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Beating negative externality through groundwater recharge in India: a resource economic analysis

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ABSTRACT. Negative externalities in groundwater irrigation arise due to overdraft of groundwater leading to premature well failure, and reduced yield and age/life of wells. A watershed development program aiming at recharging aquifers, facilitating sustainable groundwater use, is the focus of this study. Primary survey data from farmers using groundwater for irrigation in a dry land watershed in peninsular India are analysed.

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Results indicate that, even after considering (i) amortized cost of watershed, (ii) amortized cost per acre-inch of groundwater, and (iii) electricity cost of groundwater extraction, the net returns in watershed are economically viable. This can aid policy-makers, addressing groundwater overdraft leading to negative externalities, reach solutions with the assistance of a watershed development program enhancing groundwater recharge in dryland areas in developing countries.

Introduction

Though India is one of the wettest countries, several regions are fraught with drought affecting the livelihoods of millions of farmers who are solely dependent on agriculture. In the absence of surface water for irrigation, groundwater forms a vital source in many regions. In India due to rapid reduction of public investment in public irrigation and the associated environmental problems, private investment in groundwater extraction has been increasing and, as a result, about 60 per cent of the area is irrigated currently by groundwater (IWMI, 2003). With increasing vagaries in monsoonal rains and climate, farmers are not achieving even one successful crop in a year. This is *prima facie* evidence of the scarcity of water for irrigation. Marginal (less than one hectare) and small farms (between one and two hectares) have relatively little access to groundwater resources for irrigation. This constrains livelihood and income earning opportunities and is the cause of unemployment and disguised employment in farming.

According to the Indian Easement Act of 1872, groundwater rights are appurtenant to land owner *de jure*. But *de facto*, these rights are ambiguous (Chandrakanth and Arun, 1997; Chandrakanth and Romm, 1990), since in the unconfined and semi-confined aquifers of the hard rock areas there is no surety regarding the right to a given volume of groundwater for a given number of years to any well owner, as groundwater is an unreliable resource. Groundwater being an invisible resource puts researchers in a nebulous state, as neither its availability nor its extraction is known with certainty; both are estimated/guesstimated using several assumptions. For instance, according to the Central Water Commission (2000), in India the net draft of groundwater is 11.52 million hectare meters per year, while the amount of groundwater for irrigation is 36.08 million hectare meters per year, implying only 32 per cent of groundwater is extracted. The level of groundwater extraction in Karnataka is similar. Thus, the official groundwater statistics present a rosy picture of its sumptuous availability, but the reality reveals a very different picture. Even with this modest level of groundwater extraction, the large-scale failure of shallow dug wells, the increase in the proportion of deeper bore wells, the reduced area irrigated per well, and the increasing cumulative interference among wells, depict *prima facie* a situation that cannot be as rosy as the availability figures suggest. In addition, the position of groundwater cannot be generalized considering one or a few locations, since its potential and availability varies widely across locations, as the effects of withdrawal of groundwater are felt over a period of time.

In the literature on law and economics, better protection of environmental goods could be achieved at lower costs by replacing regulatory regimes with a system of well-defined private property rights (Coase, 1937; Hardin, 1968;

Gisser, 1983). But this requires low transaction costs of bargaining among the different stakeholders. In groundwater extraction, this is a myth as the number of extractors is increasing in leaps and bounds with the decline in rainfall in India.

Thus, assigning to groundwater users particular units of groundwater stock is not plausible; exclusive property rights, the basis for an exchange economy, are difficult to establish and enforce (Young *et al.*, 1986: 787). Thus, groundwater resources in hard rock areas of India can pose potential challenges for institutional innovations. The Karnataka Government prepared in detail the draft Groundwater bill on regulating groundwater use way back in 1996. However, the same is yet to be tabled before the legislative assembly. Thus, any institutional reform in groundwater would seem to stumble when it comes to the implementation part.

Even though the Government of India sought all the States to expedite groundwater regulation, few States have progressed. Karnataka having prepared the draft groundwater bill in 1996 is yet to table it on the floor of the Legislature, as political parties are apprehensive of losing electoral support from farmers whose extraction constitutes more than 85 per cent of groundwater use.

Farmers have a perception that their access to groundwater increases by drilling deeper wells. However, groundwater availability is a function not of depth, but of weathering and recharge, which are complemented by: (i) intensity of rainfall, (ii) topography, and (iii) type of the soil. Recharge effort is through desiltation of irrigation tanks, land levelling, and watershed development programs. In this regard, the role of groundwater recharging structures, such as check dams, farm ponds, percolation tanks, and ravine reclamation structures, is crucial. In the areas with limited access to surface water, access to groundwater is a significant function of recharge. Hence, watershed development programs (WDP) provide opportunities for augmenting groundwater resources.

Watershed development program

A watershed is an area where water drains to a common point, enabling capture of *in situ* moisture conservation. Preliminary studies have indicated that areas irrigated from wells have increased after the watershed development program in a few watersheds (table 1) in Karnataka, India (Ninan, 1997).

Tuinhof *et al.* (2003) suggest that recharge enhancement and increasing the storage function of the aquifer will become important in water resource management in the coming decades. Cost of groundwater extraction and the associated transaction costs will be lower, increasing equity in access to groundwater (Sastry, 1997; Diwakara and Chandrakanth, 2003; Nagaraj *et al.*, 1999). In Karnataka State during 1997, the average cost of watershed treatment was US$82[1] per hectare (Sastry, 1997). This provided an incremental yield of 50 per cent. The cost of providing major irrigation

[1] The cost of watershed treatment was Rupees 4,000 per hectare, which was converted to US dollars based on an exchange rate of 1USD = 48.75 in the year 2000 when this study was conducted.

Table 1. *Area irrigated from wells after watershed treatments in Karnataka State, India*

		Area irrigated from wells (hectares)		
Watershed	*Districts*	*Before watershed program*	*After watershed program*	*Percentage increase*
Seethanadi	Dakshina Kannada	316	371	17
Chandakavathe	Bijapur	31	35	13
Mugalikatte	Chikmagalur	95	122	28
Hirehalla	Belgaum	225	379	68
Tattihalli	Uttara Kannada	2	14	600
Doddahalla	Bidar	42	67	60
Asundinala	Dharwar	177	213	20

Source: Ninan (1997).

was $2,050 per hectare, which is expected to provide an incremental yield increase of 400 per cent; this cost has a ratio of 25:1, while the returns have a ratio of 8:1 between major irrigation and watershed development. This is the economic rationale for the watershed development program in dry land areas, promoting equity in access to water resources.

Watershed treatment typically is through afforestation, construction of percolation tanks, farm ponds, check dams, ravine reclamation structures, boulder checks, rubble checks, and vegetative checks for *in-situ* moisture conservation. These structures cause the running rainwater to walk, walking water to crawl, and crawling water to infiltrate, thus augmenting the groundwater regime. Watershed treatments are provided from ridge to valley irrespective of the ownership of land, considering technical feasibility and farmers' acceptance. This program is people centered, as participation is a crucial element in location, management, and cost and benefit sharing.

This study analyses the economic impact of the watershed development program implemented by the Dryland Development Board of the Government of Karnataka for sustainable rainfed agriculture.

Data and methodology

This study is conducted in the Haikal Watershed in Chitradurga District, Karnataka, India. The watershed is spread over 3,820 acres (1,528 hectares) of which 402 acres (160.8 hectares) are irrigated, forming 10.5 per cent, and the rest is rainfed land. The annual rainfall is 650 mm, occurring between May and October, with a mean temperature of 36 degrees Celsius. This is included in the Drought Prone Area Program of the Government of India (Central Water Commission, 2000).

Farmers were sampled after participatory rural appraisal (PRA) mapping *inter alia* of irrigation well(s), year of drilling, distance from water harvesting structures, surface water bodies like irrigation tanks, drinking water wells. The population of 65 farmers in the watershed owning irrigation well(s) was selected. After a preliminary survey and pre-testing, the field data from farmers were collected using a structured schedule during April 2000.

Groundwater recharge is a positive externality of the watershed development program. Farmers whose irrigation wells served and/or are serving beyond their average age, are hypothesized to have experienced/to be experiencing positive externalities. This reduces the cost per acre-inch of groundwater and the proportion of well failure.

Stratification of farmers

Among the farmers who possessed irrigation wells in the watershed, there were: seven marginal farms (below 2.5 acres), 27 small farms (2.5 acres to 5 acres), and 31 large farms (above 5 acres). These farmers possessed 90 irrigation wells (80 functioning and ten failed wells); a majority of them were drilled after the watershed program. Bore wells were the predominant mode of water extraction. Investment in irrigation wells is a sunk cost, and obviously does not enter the decision-making process. However, due to increasing probability of (premature and initial) failure of wells, accompanied by the declining yield of wells due to cumulative interference among irrigation wells in hard rock areas, the sunk cost becomes a recurring cost due to increased incremental costs of follow-up investments *inter alia* new additional wells, well deepening of old wells, different sites. *Ceteris paribus*, these factors exacerbate amortized cost of irrigation as farmers invest in additional well(s) or other coping mechanisms after the initial well(s) fail to yield adequate volumes of irrigation water for the expected number of years. In principle, the sunk cost is a fixed cost and treating it as a variable cost may negate amortization.[2] In the hard rock areas, as the average life and age of wells is fast reducing, farmers are forced to invest in new well(s) and thus fixed investments become variable costs to be amortized over the average life of irrigation wells. Thus, the presence of a cumulative interference externality leads to fixed costs to be treated as variable costs due to shortened life and yield of irrigation wells, thereby encouraging greater investments.

The economics of groundwater resource is usually discussed independently of watershed programs. Groom *et al.* (2003) discussed the economic approach to watershed management with an application in Cyprus. Kelso (1961) discussed the problem of the water stock in central Arizona. Gisser (1983) discussed the impact of assigning property rights to groundwater. Gisser and Mercado (1973) discussed the integration of economic theory of agriculture with a hydrologic theory of groundwater. Shah *et al.* (1995) discussed technology adoption in the presence of an exhaustible resource. Acharya and Barbier (2002) valued groundwater recharge in Nigeria, and Koundouri (2004) highlighted the economics of groundwater management. In this study, the economics of groundwater use within a watershed context is analysed.

[2] For instance, Coase (1946) argues that the fixed costs are in fact outlays which were made in the past for factors the return to which in the present is a quasi-rent, and a consideration of what the return to such factors ought to be raises the problem of great intricacy (p. 170). Also, see Coase (1970) on marginal cost pricing.

Amortization cost of irrigation well(s)

Accordingly, investments in irrigation well(s) have been amortized,[3] considering the drilling cost, average age of the wells, and an intergenerational equity interest rate of 2 per cent – comparing investment in irrigation wells between different periods, this interest rate was found to be around 2 per cent. As the method of compounding/discounting follows the usual exponential relationship between present and future values, even a modest interest rate of 4 per cent, but considered over say 20 to 30 years, will outgrow the investment in leaps and bounds. This is not pragmatic, as it does not reflect the actual rate of increase in investment in well irrigation. A real interest rate of 2 per cent covers sustainable extraction of groundwater in watershed development. However, it is worth noting the ongoing debate on use of discount factors in economic analysis.

The choice of discount rate has been a theoretical puzzle surrounding evaluation of public policies and programs.[4] An issue that divides economists and others is whether the discount rate should be in the range of 5–10 per cent or 0–3 per cent (Lind, 1997). One outcome of a steamy debate among economists is that the *discount rate should be small* for distant futures (see, Weitzman, 1998; Gollier, 2002; Newel and Pizer, 2003; Pearce *et al.*, 2003). A meticulous review by Pearce *et al.* (2003) suggests that the discount rate is no longer a single number, rather it varies in a declining fashion with time.

An exercise undertaken by Chandrakanth *et al.* (Chandrakanth, personal communication, 2006) in Karnataka revealed that the vintage of bore wells at different points in time indicates the nature and degree of groundwater extraction. The depth of bore wells ranged from 80 to 150 feet in 1985, which doubled during 2001. The bore wells, yielding 3,500 gallons per hour during 1985, dwindled to yield 800 gallons per hour in 2001. Further, there has been increase in irrigation pump capacity from 5 to 7.5 horse-power (HP). In addition, farmers also consider the number of stages of pumps due to increased depth to groundwater. Investment per well increased from Rs. 53,605 to Rs. 74,190 over the last two decades, an increase to the tune of a 2 per cent compound growth rate. These data show that on an average for Karnataka the rate of increase in nominal investment in irrigation wells is around 2 per cent compound growth rate, and this has been taken even allowing for amortization; in addition, the real growth of investment in irrigation wells is negative. When investments made by farmers in irrigation wells for different years were compounded to the present, the rate of 2 per cent offered a close approximation to the growth of investment in irrigation wells. Further, the rate of growth of nominal investment in irrigation wells for different parts of Karnataka is 2 per cent and hence the 2 per cent

[3] The amortization cost does not include a uniform life span year's '*t*' over which all costs have been amortized. This limitation has been ignored for analysis purposes.

[4] We thank the Editor and an Associate Editor of this journal for highlighting this point, which led to review of recent literature on social discounting, especially Pearce *et al.* (2003), Weitzman (1998), and Gollier (2002).

discount rate is taken in this study.[5] Two per cent is the rate of investment per well. However, if we consider investment in all irrigation wells over say 30–40 years divided by the number of functioning wells as of 2006, then the investment per functioning well would have certainly increased. So if economists argue that 2 per cent is low, it is not true. The low rate of investment per well is reasonable, but, if we include externalities, then it may not be economical.[6]

For dug wells constructed during 1960s and 1970s, the investment is compounded to reflect the current costs and then amortized as

$$\text{Compounded investment on dug well} = \text{DW cost}^{*}(1+i)^{(AA)} \tag{1}$$

where i = interest rate (2 per cent per year), DW = Dug Well, and AA = the average age of the well, computed as the difference between the year of data collection (2000) and year of well construction.

Similarly, the investment on bore well was compounded as

$$\text{Compounded investment on bore well} = \text{BW cost}^{*}(1+i)^{(AA)} \tag{2}$$

The compounded investment on irrigation pump set is computed as

$$\text{Compounded investment on pump set} = \text{Pump set cost}^{*}(1+i)^{(AA)} \tag{3}$$

where AA = the average age of the irrigation pumpset (about ten years).

The above compounded investment is amortized as

$$\begin{aligned}&\text{Amortization cost of dug well}\\&\quad = \left[\text{Compounded investment on dug well}^{*}(1+i)^{AL)*}i\right]/[(1+i]^{(AA)}-1\right]\end{aligned} \tag{4}$$

Here, AA = the average age of the well; the average is the difference between the year of data collection (2000) and year of well construction.

$$\begin{aligned}&\text{Amortized cost of pump set and accessories}\\&\quad = \left\{\left[\text{Sum of compounded cost of pump set + pump house}\right)^{*}(1+i)^{(10)*}i\right]/\\&\qquad \left[(1+i)^{(10)}-1\right]\right\}\end{aligned} \tag{5}$$

The working life of pump set, pump house, and conveyance pipe and accessories is assumed to be ten years

$$\begin{aligned}&\text{Amortized cost of conveyance structure}\\&\quad = \left[(\text{Compounded cost of conveyance pipe used})^{*}(1+i)^{(10)*}i\right]/\left[(1+i)^{(10)}\right]\end{aligned} \tag{6}$$

[5] Although there is uncertainty about everything in the future, the use of a 2 per cent discount rate reflects the actual rate of increase in investment in well irrigation.

[6] The externalities can be estimated by dividing the investment in all wells by only the number of functioning wells.

Thus

$$
\begin{aligned}
&\text{the amortized cost of irrigation well}\\
&\quad = [\text{Amortized cost of bore well}\\
&\qquad + \text{Amortized cost of pumpset and accessories}\\
&\qquad + \text{Amortized cost of conveyance like PVC pipe}\\
&\qquad + \text{current annual repairs and maintenance cost of}\\
&\qquad\quad \text{pump set and accessories}] \qquad (7)
\end{aligned}
$$

No energy meters for electricity to pump groundwater are installed in farmers' fields. Farmers in different parts of Karnataka are protesting against such installations as they have been supplied electrical power since the 1980s free of cost. Since there are wide fluctuations in the quantity and quality of power supply, however, 'free' power has become 'no' power to farmers in Karnataka. In addition, the electricity authority has not been able to uniformly enforce collection of dues from other defaulters. Farmers are now asked to pay a flat rate for the electricity used at the rate of around $11 per HP of pumpset per annum. For an average pumpset capacity of 5 HP, this amounts to $55. Previously, farmers have not had to pay flat electricity tariffs and this is a political economy question, as farmers expect this to be a subsidy. Chandrakanth *et al.* (2001) estimated that to pump one acre-inch of groundwater, it needs approximately energy of 42 kilo watt hours valued at US $1 (at 1 rupee per kilo watt hour). The question of whether the cost of electrical power to farmers forms a substantial portion of the pumped cost of groundwater or not depends upon the amortized cost of groundwater and is relevant, since it entirely depends upon (i) the level of negative externalities due to groundwater overdraft and (ii) the level of positive externalities due to watershed treatments of groundwater recharge. In this study, the amortized cost per acre-inch of groundwater varies from $1.94 to $5.21. For farmers incurring $5.21, the electricity cost per acre-inch would be colossal compared to farmers incurring $1.94. Primarily in hard rock areas, due to the increasing failure rate of irrigation wells, the implicit costs of well failure due to externalities are becoming far higher than the electricity subsidy offered to farmers and thus the electricity subsidy is not a windfall gain to farmers in such areas.

Estimation of the age of well is crucial as it subsumes the effect of watershed treatments. The wells, which serve beyond the average age, would have benefited from positive externalities, despite cumulative interference. The wells that serve below the average age are assumed to be affected by negative externalities due to cumulative well interference. The average age ultimately reflects the externalities due to the watershed program.

Net returns

Net returns are estimated using gross returns, costs, and amortization cost of irrigation wells for all wells on the farm. Farms are classified based on the gross area irrigated possessed and the volume of water extracted for irrigation. To study the equity implications, farmers are classified based on the location of their well(s) in relation to water harvesting structures in the watershed, the amortized cost per acre-inch of water, gross area irrigated, well yield, and net returns.

Annual externality cost

The externalities associated with groundwater have been documented theoretically and empirically (Dasgupta, 1982; Provencher and Burt, 1993 1994a, b; Gisser, 1983; Gisser and Sanchez, 1980; Eswaran and Lewis, 1984; Groom and Swanson, 2003). In this study, the well failure externality is defined as declining yield of the well or well becoming dry due to cumulative well interference, and not due to faulty location of wells or low rainfall. The effect of cumulative well interference on yield of the well can be sudden or gradual. If the effect is gradual, then the interfered well begins to experience declining yield over a period of time; if the effect is sudden, then the interfered well suffers from initial failure.

The annual externality cost (AEC) of irrigation is estimated as the difference between the amortized cost per well and the amortized cost per working well as

$$\text{AEC} = \text{Amortized cost per well} - \text{Amortized cost per working well} \tag{8}$$

If the amortized cost per well (considering all the wells on the farm) is equal to the amortized cost of working well, then all wells are functional and there are no failed wells on the farm and thus no externalities. If the failure rate of wells is high, then the gap between the amortized cost per well and that per working well would also be large, as the cost of well failure due to interference would be apparent and hence the externality cost.

Economics of irrigation

Amortized cost per acre-inch[7] of groundwater is obtained by dividing amortized cost of irrigation well by total groundwater used on farm. The cost of cultivation for each crop on the farm is obtained as the expenditure on human labour, bullock labour, machine hours, seeds, fertilizers, plant protection chemicals, manure, transportation and bagging, and the amortized cost of groundwater, besides the opportunity of working capital. The opportunity cost of working capital is computed at 10 per cent. Cost of production is, cost of cultivation + amortized cost of irrigation + interest on variable cost + opportunity cost of dry land agriculture. The opportunity cost of dry land agriculture is the average net return obtainable from that area of land devoted to irrigation, if that land were to be cultivated on a rain-fed basis. The gross cropped area (GCA) is the sum of areas under crops in all the three seasons (rainy, winter, and summer) + area under dryland crops. The net cropped area (NCA) is the sum of areas under all crops in the rainy season; gross irrigated area (GIA) is the sum of irrigated areas under all crops in all the seasons. net irrigated area (NIA) is the irrigated areas under all crops in rainy season. The cropping intensity (CI) is

[7] One acre-inch of groundwater has 22,611 gallons of water.

computed as [gross cropped area/net cropped area] × 100 and the irrigation intensity (II) is computed as [gross irrigated area/net irrigated area] × 100. Gross returns for each crop are the value of the output at the prices realized by farmers (during the 1999–2000 agricultural year). Net return from well irrigation is the gross return from irrigated area minus cost of production of all crops.

Physical access and economic access to groundwater

Equity is a vital aspect in the study of economics of watershed management and emphasizes those classes of farmer who benefited from watershed program (Chandrakanth and Diwakara, 2001). In order to capture the synergy involved in the role of watershed structures in augmenting the groundwater recharge, farmers are classified with the hypothesis that wells located within 800 feet from water harvesting structures have fairly reasonable well yield compared to wells located more than 800 feet. The water yield of wells in close proximity to a water harvesting structure, cost of water per acre-inch, and the gross area irrigated are considered for equity analysis.

In addition to amortized cost per acre-inch of groundwater extracted, amortized cost of watershed development program is considered by amortization of the total cost of watershed across the total water used by all farms for 20 years, assuming that benefits from the watershed development project span over 20 years.[8]

Groundwater in hard rock areas is largely dependent upon the degree of natural recharge through rainfall and percolation and human efforts through efforts *inter alia*, desiltation of irrigation tanks, soil and water conservation, bunding, contour bunding, contour ploughing, construction of farm ponds, percolation ponds, ravine reclamation structures, and gully checks, which form a part of the watershed development program. According to the latest Minor Irrigation Census of Karnataka[9] in Karnataka, 92 per cent of dug wells and 95 per cent of bore wells are outside the command area of surface water bodies. Thus a vast majority of the irrigation wells, as well as drinking water wells, suffer from low recharge. With absolutely no initiative from farmers to recharge groundwater, Watershed Development Projects/Programs are the only public funded programs responsible for groundwater recharge. These programs are implemented with participation from farmers and function for a period of five years. Since *in situ* moisture conservation is the key component of a watershed program, farmers' commitment to maintain watershed structures influences the performance of the watershed program. This apparently influences the groundwater recharge, which in turn influences the 'life' and 'age' of irrigation wells. 'Life' of well refers to the well/s which already served and are no longer functioning at the time of field data collection, and includes

[8] The life of the watershed project is assumed to be 20 years. However, this depends upon the commitment of the farming community in maintaining the watershed over such a long period.

[9] Water Resources Informatics Division, National Informatics Centre, New Delhi, 2005.

wells which failed initially, prematurely and wells which functioned for their normal or average life and beyond. 'Age' refers to the well/s functioning at the time of field data collection. Thus, there are two averages – the average life and average age. As initial failures of irrigation wells gives the life as zero, if a majority of wells have initial failure, then amortized cost will be infinity. Thus, to avoid such an extreme, both 'life' and 'age' of wells are clubbed to find the average 'life' or 'age'. In watersheds where there is commitment of farmers for maintenance of watershed structures, with good rainfall, both the 'age' and 'life' of wells would increase. However, as the impact of the watershed development program is over a period of time, not apparent but implicit, the discount rate is low. The low discount rate in watershed programs is reflected in (i) relatively poor commitment of farmers in maintaining the watershed structures after the project/program is over and (ii) low or no willingness to pay for maintenance of watershed structures. These are not unusual for a tropical rainfed agricultural area, since efforts to form effective 'water user associations' of farmers in the relatively better endowed surface water irrigated areas, to transfer the responsibility of water use, management and collection of water rates under Participatory Irrigation Management (PIM), have seldom been fruitful.

Physical access to groundwater

Physical access is analysed by regressing groundwater used per acre of gross irrigated area as a function of average well depth, distance of well to water harvesting structure, well yield, and the amortized cost per acre-inch of groundwater. It is hypothesized that physical access to groundwater varies directly with well depth, distance from water harvesting structure, well yield, and inversely with the amortized cost of groundwater per acre-inch in the log-linear relation

$$\text{Ln WU} = \ln \alpha + \beta_1 \ln \text{WD} + \beta_2 \ln \text{WDWHS} + \beta_3 \ln \text{WY} + \beta_4 \ln \text{CW} \tag{9}$$

where, α = intercept, β = coefficients, WU = water used per acre of gross area irrigated, WD = well depth (feet), WDWHS = well distance from water harvesting structure (feet), WY = water yield of the well (gallons per hour), and CW = cost of water (dollars per acre-inch of water).

The hypothesis that the groundwater used on the farm directly varies with consumptive use of groundwater by onion crop is tested with the log-linear equation

$$\text{Ln WUI} = \ln \alpha + \beta_1 \ln \text{WUO} \tag{10}$$

Here, WUI = total groundwater used on the farm (acre-inches), WUO = groundwater used for onion crop on the farm (acre-inches). Onion crop consumes relatively more water compared with all other crops.

Economic access to groundwater

The economic access to groundwater is measured by amortized cost of groundwater per acre-inch and is hypothesized to vary inversely with well depth, directly with well distance from water harvesting structure, and inversely with water yield from the well and gross irrigated area. The economic access to groundwater is regressed on well distance from water harvesting structure (in feet), water yield for the well (in gallons per hour), and gross irrigated area (in acres). The estimated function in log-linear form is

$$\text{Ln CW} = \ln \alpha + \beta_1 \ln \text{WY} + \beta_2 \ln \text{WDWHS} + \beta_3 \ln \text{GIA} \tag{11}$$

Here CW = amortized cost of groundwater (dollars per acre-inch), WY = groundwater yield from the well (gallons per hour), WDWHS = distance of well from water harvesting structure (feet), and GIA = gross irrigated area (acres).

Net returns per farm are regressed with amortized cost of groundwater per acre-inch, total groundwater used for irrigation on the farm, and total labour used on the farm using the log-linear form

$$\text{Ln NRPF} = \ln \alpha + \beta_1 \ln \text{CW} + \beta_2 \ln \text{WUI} + \beta_3 \ln \text{LAB} \tag{12}$$

Here, NRPF = net returns per farm (dollars), CW = amortized cost of water (dollars per acre-inch of water), WUI = total groundwater used for irrigation on farm (acre-inches), and LAB = total labour on the farm (man-days). The net return per farm is hypothesized to vary inversely with the cost of water, directly with the labour used and water used for onion crop on farm.

Results and discussion

In the Haikal watershed program, 44 check dams, 13 ravine reclamation structures, and 10 rubble field checks were constructed. The total investment of watershed treatment was US$64,794. The amortized cost of watershed treatment forms around $7,897 (amortized at 2 per cent for 20 years, assumed to be the life of the watershed). The cost of training farmers formed 0.23 per cent of the total cost of the watershed treatments and administrative cost formed 0.22 per cent. The cost of watershed per acre-inch of water is $0.65 (see table 2).

Irrigation wells before and after watershed

Among the 90 irrigation wells in the watershed, 80 wells were functioning and ten wells (11 per cent) were not. This failure rate of 11 per cent fares better than that of 40 per cent estimated for the Eastern Dry Agroclimatic Zone (Nagaraj *et al.*, 1994).

However, it is important to note that the volume and quality of groundwater for irrigation is highly location specific and it depends on *inter alia* hydrogeological characteristics. India has a varied hydrogeological setting. The entire state of Karnataka, excepting the coastal region, is classified as a hardrock area for hydrogeological purposes. The major types of rocks are gneiss, granite, basalt, and schist. The schists have low groundwater yielding capacity. The study area of the Haikal watershed in Chitradurga District is largely composed of crystalline schists, granitic gneisses, and the newer granites with a few later intrusive basic dykes belonging to the oldest rock formations in India. Granitic gneisses forms occupy more than 50 per cent of Chitradurga district (Mysore State Gazetteer, 1967: 11–12). In eastern dry zone where the well failure rate is

Table 2. *Details of water harvesting structures constructed and investment in Haikal watershed, Karnataka, India, April 2000*

Particulars	*Numbers*	*Investment (US dollars)*
Check dam	44	26.96
Ravine reclamation structures	13	2.95
Rubble field checks	10	2.22
Training cost		153.84
Administrative cost		143.58
Total cost of watershed treatments		64,779
Amortization cost of watershed		7,897
Amortized cost of watershed		0.65
Treatment per acre-inch of water		

Notes:
1. Amortized cost of watershed is calculated at a modest rate of 2 per cent interest rate for amortization for 20 years, considered as the life of the watershed development project.
2. Amortized cost of watershed treatment per acre-inch of water is calculated by dividing the total water used for irrigation by the sample of farmers. Even though the current water extracted in the watershed is around 6,000 acre-inches, the total water used is projected at 12,000 acre-inches assuming that the water used will be doubled in due course.

Source: Dry Land Development Board, 2000, Chitradurga District, India.

Table 3. *Irrigation wells before and after watershed, Haikal DPAP Watershed, Karnataka, India, April 2000*

	Before watershed		*After watershed*	
Particulars	*Functioning*	*Non-functioning*	*Functioning*	*Non-functioning*
Dug well	0	2	0	2
Bore well	8	6	78	6
Dug-cum-bore well	0	2	2	2
Total	8	10	80	10

Source: Field Survey (2000).

high, the major type of rocks include lateritic masses occurring as irregularly distributed patches in the form of flat hills (Chandrakanth *et al.*, 1998).

It is crucial to note that the number of wells mushroomed from eight to 78 before and after the watershed program and, in addition, more than 97 per cent of them are functioning. That the watershed development program has been able to attract this impressive level of private investment from farmers to drill irrigation wells is in itself a pointer to the positive externalities of the watershed program. This is also *prima facie* evidence of the synergistic effects of watershed treatment to groundwater recharge resulting in positive externalities (refer to table 3).

Table 4. *Details of irrigation well(s) in the Haikal DPAP watershed, Karnataka State, India, April 2000*

Particulars	*Marginal farms*	*Small farms*	*Large farms*	*All farms*
Number of farmers	7 (10.8)	27 (41.5)	31 (47.7)	65 (100)
Total number of wells	7 (7.8)	31 (34.4)	52 (57.8)	90 (100)
Number of functioning wells	7 (8.8)	28 (35)	45 (56.3)	80 (100)
Number of non-functioning wells	0 (0.0)	4 (40)	6 (60)	10 (100)
Total investment on all wells on all farms ($)	7,010 (9.7)	2,593 (35.85)	39,495 (54.5)	72,442 (100)
Investment on well irrigation per farm ($)	1,001 (30)	960 (29)	1,274 (41)	1,078 (100)
Amortized cost of all wells per farm ($)	688 (9.9)	2,519 (36.2)	3,753 (53.9)	6,961 (100)
Amortized cost per well ($)	98 (36.2)	81 (33.1)	72 (30.7)	77 (100)
Amortized cost per functioning well ($)	98	90	83	87
Annual externality cost per well ($)	0	8.7	11	9.6

Notes:
1. Marginal farms: < 2.5 acres; small farms: 2.51 to 5 acres; large farms: > 5.1 acres.
2. As the population of irrigation wells consisted of 65 wells, all have been considered in this study and hence this is a population study.
3. The annual externality cost is taken as the difference between the amortized cost per well and the amortized cost per functioning well.
4. The figures in parentheses indicate percentage of the total.

Distribution of irrigation wells

Considering the population of farmers who possessed irrigation wells in the watershed, 53 per cent belonged to the marginal and small farm category (landholding below 5 acres). Considering the distribution of functioning wells and amortized cost of all wells, 44 per cent of farmers belong to the marginal and small category and 56 per cent belong to the large category. The amortized cost per functioning well is uniform across all classes of farmers ($82). The large farms have an economic advantage, as their proportion of functioning wells is higher than that of other classes.

The negative externality (cost) per well is a modest $9.6. The marginal farms incurred no externality cost, since they did not face failure of irrigation wells. With this low level of externality, the effect of cumulative interference is low. It was indicated by farmers that it was after the Haikal watershed program in 1994 that they began tapping groundwater for irrigation on a relatively larger scale. In the process, farmers faced a modest failure rate (11 per cent) of irrigation wells. This rate of failure is low and is due to the watershed development program contributing to groundwater recharge (table 4).

Table 5. *Distribution of wells and area irrigated and in the Haikal DPAP Watershed, Karnataka, India, April 2000*

	Marginal farmer		*Small farmer*		*Large farmer*	
Type of irrigation well(s)	*No.*	*GIA (acres)*	*No.*	*GIA (acres)*	*No.*	*GIA (acres)*
Bore well	7	34	28	246	41	801
Dug well	0	0	0	0	2	4
Dug-cum-bore well	0	0	0	0	2	2
Total	7		28	246	45	807
Average gross irrigated area per functioning well (acres)	4.85		8.79		17.93	

Note: GIA = gross irrigated area, No. = number.

Distribution of area irrigated

Considering the vintage of functioning wells, 98 per cent were bore wells drilled in the early nineties. About 75 per cent of the gross irrigated area is made up of large farms, 23 per cent small farms and 2 per cent marginal farms. Even though the watershed development program facilitated physical access to the groundwater resource, economic access in terms of gross irrigated area is skewed. The gross irrigated area per functioning well for large farms is 17.93 acres, while that for small farms is 8.79 acres and 4.85 acres for marginal farms. Large farms thus have 4.5 (=18/4) times higher physical access to irrigation and small farms have 2 (=8/4) times higher physical access than marginal farms (table 5).

Assuming that distribution of groundwater use follows the normal distribution, mean plus or minus one times the standard deviation, 66 per cent of farms are included. Accordingly, farmers were classified as those using up to 4.4 acre-inches of groundwater per acre as in 'low water regime', those using between 4.41 and 6 acre-inches as in 'medium water regime' and those using beyond 6.1 acre-inches as in 'high water regime'.

Results indicated that large farms in all the three water use regimes have the largest access to groundwater, ranging from 65 per cent in the last category to 81 per cent in the second category (table 6).

From regression analysis, it was found that well yield has a positive (elastic) influence on the volume of groundwater used, while cost of groundwater exerted a negative (inelastic) influence. The results show that for a 1 per cent increase in groundwater yield per well, the groundwater used per acre increased by 1.48 per cent, while for a 1 per cent increase in cost of groundwater, the groundwater used declined by 0.29 per cent. The distance to water harvesting structures had no significant influence on well yield. About 80 per cent of all the irrigation wells were located within a distance of 800 feet from water harvest structures and a majority of the irrigation wells were recharged (table 7).

Table 6. *Physical access to groundwater for different classes of farmers in the Haikal DPAP watershed, Karnataka, India, April 2000*

	Low water accessibility regime			*Medium water accessibility regime*			*High water accessibility regime*		
Particulars	*MF*	*SF*	*LF*	*MF*	*SF*	*LF*	*MF*	*SF*	*LF*
No of functioning wells	3 (15)	5 (25)	12 (60)	2 (6)	8 (26)	21 (68)	2 (5)	17 (46)	18 (49)
Average depth of the well (feet)	202	220	244	150	153	189	203	134	155
Distance to WHS (feet)	233	383	509	300	371	625	1,300	390	659
Average yield of the well (gallons per hour)	2,013	2,425	2,743	2,227	2,196	2,120	2,080	2,138	2,173
Total water used on all the farms (acres inches)	64 (9)	141 (20)	509 (71)	41 (2)	377 (17)	1,845 (81)	56 (2)	1,020 (33)	2,005 (65)

Notes:
1. Figures in parentheses indicate percentage of the total.
2. MF = marginal farms, SF = small farms, LF = large farms.
(a) Low water accessibility regime is farmers using up to 4.4 acre-inches per acre of irrigated area, Medium water accessibility regime: 4.41 to 6 acre-inches, and High water accessibility regime: > 6 acre-inches.

Table 7. *Dependence of physical access to groundwater in Haikal DPAP watershed, Karnataka, India, April 2000, on irrigation well variables*

Variables	*Coefficients*	*t-statistics*	R^2
Intercept	−7.39	−1.708	0.30
Well depth (feet)	−0.122	−1.352	
Well distance from WHS (feet)	−0.022	−0.69	
Well yield (GPH)	1.479*	2.68	
Cost per acre-inch (dollars)	−0.297	−3.08	

Notes:
1. *Significant at the 1 per cent level.
2. WHS = Water Harvesting Structures, GPH = Gallons per hour.
3. Dependent variable is groundwater used per acre of gross irrigated area (acre-inches).

Cropping pattern

The cropping pattern in the watershed across different groundwater accessibility regimes indicated that of the area devoted to the high value crop (onions), 78 per cent was with farmers of large holdings, the remaining 22 per cent with marginal and small farm haldings. In the medium water accessibility regime, large farms, when compared with marginal and small farms that had the remaining 39 per cent of the area, made up 61 per cent of the area devoted to onions. In the high water accessibility regime, large farms had 76 per cent of the area devoted to the onion crop and the remaining 24 per cent was with marginal and small farms (table 8). In the case of maize, a water intensive and relatively less risky crop, in the low water accessibility group, 33 per cent of the area was with large farms, while 67 per cent was with small farms. In the medium water accessibility regime, similar results are obtained. In the high water accessibility regime, 48 per cent of the area under maize crop is with large farms and the remaining 52 per cent is with marginal and small farms. Considering low water intensive crops (groundnuts, wheat, sunflowers, jasmine), in all the groundwater accessibility regimes, a relatively higher area is with large farms when compared with small farms.

It is, therefore, crucial to recognize that (i) irrespective of the size of holding, in a higher water accessibility regime, all farmers used more water, (ii) net returns per acre are higher for marginal farms than for the other two categories in both the medium and high water accessibility regimes. There is no discernible difference in the crop patterns followed. However, considering the net returns per acre-inch of groundwater, marginal and small farms realized greater net returns per acre-inch of groundwater than large farms. Thus, while farmers with larger holdings have relatively higher access to groundwater, they are not as prudent as marginal and small farm holders who, with similar crop patterns, are relatively more water use efficient than large farm holders.

Similarly, considering the percentage share of the area under irrigated crops, this reflects that most of the groundwater extracted has been for onions. Thus, onions are a relatively high water requirement crop in terms of absolute water extracted and used on the farm (table 9).

A 1 per cent increase in groundwater used for the onion crop indicated that physical access (in terms of total groundwater used on the farm) increased by 0.34 per cent. Thus, the demand for groundwater increased with cultivation of the high value commercial crop. The results were significant at the 1 per cent level with an R^2 of 0.82. Thus, onion crop economics has a signiffcant impact on total groundwater used on the farm (table 10).

Groundwater benefits across different water accessibility regimes

In the 'low water regime', large farms with access to 71 per cent of groundwater and 55 per cent of GIA used 4.4 acre-inches of water per acre and realized 60 per cent of net returns. The shares of marginal and small farms in realizing net returns were 30, 42, and 54 per cent respectively for the three regimes. The net return per acre-inch of groundwater was higher for small and marginal farms compared with large farms. The marginal and small farms using more than 6 acre-inches of groundwater realized 10 per cent of the total net returns with less than 37 per cent of total GIA.

Large farms across all water accessibility groups have a larger share of the total groundwater used on the farm than other groups of farmers. Marginal and small farms using up to 4.4 acre-inches of water per acre realized 40 per cent of the total net returns in this group possessing 45 per cent of the GIA. Marginal and small farms in the second group (using 4.41 to 6 acre-inches)

Table 8. *Cropping patterns across water accessibility regimes in the Haikal DPAP Watershed, Chitradurga District, Karnataka State, India, April 2000 (area in acres)*

	Low water accessibility regime				*Medium water accessibility regime*				*High water accessibility regime*			
Particulars	*MF*	*SF*	*LF*	*Total*	*MF*	*SF*	*LF*	*Total*	*MF*	*SF*	*LF*	*Total*
No of farms	3 (22)	5 (35)	6 (43)	14 (100)	2 (10)	6 (30)	12 (60)	20 (100)	2 (6)	16 (51)	13 (43)	31 (100)
Onions	2 (2)	20 (20)	80 (78)	102 (100)	2 (2)	30 (37)	50 (61)	82 (100)	4 (2)	39 (22)	133 (76)	176 (100)
Maize	0 (0)	10 (67)	5 (33)	15 (100)	0 (0)	10 (67)	5 (33)	15 (100)	4 (9)	18 (43)	20 (48)	42 (100)
Groundnut	2 (5)	15 (41)	20 (54)	37 (100)	4 (8)	10 (20)	35 (71)	49 (100)	2 (3)	12 (21)	44 (76)	58 (100)
Wheat	0 (0)	0 (0)	15 (100)	15 (100)	0 (0)	0 (0)	15 (100)	15 (100)	6 (6)	32 (32)	62 (62)	100 (100)
Sunflower	2 (14)	10 (71)	2 (14)	14 (100)	0 (0)	0 (0)	0 (0)	0 (100)	0 (0)	9 (33)	18 (67)	27 (100)
Jasmine	0 (0)	0 (0)	0 (0)	0 (100)	0 (0)	0 (0)	0 (0)	0 (100)	0 (0)	10 (19)	44 (81)	54 (100)
Chrysanthemum	0 (0)	0 (0)	0 (0)	0 (100)	0 (0)	0 (0)	0 (0)	0 (100)	0 (0)	3 (60)	2 (40)	5 (100)
Tomato	0 (0)	2 (100)	0 (0)	2 (100)	0 (0)	0 (0)	0 (0)	0 (100)	2 (50)	0 (0)	2 (50)	4 (100)
Chillies	0 (0)	0 (0)	0 (0)	0 (100)	0 (0)	0 (0)	0 (0)	0 (100)	0 (0)	0 (0)	2 (100)	2 (100)

Notes:
1. Figures in parentheses indicate percentage of the total.
2. Low water regime = up to 4.4 acre-inches per acre of GIA; medium water regime = 4.41 to 6 acre-inches per acre of GIA; high water regime = > 6 acres inches per acre of GIA; MF = marginal farms; SF = small farms; LF = large farms.

Table 9. *Per cent share of area (acres) under irrigated crops by groundwater accessibility regimes in Haikal DPAP watershed, Karnataka, April 2000*

Particulars	*Low water accessibility regime (acres)*	*Medium water accessibility regime (acres)*	*High water accessibility regime (acres)*	*Total (acres)*
Onions	102 (28)	82 (23)	176 (49)	360
Maize	15 (21)	15 (21)	42 (58)	72
Groundnut	37 (26)	49 (34)	58 (40)	144
Wheat	15 (12)	15 (12)	100 (77)	130
Sunflower	14 (34)	0 (0)	27 (66)	41
Jasmine	0 (0)	0 (0)	54 (100)	54
Chrysanthemum	0 (0)	0 (0)	5 (100)	5
Tomato	2 (33)	0 (0)	4 (67)	6
Chillies	0 (0)	0 (0)	2 (100)	2

Note: Figures in parentheses indicate percentage of the total.

Table 10. *Influence of water used for onion crop on total water used on farm in Haikal DPAP watershed, Karnataka, India, April 2000*

Variables	*Coefficients*	*t-value*	R^2
Intercept	3.156	21.37	0.82
Independent variable:			
Water used for onion crop (acre-inches)*	0.339	8.18	

Notes:
1. Dependent Variable is Logarithm of groundwater used per farm (acre-inches).
2. Independent variable is logarithm of groundwater used for onion crop per farm.
3. *Significant at the 1 per cent level.

realized 64 per cent of the total net return with 37 per cent of GIA. Marginal and small farms in the third group (using more than 6 acre-inches of water per acre) realized 54 per cent of total net return possessing 45 per cent of GIA (table 11 and figure 1).

Economics of groundwater use indicated that marginal farms garnered 40 per cent of the net returns per farm compared with 27 per cent by small, and 33 per cent by large farms respectively in high water regime (figure 1). Further, small farms are relatively as efficient as large farms are as they shared equal amounts of net return per farm ($5,687 for small and $5,682 for large farms (figure 2).

Economic access to groundwater

Economic access to groundwater increased with yield of irrigation well, reduced with the distance of well from water harvesting structures, and increased with the gross irrigated area. This is a pointer to bringing water

Table 11. *Benefits accrued from groundwater usage for irrigation for farmers across different water accessibility regimes in the Haikal DPAP Watershed, Karnataka State, India, April 2000*

	Low water accessibility regime			*Medium water accessibility regime*			*High water accessibility regime*		
Particulars	*MF*	*SF*	*LF*	*MF*	*SF*	*LF*	*MF*	*SF*	*LF*
No of farms	3 (22)	5 (35)	6 (43)	2 (10)	6 (30)	12 (60)	2 (6)	16 (51)	13 (43)
Water used per acre of GIA (acre-inches)	4 (36)	4 (36)	3 (28)	5 (31)	6 (38)	5 (31)	7 (33)	7 (33)	7 (34)
Total water used across all farms (acre-inches)	64 (9)	141 (20)	509 (71)	41 (2)	377 (16)	1,845 (82)	56 (2)	1,020 (33)	2,005 (65)
Gross irrigated area (acres)	6 (19)	8 (26)	17 (55)	4 (9)	10 (23)	27 (64)	4 (11)	9 (26)	22 (63)
GIA per functioning well (acres)	6 (22)	8 (30)	13 (48)	4 (14)	8 (28)	16 (58)	4 (14)	9 (33)	15 (53)
Total net returns across all farms ($)	443	748	2,733	556	2,887	4,456	1,052	5,687	5,682
Net returns per farm ($)	147 (19)	148 (20)	455 (61)	278 (24)	481 (42)	371 (34)	526 (40)	355 (27)	437 (33)
Net returns per acre of GIA	24.6	20	35	69	48	23	131	39	29
Annual net returns per acre-inch of water ($)	7	5.25	5.3	13.5	7.6	2.4	18.7	5.5	2.8
Amortized cost of irrigation per acre-inch ($)	5.2	3.9	1.9	4.8	2.4	1.5	4.6	2.0	1.3
Economic access to groundwater = acre-inch of water used for irrigation per dollar of amortized cost of well	0.190	0.248	0.487	0.204	0.414	0.648	2.135	0.487	0.726

Notes:
1. GIA = gross irrigated area.
2. MF= marginal farms, SF = small farms, LF = large farms.
3. Low water accessibility regime = up to 4.4 acre-inches, medium water accessibility regime = 4.41 to 6 acre-inches, and high water accessibility regime = >6 acre-inches.

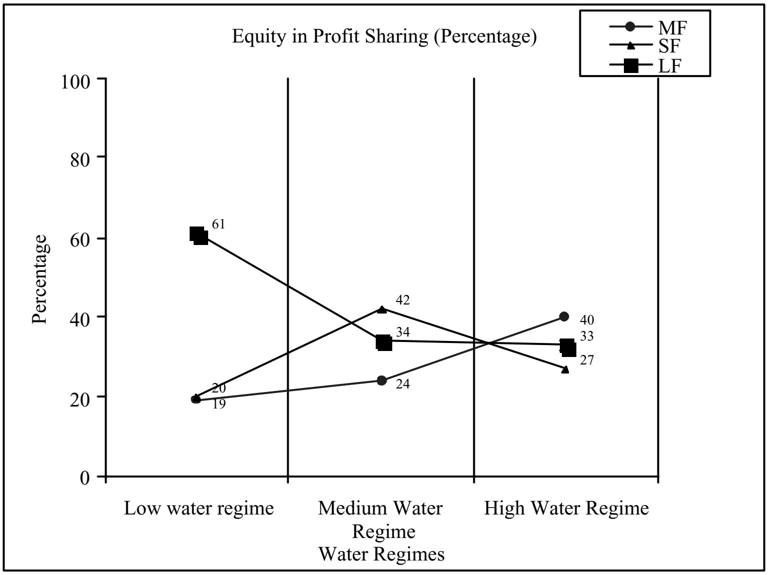

Figure 1. *Equity in profit sharing (percentage) across farms and water accessibility regimes.*
Note: MF = marginal farms; SF = small farms; LF = large farms.

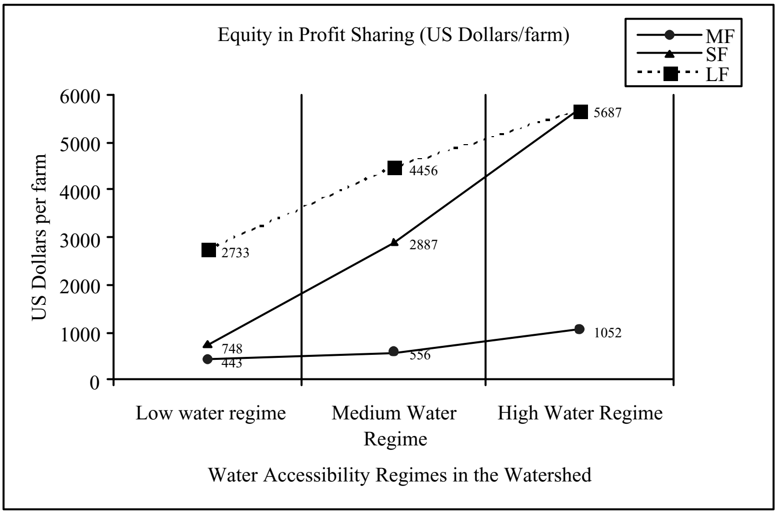

Figure 2. *Equity in profit sharing (US Dollars/farm) across farms and water accessibility regimes.*
Note: MF = marginal farms; SF = small farms; LF = large farms.

Table 12. *Dependence of economic access to groundwater on well variables in the Haikal DPAP Watershed, Karnataka, India, April 2000*

Variables	*Coefficients*	*t-statistics*	R^2
Intercept	−9.52	−2.38	0.53
Well yield (GPH)	0.51	0.98	
Well distance from WHS (feet)	−0.041	−1.37	
Gross irrigated area (acres)	0.35*	7.81	

Notes:
1. * Significant at the 1 per cent level.
2. GPH = gallons per hour, WHS = water harvesting structures.
3. Dependent variable = natural logarithm of (1/cost per acre-inch of water).

Table 13. *Dependence of net returns per farm on water and labour variables in the Haikal DPAP Watershed, Karnataka, India, April 2000*

Variables	*Coefficients*	*t-statistics*	R^2
Intercept	10.92	4.53	0.71
Cost per acre-inch of water (dollars)	−0.72*	−1.95	
Water used on the farm (acre-inches)	0.53*	2.24	
Labour on the farm (man days)	0.37*	2.90	

Notes:
1. *Significant at the 1 per cent level.
2. WHS = water harvesting structures.
3. Dependent variable: log of (1/cost per acre-inch of water).

use efficiency through adoption of water saving technologies and thereby expands the area under irrigation. For a 1 per cent increase in well yield, the economic access increased by 0.51 per cent. For a 1 per cent increase in the gross irrigated area, economic access increased by 0.35 per cent. For a 1 per cent increase in well distance from the water harvest structures, economic access to groundwater reduced, but this effect is not significant. The R^2 is 0.53 (table 12).

The net return per farm is regressed on the amortized cost per acre-inch of irrigation, volume of groundwater used, and labour used. Net returns up to \$1,134.65 (Rs. 55,314) (anti-log of intercept value) are influenced by factors such as land, capital, and other inputs not considered in the regression. For a 1 per cent increase in groundwater used, net return increased by 0.53 per cent. For a 1 per cent increase in cost per acre-inch of groundwater, net return reduced by 0.72 per cent, both being inelastic (table 13). This lends support to previous findings that (in areas where negative externalities due to groundwater overdraft are not apparent) the main variable affecting net revenue in a farming system is the pumping cost (Kelso, 1961).

Considering total groundwater used on the farm, marginal and small farms together used 50 acre-inches when compared with 141 acre-inches used by large farms. This is obvious as large farms have higher gross

Table 14. *Statistical significance of groundwater benefits for Haikal DPAP Watershed, April 2000, Karnataka, India*

	Mean		*Standard deviation*		
Particulars	*Marginal and small farms*	*Large farms*	*Marginal and small farms*	*Large farms*	*t-value*
Total water used on the farm (acre-inches)	50	141	22.38	110.46	4.55**
Net returns per farm ($)	2,741.78	8, 054.48	2,187.15	5, 648.45	5.08**
Net returns per acre of gross irrigated area ($)	334.31	415.24	212.	02169.35	1.70*
Net returns per acre-inch of water ($)	51.95	61.16	30.33	32.20	1.13
Cost per acre-inch of water ($)	3.69	2.44	1.43	0.70	4.61**

Notes:
1. **Significant at the 1 per cent level.
2. *Significance at the 5 per cent level.

irrigated area as demonstrated earlier. The net return per farm is almost three times higher ($8,054.48) for large farms than their counterparts ($2,741.78). The cost of groundwater per acre-inch is one and a half times higher for small farms compared to large farms. The results are statistically significant (table 14).

Concluding remarks

Watershed impact on farm economy is apparent, as most of the irrigation wells drilled after the watershed development program are functioning. This was even evident during the field visit, as farmers had positive attitudes toward drilling new well(s) due to the watershed program. Further, the amortized cost of groundwater here is lower ($2.42) compared with $51.46 per acre-inch of groundwater in non-watershed area in Shimoga district in the southern State of Karnataka (Basavaraj, 1998). Large farms by virtue of their larger gross irrigated area are reaping a larger proportion of the net returns, compared with marginal and small farms. The well failure rate is a meagre 11 per cent when compared with the corresponding failure rate of 40 per cent in eastern dry zone of Karnataka state. About 56 per cent of the beneficiaries belong to marginal and small farms.

Watershed treatment has enhanced groundwater availability through groundwater recharge with positive spillovers by (i) reducing the cost of groundwater used for irrigation; (ii) reducing negative economic externalities due to well interference; (iii) increasing physical access (water used per acre of gross irrigated area) to groundwater resource for irrigation through groundwater recharge. In all the three-groundwater accessibility regimes, the large farms by virtue of their larger gross irrigated area garnered a larger proportion of the net returns. The watershed program facilitated cultivation of high value crops (such as onions) by those farmers who were cultivating low value crops before the watershed program, thereby improving their economic position.

Thus, the watershed development program is a means to reduce the negative externalities due to frequent well failure in dryland areas. The watershed development program with the objective of groundwater recharge is a viable policy option for the development of dryland areas. Such programs must be embedded in the National Water Policy to ensure effective and equitable implementation in the needy regions of India. Nevertheless, farmers need to be cautious regarding judicious use of groundwater, since they need to respect the needs of all farmers who have the right to tap and use groundwater but are precluded due to low economic access. Therefore, there is a need for a blend of policies to focus on (i) allocation of groundwater on annual/season/crop basis; (ii) regulating extraction through permissible annual extraction, through water metering; (iii) restriction on number of wells drilled on the farm; (iv) provision of sale of water entitlements when it is surplus to a needy neighbouring farm; and (v) promotion of groundwater markets. Nevertheless, farmers need to take collective action to maintain the water harvesting structures to enhance the sustainable recharge of the aquifer.

However, it is to be considered that the proposed policy instruments for managing groundwater depend on the allocation of rights for extraction. Finally, even though private net returns are economically viable in the watershed, the groundwater is still underpriced, not reflecting the true value. This implies that farmers maximize private net benefits and pump water until its marginal net benefit is zero (Hellegers and van Ierland, 2003). Hence, we suggest considering pro-rate charging of electricity. Other scholars have expressed similar views (Diwakara and Nagaraj, 2003; Shah, 1993; Moench, 1996, Nagaraj *et al.*, 1999).

References

Acharya, G. and D. Barbier (2002), 'Using domestic water analysis to value groundwater recharge in the Hadejia-Jama' area floodplain, Northern Nigeria', *American Journal of Agricultural Economics* **84**: 415–426.

Basavaraj, G. (1998), 'Groundwater scarcity and coping strategies in Channagiri Taluk of Shimoga District – an economic analysis', unpublished M.Sc. thesis, Department of Agricultural Economics, University of Agricultural Sciences, GKVK, Bangalore, India.

Central Water Commission (2000), 'Water and related statistics', Information Systems Organization, Water Planning and Project Wing, Central Water Commission, New Delhi, India.

Chandrakanth, M.G., S. Adhya, and K.K. Ananda (1998). 'Scarcity of groundwater for irrigation: economics of coping mechanisms in hard rock areas', Monograph, Department of Agricultural Economics, University of Agricultural Sciences, GKVK, Bangalore, India.

Chandrakanth, M.G. and V. Arun (1997), 'Externalities in groundwater irrigation in hard rock areas', *Indian Journal of Agricultural Economics* **52**: 761–771.

Chandrakanth, M.G. and H. Diwakara (2001), 'Synergistic effects of watershed treatments on farm economy through groundwater recharge – a resource economic analysis', Monograph, Department of Agricultural Economics, University of Agricultural Sciences, Bangalore, India.

Chandrakanth, M.G. and J. Romm (1990), 'Groundwater depletion in India – institutional management regimes', *Natural Resources Journal* **30**: 485–501.

Chandrakanth, M.G., B. Shivakumaraswamy, K.M. Sathisha, G. Basavaraj, S. Adya, M.S. Shyamasundar, and K.K. Ananda (2001), 'Paying capacity of farmers considering cost of groundwater and electricity in Karnataka', Paper presented to Karnataka Electricity Regulation Commission, 20 and 21 August 2001, Bangalore.

Coase, R.H. (1937), 'The nature of the firm', *Economica* **4**: 386–405.

Coase, R.H. (1946), 'The marginal cost controversy', *Econometrica* **13**: 169–182.

Coase, R.H. (1970), 'The theory of public utility pricing and its application', *The Bell Journal of Economics and Management Science* **1**: 113–128.

Dasgupta, P. (1982), *The Control of Resources*, Cambridge University Press.

Diwakara, H. and M.G. Chandrakanth (2003), 'Impact of watershed treatments on farm economy through groundwater recharge: resource economic analysis in peninsular India', Poster presented to the XI World Water Congress held in Madrid, Spain, 5–9 October 2003.

Diwakara, H. and N. Nagaraj (2003), 'Emerging informal groundwater markets in peninsular India and its impact on local food security and employment', *Journal of Social and Economic Development* **5**: 95–105.

Eswaran, M. and T. Lewis (1984), 'Appropriability and the extraction of a common property resource', *Economica* **51**: 393–400.

Gisser, M. (1983), 'Groundwater: focusing on the real issue', *Journal of Political Economy* **91**: 1001–1027.

Gisser, M. and A. Mercado (1973), 'Economic aspects of groundwater resources and replacement flows in semiarid agricultural areas', *American Journal of Agricultural Economics* **55**: 461–466.

Gisser, M. and D.A. Sanchez (1980), 'Competition versus optimal control in groundwater pumping', *Water Resources Research* **16**: 638–642.

Gollier, C. (2002), 'Discounting an uncertain future', *Journal of Public Economics* **85**: 149–166.

Groom, B., P. Koundouri, and T. Swanson (2003), 'The watershed economics management approach: an application to Cyprus', in P. Koundouri, P. Pashardes, T. Swanson, and A. Xepapadeas (eds), *Economics of Water Management in Developing Countries: Problems, Principles and Policies*, Edward Elgar Publishers, pp. 181–214.

Groom, B. and T. Swanson (2003), 'Missing markets and redundant reservoirs: dams as a consequence of inefficient groundwater management policies', *Environmental and Resource Economics* **26**: 125–144.

Hardin, G. (1968), 'The tragedy of the commons', *Science* **162**: 1243–1248.

Hellegers, P. and E. van Ierland (2003), 'Policy instruments for groundwater management in the Netherlands', *Environmental and Resource Economics* **26**: 163–172.

International Water Management Institute (2003), 'The socio-ecology of groundwater in India', Recent Research, Colombo, Sri Lanka.

Kelso, M.M. (1961), 'The stock resource value of water', *Journal of Farm Economics* **43**: 1112–1129.

Koundouri, P. (2004), 'Current issues in the economics of groundwater resource management', *Journal of Economic Surveys* **18**: 703–740.

Lind, R.C. (1997), 'Intertemporal equity, discounting, and economic efficiency in water policy evaluation', *Climatic Change* **37**: 41–62.

Moench, M. (1996), 'Groundwater policy: issues and alternatives in India', IIMI Country Paper, India, No. 2, Colombo, IIMI.

Mysore State Gazetteer (1967). 'Chitradurga district', in B.N. Sathyan (ed.), *Mysore State Gazetteer: Chitradurga District*, The Director of Printing and Stationery, and Publications at the Government Press, Bangalore.

Nagaraj, N., M.G. Chandrakanth, and Gurumurthy (1994), 'Bore well failure in drought prone areas of southern India – a case study', *Indian Journal of Agricultural Economics* **49**:101–106.

Nagaraj, N., W. Marshall, and R.K. Sampath (1999), 'Groundwater institutions in US and India: sustainable and equitable resource use', *Economic and Political Weekly* **34**: A93–A104.

Newell, R.G. and W.A. Pizer (2003), 'Discounting the distant future: how much do uncertain rates increase valuations?', *Journal of Environmental Economics and Management* **46**: 52–71.

Ninan, K. (1997), 'Economic benefits of watershed based dryland development programs in india', in A. Agarwal (ed.), *The Challenge of Balance Environmental Economics in India*, New Dehli: Centre for Science and Environment.

Pearce, D., B. Groom, C. Hepburn, and P. Koundouri (2003), 'Valuing the future: recent advances in social discounting', *World Economics* **4**: 121–141.

Provencher, B. and O. Burt (1993), 'The externalities associated with common property exploitation of groundwater', *Journal of Environmental Economics and Management* **24**: 139–158.

Provencher, B. and O. Burt (1994a), 'A private property rights regime for the commons: the case of groundwater', *American Journal of Agricultural Economics* **76**: 875–888.

Provencher, B. and O. Burt (1994b), 'Conjunctive-use of surface water and groundwater', in D. W. Bromley (ed.), *The Handbook of Environmental Economics*, pp. 503–521.

Sastry, K.N.R. (1997), 'Development of natural resources: a solution of environmental problems', in A. Agarwal (ed.), *The Challenge of Balance Environmental Economics in India*, New Dehli: Centre for Science and Environment.

Shah, F.A., D. Zilberman, and U. Chakravorty (1995), 'Technology adoption in the presence of an exhaustible resource: the case of groundwater extraction', *American Journal of Agricultural Economics* **77**: 291–299.

Shah, A.T. (1993), *The Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*, Bombay: Oxford University Press.

Tuinhof, A., F. Attia, and J.E. Saaf (2003), 'Major trends in groundwater development opportunities for public–private partnership', *International Journal of Water Resources Development* **19**: 203–219.

Weitzman, M.L. (1998), 'Why the far-distant future should be discounted at its lowest possible rate', *Journal of Environmental Economics and Management* **36**: 201–208.

Young, R.A., J.T. Daubert, and H.J. Morel-Seytoux (1986), 'Evaluating institutional alternatives for managing an interrelated stream-aquifer system', *American Journal of Agricultural Economics* **68**: 787–797.