikely to alter rate of groundwater extraction is to be found in the preceding section. In view of the overall scarcity of groundwater savings in water as a result of crop switching is likely to be used to increase water application intensity and/or irrigate additional land.

These considerations suggest that significant crop switching is unlikely and if it does occur overall water consumption may be unaffected.

5.3.3 Impact of power tariff on water conservation investments: In this section we shall consider if power tariffs could create an incentive for farmers to invest in water conservation measures. In Kolar poor quality of power supply to the agriculture sector has led farmers to store water in tanks constructed in their field. These tanks are usually made of mud though

led farmers to store water in tanks constructed in their field. These tanks are usually made of mud though stone slabs and cement tanks are also constructed. Often the water is pumped at night and used the following day. Most farmers report that the stored water is reduced by as much as 25% at the time of irrigation due to seepage, percolation and transpiration losses. The implied energy losses at some tariff rate may become prohibitive enough to impel farmers to invest in tank improvements. In the table below we give the value of energy at various tariff rates that could be saved as a result of tank improvements. We assume that the avoidable losses are about 15% of total water extracted annually. We ignore the Kharif season in our calculations. To estimate the avoidable energy losses we utilize information on average discharge of the pump, the average horsepower of the pump used, the total pumpage hours.

The table below gives the average number of pumping days for two seasons and the average hours of pumping per day.

	Summer	Rabi
Pumping Days	85	69
Pumping Hours/day	10.5	9

Thus total energy that could be saved in a year (E) as a result of tank improvements is

$$E = (85 \times 10.5 + 69 \times 9) \times 4.5 \times 0.15 = 1022 \text{ Kwh}$$

where the terms in the bracket denote the total pumping hours in summer and winter seasons, power consumed per hour by a 6hp is 4.5kwh and 0.15 denotes the proportion of energy that could be saved.

For cost-benefit analysis we need to compare the present value of value of energy saved against the cost of investment in the tank. Investment in better tank structures would be taken up if the benefits are as at least as large as the cost of improving the tank structures. Assuming that the life time of tank is 10 years, all relevant parameters remain unchanged over that period and farmers perceive that groundwater resources would last for at least 10 years the following table shows the present value of energy savings from tank improvements. Future values are discounted at the rate of 10%.

Tariff rate (Rs/kwh)	0.2	0.4	0.6	0.8	1.0	1.2
Present value of energy saved	1460	2920	4380	5840	7300	8760

The table below gives the cost of tanks of two different materials.

Tank material	Cost ⁷
Cement	1550
Stone	13028

From the above data on costs and benefits it seems that farmers may be willing to line their tanks with cement if tariff rates are above 40 paise per kwh while stone lined tanks would not be a worth while investment even at very tariffs. There are several caveats in this conclusion. First of all the values of energy savings are based on the assumption of a ten year long planning horizon. The high rate of borewell failure reported by some authors may shorten the farmers' planning horizon. Secondly in our framework the stone tanks are really a redundant option since we have used the same figure for energy savings irrespective of the tank material.

However in addition to benefits on account of energy saved benefits would also accrue from the use of additional water for irrigation purposes. The volume of water saved in the two seasons on the assumption of an average discharge of 2500 gallon per hour is shown below.

⁷ The cost concept here excludes the cost of excavation since we are only comparing the benefits of better tank material with the cost of improving the tank.

	Summer	Rabi
Average water saved (acrefit)	1.23	0.86

This suggests that an additional 2 acres of land could be brought under cultivation if capital and land availability so permitted or the crops could be irrigated more intensively with the additional water. In any case it seems that the present value of opportunity cost of this additional water may be much larger than the present value of energy savings. Further the former gains are not only larger they exist even if power is free at the margin as is the case in Kolar at present. Thus the water efficient storage structures should be fairly widespread. From our survey we have information on the number of tanks and material used for the tanks for the different farmers. Since tanks involve significant capital investment we present the statistics according to size-class of farmers.

	ClassI	ClassII	ClassIII	ClassIV
Tank Numbers	1.07	1.23	1.31	1.59
Tank Material	1	1.24	1.6	1.34

We have used numbers 1, 2 and 3 to denote alternative tank material; mud, cement and stone respectively. Thus average values higher than unity indicate existence of relatively more water efficient tanks. It can be seen from the table above that farmers with higher land endowments not only have more tanks they also use better material. It may be seen from the table below that the command area per bore decreases whereas the command area of the tanks increases with the land holding size of the farmers. This seems to suggest opportunity cost of water may be higher for large farmers. Therefore the larger farmers not only have the means to invest in better tanks they also may have more incentive.

The message from our discussion in this section seems to be that higher rate of power tariffs may make little difference to water conservation since significant gains from tank improvements may be present even in a flat rate tariff regime. Moreover those who might have the means to carry out the necessary improvements have to a certain extent already done so. This has however serious equity implications. This is because in a regime of consumption based tariff structure the burden of energy bill would be relatively higher

for the smaller farmers since they are probably disadvantaged in their ability to carry out the necessary tank improvements either on account of lack of sufficient capital and /or risk averse behaviour. It may be noted in passing that the farmers perception about time span over which the groundwater resources would be available may also hinder investments. The high rate of borewell failure reported by some researchers(Nagraj 1993,Rao 1993) can be expected to make investments in most kinds of water conservation measures unattractive.

We would like to point out another possible impact of switching to high tariff rates but this effect is not confined to consumption based tariff structure. The high energy bills implied by high tariff structure would by increasing the expected loss from crop failure and /or by imposing some capital availability constraint may lower demand for water. This effect is likely to be more pronounced for the less well off farmers. However since smaller farmers account for a small proportion of total water consumption, the impact on overall water consumption may not be significant. However this effect may have serious equity implication since smaller farmers are likely to be the affected party.

5.4 Limitations of the study: There are several limitations of our study some of which need to be pointed out. Firstly the estimation of yield function considered only one factor of production ignoring at least one critical factor, fertilizer and therefore the estimates maybe biased unless water and fertilizer are uncorrelated. Secondly the quantum of water was only indirectly estimated and therefore may involve measurement errors.

5.5 Policy implications: The discussion presented here casts doubt over the efficacy of consumption based tariff in management of groundwater . From the management perspective there is definitely a need to improve the **quality of power supply** . Current power supply situation involves wastage in several respects such as wastage of land to build storage tanks, losses on account of damage caused to pumps from poor power supply, wastage of energy and water due to seepage and percolation . The cumulative losses are likely to be considerable . Secondly there is both a need and scope to devise an **incentive package** to encourage adoption of drip irrigation system on a large scale. The scope is considerable because a large part of cropping pattern is accounted for by crops such as mulberry, grapes , coconut and certain vegetables like tomato and potato. These crops can easily be covered by drip systems. While a high tariff rate may not alter the overall rate of extraction directly , in conjunction with a cheap credit policy it could create an incentive for its adoption . Finally in view of limited groundwater resources in hard-rock region the need for strengthening surface irrigation cum water recharging structures(tanks) cannot be overemphasized.

5.6 Summary and conclusion: In this study we examined the impact of tariff changes in a consumption based power pricing regime by linking it to the cost of extracting water and examining the impact of latter on water demand. This was accomplished by deriving the (value of) marginal product of water equations from the yield -water relationship and equating it to the cost of extracting water. Our results showed not only very low values of elasticities but also its irrelevance. The irrelevance of elasticities emerged from the fact that the desired water application intensity for a wide range of power tariff was much higher than the current application intensity indicating an overall scarcity of water.

However the impact of power tariffs on overall water extraction could also work in other ways . One of these could be through a change in cropping pattern . Our brief discussion of this factor suggested that such an effect is unlikely. The third channel through which consumption based tariffs could affect groundwater extraction is by encouraging investment in water efficient tank structures. We argued that incentive to invest in tank improvements is present even under a free power tariff regime since there seems to be a general scarcity of water and opportunity cost of water is high . Our conclusion in this regard was that lack of sufficient funds and /or risk-averse behaviour of farmers especially small farmers may have hindered such investments.

Therefore the answer to the question whether power tariffs would be a good water management tool is in the negative. High consumption based tariffs may lead to more efficient use of water though even this is doubtful but overall rate of water withdrawal is likely to be unaffected. However irrespective of its impact on groundwater withdrawal the switch to consumption based tariff is likely to affect the incomes of the less well farmers.

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