A Comparative Study of Groundwater Institutions in the Western United States and Peninsular India for Sustainable and Equitable Resource Use.

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Introduction

Groundwater has contributed significantly to the development of Indian agriculture particularly during the last four decades. It has been responsible for attaining food security through green revolution, commercialization of farming and promoting equity. Its exploitation in India is largely in the hands of private individuals and its development has grown exponentially over the years. The introduction of short duration, high -yielding crops along with intensive application of fertilizers, pesticides and mechanization enabled farmers to adopt multiple cropping practices that increased cropping and irrigation intensity substantially. Further, the advantages of groundwater irrigation coupled with favorable government policies and market forces induced farmers to intensify well irrigation and convert vast dryland areas to water intensive commercial crops. Thus the demand for groundwater increased remarkably.

The traditional open-wells ability to cope with the increased demand for groundwater virtually crumbled. Hence, with the introduction of better techniques of groundwater exploration and extraction there has been a shift from traditional labor intensive dug-wells to the modern capital intensive bore-wells. The rate of growth of shallow and deep tube wells during 1980s were 7.2 and 5.3 percent as against a meagre 1.8 percent for dug-wells. In 1950 there were 3.86 million dug-wells and 3 thousand deep tube-wells. In a span of 4 decades, as many as 10.2 million dug-wells, 5.4 million private tube-wells and 60 thousand deep tube-wells were in operation in the country. This rapid expansion reflects the increasing signs of over-development of well irrigation and large-scale extraction of groundwater leading to overdraft. Additionally, it has also been recognized that groundwater quality has been degraded due to leaching of fertilizers and chemicals posing an environmental and public health concern to the many rural communities who subsist on this resource. Again after1990 due to liberalization policies, farmers started producing commercial products for exports, which are highly groundwater based. Since the payoffs from the production of high value crops have been impressive, it has driven to a constant race for further investments on new wells, deepening the existing wells in order to extract more water and produce more for the markets. Thus, overcrowding of wells and indiscriminate pumping of groundwater by a large majority of well owners in some regions in India, has led to much faster rate of depletion of groundwater than the recharge rate resulting in drastic fall in water tables, well interference, failure of dug-wells, dug-cum-bore-wells and shallow tube wells and subsequent loss of investments. This has created a chaotic situation especially in the water scarce hard-rock regions, where there is no assured source of surface irrigation and rainfall is ill distributed. Since groundwater forms a vital base for increasing agricultural productivity and production for a large majority of rural population its overexploitation poses three important inter-linked issues viz., sustainability, efficiency and equity.

Peninsular India

A large number of groundwater irrigation wells are concentrated in the peninsular India (hard-rock area) where the recharge potential is extremely low. About two thirds of the geographical area of India is composed of hard rock formation lacking primary porosity. Currently the groundwater resource for irrigation is facing the threat of overexploitation in this region. Though the Government of India hinted at a regulation of groundwater through groundwater law on several occasions, concerted efforts have not been forthcoming for several economic and political reasons. In addition, the markets have failed to correct the existing distortions in groundwater irrigation. Hence it is imperative to manage the resource by devising institutional and market mechanisms to foster sustainable and equitable use. Ciracy-Wantrup (1969), emphasizes that when groundwater use by farmers affects their neighbors by pumping cone and seasonal depletion due to use of modern deep well pumps, appropriate institutions such as water rights water districts, water markets, public agencies and voluntary organizations engaged in building maintaining and operating facilities are necessary to manage it.

In India, as well as in most of the developing countries the lack of groundwater institutions has led to intergenerational, inter-temporal and inter-spatial misallocation and serious overdraft situation creating several externalities, which are pervasive. Thus there is a dire need now for new types of information on both resource availability extraction and use and new institutional approaches to deal with the current and emerging problems of groundwater more effectively.

Of late in most of the countries the groundwater depletion and quality impairment have become major issues. These problems have been addressed by a combination of market and non-market institutional approaches. In this endeavor, the Western U.S. has been a forerunner to initiate a variety of institutional approaches to tackle the groundwater management problems. In this regard it is pertinent to note certain parallels of the Western U.S. with India, before examining these management approaches for their feasibility.

Some similarities with the Western USA

Groundwater development throughout much of the western U.S. occurred several decades before the main burst of development activity in India. Many of the social, physical and institutional issues beginning to emerge in India have been major topics of debate in the western U.S. over the past few decades (Moench, 1992). The groundwater depletion is evident in most of the western U.S. followed by water quality impairment due to widespread use of chemicals as in the case of India. In Western U.S. there is a rural-urban competition for use of groundwater, as urban demands are enormously raising. In India there is a similar competition between agriculture and rural drinking water supply schemes. Currently this problem is being effectively addressed in some areas through appropriate institutional policy instruments like correlative rights to reasonable water use doctrine of prior appropriation and issue of permits for extraction of groundwater. Further various approaches such as legal structures, local user groups and negotiation between interest groups exist in Western U.S. These approaches have achieved some degree of success in containing the problems of over-mining. Thus this study focuses on an examination of the relevance and socioeconomic and political feasibility of management approaches of the western U.S. to the field situation in the peninsular Indian context.

Structure of the study

The first part of this study focuses on the sustainability and equity issues involved in groundwater development of hard-rock areas, along with a discussion on the existing institutional management scenario. This then is followed by an examination of various groundwater management approaches in the Western U.S. The final section deals with the policy lessons learned for the Indian situation from the Western U.S. experience in managing groundwater.

Sustainability issues

When there is mining of groundwater beyond the natural rates of recuperation it would lead to unsustainability of the resource in the long run. There are several measures, which can reflect whether the groundwater development and use is tending towards sustainability or unsutainability. We discuss these measures in the three different phases of groundwater development scenario that occurred in the Karnataka State, which is a typical hard-rock belt in peninsular India (table-1).

First phase of well irrigation development

The sprawl of well irrigation began in the 1950s in Peninsular India. The Karnataka State has witnessed three distinct phases in the growth of groundwater development. The first phase of groundwater extraction was dominated by traditional dug-wells with a depth of 25-30 ft and a diameter of 25 ft depth, till the mid 1960s. Historically, traditional labor intensive water lifting devices like “persian wheel” and other labor-intensive devices were used prior to mid 1960s. These devices formed around 62 percent of all irrigation devices in 1960s (Chandrakanth and Romm, 1992). There was conjunctive use of groundwater with tank water during this period implying hydrological nexus between well irrigation and tank irrigation. The cropping pattern was in consonance with well productivity. Though there was some seasonal and secular overdraft due to low rainfall, the depletion problem was not pronounced. The depth of available water over time in wells was subjected to minimum fluctuations as the demand and supply was matching

and dug-wells were functioning for a longer span. Moreover, the distance between well to well were beyond the hydrological threshold limits of 600 ft. Another striking feature with regard to distribution pattern of the wells was that most of the wells was located nearby water bodies, which use to recharge the wells. The water quality was also not a problem as farmers used less quantum of chemical fertilisers and pesticides.
Some of the measures reflecting the sustainable use of groundwater during this phase include depth of availability of water over time, the use of traditional lifts for extraction of water that is within the recharge capacity of the wells, spacing of the wells and cropping pattern. Thus this phase was marked by more stable and sustainable use of groundwater, as there was an overall balance between extraction and recharge.

Second phase of well irrigation development

The second phase between 1970 and 1980 was characterized by the predominance and growth of the use of dug-cum-bore-wells. In the early 1970s farmers were drilling one or more bore wells inside their dug-wells (dug-cum-bore well). The in bores had a depth ranging from 45 to100 feet and centrifugal pump was the major mode of extraction. The water yield of the dug-cum-bore-wells was higher compared to dug-well yield; hence farmers brought more area under groundwater irrigation. During this period there was a gradual shift in the cropping pattern from food to commercial crops, which are hydrophilic demanding more water. Since, farmers were using centrifugal pumps they started pumping more water to meet the increased demand, without regard to the recharge capabilities of wells. This caused recurring shortfall of water in the wells for the assured crop production. Further, to augment more water yield in the dug-wells they ventured on multiple bore-wells with in the dug-wells involving additional investments and increased extraction cost as farmers were paying electricity charges based on pro-rata. Thus, as compared to dug-wells, the dug-cum-bore wells served for a shorter period, the depth to water table increased over time, extraction rates were more than recharge rates causing draw down of water in the wells. These changes leaned towards unsustainable development of the resource. With a marked shift in the cropping pattern from food crops to commercial water intensive crops, the demand for ground water escalated sharply. The dug-cum-bore-wells capacity to meet increased demand for groundwater reduced. This forced farmers to venture further in exploring groundwater through deeper fractures of the aquifer by means of deeper surface bore-wells. Since the nationalization of commercial banks in 1969, agricultural sector has been considered as a priority sector and hence received liberal credit incentives for well drilling and for crops, which are groundwater dependent. As a result the institutional credit for well irrigation increased many folds in the state. Thus, access to institutional finance has largely been responsible for a rapid spurt in the wells all over the state. With the gain of well irrigation, the dependence on tank irrigation has considerably reduced. In addition the irrigation tanks have also become unreliable source of water supply due to siltation and poor management causing further pressure on groundwater development.

Table: 1. Profile of well developments in a typical hard-rock area of peninsular India during 1950-90s

Type of well	Depth (ft)	No. of years served	Invest. at historical prices (Rs)	% of area under food crops	Yield of the well (g/h)	Inter well spacing	Gross area irrigated (acres)
Dug-well (1950-70)	40-50	15-20	23,000	80-85	600-900	900	3-5
Dug-cum-borewell (1970-80)	45-100	5-7	4000-7500	55-60	600-1000	-	4-6
Bore wells (1980-90)	300-450	8	50,000-70,000	27-40	1700-2000	260-300 200-300	4-10
(1990’s)	>450	7-8	>60,000	25-30	1000-1500		2-5

Source: Nagaraj, 1994

Third phase of well irrigation development

Thus the third phase began from the early1980s with surface bore wells with a diameter of 6 inches and a depth of 300-450 ft. Compared to dug-wells and dug-cum-bore-wells, the surface bore-wells yielded more water and the extraction mechanism shifted towards submersible pump-sets of high capacity up to 10 HP. Thus, with the introduction of modern extraction mechanisms, the groundwater extraction scenario has drastically altered. Further, during this period government completely subsidized electricity to the agricultural pump-sets, as a result the marginal extraction cost became zero. This acted as a strong incentive to go for more number of wells and draw more volume of water instantaneously for meeting the increased demand of the commercial agriculture. The bore-wells constructed after 1980s virtually spread all over without consideration to isolation distance and water bodies. This is also one of the reasons for well-interference and high degree of well failures. The share of less water intensive food crops dropped drastically. The high value water-intensive crops like vegetables, flowers, fruit crops, cereals, sugarcane have been gained.

After the emergence of surface bore-wells, the dug-wells and dug-cum-bore-wells became virtually infructuous. The scale of investments on deep bore-wells went on enormously and increased manifold. The repairs and maintenance cost of irrigation pump-sets was also considerable because of increased depth to water. As compared to the dug-wells the productive life span of the bore-wells has fallen by three times. In the beginning though the yield of wells and the gross area irrigated per well was high but latter on, gradually water yield in the wells declined leading to increased investment on coping mechanisms like the drip irrigation system and storage structures indicating economic scarcity of groundwater. The rapid changes witnessed over a span of 4 decades in groundwater irrigation sector include increasing depth of wells, failure of all three types of wells namely dug, and dug-cum-bore-wells, bore-wells, disappearance of traditional lifts, high density of wells per unit area without regard to spacing norms, increased irrigated area under commercial crops, increased investments on well improvements and coping mechanisms, increased extraction cost, reduced well yields, reduced gross area under irrigation and shift to dryland agriculture in some cases. Thus the lack of sustainability is evident from the above indicators in groundwater irrigation.

Tracing the development paths in well irrigation it has been evident that the open wells served for a longer period ensuring sustainability till early1980s. The changes witnessed thereafter indicate that three has been constant chasing of groundwater with rapid strides in technology of well drilling, access to credit and free electricity. The failure of dug-wells, shift to high water using high value crops and favorable policy instruments promoted rapid groundwater depletion affecting sustainability. In the process, the intensive groundwater development for agriculture purposes has severely hampered the needs of other sections like domestic, industrial and environment.

Further, some of the macro level indicators also show the unsustainable pattern of groundwater development in the state. According to the 1987 census of irrigation wells in the state, more than 90 % of the wells have a depth of below 60 meters. Further, more than 60 % of the bore-wells yield below 1000 gallons per hour. In hard-rock areas the recuperation time to regain the water level after pumping is considerable hence the use of 3 HP pump is recommended. On the contrary more than 50 % of the electrical pump-sets have 4-5 HP. According to the National Bank for Agriculture and Rural Development the minimum yield of groundwater should be 5000 gallons per hour for economic viability of the well. Thus 60 percent of the wells are not economically viable based on the definition of NABARD. The number of irrigation wells in the state increased from 1.35 lakhs in 1960 to around 5.1 lakhs in 1984-85 on to around 9 lakhs by 1993, registering a compound growth rate of 6 percent. The net area irrigated from wells increased from 4.6 lakhs hectares in 1970 to 7.2 lakhs hectares by 1993, registering a compound growth rate of 2 %. In terms of quantity, between 1971 to 1991 the groundwater utilisation has increased three folds from 200,000-hectare meters to 600,000- hectare meters. Over the years the well density has been increasing in the state. During 1950-1970s there was one well per 100 acres of cultivated area and it has increased sharply to 5 wells per 100 acres of cultivated area during 1990-97. The water table dropped from 25 ft below the surface to 160 ft in different parts of karnataka between 1946 to 1986. Thus, the pattern of well irrigation development at macro level paints a disturbing trend showing clearly the unsustainable nature of development over a period of time.

According to the Brundtland Commission report (1987) sustainable development is defined as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs". Based on this definition one may conclude that groundwater development that took place in India during the last few decades does not meet the criteria of sustainability of even needs of the present generation itself.

Sustainability issues are directly related to the extraction and recharge rates of groundwater. When the rate of recharge is greater than or equal to the rate of extraction then, sustainability is not an issue at all since the water table is not affected; but when the rate of extraction exceeds the rate of recharge over a period of time that would overdraft resulting in lowering water table with environmental implications. In this situation sustainability is a major issue. In the coming decades the sustainability issues in groundwater development and its use are going to assume greater importance. The important questions that arise are:

Given the current rate of growth in population, income, other sectoral growth in the demand for water, environmental and ecological needs whether we will be able to realise the needed groundwater development and use without change in the improvement of technology of utilisation?

Answering this question involves looking in to the following aspects of the groundwater development and utilisation with implications for efficiency, equity and sustainability.

1. The current status of over-extraction rate of groundwater in relation to the recharge rate and the techno-economic feasibilities of compensating for the over-extraction rate by either artificial groundwater recharging through harvesting the excess run-off of surface water during the rainfall season or by storing through tanks that could be used as a supplementary irrigation so as to maintain the level of groundwater

extraction to the rate of recharge. There are several intricate issues involved here with socio-economic-institutional-legal aspects.

2. If one is only partially feasible or totally infeasible, then one has to look in to reducing the level of extraction by
   a. Simply reducing the level of irrigated area gross or net or
   b. Changing the cropping pattern so that the amount of irrigation water required matches the recharge rate or
   c. By introducing irrigation technologies that would increase water use efficiency or reduce the demand for water or
   d. By introducing economic instruments such as pricing of electricity, water or increasing the interest rate for well loans
   e. Government interventions in the form of property rights, laws etc.

Thus the challenges of growing water scarcity could be addressed through demand and supply interventions. The demand side interventions include diversion of crop pattern towards less water intensive crops, improving conveyance and irrigation efficiency through the use of water conservation technologies and pricing of electricity to reflect the marginal extraction cost. Similarly the supply side interventions include recharging of aquifers through water harvesting technologies, promoting conjunctive use of ground and surface water along with inter-basin transfer.

One of the most important problems pertaining to water use is that much water is being wasted in existing irrigation practices leading to gross irrigation inefficiencies.

In hard-rock area most of the groundwater irrigators are in a dilemma whether to invest in more efficient water distribution systems with greater application efficiency or to remain with the existing systems of conventional irrigation system because of uncertainty in water yields of their wells and huge initial capital investment. However, some of the farmers are managing the scarce groundwater by adopting drip irrigation system and thus reducing inefficiency in water use. We discuss below some of the sources of inefficiencies in groundwater irrigation and possible potentialities to reduce the same.

Efficiency and conservation

Water use efficiency assumes a greater importance when there is growing scarcity of water. This factor is particularly very important in the hard-rock aquifers where the return flow from the use is not adding to the recharge due to the peculiar geo-morphological nature of the aquifers. When water is put to most efficient use it would result in not only reduction in wastage of water but also amounts to phenomenal savings that could be used for further expansion of area under irrigation. The most important instruments that could ensure water use efficiency is pricing of the resource reflecting its marginal extraction cost that induces the use of efficient irrigation technologies.

In the state about 98 percent of all the irrigation pump-sets are below 10 HP capacity. Moreover, farmers were required to pay electricity to pump groundwater at a fixed rate based on pump horsepower (HP); but after1982, even the flat rate was eliminated for pump-sets up to 10 HP. Thus the marginal extraction cost of pumping is almost zero leading to inefficient use of critical resource. Moreover, irrigation is through open channels; hence there would be substantial amount of evaporation and percolation loses leading to low irrigation efficiency.

In response to low yield of water in bore-wells and the problems of erratic and inadequate power supply to the agricultural pump-sets, the irrigators have devised some coping mechanisms. Most large farmers have installed automatic starters, which eased the drudgery of frequently monitoring of switching “on and off” operations. They have also constructed earthen storage structures or small ponds on elevated area to store water. When power is available farmers pump water to the over-ground pond and irrigate by gravity later on. This practice has also been due to the fact that the discharge from some of the bore-wells is so low that it is not viable to irrigate continuously unless the pumped water is stored. But due to this operation there has been loss of water by evaporation, seepage and percolation resulting in water use inefficiency (Nagaraj, 1994).

The adoption of efficient technologies like drip and sprinkler irrigation would substantially contribute to the conservation and thereby productive life of wells can be extended. This also avoids further investment on new wells due to failures of existing wells. Thus the investments on drips and sprinklers are compensatory for by new disinvestment in wells and other conservation measures. Table 3, below gives the amount of water that could be saved by resorting to drip irrigation.

Table: 2 Estimated benefits of using drip irrigation system in Eastern Dry Zone of Karnataka, India

Crop	Investment per acre on drip	Amount of water used in drip/acre (lakh gallons)	Water applied in conventional method (lakh gallons)	Percentage of water saved	Net returns per rupee of investment
Mulberry	30,000	4.0	7.1	43	2.5
Grapes	22,000	5.1	8.2	38	3.5
Coconut	12,000	3.6	5.9	39	3.0
Sapota	8000	3.0	5.8	48	2.75

Source: Based on the case studies of drip owners during 1986-87 in Eastern Dry Zone of Karnataka, India.

In the recent years, the demand for drip irrigation system is increasing for perennial crops like mulberry, grapes, coconut and sapota due to acute scarcity of groundwater. In response to scarcity of groundwater farmers need to reconcile between investment on an additional well or on water conservation technologies such as the drip system.

Considering the huge initial investment on an additional well, it will be better to invest on efficient irrigation technologies, which promote more efficient use of available groundwater. Despite the substantial benefits on account of adoption of irrigation efficient technologies there has not been drastic shift from conventional to efficient technologies because of small- holdings, huge investment and nature of crops grown which require intensive cultivation with frequent disturbance of soil. Thus to promote use efficiency the resource should be priced to reflect the extraction cost along with subsidizing irrigation efficient technologies to adopt on a large scale. Highly subsidized extraction costs, designed to promote equity, also discourages use efficiency and thereby sustainability. Thus there is a basic conflict between measures designed to provide incentives for efficient use and equity (Moench, 1991).

Thus in the future with respect to achieving a sustainable and equitable groundwater use in hard-rock regions seems to be very bleak; given the unregulated and current rate of overexploitation of aquifers, input intensive nature of commercial agriculture population pressure, increasing demand on land and water to improve more productivity and increasing demands for high value agricultural products.

Equity

In a welfare state equitable distribution of costs and benefits across all groups of population is of primary consideration in any developmental project. Hence there are several policies and programs aimed at achieving equity in well irrigation development. Some of these policies include subsidized power and loans, investment on community wells and promotion of water markets. Albeit these policies there is a large difference between small and large farms in access to groundwater resource mainly because of huge capital investments involved and the presence of skewed distribution of land holdings. Thus the distortions in groundwater use has been seemingly apparent. Such distortions in bore-well irrigation are three fold: 1) water access inequity leading to disparities in income distribution 2) differential impacts of well failures on farm incomes and 3) distortions due to the use of conservation measures by large farmers. These factors have constrained the access to groundwater for poor farmers who constitute 67 % of the total holdings operating 27 % of the cultivated area in Karnataka State. The creamy sections with better access to institutional finance and size of holding, are able to invest on groundwater development, deepening the existing wells and drilling additional wells. Though the increase in the number of wells over time and space may imply wider access

to the well irrigation, the amount of resource needed to own a bore-well and a pump are beyond the reach of small and marginal farmers. Thus resulting in skewed distribution of ownership of wells once again benefiting the creamy sections and exacerbating the problems of inequity.
In one of the studies in Peninsular India, it has been reported that the large farmers accounted for about 83, 74 and 92 % of dug-wells, dug-cum-bore-well, and bore-wells respectively. Contrary to this, small farmers as group owned around 17 % of all types of groundwater structures. This disparity in ownership is attributed to high cost of well technology. This clearly reflects the small farmers limited access to groundwater irrigation as compared to large farmers (Sathya Sai, 1998).

The probability of getting a successful well in hard-rock area of peninsular India is very low, rendering groundwater exploitation not only capital intensive but also risky (Nagaraj, 1995). Risk of capital loss from well failure deters poor resource base farmers to invest. Further, with the depletion of groundwater table, resource rich farmers invested huge capital in deepening and drilling additional wells, installed expensive high capacity submersible pumps and lifted a sizeable volume of water from deep bore-wells affecting the shallow wells of small and marginal farmers. Thus the large farmers appropriated the gains of well irrigation disproportionately more than small farmers did.

Due to scarcity of groundwater a large majority of the large farmers have been investing on most efficient irrigation technologies and distribution systems like drip irrigation, using pipes to deliver the water in plots located far away. Further, some of the large farmers have installed expensive generators (Rs. 60,000) to pump the water continuously from their wells when electricity is not available. This has enabled them to expand more area under well irrigation and draw more water. Since these technologies are highly capital intensive, the ability cum feasibility of investing on such technologies and the credit worthiness of small farmers is very weak. Thus the large farmers are able to tackle the problem of scarcity by resorting to coping mechanisms while small farmers have not. This shows that large farmers have several viable options available to partially abate the potential profit loss from scarcity of groundwater. This has further accentuated the distortions in extraction and use of groundwater and widened the inequality gap between small and large farmers.

Table: 3 Salient features of small and large farmers owning irrigation wells (Sample size of 105 respondents)

Particulars	Small farmers (less than 5 acres)	Large farmers (more than 5 acres)
Size of holding	4.8	16.5
Proportion of farmers owning dug-wells	37	63
Percentage of farmers availing institutional finance for sinking dug-wells	80	95
Number of years served by the dug-well	15-20	15-20
Number of wells owned per farm	1	2
Gross area under dug-well irrigation	3	5
Percentage of area under food crops	80	70
Proportion of farmers owning wells who drilled in-bores	11	76
Number of years served by in-bores	5	7
Proportion of farmers who drilled bore-wells from among the dug-well owners	49	95
Investment at historical prices	50,000	61,000
Gross area under bore-well irrigation	4.5	11
Percentage area under food crops	40	27
Net present value	23,000	74,000
IRR	25	49
Payback period (years)	4	2.7

Source: Nagaraj, 1997

Some of the striking features between small and large farmers, owning irrigation wells are provided in table 3. The small farmer landholdings are less than one third of large farmers. On average a large farmer owned 2 wells as against one well in case of a small farmer. In both cases dug-well irrigation is dominated by food crops, which were not as water intensive as commercial crops.

The dug wells provided equity for small and large farmers, as around 40 % of the farmers owned dug-wells. A great majority of the small farmers, in spite of their smallholdings owned dug-wells mainly because of institutional finance on soft terms for small farmers. The sample farmers considered for this study has passed through all the three types of wells. The dug wells besides providing irrigation also provided drinking water, as a source of water for washing clothes, swimming, and fishery. These benefits have been significantly denied for the present generation with the failure of dug-wells completely. Since dug-wells served for a longer period compared to bore-wells, the intergenerational equity issue here is that those who possessed dug-wells earlier reaped the fruits of groundwater on a sustainable basis as their water withdrawals was in consonance with the recharge rate. As evident from the table the bore-well irrigation has dominated by large farmers due to lumpy huge investments. The gross area under bore-well irrigation was almost twice higher than that of small farmers. The small farmers devoted more area under food crops compared to large farmers. With the result, there have been wider differences with respect to annuity, the IRR and the net present worth of the investment between small and large groups. Large farmers, who have been extracting substantial quantum of water, have largely derived the gains from the cultivation of high value commercial crops under bore-well irrigation. This has created serious equity problems. Now on an average every 8 years the bore-wells are going out of use losing colossal investment. Again the well-to-do farmers race to explore the productive sites for drilling new wells relentlessly. In such a situation the poor will be phased out completely from the domain of well irrigation unless there is financial support from the government for deep bore-well irrigation.

In overexploited areas well drilling, installing pumps, conveyance and storage structures entails huge investment to the tune of Rs. 60,000-75,000. Further the financial assistance for well drilling is not forthcoming in such critical areas; hence the small farmers are worst hit. Most of the small and marginal farmers abandoned well irrigation and shifted to dryland agriculture due to drying up of their wells, as they are not affordable to invest on deepening or new wells compared to large farmers. In the race for exploitation of groundwater it becomes difficult for the resource poor to make huge and risky investments

The changes witnessed for the past 4 decades in hard rock regions of well irrigation indicates that there has been constant chasing of groundwater with the rapid strides in exploration technology of well drilling, the failure of dug-wells and shift to high water high value crops. This trend is most likely to exacerbate for future generations. In the process of well irrigation development the associated externalities include groundwater depletion and scarcity, water quality impairment due to intensive chemical load on land. The economic costs attributed to the resource depletion and degradation will have terrible problems for the future generation in terms of recharging and purification of aquifers. All these developments severally jeopardised the small farmers disproportionately both inter-spatially and inter-temporally.

The brunt of these externalities on small and marginal farmers will be terrible and future is very bleak for them to prosper without dependable source of irrigation.

After discussing the issues of sustainability, efficiency and equity we now focus to highlight the prevailing institutional arrangement that has largely been responsible for the current distortions in the use of groundwater resource.

Existing management regimes

In peninsular India there are large number of small appropriators concentrating on a given aquifer, wherein each appropriator concern is very narrow to give a serious thought to how one's pumping affects others and the future use. Furthermore, the boundaries of the aquifers are not clearly partitioned in order to allocate the resource among the users. Since well-owners are not registered with any institution and installation of water meters is not part of the management program the information pertaining to resource dynamics such as availability of groundwater, extraction and recharge rate are rarely known. Hence, the inadequacy of information is posing a serious management problem.

The main stakeholders influencing groundwater development and use include farmers at the micro-level, the Department of Mines and Geology and Minor Irrigation and the Electricity board, which supplies electricity to the irrigation pump-sets at the state level. At the national level, the Central Groundwater Board under the ministry of Water Resources acts as a technical institution. The National Bank for Agriculture and Rural Development (NABARD) is the single largest central government intervention supporting groundwater development through refinancing. These interventions confine technical expertise in exploration, evaluation, monitoring and maintenance of data pertaining to groundwater.

The Central Groundwater Board, an organisation of the Government of India, monitors groundwater levels and recharge rates based on observation of a sample of wells in every state. It is only a technical body without any powers to impose the rules and regulations since groundwater is a state subject. In every state the Department of mines and Geology is in-charge of monitoring groundwater levels, documenting of data and preparing hydro-graphs. Further, it also determines the stage of groundwater development based on the ratio of extraction to recharge in each block. If the extraction rate exceeds 85 % of the recoverable recharge, the block is designated as "dark" a critical area of over-exploitation wherein there is no potential for further development. In such blocks the institutional financing for well drilling is not permitted. Similarly a "grey" block is one where the groundwater extraction to recharge rate is between 65 and 85 percent. In such blocks the institutional financing for well drilling is permitted selectively subjected to submission of feasibility report. A "white" block is one where the groundwater extraction to recharge is below 65 percent and there is no restriction for institutional finance for well drilling in such blocks.

Property rights structure

In India, groundwater development is under the private ownership regime. The legal status in terms of *de* jure rights is not transparent. Groundwater is attached like a chattel to the land, without any limits on extraction. Thus only the landowner can own the groundwater right implying that the landless does not have any stake in the resource. This clearly reflects the inequity as far as groundwater access is concerned. Table 4 summarises the existing property rights structure relating to irrigation wells in India.

The Ministry of Water Resources for the government of India mooted the groundwater (control and regulation) Bill in 1970 and revalidated it in 1992 to regulate and control the development of groundwater. This was circulated to all the states with an advice to enact it with necessary modifications since water is a state issue (Singh, 1993).

Table: 4. Nature of Property Rights for Irrigation Structures in India.

Type of well	Rights Structure	State Rights
Wells (private)	Absolute ownership	No rights
Wells (public)	Customary rights of groups/communities	State has power to regulate
Bore-wells (private)	Absolute unlimited rights to extract water beneath his land	No right to own/regulate
Bore-wells (public)	Usufruct right granted	State has power to regulate

Source: Singh, 1993

The Bill enables the state governments to establish a groundwater authority and to appoint its chairman and members. The groundwater authority can notify the specific areas of overdraft to regulate the over-extraction in the interest of the public. The draft Bill has been presented in the Legislature of several states (except in the states of Gujarath and Maharastra) but, has never been approved because of obvious reasons. The model bill was under severe criticism, as there is no representation from user groups in the management structure. The only regulatory mechanism for the state to check overexploitation is the restriction of finance through NABARD for well development in overexploited areas and enforcing spacing norms between the wells, besides limiting electricity connections. In case of privately financed wells there is absolutely no mechanism to control overexploitation

At present there are no institutional interventions pertaining to issue of permits, number of wells to be drilled and the volume of water extracted in general. However, there is a need to produce a feasibility certificate and maintenance of inter-well spacing when farmers borrow funds for well drilling from the institutional sources (For bore-wells 250 meters (800 ft) and for open wells 180 meters (600 ft) according to National Bank for Agriculture and Rural Development).

So far we have analysed the current critical and emerging issues relating to the development and the use of groundwater irrigation in the Indian context. In the following section we discuss some of the innovative management approaches, which are being tried in the western United States, to tackle similar kind of issues that have achieved a modest degree of success.

Groundwater Management approaches in Western United States-A case of Upper Republican Natural Resource District in Nebraska (URNRD)

The following part of the study is based on several reports and records, personal discussion and interviews with the Manager and faculty of URNRD and reconnaissance survey with the farmers in the Upper Republican Natural Resource District in Imperial, Nebraska.

According to water code, all water within the state is the property of the state, but the right to use may be acquired by appropriation in the manner provided by law. States and local governments have traditionally managed groundwater in Western United States. In some states the management systems have been established by state governments and regulated at the state level. In some other states the management has been delegated to local institutions such as a water management or Natural Resource District (Smith 1993). As a result of this local orientation, groundwater management systems have been developed in a unique and different way to address an array of issues pertaining to groundwater management

Compared to other western states of US, Nebraska is heavily dependent on groundwater. About 90 % of the total water withdrawn annually is being used for irrigation. Overdrafting has been a serious problem in many parts of Nebraska besides quality degradation. In some parts of the state water levels decline of up to 50 ft have been reported (Smith, 1993).

Need for regulation

Historically, in many regions of Nebraska groundwater pumping have been faster than it is recharged leading to overdraft. This has several environmental consequences in the region such as increased well depth, drilling of more wells, increased extraction cost and reduced flow in to the streams. Recognizing that continued depletion of groundwater threatens prosperity and quality of life, the Nebraska State legislature created a framework to manage the groundwater resource in 1972. This legal framework enabled to establish Natural Resource Districts (NRDs) which are unique to Nebraska with local leadership responsibilities with a functional mechanism for protecting groundwater from overexploitation and pollution. In general they do have broad responsibilities to conserve, protect, develop and manage the natural resources for the welfare of the state. In this endeavor the NRDs responded to deal with a variety of natural resources challenges with local control and local solutions.

The Upper Republic Natural Resource District (URNRD) is one out of the 23 districts in Nebraska where the groundwater depletion problem was unabated. The district is solely dependent on groundwater for agriculture and other activities. All uses other than irrigation represented only one percent of the total groundwater uses in the district as evident from the table give below. In the District around 517,000 acre-feet of groundwater were abstracted from the aquifers and used in 1998. Nearly 99 % of this annual total water withdrawn were used for irrigation (table 5).

The groundwater irrigation development in the study region has witnessed 3 distinct pattern of growth. From1940s to 1960s well irrigation was accompanied by flood and sprinkler method of irrigation. In the 1970’s there was a spurt in the number of wells with widespread use of centre pivots. This spurred unregulated withdrawal of groundwater in the district. Since1980s there has been regulation of well irrigation through the local control of Natural Resource District. Currently there are 3200 registered irrigation wells in the district irrigating around 430,000 acres.

Table: 5 Groundwater use pattern in URNRD for the year 1997-98

Type of use	Acre feet used	Percentage of total
Irrigation	512,000	98.91
Domestic/Municipal/Rural villages	3,795	0.73
Livestock	1663	0.32
Industry and Golf	202	0.04
Total	517,660	100

Management Structure

There are 3 distinct stakeholders or actors influencing the groundwater management decisions in the State of Nebraska. At first level, the State in general, provides a legal and policy framework. At the second level, the legislature has enacted local control groups in order to effectively manage the groundwater resources by establishing Natural Resource Districts. Finally at the primary level the users are involved in the management.
In order to conserve, protect, develop and manage the natural resources of the state of Nebraska, the legislation established 24 Natural Resource districts in the state based on the approximate hydrological boundaries of the recognised river basins. The state has given districts a variety of regulatory tools to deal with the problems of groundwater depletion, contamination and user conflicts. This is only the NRD currently regulating quality of groundwater while others are actively involved to deal with quantity issues.

The Upper Republican Natural Resource District (URNRD) in Nebraska State is the frontrunner to initiate a variety of controls with local efforts to manage the groundwater resource in the Ogallala region. The URNRD encompasses Dundy, Perkins and Chase

Counties began operations since July 1972. Kansas bound the URNRD on the west by Colorado and on the south.

Board

The Board of Directors is comprised of 11 members that governs the Upper Republic Natural Resource District. All eligible electors of the district landowners may vote for the election of the Board members at general elections. The election takes place once in four years. The district is divided in to ten sub-districts and one Board member is elected from each sub-district and one member at large is elected. Thus locally elected Board of Directors governs the districts and the management comprising the full-time professional management runs day to day functions. The Board is an autonomous body responsible for establishing district policies programs rules and regulations and adopting the necessary budget, in order to fulfil the responsibilities of the district as authorised and required by law. Property tax is the chief source of revenue to the board. A majority of the voting members of the Board shall constitute a quorum and the concurrence of a majority of the Directors present at any regular or special meeting at which such quorum is present shall constitute the official action of the entire Board.

Interestingly the entire Board of Directors are currently from the farming sector. The rules and regulations are approved and enforced by irrigators, with the support of the majority of the local users. The Board has forum to represent the user grievances and suggestions. In case of conflicts the aggrieved person can challenge the board decision and he can appeal for reviewing the decision within 30 days. If he is not satisfied with the decision he can approach the court for redressal. Further the information and other records are open to the public. Thus there is an element of transparency in the administration. The system is based on democratic principles and there is some degree of local control over the management system. This joint management approach enables various stakeholders to participate in the planning and decision-making process in a democratic way and therefore would legitimate the actions of the board. The URNRD long-term goal is to manage aquifers in the district by balancing groundwater withdrawals with recharge and protecting natural water quality.

It is quite interesting to analyze how local institutional arrangement collectively addressed the problem of overdraft and manage the common property resource. It is also equally interesting to identify the prime factors that explain the success in correcting the distortions in groundwater development and use. The other emerging issues that are worth investigating include: How cost effective is regulation than education? Further what are the discernible impacts of the regulation on sustainability, efficiency and equity? What are the responses of irrigators for the rules and regulations?

Institutional framework for groundwater management

Prior to 1975, Nebraska groundwater law was governed by reasonable use doctrine. According to this rule landowners are entitled to appropriate as much water as can be put to reasonable and beneficial use on their overlying land. The Nebraska supreme court also stated that in the event of inadequate groundwater supply, each user is entitled to a reasonable proportion of the whole groundwater supply (Olson, 1935). Thus Nebraska follows "Nebraska Rule of reasonable use". It is a blend of American and California rule of correlative rights. By1975, this common law framework was slightly amended by legislation. Further, the State has prioritized the uses of groundwater considering domestic as the highest preference followed by agriculture, manufacturing and industries. Thus, the concepts of reasonable and beneficial use formed legal boundaries on water rights for users.

The advent of high capacity pumps and center pivot irrigation system enabled to expand irrigation by unrestricted pumping of groundwater creating irrigation boom during 1970s. This irrigation boom ignited further spurt in the development of well irrigation creating an imbalance between discharge and recharge leading to fall in water levels in the aquifers. Thus there was heavy demand for groundwater development and use in the district (Kurt Stephenson 1996). This prolific development threatened the irrigators, as they did not have a secured claim to the water underlying beneath their land resulting in conflicts over the sharing of the resource. Further the law did not specify the user rights of the resource with other users. During the early 1970s the fall in water table was apparent across the district. Because of concern for declining groundwater levels the URNRD funded groundwater model study to explain and predict future changes in groundwater levels to the U. S. Geological survey. The results of the model revealed that the irrigation development was the chief cause for declining water table. The model also projected limiting access and cutting groundwater use in half would be insufficient to balance recharge with discharge.

In response to drastic fall in groundwater levels in several regions of the state, the Nebraska Unicameral enacted the Groundwater Management Act (GWMA) in 1975. This law granted a wide range of powers and basic responsibilities to the local natural resource management districts to control the groundwater development. Unlike other local resource districts in the region, Nebraska's NRD's are quite unique in a way they are multipurpose democratic local institutions having a local control over wide range of natural resource management issues. The responsibilities include: soil and water conservation, rural water supply, flood and soil erosion control, recreation, wildlife habitat management and forestry and range management.

In order to address the groundwater overdraft problems, the Natural Resource Districts were granted authority to alter the rules and regulations governing use and access to groundwater. In this endeavour the NRD should take approval from the state department of water resources for exercising the rules and regulations and to create a groundwater control area. Thus the NRD's play a key role in state groundwater policy formulation and implementation.

Within a designated control area the GWMA provides the NRD's board discretionary options and powers to regulate groundwater development and use. In this endeavour the board has formulated several management approaches to deal with groundwater management problems. These include access and allocation rules, regulatory measures and economic instruments.

Access and allocation rules

1) Well licensing and permits: All wells with pumping capacity over 50 gpm in the district require a permit, a meter and an allocation. Thus the free access has been restricted by licensing and permit system.

2) Allocation procedure: Each certified acre within an irrigated tract is granted an allocation of 14.5 acre- inch annually. Thus for a 5 year period the total allocation would be 72 acre inches i.e., (14.5" x 5 = 72"+ carryover from previous period). This allocation of 72" is designated as basic allocation. Groundwater users extracting less than the total basic allocation together with unused could be carry-forward to subsequent allocation period without limitation.
3) Irrigated acres and tracts: Requires Board approval and certification of irrigated acres to which allocations of groundwater can be applied and reporting of total irrigated acres. There is also a limit on certified acres to 130 per well, for new wells in the critical townships. However, no limit for old wells.
4) Pooling of groundwater: Board allows for pooling of groundwater allocation across tracts to enable irrigators to annually adjust amount of water applied on individual tracts subject to the condition that the overall allocation is not exceeded as stipulated in the pooling contract. Further, satellite pivots are allowed (transfer of allocated groundwater from one tract to another) for which the allocation is granted but prohibits an increase in the total allocation resulting from the transfer.

The above allocative volumetric management approach has set limits on the volume of groundwater withdrawals by each user. Further, per acre allocation of 14.5 inches provides a user the right to pump a maximum of 72-acre inches of water over a period of 5 years. There are no restrictions regarding the allocation of this quota by the user when, how and how much to be used. If the allotted quota is negative at the end of the 5th year, then for the ensuing 5 year period the irrigator/s will not be eligible to get any allotment. The district also provided options to the users on how to meet the extraction limits through a system of carry-forward and pooling provisions. The pooling system allows the well owners to combine all allocations from different wells as long as the aggregate allocation does not exceed the sum of the individual wells. The advantage of this system is that the irrigator can apply water to the crops on different scales such as 12” 13” 16” so on based on soil type still meeting the average of 14.5” of annual allocation.

The estimated consumptive requirement of water for crops in the district is around 25”. Out of this 11-12” is met through rainfall and remaining is through groundwater. Hence, based on the consumptive use norm an allocation of 14-acre inches has been arrived. As evident from the table: 6, the actual use between two periods has been less than the allocated water. Another interesting feature is that the average actual use has been reducing between the two periods. This clearly indicates that irrigators are managing the water more efficiently through improved irrigation technology.

Table: 6 Water allocated and actual use pattern in URNRD

County	1988-92	1993-97
Allocated (ac. inches)/yr.	14.5	14.5
Dundy:		
Av. Actual use (ac. inches)	12.6 (13)	12.2 (16)
Perkins:		
Av. Actual use (ac. inches)	10.3 (29)	9 (38)
Chase:		
Av. actual use (ac. inches)	12.5 (14)	10.4 (28)

Note: The figures in the parentheses indicate percentage reduction from the allotted quota.

In the study area the land values are directly related to the amount of water conserved out of the allocated quota. Thus, the conservation of groundwater has a profound effect on land values in the region.

Regulatory measures

1) Spacing requirements: The Board has set minimum well spacing requirements for all new wells drilled in the district. Well spacing requirements have been accepted as a

regulatory norm in the district. These regulatory norms have been established basically to prevent direct well interference problems while pumping rather than restricting the access to the resource. Under Nebraska State law the isolation distance from well to well be 600 ft. In critical Townships the spacing requirement is 5,280 ft except those wells used strictly for domestic, livestock or monitoring purpose. Further any irrigation well drilled after June 1981, in the control area the spacing must be at least 1,320 ft from any stock or domestic well not belonging to the groundwater user. In critical area for replacement well in lieu of an abandoned well which is located within 1,320 ft shall be drilled within 150 ft of the abandoned well it replaces.

2) Flowmeters: All existing wells for the purpose of irrigation, commercial livestock, municipal and industrial use with a capacity of more than 50 gpm shall have an approved flow-meters installed before April 1980. And the annual water use is reported to the district. This would facilitate for the management to know the actual total volume of water abstracted on each well.

3) Critical Townships: Under the current rules, townships are designated critical if the average 3 year groundwater level decline exceeds 0.25 % of the saturated thickness of the aquifer. Once designated critical, the township must remain so designated for a period of 5 years. At the end of 5-year period, the township is either removed from the critical designation or re-designated as critical depending on the change in the saturated thickness of the aquifer. Currently there are 42 critical townships in the district out of 84. This clearly indicates that 50 % of the townships are in critical area.

4) Supplemental irrigation wells: The management prohibited supplemental irrigation wells. After 1990 no permit was approved for any supplemental wells.

5) Water quality: Board has established water quality criteria and monitoring and remediation procedures. In this regard the URNRD entered into a co-operative agreement with the U.S. Geological Survey to conduct groundwater quality survey. The focus of this survey is to establish a scientifically sound baseline on quality of the groundwater in the district.

6) Moratorium: In response to increased pressures to drill new wells in the district the board approved moratorium on well permits and new groundwater allocation in critical areas of the district since Feb 1997. This is the first of its kind to impose the

moratorium in the state of Nebraska. This will expire in the month of August 1999. Again continuation or removal of this issue has to be discussed in the Board.

7) Variances: The Board may grant variances from the strict application of rules or regulations upon good cause is shown.
8) Adjudication: Provides for formal adjudicatory hearings detail general enforcement provisions for carrying out the rules and regulations of the district and specifies conditions for cease and desist orders. Any groundwater user aggrieved by the Board action may request for a formal adjudication hearing. Any groundwater user found to be violative of these rules and regulations may be required to cease and desist withdrawing groundwater until such time the compliance is met.

Market interventions

Market interventions particularly electricity and water pricing are considered to be the strong economic levers that promote adoption of efficient irrigation technologies. However efficient technologies may not ensure the protection of the resource unless there is quantity regulation as farmers continue to expand irrigation as long as it is profitable. The extent of government support for farmers in subsidizing fuel and electricity, credit for well drilling and also support price for the product is virtually absent. Hence the market forces are also playing an important role in irrigation development and use. Unlike in India energy is not subsidized for irrigation pump-sets. Hence the energy cost is most important component influencing the amount of water to be applied. Based on the case studies in the district the energy expenditure alone accounted for 17 % of the total cost per acre. The share of irrigation expenditure in the total cost is around 40 % per acre. Thus the pricing of energy and quantity restriction on the use of groundwater strongly propelled to go for irrigation efficient technologies such as center pivots. The demand for center pivots is also swelling over the years, mainly because of water scarcity, shortage of labor to irrigate and high prices of energy. Nevertheless the center pivot irrigation system has a distinct advantage over other systems. It promoted scale economies and made very easy to manage moisture, nutrients and weed control on the farms with this system of irrigation. The efficiency in water applied is more than 85 %. Thus it served as a comprehensive crop and water management tool for the irrigators operating giant farms ranging from 1000 to 1500 acres. Thus the management approaches followed have two fold impacts. The 1st notable positive effect is stabilization of water table over the years. And the 2nd impact is in terms of increasing irrigation cost to the user by way of huge investments on irrigation equipment. The regulatory institutional framework enabled to create groundwater legally scarce and thus accomplished the objective of sustainability.

Education

The Natural Resource District Board has made concerted efforts towards mobilizing consensus for action through a variety of educative programs. The district has developed hydro-graphs to show the changes in water table in different counties, which can be easily understood by the irrigators. Board also disseminates information for better understanding of the occurrence movement, recharge and discharge of the aquifer. Provides reliable information regarding changes in water quality and quantity. Besides, board also mails letters informing the actual use of water out of the allocated quota based on meter readings. The NRD makes efforts through communication of information to the public relating to meetings, public hearings and rule making. This process has stimulate public discussion and participation in the decision making process. Thus these educative programs contributed for collective understanding and appreciation of the problems. This served as basis for negotiating feasible and reasonable solutions to the pressing problems. Thus the joint management approaches to address groundwater depletion issue with active people role and co-operation in Western US has yielded viable solutions to tackle the issues of groundwater over-mining.

By and large, the responses of irrigators to the groundwater rules and regulations in the district is favourable and encouraging. They have shown adequate faith in the local control body. This is mainly because ever since the NRD came in to the existence the directors have been primarily irrigators. Further, the users strong faith in the local management institution for compliance of the rules reflects a sense of conservation ethics. Added to this, farmers in the area have strong progressive outlook towards science and technology in order to provide solutions to the problems. Notwithstanding these positive outlook a few farmers have criticised that within the district farmers are penalised in terms of imposing rigorous rules letting others 50 miles away from the region.

Discernible impacts of regulations:

It is clear that most of the rules and regulations primarily targeted to deal with demand management by setting limits on the upper bound for the extraction of groundwater resource. Hence, there has been a remarkable change in the water extraction and use pattern in the regulation regime.

Table: 7 discernible impacts of groundwater regulations in URNRD

Year	Water extracted and applied (ac.ft)	Area irrigated (in acres)	Average use per acre	Yield per acre (bushels**)**	Water used per bushel of corn
1975-80 (Average)	520,000	419,920	14.86	**-**	**-**
1988-92 (Average)	436,000	442,000	11.8	151	0.08
1993-97 (Average)	398,000	455,000	10.5	200	0.05
Percentage change from:					
1980-92	-16.0	+5.2	-20.0		
1992-97	-9.0	+3.0	-11.0		
Overall change	-23.0	+8.3	-29.0		

Table: 8 Temporal and spatial decline in groundwater level below land surface in the observation wells in the study area (ft)

County	1975	1985	1997	Difference between 1975-85	Difference between 1985-97
Dundy	86	102	116	-16	-14
Perkins	165	172	176	-7	-4
Chase	75	90	95	-15	-5

Source: Upper Republican Natural Resource District Information Packet, Feb 9, 1999.

As evident from the table 7, there has been decline in the quantity extracted, despite gradual increase in the area irrigated. The per acre water applied has also been dipped from 15 acre inches to 10.5 acre inches. The water level decline in the aquifers also reduced after 1985 (table 8). The main contributing factors for this change include the local control in terms of allocation and regulation rules, use of more efficient irrigation technologies and improved farm management practices. Thus there is a discernible effect on water savings leading to conservation. Further, the legal framework has defined the user right boundaries hence; free rider problem has been reduced considerably.

With regard to nitrate contamination in groundwater the water samples taken in 1995 indicated nitrate level of 1.2 to 16.5 parts per million with the majority being in the 3-6 ppm. This is within the limits of U.S. Environmental Protection Agency standard of 10 ppm. However the district has some high nitrate readings in localised areas (URNRD, 1995). Thus the rules and regulations of NRD had a considerable impact on altering the rate of groundwater extraction.

Further these regulations induced farmers to shift to better water management practices. However there are many anticipated benefits to the users due to regulations. The land values are increasing in the area, as the selling price of land varies directly with the amount of water conserved out of the allotted quota. The rental/lease value of land is also

appreciating with the conservation of water. The actual draw down of the aquifer has been reduced for the past 5 years and water table has been stabilised.
The URNRD is one of the most innovative institutional governance structure for taking collective decisions and actions on behalf of water users by developing a combination of management approaches addressing the most pressing issues of groundwater overexploitation in the region**.**

Some of the key components responsible for the success of URNRD programs are outlined as below:

The legal and physical boundaries of the groundwater resource are generally delineated based on hydrological rather than on political lines. This has facilitated more ease for effective management. Establishment of an enabling framework that is responsive to the local conditions and water management needs of the community formed a hallmark of URNRD. The enabling framework comprised modification in property rights for groundwater use, definition of user rights on volumetric basis, permits and water metering system and allocation of quota has been largely responsible to limit the extraction rates and curtailed the excessive pumping of groundwater. Further the board has a forum for conflict resolution in case of any disputes. The management approaches have been perceived as fair and worthy because local users had developed them collectively hence adaptable to the local situation as the problem is localized in nature. Thus the process of control and command has been replaced by collective and coalesced action locally. The rules evolved and crafted collectively by the board are transparent enabling for the development of the groundwater management system. In the region according to the survey of the board 90 % of the farmers supported the moratorium on new wells. This clearly implies their collective concern for the appreciation of the problem. The measure of moratorium on new wells has reduced further pressure on groundwater. Added to the institutional factors, the two important technological components enabled for better management are; shift in irrigation technologies from flood to center pivots and access and availability of technical information relating to water tables, extraction and recharge rate of groundwater. Thus based on the experiences of the western case we discuss some of the relevant policy options for India.

Policy lessons for Peninsular India

Before deriving policy options based on western US experiences especially that of Nebraska, it is important to note the commonalities and primary differences that exist between two countries. Both countries have similar semiarid conditions hence irrigation is playing a critical role for agricultural development. Groundwater depletion and its quality impairment have been evident in both the countries. Pricing of water and electricity have been advocated to encourage the adoption of efficient technologies. Of late rural-urban conflicts for use of groundwater are increasing in both the countries. This will have large impacts on groundwater management options in agricultural areas. In addition, both are democratic countries functioning based on certain legal systems. Both depend largely on market system and government interventions to achieve common objectives.

With regard to differences, a sizeable proportion of aquifers in India is comprised of hard rock as against alluvial aquifers in the case of western US. In India, the density and spread of appropriators on a given aquifer is much higher than the western US. There are differences with respect to agro-climatic conditions, crop patterns, technology used and nature of agricultural holdings. The agricultural holdings are highly fragmented and rural population density is much greater in India than western US. Further the resource supply and use dynamics of groundwater is poorly understood in India, as compared with US. Hence we need a blend of institutional management approaches that are capable of addressing the upcoming issues in groundwater development and management. When surface and groundwater are interdependent we need to devise a system that recognizes this synergistic relationship for achieving best results. Similarly when groundwater aquifers are independent of surface water bodies we must develop a management system that takes care of the protection of aquifers from overexploitation and quality degradation.

In some of the western US states the local Groundwater Management Districts are the most common institutional arrangement to deal with a wide spectrum of issues relating to water management. The Nebraska's case provides a classic example of local control over the resource to deal with overdraft issues as well as efficient allocation and use, tuned to the local needs and context of the people.

In order to replicate the Nebraska model to the peninsular India, we require institutional reforms mainly in the sphere of legal issues and the formation of user groups. The legal framework has to be clearly defined in terms of modification in property rights from absolute doctrine of prior appropriation to reasonable use as in the case of Nebraska. Further, physical and hydrological boundaries of the resource have to be delineated on a basin or aquifer level.

Currently, the scale of management relating to water resources is highly sectorized and disorganized. The government organizations such as State and Central Ground Water Board are the formal institutions dealing mainly with the technical issues of groundwater at macro level without any executive powers. Further these institutions do not reflect the local needs and aspirations, as many issues of groundwater are regional or local in nature. Since water is a state subject most laws should be passed at the state level. The model groundwater bill of 1992 has not yet been implemented in any state. The bill in its present form establishes a command and control system for groundwater regulation (Moench, 1998). This bill has been highly criticized, as it has not included local users' representation. In the light of this, the Natural Resource District model, a joint management approach with active people participation could be a promising solution to the Indian context. This could be developed at the regional or a cluster of village's level based on aquifer or watershed, where there is acute overdraft problem. The criteria to delineate a hydrological boundary for management should be flexible reflecting the local nature of the problem. The district can initiate a variety of programs and controls for recharge and discharge and other regulatory measures such as spacing norms, control of new wells and regulation of water intensive crops. Elected board of directors through which the interests of all stakeholders can be voiced could govern these organizations.

The board should have an overall body comprising of all the users and an executive body ratified by the committee of the farmers. In addition to the elected representatives one from each village, there should be nominated members in the board comprising one member from irrigation department, one from Mines and Geology and one representative from a commercial bank. The NABARD can explore the possibility of funding seed money for establishment of such NRD institutions initially. Later on they can generate their own source of revenue through licensing, well permit fees, share amount and other taxes. The members should be required to buy the shares in the groundwater district based on the irrigation command as stipulated by the district.

Designation of critically overexploited fragile areas as done in the case of Nebraska is very important for regulating further overexploitation. In these areas there is a need for regulation of bore-well drilling in terms of declaring a moratorium till the water tables are improved. Management can set allocation quota in overexploited areas for every 5 years based on crop water requirement using most efficient irrigation techniques. The limits should be based on the minimum area or share basis, which ensures reasonable income to the farm family to lead a decent life. Farmers who extract only a part of their quota could carry forward remaining amount to the next period or they can sell them to other needy users. This promotes water markets and efficient allocation of the scarce resource. Those who exhaust their quota before the allotted period would forfeit their rights and this way the farmers are refrained from using more within a short span of time instead of spreading the use of their quota over the time horizon. This obviously promotes the use of efficient irrigation technologies and leads to conservation.

The regulatory and allocative management approaches based on permits and metering, spacing of wells has been widely used in Nebraska. These approaches need accurate data pertaining to the stock of the resource, flow, and recharge and discharge rates. Further the logistical costs associated with this approach is colossal since in India there are large number of well owners involved over space, so these measures could be restricted to those in dark areas where there is no scope for further expansion of well irrigation.

The districts can also regulate the new wells, spacing of wells and well drilling agencies by issuing permits. For all unauthorized wells without permit system power supply can be stopped and penalties imposed.

The real cost of extraction of groundwater has been increasing over time and this has serious equity implications for small farmers. Hence, special programs aimed at improving equity needs to be designed to support small farmers. Further supply of electricity may be made available on a preferential basis to these farmers who venture in-group investments.

The problem of inequity existing in well irrigation could possibly be reduced by promotion of groundwater markets, which facilitate access to groundwater to those who can not devote huge investment. For achieving equity in areas where there is no assured sources of surface irrigation, NABARD can provide financial assistance to groups of small and marginal farmers to drill irrigation bore-wells in order to provide them income generating opportunities so as to alleviate problems of poverty in rural areas. Currently in the state, there is an irrigation welfare program called ‘Ganga kalyan’ Scheme for small and marginal farmers of scheduled caste and scheduled tribes. Government provides funds to the members of this scheme for drilling wells on a group basis. This could be extended to all small and marginal farmers. Further the distribution of water can be made based on the Rawlsian criteria of fairness in distribution. Under this criteria, the distribution policy would be governed by “lexicographic” ordering combined with the maximin rule proposed by Rawls according to which “the welfare level of the worst –off individuals be made as high as possible. One way of using the above lexicographic ordering with maximin rule is to irrigate all the irrigable land of the smallest farms first and after fulfilling their demands, then go on to fulfilling the demands of the second smallest farm size groups followed by the third smallest farm size group, and so on (Sampath, 1992).

The approaches such as pricing energy and removal of subsidies for well irrigation require fewer regulations and seem to be pragmatic. Free or flat rate electricity reflecting zero marginal cost for lifting groundwater is bound to have profound impact on groundwater over-development and exploitation besides wastage of water. If energy for extraction of water is priced it will improve equity and efficiency of water transactions since the seller and the buyer will both have to be cautious in its utilization. Also, pricing of electricity induces an element of caution and prudence on the part of farmers to go for efficient irrigation technologies thereby promoting use efficiency. Nevertheless this requires political consideration for action.

Promoting the use of efficient irrigation technologies should form part of the water management strategy. The micro irrigation techniques like drip, has huge potential not only to save a sizeable quantity of when it is delivered through pipes, but also ensures water use efficiency.

High water consuming crops like sugarcane, rice, grapes and vegetables should be discouraged under groundwater irrigation. During the period of extreme scarcity of groundwater, area under irrigation should be regulated since regulation of quota of water for each farmer is difficult task.

Extension outreach to disseminate relevant information relating to pump-technologies, conveyance network, water saving mechanisms, water use and right type of crop choice based on the availability of water, scheduling of irrigation to the members of an irrigation district, plays an important role in promoting irrigation literacy and overall sustainability. In order to augment groundwater recharge in aquifers, the role of surface irrigation tanks and watershed development schemes that are specific to each area could be promoted in the districts.

Karnataka State has the largest number of irrigation tanks in India; virtually every village has an irrigation tank. Tanks are common property resources supporting the village economy. Of late a vast majority of these irrigation structures have silted up reducing their live storage capacity due to governmental apathy and lack of community efforts to manage them. Such irrigation tanks could be used to impound excess run off water when there is heavy rainfall. By utilizing these tanks water can be stored like a buffer. The role of “buffer stock operation” in water is very critical in order to ease supply scarcity of groundwater. Also, these tanks can serve as percolation tanks for recharging groundwater. Studies have indicated that rehabilitation of irrigation tanks have improved the recharge of wells (Gireesh, 1996). Thus promotion of participatory action in rehabilitating irrigation tanks for recharging groundwater would go a long way in augmenting groundwater supply.

The NABARD has been playing a big role in influencing groundwater development across all the states through its lending programs. Thus it can take a lead role to promote user groups and groundwater irrigation districts by extending lending facilities only to the members of such organizations. If users of groundwater are not willing to join the natural resource management district then government can cut all agricultural and irrigation subsidies for such a region.

Conclusions:

This study aimed at institutional perspective of groundwater management in dealing with overdraft problems in India and western US. A great deal of management problems relating to groundwater over-development and use are emerging in both India as well as in western US. In western US these problems are being effectively addressed through institutional policy instruments with local control. These include formation of natural resource districts with varying responsibilities over groundwater issues, creation of an enabling framework specifying user rights, correlative rights to a reasonable use, issue of permits for extraction, allocating quotas and declaration of moratorium on new wells in critical/over exploited areas. These regulations enabled to set an upper boundary for extraction of groundwater and made groundwater legally scarce. This has had a profound impact on use pattern and conservation of groundwater in the region. In India, lack of effective groundwater institutions at local level to deal with emerging problems in groundwater development and use has resulted in intergenerational, inter-temporal and inter-spatial misallocation and severe overdrafts creating several externalities. Further, the markets are not responding to correct the distortions in groundwater use. This has severely mauled equity, efficiency and sustainability of groundwater resource use. The emerging environmental implications on account of groundwater overdraft will be terrible for the future generation. Drawing experiences from the Nebraska model there is a need for creation of an effective user based groundwater management institutions at local level with local control that are viable and reflective of social concern for conservation ethics, environmental values, equity consideration and efficiency in resource use. Towards this endeavor a package of incentives could be extended to promote user based groundwater management institutions at gross root levels.

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