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Integrated Water Management in the face of Growing Demand and threatened Resource Base in North Gujarat: Constraints and Opportunities

A Pilot Project to Protect North Gujarat's Groundwater Ecology and Agricultural Economy

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INTEGRATED WATER MANAGEMENT IN THE FACE OF GROWING DEMAND AND THREATENED RESOURCE BASE IN NORTH GUJARAT: CONSTRAINTS AND OPPORTUNITIES

A PILOT PROJECT TO PROTECT NORTH GUJARAT'S GROUNDWATER ECOLOGY AND AGRICULTURAL ECONOMY

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Abstract

Groundwater over-exploitation problems and growing water crisis facing North Gujarat region, in western India, had attracted the attention of hydrologists, groundwater scientists, economics and sociologists worldwide. The most commonly advocated solution to the problem is artificial recharge of groundwater. While NGOs in the region had rigorously pursued local water harvesting as the panacea for the region's water problems and to protect the people's livelihoods, the government looks at the options of large-scale import of water and recharge of the region's aquifers to save the groundwater ecosystem.

The activities so far on augmenting groundwater supplies have not involved serious considerations of the hydrological systems affecting the availability of water. This leads to over-appropriation of available water with negative social and ecological consequences. The discussion on water saving has not gone beyond technological interventions for improving the productivity of water. The author argues that if productivity of water is to be enhanced on a sustainable basis through technological interventions, the productivity of land needs to be managed. The author proposes integrated water management for sustainable management of groundwater resources and improving the livelihoods of the rural communities, for an action research project being implemented by International Water Management Institute.

The fountainhead of the strategy is to augment groundwater resource, in a manner that is ecologically sustainable and do not cause major negative hydrological impacts; sustainable enhancements in economic efficiency of water use in agriculture using integrated land and water management approach, based on organic farming practices in farmers' fields that gives due consideration to improving productivity of land along with water; and reducing the water use rates in agriculture through a variety of water-saving technologies that are adaptable to the region. The author goes on to identify the major physical, socioeconomic and institutional constraints and potential future opportunities for operationalizing this strategy. Finally, suggestions are made on prioritizing geographical areas and target groups keeping in view the technical feasibility and socioeconomic viability.

1.0 Backdrop

The North Gujarat, comprising five districts, in the semi-arid, western India is one of the most water scarce regions of the world. The annual average per capita renewable freshwater in the region is estimated to be 427 m^3 (IRMA/UNICEF, 2001), while the same for the country was estimated to be approximately 2,000 m^3 (Engelman and LeRoy, 1993). Going by Falkenmark's index of physical scarcity, the region can be called "absolutely water scarce", where water becomes a constraint for human survival. However, such low levels of water availability does not seem to have any bearing on the way in which water is used in the region. The per capita water use in the region (448 m^3 per annum) is higher than that in the most water abundant South and Central Gujarat (332 m^3), and is highest among all the four regions of the State (IRMA/UNICEF, 2001). Such high levels of use, which exceed the renewable freshwater, is achieved through aquifer mining (Kumar and Singh, 2001a).

The water use pattern in the region is heavily skewed towards irrigation, which claims 89 per cent of the total water diverted for various competitive uses (IRMA/UNICEF, 2001; Kumar, 2002). It is one of the most intensively irrigated regions in the State. It extensively grows food crops, cash crops and fodder. Alfalfa, an irrigated fodder crop, extensively grown in the region, is the backbone of the region's dairy economy.

With the mining of groundwater and consequent lowering of water levels, the cost of abstraction of groundwater is increasing day by day. Observations of long-term trends in groundwater levels show that the annual rate of decline in many parts of Mehsana district is in the range of 0.92 metres to 6.0 metres (CGWB, 2001). The actual variable cost for pumping one cubic metre of groundwater is estimated to be 1.5 rupees, keeping aside the astronomically high cost of installing tube wells for pumping water. A recent analysis for well irrigated areas in Daskroi taluka of Ahmedabad district, which experiences a much less serious problem of groundwater level drops, showed the actual cost of abstraction of groundwater with a 12-year life of the tube well and an initial investment of 3.5 lakh rupees, as 1.03 rupees (based on data provided in Table 2 of Kumar *et al*., 2001a).

While this is the regional scenario emerging in absolute terms, what is more serious is the scenario emerging in relative terms. Access to groundwater in the region is highly inequitable. Hundreds of thousands of small and marginal farmers are deprived of direct access to groundwater. Many of them sustain irrigated agriculture by purchasing water from rich well owners, while some of the better-endowed farmers invest in partnership wells and continue abstraction (Kumar, 1996; Kumar, 2000). But, the rich well owners continue to enjoy un-limited access to groundwater using heavily subsidized electricity (IRMA/UNICEF, 2001; Kumar and Singh, 2001b). The price at which water is sold is far less than the implicit cost of pumping in most cases. Groundwater depletion and the emerging water markets provide large well owning farmers to maximize their economic returns from a combination of irrigated farming and water selling (Kumar *et al*., 2001a).

The high cost of well construction has not influenced the way in which groundwater is used in irrigation. By and large, the irrigation practices are inefficient. In the traditional methods of irrigation such as small border and furrow, significant amount of water is lost in percolation and evaporation from the field. Over and above this, due to the zero marginal cost of using irrigation water and with the net return from irrigated farming far exceeding the opportunity cost of using water, well-owning farmers tend to over-irrigate.

Some of the sustainable, long-term solutions to the groundwater depletion problems that are being widely debated and discussed are establishment of tradable property rights in groundwater, and introduction of unit pricing of electricity in the farm sector, in conjunction with large-scale import of water for recharging the depleted aquifers of the region. However, none of these solutions seem to be forthcoming fast. The political willingness to take drastic measures such as ban of high capacity pump sets, drilling of tube wells etc. are also lacking. Such measures might also have serious social and political ramifications. The potential equity impacts of such measures also cannot be ignored.

In the present climate, the communities, the NGOs and the government agencies are focusing solely on local recharge measures to arrest further depletion of groundwater. Over the past couple of years, several agencies have taken up large-scale building of water harvesting structures and de-silting of tanks in the region. In doing so, they have given very little consideration to the local hydrological and geo-hydrological realities, and the region's overall water balance and ecological imperatives[1]. Thus, these local solutions, implemented in a fragmented and disjointed manner do not address the problems.

Water conservation in agriculture has hardly received any attention. Sustainable water management interventions in agriculture need to address the concerns of land degradation, apart from the low physical efficiency of water use. The declining primary productivity of land, forces the farmers to increase the external inputs such as irrigation water and fertilizers so as to compensate for the loss of production, which leads to further deterioration of land.

The ongoing resource disaster could, slowly but certainly, threaten the sustainability of agriculture and the economy of the region. As groundwater levels drop, and cost of irrigation rises, the viability of farming reduces. Further, more and more farmers get deprived of their access to water. The major concerns are ensuring: [1] sustainable management of groundwater resources, with due considerations to control of land degradation, without compromising on the ecological balance; and [2] management of present and all future demands of water in agriculture without compromising on the economic outputs, with due considerations to improving the productivity of land and water, thereby ensuring sustainability of irrigated agriculture, and social advancements and environment.

The action research project being initiated by the International Water Management Institute, tries to evolve and implement local, community-based solutions to the groundwater depletion problems that focus on both augmenting groundwater recharge and reducing the demand for water in agriculture so as to improve the livelihoods of the agriculture dependent communities and the ecology of the region.

2.0 North Gujarat's Water Resource Environment

2.1 The Natural Water Resource Systems

2.1.1 Rainfall regimes of North Gujarat

North Gujarat receives low to moderate rainfall and has arid to semi-arid climatic conditions. The western part of erstwhile Banaskantha district (Santalpur taluka) receives the lowest rainfall of 350 mm per annum and the North-East part of Sabarkantha district receives the highest rainfall. The rainfall is highly erratic and the mean value of the number of rainy days varies from 25 in Banaskantha to 35 in Sabarkantha.

[1] Many of the tanks were over-designed. Many of the check dams were constructed in the upstream of the existing medium and large schemes. Since these schemes were built for runoff of low dependability, the check dams intercept their flows.

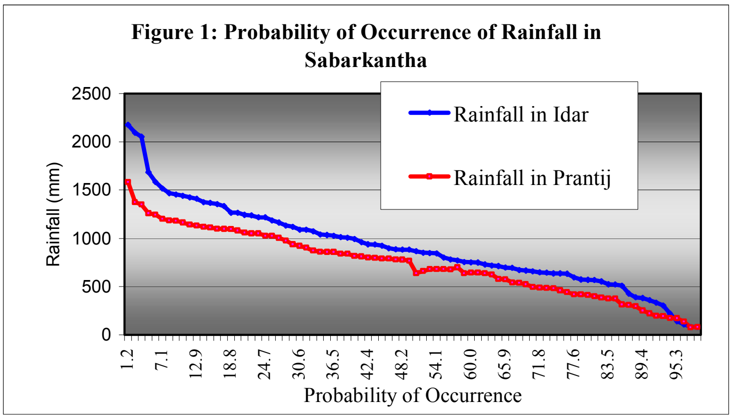
According to the district-level analysis carried out by the GAU, the mean of the average annual rainfall (1901-1990) varies from a minimum of about 578mm in Banaskantha district to a maximum of about 807mm in Sabarkantha district. The coefficient of variation of the rainfall varies from a minimum of 36.5 per cent for Ahmedabad district to a maximum of about 46 per cent for Banaskantha district, indicating very high year-to-year variation in the rainfall for the entire region. The coefficient of variation is as high as 65 per cent in the arid western parts of Banaskantha and Mehsana. The mean annual rainfall for the entire region is about 627 mm.

There is a significant variation in rainfall from taluka to taluka within the district itself. While Palanpur receives the mean annual rainfall of 682 mm, Radhanpur taluka receives only 496 mm. Again it rains for less number of days in Radhanpur (21.5) as compared to Palanpur (30.5). The coefficient of variation of rainfall is higher for Radhanpur as compared to Palanpur.

Table 1: Inter-regional variation in Rainfall in North Gujarat

NORTH GUJARAT	Years of Record	Rainfall (mm)			***Number of Rainy days***		
A. Banaskantha		STD	Mean	CV (%)	STD	Mean	CV (%)
Palanpur	83	353.60	682.20	51.83	11.73	30.43	38.54
Vav	28	251.62	346.94	73.53	8.55	15.57	54.90
B. Sabarkantha							
Idar	83	428.77	920.34	46.55	13.67	37.77	36.19
Prantij	83	336.48	740.01	45.57	11.52	33.47	34.42

Source: Kumar, M. D. 2002



The following pattern emerge from the analysis of the long-duration rainfall data for period ranging from 28 to 83 years, of four rain gauge stations in the region. The difference in mean annual rainfall is as wide as 573 mm between Vav (Banaskantha) and Idar (Sabarkantha) with Idar receiving the highest rainfall. The number of rainy days is highest for Idar and when compared to Wav; it receives rains for 22 more days. The year-to-year variation in rainfall is highest for the location, which receive the lowest rainfall (here Vav) and second least for the location, which receives the highest rainfall. Like rainfall, the inter-annual variability in number of rainy days is also highest (55) for the least rainfall location.

Figure 1 shows the probability curves for two rain gauge stations in Sabarkantha, namely, Idar and Prantij. The probability of occurrence of a given magnitude of rainfall is different for the two locations. For a 1000mm rainfall, it is 25 per cent for Prantij, while it is 40 per cent for Idar.

2.1.2 River Basins and Surface Water Resources

The north Gujarat is one of the driest regions in our country. Though the region has several small and large rivers (in terms of the river morphology), they remain dry for most part of the year except during the few days of monsoon rains. North Gujarat is poorly drained, with a very low drainage density in the alluvial tracts of Mehsana, Banaskantha, Gandhinagar and Ahmedabad. The four river basins in the region are Sabarmati, Rupen, Saraswati and Banas. These rivers, most importantly, Banas and Sabarmati, have several small and large tributaries. The surface water potential of these rivers is very low. While a 1000 sq. km catchment in South Gujarat can generate a mean annual runoff of 1,600 MCM with 50% dependability, the amount of run off (mean) generated in North Gujarat from the same amount of catchment and with the same dependability would be only 60 MCM. The runoff with 75 per cent dependability is 2,012 MCM (GOG, 1996).

The river basins of North Gujarat are characterized by high year-to-year variability in their annual flows. The runoff, which is the runoff generated on the spot of rainfall, flows in sheets and due to the high aridity, it evaporates. Most of the streams and rivers in North Gujarat are dry during these low rainfall years. The result is a "hydrological drought", as most of the surface reservoirs remain empty. On the other hand, there are a few years, when the rainfall could be extremely high. In those years, the intensity of rainfall is also found to be generally high. In such years, these rivers yield very high discharges. Flooding of the rivers is not a rare phenomenon.

Table 2 shows the drainage area, mean annual runoff, dependable runoff and variability in runoff of these basins. Estimates based on historical runoff observed at

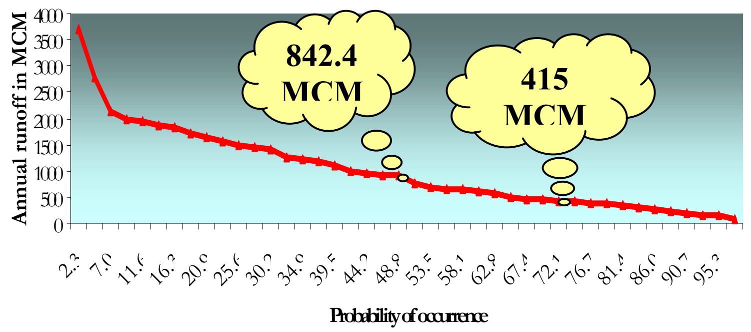
Table 2: Runoff Characteristics of River Basins in North Gujarat

Name of the basin	Drainage Area* (Sq. Km)	Stream Gauging Station	Catchment Area (Sq. Km)	Annual Runoff (MCM)	
				Mean (MCM)	Dependable Runoff (MCM)
Banas	2,264	Baluntri	2264	382.91	127.44
Sabarmati	21,678	*Dharoi*	5548	1014.18	415.00

Source: GOG 1996; ORG 2001

* The drainage area also includes the upper catchments in the neighbouring State of Rajasthan

Figure 2: Runoff in Sabarmati River at Dharoi (Damsite)



Dharoi, which had a catchment of 5448 sq. km, for the period 1951-92 shows that the dependable runoff is only 415 MCM, against a mean annual runoff 1,048 MCM (GOG, 1994). Table 2 shows the dependability curve of annual run off for Sabarmati River at Dharoi and Banas River at Dantiwada. The graph shows that the difference between runoff corresponding to 50 % dependability and 75 % dependability is as high as 427.4 MCM. Such vast differences are found in the case of Banas River at Dantiwada station, which has catchment of 2264 sq. km.

But what is also interesting is the probability of occurrence of floods in these rivers. As seen in the runoff probability curve, in three out of 42 years, the runoff was more than 2,000 MCM in Sabarmati river. All the North Gujarat Rivers had flood discharges ranging from 217 m^3 per second for Saraswati River (Sidhpur) to 2520 m^3 per second for Sabarmati (Watrak River at Bhempoda) to 3,230 m^3 per second for Banas (at Deesa). The flood flow component of the annual runoff of these rivers is ranging from 63.9 % (for Watrak River at Bhempoda) to 81.8 % (for Banas River at Roho).

There are a total of 16 large and medium reservoirs and six weirs located in different parts of these basins, to harness the surface runoff, and most of which are in the Gujarat part of the drainage area of Sabarmati basin. The recent studies showed that the surface water resources in these basins are over-appropriated (on the basis of Kumar *et al*. (2000), IRMA/UNICEF (2001), Kumar *et al*., (2001b), and Kumar (2002)). Due to this reason, in most of the years, there is no spill over from these reservoirs into the downstream. This drastically reduces the flows in these rivers downstream of the reservoirs.

2.1.3 Groundwater Hydrology of North Gujarat

The groundwater environment in North Gujarat is quite complex due to the heterogeneous geology and geo-hydrology. The geological formations bearing water show great deal of variations across the State, in terms of their accent –from Jurassic to Recent--, and type-- from igneous to metamorphic. The geo-hydrological conditions vary from shallow, unconfined and heterogeneous, hard rock aquifers to deep, alluvial, semi-consolidated and homogeneous aquifers. Both, the depth to groundwater levels and the depth of the aquifer varies drastically across the region

Hard rocks of granite origin cover East-Central Gujarat covering parts of Sabarkantha. Groundwater storage potential of this region is very poor. The whole of Mehsana, Ahmedabad, Gandhinagar, and almost the entire Banaskantha, and western part of Sabarkantha, are underlain by alluvium having good porosity, by virtue of which groundwater storage potential is high. The porosity ranges from low (for Basalt) to moderate (for Sandstone), and reasonably high (for alluvium). The hydraulic conductivity and specific yield (the geo-hydrological parameters determining the yield characteristics of unconfined aquifers), are very low in the basalt.

The alluvial aquifers are deep in Mehsana and Banaskantha districts. These aquifers have very high transmissivity and storage coefficients, the geo-hydrological parameters determining the yield of the confined aquifers. In this region, groundwater from the deep aquifers is being tapped using deep tube wells and high capacity pumps.

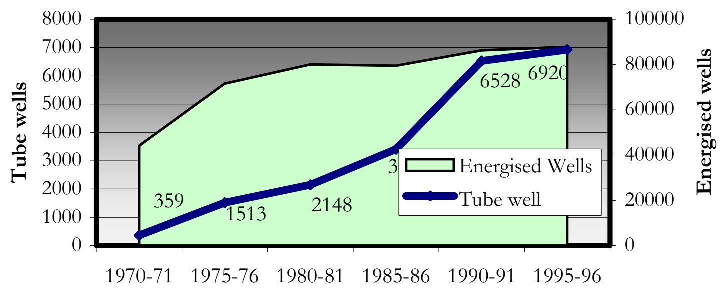
There are four important factors that affect the recharge to groundwater and they are rainfall, soils, topography and geo-hydrology. The soils in North Gujarat are generally alluvial in nature and the soil types are "alluvial sandy" in Banaskantha, Mehsana and western part of Sabarkantha and “alluvial sandy loam” in Gandhinagar and Ahmedabad. As these soils have high permeability and infiltration capacities, recharge rates are high for the medium rainfall the region receives. The deep, confined and semi-confined alluvial aquifers of North Gujarat, mainly Mehsana and Banaskantha, have outcrops in the foothills of the Aravally ranges. In these foothills, they are in phreatic condition. Coarse -grained soils, having very high rates of infiltration, are found in the region. These areas once used to be covered by rich forests, which used to provide high vertical recharge.

The total utilizable groundwater recharge in the State is 12,848.27 MCM per annum. Of this, 25.5 %, ie.3274.33 MCM is from North Gujarat alone. The groundwater recharge rate is 0.106 MCM per sq. km for North Gujarat (GOG, 1999). Though canal commands are present in North Gujarat, the return flow contribution is quite insignificant. The reasons being: the cropping pattern in these command areas is heavily skewed towards low-water intensive (such as wheat, bajra and mustard), and are not irrigated either under submerged conditions or partially submerged conditions and as a result the rate in infiltration is low; and [ii] the depth to groundwater levels in these areas is so high that only a small percentage of the infiltrating water does reach the groundwater table.

Surface-water, groundwater interaction also affects the inflows into and outflows from aquifers. Several rivers are hydraulically inter-connected to the aquifers lying underneath. However, such interactions will be governed by the hydro-geo-morphological conditions existing in a locality. There are significant intra-regional variations in recharge rates from low values in hard rock areas to the high values in alluvial areas.

2.2 The Socioeconomic Systems Affecting Water Use

Figure 3: Growth in groundwater abstraction structures



Irrigated agriculture is an important socioeconomic activity influencing water use in North Gujarat region heavily. Though surface water resources are very scarce, by virtue of the presence of the rich endowment of groundwater, the farmers in this region have taken to irrigated-farming. Over the years, irrigated farming had undergone major transformation in terms of the technology adopted[2]. Figure 3 shows the growth in energized wells and

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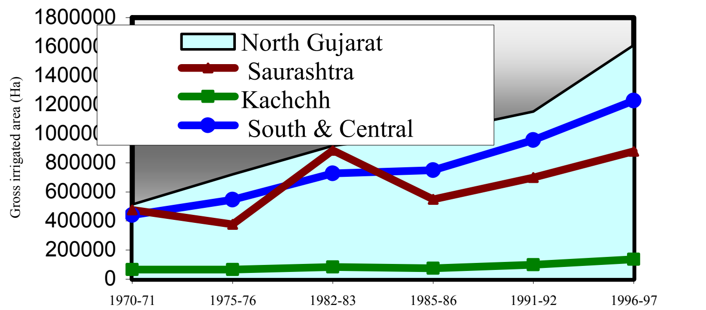
[2] In the past, farmers in the region used human power to lift water from shallow open wells. As water levels dropped, and the demand for water increased, the farmers started depending on bullock power for lifting water. With the advent of diesel engines and subsequently electric motors, the farmers started energizing their wells. Rural electrification also made a boost to this. Energisation enormously increased the irrigation potential of wells. The area under irrigation increased substantially. Increased abstraction of groundwater from shallow aquifers as a result of proliferation of wells and their Energisation led to

tube wells in 20 talukas of North Gujarat covering the districts of Mehsana, Ahmedabad, Sabarkantha, Banaskantha and Gandhinagar during 1970-71 to 1995-96.

The availability of energized wells and deep pumping technology further increased the ability of farmers to expand the irrigated area. With assured irrigation water supplies throughout the year, the farmers started taking winter and summer crops. Subsequently, the abstraction increased. Not only the area under irrigation has been much higher in North Gujarat as compared to other regions, but also the growth rate in irrigated area has been much faster (see Figure 4). The gross irrigated area in the region increased from nearly 5 lakh hectares in 25 years from 1970-71 onwards at an annual growth rate of 4.5 per cent. Today, groundwater accounts for 92 per cent of the gross irrigated area in the region (Kumar, 2002).

2.2.1 Water markets and Tube well companies

Figure 4: Irrigation Growth in Four Regions of Gujarat



Though tube well technology increased the irrigation potential, direct access to irrigation water became limited to a small section of the farmers, who were resource rich. The poor farmers had to resort to buying water from the rich well owners. The flat rate system of pricing electricity in the farm sector provided the necessary incentive for the well owners to pump out more water than what is required to irrigate their own field and sell to neighbouring farmers in an effort to recover the fixed cost of the well and the energy and to generate extra income. The water markets became the organizing feature of agriculture in the region.

Well-developed water markets exist in Gujarat for the last six to seven decades and have become more pervasive and important after the introduction of modern water lifting devices (Shah, 1989). Groundwater markets are common both in the water scarce Mehsana and in the groundwater abundant Kheda district. With the water levels falling every year, the groundwater markets become more pervasive. With the investment for well construction reaching astronomical levels, more and more farmers become vulnerable to it. The only way they could sustain their irrigated agriculture is to buy water from the neighbouring well owner.

Studies show that the water markets are vibrant institutions, and are economically and financially viable (Shah, 1993; Shah and Bhattacharya, 1993; Shah and Ballabh, 1993; Kumar, 1996; Kumar, 2000). There are several variations found in the pattern of the configuration of water markets (Shah and Bhattacharya, 1993; Gass *et al.*, 1996; Kumar, 2000; Dubash, 2001).

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over-draft conditions. The farmers subsequently drilled tube wells with high capacity submersible pumps to abstract water from the deeper aquifers.

Water markets are found to be operating, mainly in two different ways in Gujarat. In the first case, water is sold on hourly basis. In the second case, water is sold on crop share basis. Along with water, the well owner also provides fertilizers and pesticides. The sharecropper gives one third of the crop yield to the well owner for the services provided. Though the option of sharing one third of the crop with the well owner guarantees adequate and timely water delivery, this is economically less viable for the buyer. During the discussion with some of the farmers in Mehsana, it has been found that the large well owners prefer to charge water on hourly basis and doesn't care for providing other services to the buyer (Shah, 1993; Kumar, 1996).

Investment in partnership wells or tube well companies is one of the most energetic social responses to groundwater depletion. They are common in many parts of Mehsana and Banaskantha districts. With the water levels falling deep and the cost of well construction becoming astronomically high, farmers in these areas invest in partnership wells. They lay out underground pipelines for conveyance of water from the tube well location to the member farmers' fields. Tube well companies with a membership of 30-50 farmers are very common in Mehsana district. Each shareholder has a stake in the tube well company proportional to his/her land holding (Shah, 1993; Gass *et al*., 1995; Kumar *et al*., 1998).

In situations where the total land holding is less than the capacity of the well to irrigate, the group sells the water to the neighbouring farmers who do not have wells. As the marginal cost of extraction under the flat rate system is zero, this is one of the ways they could cope up with the high cost operation of tube wells. However, with the well yields declining every year, and the power supply being restricted to a maximum of 12 hours a day, it becomes practically difficult to provide efficient services to all the beneficiaries including the partners[3].

Water is given to the shareholders on demand, with an upper ceiling on the hours of watering decided by the share value. The water is charged on hourly basis and rates fluctuate across seasons with changing demand. Generally, the price of water comes down during summer, when the demand is less as compared to winter. Normally, the buyers are assured of the quantity and reliability. These tube well companies are found to be financially very vibrant.

2.2.2 The Vibrant Dairy Economy of North Gujarat

The North Gujarat region supports one of the fastest growing dairy economies. Dairying is an integral part of the farming enterprise in the region. Milk production in the region has been growing steadily over the years. The three dairy unions of North Gujarat, namely Banas dairy, Dudhsagar Dairy, and Sabar dairy, procure approximately 24 lakh litres of milk a day during the peak of winter[4].

[3] But, such situations are encountered where the shareholding pattern is highly non-uniform. It mostly affects the farmers whose share holdings are small. In such circumstances the farmers start denying the payment of water charges and conflicts emerge. The result is the breaking of partnerships. The farmers who break away from the partnership either mobilize resources to form their own well, or start buying water from the neighbouring commands to irrigate their fields.

[4] The average daily milk collection in Dudhsagar dairy, Mehsana is nearly 10 lakh litres, that in Banas dairy is 8 lakh litres and that in Sabar dairy is 6 lakh litres.

Green fodder is an important input for the livestock such as buffalos and cows. The natural availability of biomass in the form of green fodder during winter and summer is very limited in the region. Therefore, the farmers take to growing fodder grasses with the help of irrigation. The most common green fodder in the region is alfalfa, followed by *elephant grass*. While alfalfa is grown in the farms, elephant grass is grown on the farm bunds. Alfalfa is a highly water intensive crop (Kumar and Chauhan, 1995). The entire dairying is heavily dependent on the availability of and access to water for irrigating fodder crop. Almost every farmer in the region has dairy animals, maintains fodder plots, and therefore needs irrigation water for fodder, if not for other crops. The farmers who do not have wells buy water for irrigating their fodder plots.

The recent analysis carried out for the *White Paper on Water in Gujarat* showed that alfalfa alone takes nearly 675 MCM of water annually in the form of irrigation (IRMA/UNICEF, 2001). Almost the entire water is coming from pumped groundwater. Water is also needed for livestock feeding and washing. The estimates for White Paper on Water in Gujarat showed a total water use of 66.70 MCM.

2.3 The Precarious Hydrological Balance of North Gujarat Region

The total renewable freshwater in North Gujarat region is estimated to be 6015 MCM. This is based on the average gross groundwater recharge (4003 MCM) and the runoff with 75 per cent dependability (2012 MCM). Many catchments in North Gujarat are already over-appropriated (Kumar *et al*., 2000; Kumar and Singh, 2001a; Kumar, 2002). To mention a few are: Dharoi and Hathmati catchments in Sabarmati, and Dantiwada catchment in Banas river.

The catchments, which have un-utilized runoff, are Watrak sub-basin of Sabarmati river basin, downstream of Watrak reservoir; the free catchments in Banas river basin, downstream of Dantiwada and Sipu reservoirs, and those in the eastern hilly tracts. The total minimum runoff, harnessed in the region with 75% dependability, is therefore, less than the dependable runoff by 590 MCM. Here, we consider only the un-utilized runoff of Watrak sub-basin, as estimated by GOG 1994 and provided in Kumar and Singh (2001a). This means, the maximum utilizable renewable freshwater is only 5,425 MCM. The recent estimates made for the *White Paper on Water in Gujarat* showed that (in the year 1997, which is a normal rainfall year) the total water use in North Gujarat as 6,008 MCM (IRMA/UNICEF, 2001). If we consider this figure as the total water diverted annually from surface and groundwater resources in the region, the excess water has to come from mining of aquifers. The extent of mining is, therefore, 583 MCM per year on an average.

Now, out of the total water diverted from the region, 5,372.8 MCM is used up for irrigating different crops. Therefore, the water use pattern is heavily skewed towards agriculture. The region's water balance changes significantly in those years during which the rainfall departs from the normal values. Given the high variability in rainfall of the region, it is most likely to be so. In those years when the rainfall is less than the mean –standard deviation (it will be so in $1/6^{th}$ of the years), the runoff will be less than the dependable runoff. In those years, the dependence on groundwater for irrigation will increase in canal command areas.

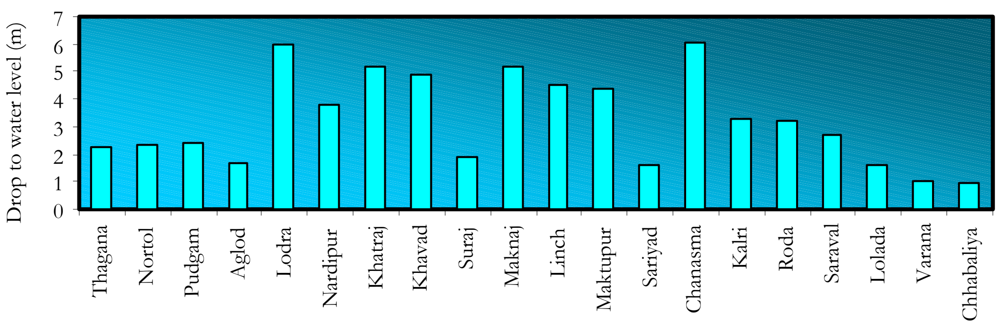
2.4 The Resource Problems, and Socioeconomic and Ecological Fallouts

With the annual abstraction exceeding annual recharge for several years now, groundwater in the shallow aquifers of North Gujarat has already depleted. The farmers are pumping water from the deeper layers of aquifers through high capacity tube wells. These confined layers are not replenished by vertical recharge from annual rains. Thus, the deep aquifers are getting mined. The alarming drops in piezometric levels manifests this. Based on 20-year observation, it has been found that the average annual drops in water levels in twenty observation tube wells vary from 0.92 metres to 6.1 metres per annum (see Figure 5) (source: CGWB 2001). The groundwater pumped from deep aquifers also contains high levels of total dissolved solids (TDS). Irrigation with saline water causes salinisation, land degradation and declining primary productivity of land (Kumar *et al*., 2001a). As the productivity of land declines, farmers try to compensate it with increased irrigation and fertilizer inputs, which further deteriorates the land. These are analyzed in detail in the Section 3.1.

Increasing levels of fluoride in groundwater, which is found to be associated with falling piezometric levels of deep aquifers, affect a large number of villages in North Gujarat. Continued exposure to drinking water containing high levels of fluoride cause problems of dental and skeletal fluorosis (Kumar *et al*., 2001a; Kumar, 2002). Large populations in the regions are affected by this menace.

Increasing social and economic cost of abstraction of groundwater is one fall out of groundwater depletion. The cost of installing a tube well with electricity connection and laying down the distribution network in the field works out to be a staggering Rs.8-10 lakh in most parts of Mehsana district. Further, the tube wells in North Gujarat have a very short life span, normally in the range of 8-10 years. Therefore, the initial investment would be quite a significant factor in determining the economic viability of well irrigation. Now, the energy required for pumping one cubic metre of groundwater is in approximately 0.38 kilowatt-hours in Mehsana. In the district, the annual electricity charge for running a submersible pump varies from Rs.20, 000-Rs.37, 500 (IRMA/UNICEF, 2001). At the societal level, the economic viability of irrigated agriculture itself is questionable. A recent analysis by Kumar and others have shown that if the full cost of electricity required for groundwater pumping is taken into account in the economic cost benefit analysis, irrigated farming would be unviable in North Gujarat (Kumar *et al*., 2001a).

Figure 5: Yearly Rate of Decline in water levels in Wells of Mehsana



The small and marginal farmers, who purchase water from well owners, pay at a rate ranging from 0.5 –1.0 rupees per cubic metre. This reduces the viability of irrigated farming even in the short run (IRMA/UNICEF, 2001). As large parts of North Gujarat is heavily drought-prone, and groundwater acts as the buffer during droughts, depletion of groundwater resources, would also increase the vulnerability of North Gujarat region to droughts.

As regards ecology, depletion of groundwater in the region also has serious impacts on the surface hydrology. Due to the lowering of groundwater levels and drying up of shallow aquifers, including the riverbed aquifers, the infiltration capacity of the riverbed soils could increase enormously. The stream flows in the free catchment areas of the river basins could therefore infiltrate down to join the groundwater table except in years of heavy rainfall and flash floods. However, no empirical evidences on rainfall-runoff relationships are available to establish how groundwater degradation impacts on surface hydrology and riverine ecology.

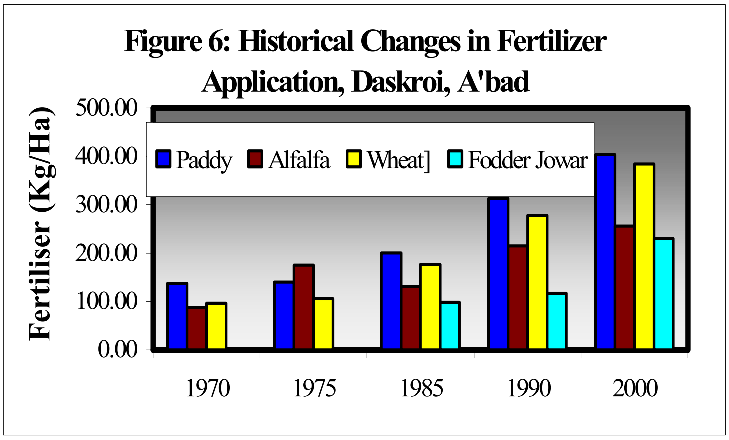
3.0 Strategy for Sustainable Groundwater Management in North Gujarat: Ways Forward

3.1 The Basic Premise

There are two major pre-requisites for sustainable groundwater management in North Gujarat: [1] increasing the recharge to groundwater on a sustainable basis locally, without causing negative ecological impacts; and [2] reduce the demand rates for water in agriculture progressively, so as to bring down the pumping rates. As regards the first one, local recharge systems alone will not be effective in increasing the recharge. **The water harvesting structures have to be complemented by catchment treatment measures, to increase the natural infiltration from rainfall, and to prevent soil erosion, which would help maintain the capacity of recharge systems. Thus integrated water resource management strategy has to be adopted**. As regards cutting down the demand for water in agriculture, the technological interventions have several limitations. They are discussed here. Farming involves the use of three different basic resources, namely land, water and biomass to produce biomass. To what extent any one of these resources shall be used for farming depends on the availability and condition of other two resources. For instance, if the land is degraded, the extent of use of water and biomass in farming will have to be increased to compensate for the potential reduction in aggregate production due to poor productivity of land.

The existing farming practices in the region, like elsewhere in Gujarat, which involve excessive use of chemical fertilizers and irrigation water, lead to salinization of land and its consequent degradation. These changes had major imperatives for irrigation water requirement of crops. The following paragraphs illustrate the process of degradation of land.

One immediate consequence of groundwater level drops and drying up of shallow aquifers was the adoption of tube well technology. Though tube well irrigation was costly for the farmers, the technology turned out to be a blessing in disguise for them in the initial years. Tapping of groundwater from confined systems through tube wells resulted in higher well yields throughout the year and round the clock. The immediate impact of this was the expansion in area under irrigated crops and cultivation of irrigated summer crops. The land, which used to receive irrigation water only once in a year, started getting water in most of the cases in two seasons, and in a few cases in three seasons.



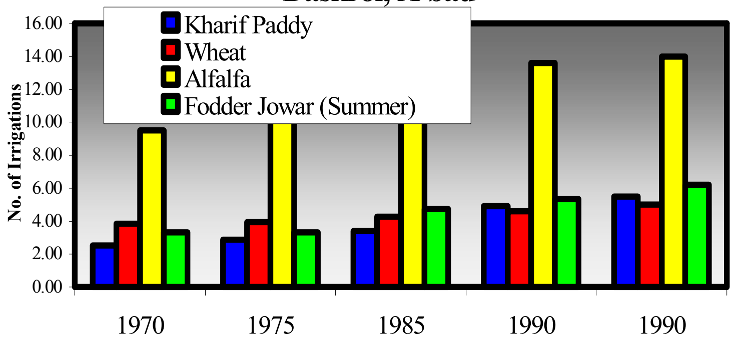
Excessive irrigation resulted in leaching of minerals and organic matter in to the soil. As irrigated area increased, availability of organic manure per unit area of cultivated land got reduced substantially. Chemical fertilizers had to be used in greater quantities. This, in a way, substituted for the organic, bio-fertilizers, which fell far short of the requirements. The chemical fertilizers enhanced the secondary productivity of the soils. On the other hand, the organic fertilizers were necessary to maintain the soil structure; provide necessary soil nutrients; and maintain the primary productivity of the soils. Increased fertilizer use also became necessary for modern farming using green revolution, hybrid varieties.

Figure 6 shows the historical changes in the intensity of fertilizer application for three major crops in Daskroi taluka of Ahmedabad (source: Kumar *et al*., 2001a). The bars show the rising trend in the use of fertilizers (urea and di-ammonium phosphate) per ha of land. The intensive use of fertilizer was accompanied by increased rate of application of irrigation water. This resulted in breaking of soil structure. In a nutshell, three major changes in land use occurred and had serious implications for land productivity; increase in cropping and irrigation intensity; increased rate of water application for each of the irrigated crops; and increased rate of application of fertilizers.

Irrigation with saline groundwater is leading to soil degradation in the groundwater irrigated areas. A study carried out by GUIDE in 2000 cites groundwater over-exploitation as one of the major causes of inland salinity in Gujarat, like increased use of fertilizers, and lack of soil nutrient management practices (Singh *et al*., 2000).

Farmers are continuing irrigation with the saline groundwater in these areas. Irrigation with high TDS groundwater is also leading to increase in soil salinity causing hardening of soil surface and lump formation. In order to break the soil lumps to enable better growth of crops, the farmers had to increase the water application rates. Thus, over a period of time, more salts get accumulated on the soil surface and thus the soils become saline. Excessive irrigation to leach the salts causes faster loss of organic matter and nutrients present in the soils. All these ultimately result in soil degradation. This leads to decline in water productivity and land use productivity of biomass production. As a consequence, the farmers continue increasing irrigation inputs for their crops. Figure 7 shows the historical changes in water application rates for four crops, namely paddy, alfalfa, wheat and jowar, grown in Daskroi taluka of Ahmedabad district. It shows that the water application rates for these crops (in terms of total hours of water per unit area) had increased consistently and remarkably.

Figure 7: Historical Changes in Irrigation Rates, Daskroi, A'bad



This reinforces the point that unless productivity of land, the basic resource for farming, is not managed, the ability of water-saving technologies to improve the productivity of water (efficiency of water use) in the region will be severely limited.

There are several on-farm management practices that the farmers in North Gujarat region can practice. These practices, if carried out consistently, can progressively reduce water requirement of the existing crops, along with improving primary productivity of the cultivated land. They are increased use of organic manures gradually reducing the extent of use of chemical fertilizers, vermin-culture, and agronomical practices such as mulching, crop rotation and use of bio-pest control measures. Organic manure can help regain structure and texture of soils and enhance their moisture retention capacity along with improving soil nutrients. Use of farm management practices such as mulching can reduce the evaporation from soil surface thereby increasing the efficiency of utilisation of irrigation water. A recent study of organic farming practices adopted by nearly 250 farmers in Gujarat showed that over a period of three years, the irrigation water requirement of the crops in the organically farmed field, had reduced by half.

In a nutshell, in order to increase the water productivity of biomass production, the primary productivity of land needs to be increased through nutrient management measures, along with increasing the biomass inputs to increase the efficiency of utilisation of irrigation water. In order to increase overall productivity[5] of land, the

[5] It is the sum of primary productivity and secondary productivity.

moisture retention capacity of soil needs to be enhanced along with increasing the biomass inputs. Thus, there is a need to manage land, water and biomass in an integrated manner.

3.2 Fountainhead of the Strategy

The major concern in the case of North Gujarat are to ensure: [1] sustainable management of groundwater resources, with due considerations to prevention of soil erosion, without compromising on ecological balance; and [2] management of present and all future demands of water in agriculture without compromising on the economic outputs, with due considerations to improving the productivity of land and water, thereby ensuring sustainability of irrigated agriculture, and social advancements and environment. Going by Mitchell (1990), this calls for integrated water management with three major, but distinct concerns: integration of various interdependent components of natural water resource system—surface water, groundwater, catchments--; integration of natural water system and other ecological systems; and inter-relationship between environment and socioeconomic development in the region.

3.3 The Local Strategies for Integrated Water Management

The local options for integrated water management that address these three concerns are: [1] local water harvesting and recharge activities to augment groundwater and surface water supplies, using an over-arching framework of river basins so as to reduce negative hydrological and ecological impacts downstream; [2] wasteland re-vegetation in the catchment areas of the local water harvesting systems so as to reduce soil erosion and to increase the natural rate of infiltration of rainwater; [3] integrated land and water management practices using a biomass-based approach in the farmers' fields for reducing the irrigation water requirement of crops and increasing land and water use productivity; and [4] water-saving technologies to increase the physical efficiency of water use in agriculture.

The specific strategies are:

- Check dams in the hilly areas in the eastern part of Banaskantha, north-eastern parts of Mehsana, and Northern parts of Sabarkantha;
- Percolation tanks with recharge tube wells in the deep alluvial areas of Banaskantha, Mehsana, Gandhinagar, and Ahmedabad districts;
- Wasteland re-vegetation, specifically grass plantation, in the main recharge area located in the foothill of Aravally ranges;
- Organic farming practices with FYM produced from the biomass of trees and animal dung, and mulching;
- Irrigation using small, level borders for irrigating field crops, with plastic-lined (LDPE lining) channels for water conveyance to the field.
- Water saving technologies for irrigation, which include:
  - Pressurized irrigation systems (micro-sprinklers and mini-sprinklers) for alfalfa, elephant grass, potato, coriander leaves and onion
  - Big sprinklers for wheat, mustard, bajra, and jowar
  - Pressurized conventional drips for row crops, viz. castor, cotton, fennel, chilly brinjal,
  - Micro-tube drips for horticultural crops, viz. chickoo, mango, lemon, and papaya.

- Sub-surface irrigation systems (gravity flow type) for crops, viz. alfalfa, potato, and several of the horticultural and row crops.

4.0 The North Gujarat Sustainable Groundwater Initiative

In recognition of the groundwater depletion problems and their adverse socioeconomic and ecological impacts, the International Water Management Institute launched a project on community-based local groundwater management in North Gujarat. In order to explore and experiment a variety of local options for groundwater management that would address supply and demand side issues in water management in terms of their impacts on the hydrological regimes, and the livelihoods, an action research project is initiated in 30 villages of Banaskantha district.

4.1 The Goal and Objectives of the Project

The goal of the project is to develop, local groundwater management regimes for the poor, based on technically sound, socially and economically viable and replicable practices, that strengthens the livelihoods of the poor through participatory resource management approaches.

The objectives of the pilot project will be:

1. Establish a groundwater management regime involving demand and supply side approaches that rely on a strong footing laid by a powerful education campaign on water.

2. Study the impacts of the comprehensive intervention on the water balance, livelihoods, agricultural and dairy economy of the pilot villages assessed through project monitoring systems as well as independent studies and assessments.

3. Lay the groundwork for a larger, regional sustainable groundwater initiative based on lessons learnt from the pilot.

4.2 Action Items

Following are the major, specific action items to be achieved to realise the project objectives.

Objective 1*: Establish a groundwater management regime involving demand and supply side approaches that rely on a strong footing laid by a powerful education campaign on water.*

2. Mass awareness and educational campaigns
3. Preparation of plans for local resource management interventions using participatory approaches.
4. Building of water harvesting structures such as tank de-silting, construction of percolation tanks, check dam, and wasteland re-vegetation through community involvement.
5. Field trials and demonstrations of low-cost, water saving technologies such as drips and sprinklers (both conventional and non-conventional) on a variety of crops such as alfalfa, castor, cotton, potato and wheat.
6. Promotional and market support activities for low cost drips and sprinklers

7. Training and demonstration on integrated land and water management practices in farmers' fields.

Objective 2: *Study the impacts of the comprehensive intervention on the water balance, livelihoods, agricultural and dairy economy of the pilot villages*.

1. Benchmark studies on hydrology, agricultural water use, livelihoods, and farm economy in the pilot villages
2. Participatory groundwater and water use monitoring in the pilot villages
3. Project monitoring, independent impact assessment studies

Objective 3: *Lay the groundwork for a larger, regional sustainable groundwater initiative based on lessons learnt from the pilot*.

1. Documentation of participatory planning and implementation processes
2. Documentation of the results of field trials with low cost water saving technologies; and impact studies and assessments.
3. Dissemination of learning to within and outside the project areas

5.0 Constraints in and Opportunities for Integrated Water Management

The degree of success in implementation of any field project lies in identifying the variety of constraints posed, and the opportunities provided by the existing physical, social and cultural environment, and the socio-economic and institutional setting. This will help identify the technical feasibility and socioeconomic viability of the options vis. a vis. geographical locations and target groups. Here, an attempt is made to analyze the range of physical, socioeconomic and institutional constraints and identify the opportunities in operationalizing the project on sustainable groundwater management, using the integrated water management approach.

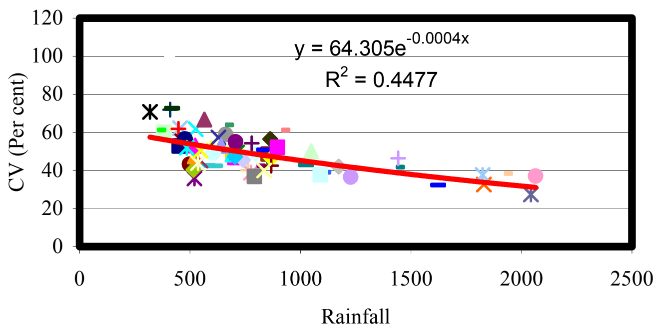
5.1 Augmenting Water Availability: Constraints and Opportunities

5.1.1 The Hydrological Constraints in Providing Reliable Local Supplies

Due to high inter-annual variability in rainfall and runoff, the reliability of local water harvesting systems could be extremely poor. The catchment areas, which the local water harvesting systems integrate, are normally very low. According to the study carried out by the Tahal Consultants for the Government of Gujarat, for a catchment of 1.0 sq. km (100 ha), the average mean runoff potential with 50 per cent dependability will be 0.06 MCM for North Gujarat (GOG, 1996). The following inferences can be drawn from this data. First: for a 100 ha catchment, the average runoff of North Gujarat (with 50 per cent dependability) in some of the good rainfall years will be less than 60,000 m^3 and more than 60,000 m^3 in some other. This variation is due to the possible variation in the runoff within those 50 per cent years. Second: for a 100 sq. km catchment, the runoff in the poor rainfall years (having more than 50 per cent dependability) will be far less than 60,000 m^3.

Now, what is discussed in the above paragraph is the average situation for the region. There is the high spatial variation in the mean annual rainfalls (as seen in Section 2.1.1), with corresponding variation in the runoff rates. The mean values of 50 per cent dependable runoff will be low in the low rainfall areas. Again, as Figure 8 clearly indicates, there is higher inter-annual variability in the annual rainfalls in areas of low mean annual rainfall (Kumar, 2002).

Figure 8: Relation between rainfall and its variability



The gradient of runoff dependability curve will be high in the low rainfall areas. Due to these two factors, the runoff corresponding to high dependability will be extremely low in the region. The chances of getting zero runoff are potentially high in several areas. The very low surface water potential is one major constraint for local water harvesting for direct uses in irrigation and drinking water supplies.

The existing irrigation schemes pose constraints for building of new water harvesting schemes in good catchment areas of the region. The potential for local water harvesting is low in the upstream of the catchment areas of Dharoi, Dantiwada, Watrak, Mazam, Hathmati, Guhai, Waidy, Indrasi and Meshvo.

5.1.2 Socioeconomic and Institutional Constraints

First: the effectiveness of water harvesting systems is heavily dependent on the ability of the communities to mobilize the human and material resources needed for carrying out the physical activities involved. The water harvesting structures that are technically viable in most parts of the region are "percolation tanks with recharge tube wells" due to the reason that the alluvial aquifers that are being tapped are very deep. The design and construction of these water-harvesting systems involve technical considerations of the hydrology (rainfall, runoff, catchment areas, number of large rainfall events etc.), geology (formation structures, etc.), and geo-hydrology (depth to groundwater levels, quality of groundwater).

This would require high level of technological inputs from experienced water engineers, hydrologists and geo-hydrologists due to the complicated design features to make them function effectively. Today, such expertise is available with the scientific agencies such as the Central Design Office of the Department of Narmada, Water Resources and Water Supplies, the Central Ground Water Authority (CGWA) and is hardly available locally with the NGOs or community organizations. The local NGOs and community groups rather prefer to follow certain ad hoc norms for designing the systems than approaching these government bodies, in lieu of the long procedure involved. Improper design affects the performance of the systems adversely.

The absence of adequate number of non-governmental and voluntary agencies with sufficient expertise and commitment towards promoting local water harvesting and water management, unlike Saurashtra is also an issue.

Second: construction requires heavy earth moving equipments like the bulldozers and shovels, and drilling rigs. These are too expensive for the local communities to afford. As on today, only the Motibhai Foundation of Mehsana is having such equipments that are made available at reasonable rents to the local communities for use. The installations such as the recharge tube well with the filter pit required for the water harvesting/recharge systems are also expensive. The total cost of de-silting, deepening of tanks and installation of recharge tube wells would work out to be 1-5 lakh rupees per tank, where in the case of construction of check dams the cost of one structure works out to be in the range of Rs.20, 000-Rs.1, 00,000 depending on the size of the structure. Though the participatory water conservation scheme launched by the government provides opportunities for the communities to tap government funds to construct the structures, people's contribution of 40 per cent required works out to be much higher than what the communities could afford.

Third: planning of local water harvesting systems (LWHSs) should involve the fundamental consideration that the local catchments are integral parts of the river basins in which they fall. Unfortunately, planning and construction of LWHSs, being undertaken by various agencies including government bodies, seem to have ignored this hydrological reality. They fail to think beyond the geographical area of operation, which is a village. This "hydro-schizophrenia" has led to over-estimation of the potential of local water harvesting.

5.1.3 The Hydrological Opportunities for Recharging

While on the one hand, the high inter-annual variability in the rainfall and runoff reduces the reliability of local water harvesting systems, on the other hand, it increases the opportunities available for these systems. The excessively high runoff generated in some of the years increases the potential of local water harvesting systems in terms of the amount of runoff that is available for harnessing. For instance, based on the historical data of rainfall (point rainfall) in Idar located in Sabarkantha district (also falling in Hathmati sub-basin of Sabarmati river basin), once in every six years, we can have a minimum rainfall of 1348.34 mm in Idar. The runoff corresponding to this rainfall (on the basis of the rainfall-runoff relationship established for Hathmati sub-basin as per GOG (1994) is 0.39 MCM from a catchment area of 1.0 sq. km in Hathmati sub-basin of Sabarmati basin. Thus the quantum of water, which is generated from 100 ha of catchment with a probability of occurrence of 16.7 per cent, is sufficient to irrigate nearly 78 hectares of land in one season, if one assumes a delta of 0.50 metres for the winter crop.

Such large potential for water harvesting exists in areas with similar topography, rainfall and soils in other parts of Hathmati sub-basin downstream of the reservoirs and weirs, which are falling in Ahmedabad and Sabarkantha districts. In areas such as Danta, in the eastern hilly tracts of Banaskantha, which is topographically similar to Dharoi cachment, located inside Sabarmati basin, the minimum runoff that will be generated once in 6 years will be 555 mm. This means, a catchment of 1 sq. km can generate a runoff as high as 0.555 MCM, which if captured underground can irrigate an additional area of nearly 110 hectares.

Table 3: Rainfalls and Runoff Rates in Hathmati and Dharoi sub-basin area

Name of the Basin	Name of Sub-basin	Name of Station	Mean Annual Rainfall/ STD	Highest Rainfall with 1/6th Probability (mm)	Rainfall-Runoff Relationship	Estimated Runoff (mm)
Sabarmati	Hathmati	Idar	920.34/428	1348.34	$0.00193*r^{2.022}$	390.60
Sabarmati	Dharoi	Danta*	795.82/387.51	1183.34	$0.0125*^{r2.6019}$	559.00

Source for rainfall-runoff relationship: GOG 1994

*Located close to Dharoi catchment

In Mehsana and Banaskantha, the potential for local water harvesting is great due to the fact that mostly the local catchments of rivers, namely, Rupen, Saraswati and Banas, are not integral parts of large catchments that are harnessed, or in other words, they are free catchments. The exceptions are the areas up stream of Dantiwada and Sipu reservoirs in Banaskantha, and Dharoi reservoir in Sabarmati. The upper catchment areas of these reservoirs that are falling in these districts are quite small.

The large depth of unsaturated zones in the depleted alluvial aquifers provides excellent opportunities for recharging. This is complemented by the sandy soils, and the presence of several hundreds of local ponds that act as the sink for the local sheet runoff generated in those parts of the region that are relatively plain.

5.1.4 Socioeconomic and Institutional Opportunities

The North Gujarat region is unique in terms of the range of group enterprises for economic development. The three districts of Mehsana, Banaskantha and Sabarkantha have very vibrant dairy cooperatives. Almost every village in the region is having a village dairy cooperative with apex unions at the district level. The stakes that the dairy cooperatives have in water cannot be over-emphasized.

The apex cooperatives can help the village dairy cooperatives in channelising necessary technical inputs (such as regional/basin planning); and mobilizing financial resources for equipments. The financial resources can come from the cooperatives themselves. The village dairy cooperatives can be instruments for leveraging social actions for implementing local water harvesting systems. Since these cooperatives posses their own system of accounting, which are transparent, and they being legal entities, it would be possible for the governmental and non-governmental organizations to channelize the financial resources needed to carry out the water harvesting activities.

5.2 Organic Farming Practices for Reducing the Demand for Water in Agriculture: Constraints and Opportunities

5.2.1 Socioeconomic Constraints in Adopting Organic Farming Practices

Farmers in this region use Farm Yard Manure (FYM) or compost in a given plot only once in three years. They use cattle dung and straw for preparing FYM. However, the practice followed for this is highly unscientific and the efficiency of utilisation of biomass is extremely low. Studies show that if scientific methods of composting are practiced, the efficiency of production of FYM can be substantially increased (Datye, 1998; Paranjape and Joy, 1995). The farmers need to practice scientific methods of composting in order to increase the effective availability of organic manure for farming. This is the first constraint.

The second constraint is the availability of biomass for preparation of organic manure and mulching. Cattle dung is the major source of biomass. The other sources of biomass are crop residues, and trees. Farmers use cattle dung for preparing “dung cakes” (to be used as domestic fuel) apart from using it for compost making. They often use leaves and branches of the trees planted on the farm bunds for feeding cattle during drought years, apart from using it for compost making. On the other hand, crop residue is an important source of fodder and domestic fuel. While increase in cattle holding per family can increase the availability of biomass, the requirement of biomass for fodder will also increase, which would increase the water requirement for growing fodder. This means, the farmer should have a matching size of land holding at his/her disposal to generate surplus biomass (green fodder and crop residue for dry fodder), which can be used as cattle feed and farm input, without using exogenous water inputs. For a farmer, the availability of surplus biomass for best farming heavily depends on how he/she is positioned with respect to cattle vis. a vis. land holding, his ability to invest for efficient compost making practices; and find alternative sources of fuel for cooking.

This means that small and marginal farmers who own cattle are likely to face severe constraints in shifting to more sustainable ways of farming. At the same time, farmers having large holdings along with cattle are likely to experience relatively lower stress in managing their biomass needs. One main reason for this is the fact that the size of cattle holding is not proportional to the land holding size. As a matter of fact, livestock keeping and dairying have become the most important source of livelihood for the small and marginal farmers of the region, due to the reason that their ability to generate sufficient income from irrigated farming, with increased dependence on purchased water, is reducing. This means, the percentage of farmers, who are likely to face difficulty in adopting sustainable agricultural practices, will be higher in districts such as Mehsana, Gandhinagar and Sabarkantha.

Table 4 shows that small and marginal farmers account for 43.7 per cent (21.45+22.22) of operational holdings in the case of Ahmedabad district, 68 per cent in the case of Gandhinagar district, 34.64 per cent in the case of Banaskantha district, 56.53 per cent in the case of Sabarkantha district, and 60.65 per cent in the case of Mehsana district. They control only 11.62 per cent of the operational holdings in the case of Ahmedabad.

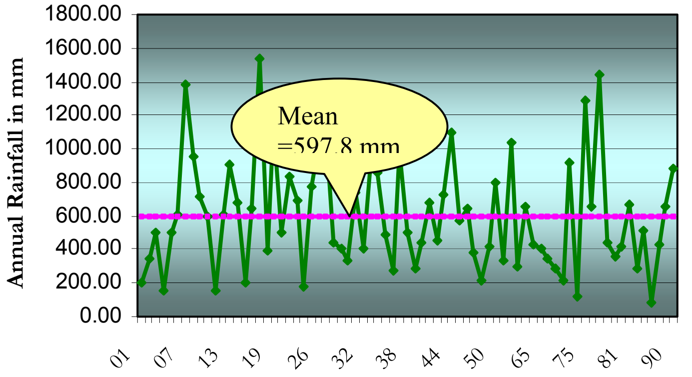
Table 4: Pattern of Ownership of Operational Holding in the Five Districts of North Gujarat

Type of Farmer	Percentage number and % area of operational holdings in				
	A'bad	G'nagar	B'kantha	S'kantha	Mehsana
Marginal (<1.0 ha)	21.45/3.01	39.69/10.59	13.00/1.81	32.67/7.77	33.16/8.20
Small (1.0-1.99 ha)	22.22/8.61	28.44/20.61	21.64/7.97	23.86/19.27	27.49/17.62
Semi-Medium (2.0-3.99 ha)	24.87/18.74	21.16/30.04	29.19/20.69	23.86/30.14	23.44/29.26
Medium (4.0-9.99 ha)	24.26/39.81	10.18/29.83	29.80/44.89	12.85/33.16	14.42/34.77
Large (> 10.0 ha)	7.20/29.83	0.53/10.05	6.37/24.66	1.24/9.66	1.49/10.15

Source: Dutta, Rajashree. A (1997)

5.2.2 Physical Opportunities for Increasing Biomass Production

Figure 9: Historical Annual Rainfall in Deesa (1901-90)



As the earlier analyses have shown, the level of use of organic manure or FYM in farming needs to be increased substantially to arrest the process of degradation of the soils and to enhance the water use and land use productivity of biomass production (Datye, 1998; Paranjape and Joy, 1995). One main reason for the low level of use of organic manure in agriculture in the region is the shortage of biomass. The other, of course, is the unscientific composting practice that result in low level of efficiency in the production of biomass. The challenge is to produce surplus biomass that can be used as input for farming, without causing any increase in the dependence on exogenous water for producing biomass in the form of fodder and leafy biomass.

The only endogenous source of water is rainwater. As we have seen, hydrology of North Gujarat region is characterized by high inter-annual variability in the rainfall. Figure 9 shows the historical rainfall in Deesa for the period 1901-90. The mean annual rainfall is 597.8mm. But the station received rainfall in excess of the mean rainfall in 34 out of 90 years. In ten years, the annual rainfall was more than 1000mm. In those years, the number of rainy days is also high. During the high rainfall years, the farmers can take up plantation of trees in common land as well as private land. The resistance of trees to moisture stresses is high, by virtue of which they would survive even during years of low rainfalls and droughts. In the absence of moisture in the soil moisture zone of the sub-surface strata, the deep-rooted trees can such the water in the vadose zone, which is also known as the hygroscopic water. Once matured, the trees will provide biomass throughout the year.

In the case of plantation on private land, the farmers with large holdings can adopt block plantation and those with smaller holdings can adopt peripheral plantation. In the case of common land, soil moisture conservation measures can be adopted.

On-farm water conservation practices such as construction of "farm bunds and farm ponds can also be taken up to ensure availability of moisture and water, necessary for the growth of trees. Farmers in the region practice farm bunding widely, which help store field runoff generated during the high rainfall years.

5.2.3 Socioeconomic and Institutional Opportunities

One of the ways to produce surplus biomass for use as input in agriculture as a part of the overall strategy for sustainable agriculture is to go for rain-fed crops in large areas that would yield sufficient green fodder during Kharif and dry fodder during other seasons, and crop residues for mulching and compost making. However, this is viable only in the case of farmers having large holdings. By virtue of the pattern of operational holdings, the percentage of farmers, who can adopt sustainable agricultural practices, is likely to be higher in Banaskantha and Ahmedabad. The percentage of farmers belonging to the medium, and large holding, is these two districts, are 36.17 per cent and 31.46 per cent, respectively (derived from Table 4).

For the small farmers, the amount of biomass obtained from Kharif crop is hardly sufficient to meet their requirements for dry fodder throughout the year. For this group of farmers, one of the ways to increase the biomass production is to go for peripheral tree plantation, which would not lead to any reduction in area under agricultural crops.

The other way is to go for community plantations. The region has sufficient amount of wasteland, which are under the official ownership of either the village Panchayat or the revenue department. The land can be transferred to the village dairy cooperatives, they being legal entities, for taking up plantation activities under wasteland re-vegetation programme. The village dairy cooperatives can take up plantation of tree crops, grasses and some of the green fodder. The members of the dairy cooperatives are likely to show interest in wasteland re-vegetation due to their direct stake in biomass for fodder and organic manure.

5.3 Technological Interventions for Reducing the Demand for Water in Agriculture: Constraints and Opportunities

5.3.1 Physical Constraints in Adopting in Water Saving Technologies

If we do not consider harder options such as shifting to less water intensive and more economically efficient crops (crops that use less amount of water per unit area and yield high returns per every unit of water used) and moving out of agriculture, there are two major pre-requisites for reducing the overall demand for water in agriculture in the region. They are reducing the intensity of water application for the crops by increasing the efficiency of water utilisation, or in other words reducing the wastages in irrigation practices, and maintaining the area under irrigation.

The time-tested, and widely available technology for increasing the efficiency of water use is use of pressurized irrigation systems such as sprinklers and drips. However, their adoption is very low in North Gujarat region, especially in the alluvial tracts comprising Mehsana, Banaskantha, Ahmedabad and Gandhinagar. This is in spite of the fact that the capital investment for irrigation facilities is of the order of 3-10 lakh in the region and the economically accessible groundwater has become very scarce over the years. While, there are several constraints at the field level, which limit the adoption of this technology by the farmers, some of the very critical ones that are physical in nature are analyzed here.

First of all, almost the entire alluvial part of the region is irrigated by 17,500 tube wells. A large number of farmers in districts, namely, Mehsana, and Banaskantha receive water from tube wells owned by groups. A large number of others secure irrigation water through water purchase. They get water through underground pipelines at almost negligible water pressure (head). These farmers constitute a major chunk of the irrigators in the region. In order to use the conventional sprinkler and drip systems, great amount of water pressure (1.0-1.2 kg/cm2) is required. Unless the systems are directly connected to the tube well, the required amount of "head" to run the sprinkler and drip system cannot be developed. If the systems are not connected to the delivery pipe of the tube wells, a static head of nearly 12 metres is required to run the sprinklers. This is a major constraint for both the farmers who purchase water and those who are partners in jointly owned wells.

Another important constraint is the poor quality of groundwater that is pumped from the deep aquifers of the region. Due to the high TDS level of the pumped groundwater (the TDS levels are as high as 2000 ppm (parts per million) in many parts of Mehsana and Banaskantha where groundwater is still being used for irrigation), the drippers that are exposed to sunlight get chocked up due to salt deposition in the dripper perforations. This needs regular cleaning using mild acids like the hydrochloric acid. This is a major maintenance work, and farmers are not willing to bear the burden of carrying out this regular maintenance.

5.3.2 Physical Opportunities for Creating "Wet Water"

Apart from the conventional water saving irrigation technologies, there are new irrigation technologies, which do not require pressure head for their running such as sub-surface irrigation systems and the micro-tube drips. Those farmers who get water through underground pipelines can lift it to small heights to generate the required head for running the sub-surface drip system so as to make it capable of delivering adequate discharges. Thus, the technical feasibility of using the new non-conventional water saving technologies is high among the farmers who are either members of the tube well companies or the water buyers.

On the other hand, technical feasibility of using conventional water saving technologies is relatively high among all the tube well owners in Mehsana, Banaskantha, Gandhinagar and Ahmedabad, and those farmers who have individually owned dug wells (in Sabarkantha district).

If we get the farmers to adopt the water saving technologies, on the other hand, the actual scope for water saving exists in the areas where groundwater levels are deep. With the conventional irrigation practices (small border and furrow irrigation), a significant amount of water is lost in evaporation from the land surface. Secondly, the return flows from irrigation do not percolate deep to join the groundwater table. The reason being that the depth of groundwater table is in the range of 60 metres to 135 metres. The vadose zone (the zone between the capillary zone and the soil moisture zone), the depth of which ranges from 60-135 metres, holds the water moving vertically downwards as hygroscopic water. This water later on gets sucked away by the deep-rooted trees around the farms during the non-rainy season.

Nevertheless, in areas where groundwater levels are still within 30 metres below ground level, the saving in water achieved through the introduction of water saving technologies would only result in saving in pumping cost, but not overall saving in water from the system, the reason being that the a good share of the excess water used in irrigation under the traditional irrigation practices finally goes back to the groundwater system.

5.3.3 Socioeconomic and Institutional Constraints

Power supply regulation is a major constraint in the adoption of pressurized irrigation systems in the case of jointly owned tube wells. Given the fact that the available power supply is fully utilized during the seasons such as winter and summer), the amount of time for which the tube well will be operational will be just sufficient to irrigate the entire command. This is because the discharge of the tube well would decline sharply when the sprinkler and drip systems start running due to increase in pressure developed (please see equation below), though the water requirement for unit area of irrigated land would reduce due to the new water application technique. Due to this reason, the farmers might not have significant incentive to adopt the conventional pressurized irrigation systems. Creating overhead storage for the pumped water to generate adequate pressure will not be an economically viable proposition.

$$\mathbf{Q = BHP*75*n/H*w}$$

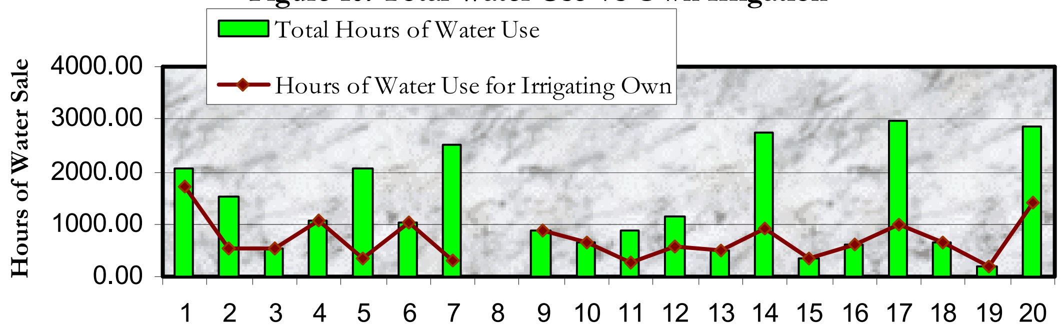
where, “BHP” is pump horsepower, “H” is the total head, “Q” is the discharge and “w” the specific weight of water.

Another major socioeconomic constraint in adoption of conventional water-saving technologies is the existing cropping patterns in the region. Among all the water saving irrigation technologies, which are now easily available in the market, the conventional drip irrigation systems are the best in terms of achieving highest physical efficiency of water use. These systems are best adaptable for horticultural crops. Percentage area under horticultural crops is very small is North Gujarat. Very few farmers in the region grow crops such as mango, chickoo, lemon, *ber* and guava.

The system can be used for some of the row crops such as castor, cotton and (fennel) *variali*, which are very common in the region. However, to use the system for these crops, it is very important that the farmers maintain a fixed spacing between different rows and different plants. So far as maintaining the spacing between rows is concerned, farmers pay sufficient attention. But, spacing between plants is not maintained. Due to this un-even (un-favourable) field conditions, designing and installing drippers become extremely difficult. Therefore, for adoption of these water saving technologies, the farmers’ agricultural practices need major changes.

Further, there are crops such as paddy for which neither drips nor sprinkler irrigation systems are feasible. Paddy is an important crop in Ahmedabad district. Adopting suitable cropping patterns that would increase the adoptability of water saving technologies is one strategy. But, as mentioned in the beginning of the section, "crop shift" is a harder option for farmers. **The socio-economic viability of crop shifts increases with the size of the operational holding of farmers**. Given the fact that small and marginal farmers account for large percentage of the operational holdings in Mehsana, Gandhinagar and Sabarkantha (see Table 4), the adoptability of horticultural crops by farmers in these districts will be very low. This is because these crops need at least 3-4 years to start yielding returns. It will be extremely difficult for these farmers to block their parcel of land for investments that do not give any returns in the immediate future, say after a season or so.

Figure 10: Total Water Use Vs Own Irrigation



In the case of tube well owners, who have good sources of water supply, the present institutional framework does not provide clear economic incentives to use water efficiently. Under the present flat rate system of pricing, the marginal cost of pumping and using groundwater is zero. Though it is the opportunity cost of using water, which influence farmers' decision-making framework, such opportunity costs are not felt clearly, in spite of the water markets. The reason being that the demand for water from the water buyers (in terms of the hours of irrigation service) and for ones own irrigation use, is much less than the number of hours for which the farmers could run their pumps. For instance, a survey of 19 tube well owners carried out in Daskroi taluka of Ahmedabad district showed that the total hours of pumping including that for providing irrigation services to the neighbouring farmers (over the three seasons) is in the range of 80 hours and 2930 hours. Most of them are found to be in the range of 1000 hours. But, the hours for the farmers could run the pump is as high as 3600. In such cases, the direct additional financial returns from irrigated farming, which the farmers can get by introducing water saving technologies, are from the increased crop yield. This will not happen unless the farmer adopts new agronomic practices.

Therefore, the farmers would rather prefer to pump extra hours (equal to the hour equivalent of water he otherwise would have wasted) to sell water to the needy farmers than trying to use water more efficiently in his field which involve substantial financial investments[6]. The reason being that the economic efficiency of water use for the irrigated crops grown in the area even with the current inefficient practices is much higher than the price at which water is traded.

Conventional water saving technologies will be physically and economically less feasible for smaller plots due to the fixed overhead costs of energy, and the various components of these irrigation systems such as filters, overhead tanks. The following equation calculates the pressure "head" required to pump water for running pressurized irrigation systems.

$$\mathbf{P_{(req\cdot)} = (P_2 + P_L)/w + Z}$$

Here, P_{req}. is the residual pressure required at the well outlet. P_2 is the pressure required at the sprinkler nozzle or dripper and P_L is the pressure loss during conveyance of water from the tube well to the sprinklers or the drips. Z is the difference in elevation. If the sprinkler systems are located at a higher elevation than the pump outlet, then 'Z' will be negative. The equation shows that the additional energy required for running the system will reduce with every additional sprinkler, the reason being that only the pressure loss increases with increase in number of sprinklers.

5.3.4 Socioeconomic and Institutional Opportunities for Water Saving Technologies

The situations where the farmers will have strong incentive to go for conventional, pressurized irrigation systems are those where the amount of water that can be pumped from the wells is far less than what the crops would require to irrigate the fields under traditional methods. For example, dug wells and bore wells in hard rock areas of Sabarkantha district have very poor yield and well owners leave a part of their land fallow due to shortage of water. The farmers will have to discontinue pumping after 2-3 hours for an equal or more number of hours for the wells to recuperate. When pressurized irrigation systems are used, the rate at which water will be pumped with reduce. This will also give enough opportunity time for pumps to recuperate. Since, pump will eventually run for more number of hours, pumping out the same quantity or more water, the command area will increase.

The new water saving technologies such as the sub-surface irrigation systems and the micro-tube drip systems discharge water to at very low rates like the conventional drips and sprinklers. At the same time, they only need very low pressure to run. In the case of large tube well commands, if a low height overhead tank can be constructed in the middle of the command, the hours of water delivery can be increased from 10 hours of watering a day to 24 hours for the entire command. This will not only ensure that the entire command is covered, but also an additional area is irrigated. This is because the discharge of the tube well remains unaffected, but the water requirement reduces significantly. Instead of applying water in weekly intervals, the fields can be irrigated daily or on every alternate day. This is important from the point of view of increasing the physical efficiency of water application like *storage efficiency*. The

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[6]The cases, where all the farmers in a command use from a jointly owned well, however, are exceptions. In such cases, since the hours of delivery for each farmer, for a given amount of shareholding is limited, the farmers try and use the water more efficiently within the constraints imposed by the physical conditions (Kumar, 2000).

storage efficiency will be more when the amount of water applied is less than or equal to the field capacity of the soil. Different holdings can be covered in rotations over a day.

The existing institutions that have evolved around the use of groundwater such as the tube well companies, and the groundwater irrigation cooperatives provide great future opportunities for large-scale adoption of new water saving technologies from the socio-economic point of view, though the technical feasibility of conventional water saving technologies is very low. In such joint ventures, the cost per unit area of the system could be significantly brought down, as additional cost of equipments will be shared amongst a large number of farmers.

The factors that increase the socioeconomic feasibility of new water saving technologies are: 1) the operational rules of these irrigation organizations are based on principles of equity, and these rules are strictly followed by all the farmer members; and 2) there is a great deal of transparency and accountability in the transactions, including water allocation, payment and collection of water charges, operation and maintenance works, and account keeping; 3) the groups are already conversant with the operation of tube well systems, which are very sophisticated systems and the chances of building the required level of confidence in running such water saving irrigation systems are likely to be very high. These groups can invest in overhead tanks and distribution systems, from which water can be directly taken to the irrigation devises.

5.4 Summary

The analyses, both qualitative and quantitative, show that while there are constraints for certain technologies and approaches, these constraints become opportunities for promoting new technologies.

First: there are constraints in providing adequate quantities of reliable water supplies, through harnessing water on the surface due to the high inter-annual variability in rainfall and runoff. But, great opportunities exist for recharging groundwater in good rainfall years due to the high variability and the presence of good storage potential of aquifers. While there are quite a few constraints in implementing sophisticated water-harvesting systems imposed by the current institutional settings, opportunities also exist for scaling up of local water harvesting interventions.

Second: great physical constraints exist in the adoption of pressurized irrigation systems due to the fact that most of the irrigation sources are owned by irrigation groups. At the same time, they provide great opportunities for adoption of some of the new water saving technologies that do not require pressure heads, from the socioeconomic point of view. The existing physical climate vis. a vis., groundwater conditions (with large water table depths) provide great opportunities for saving of wet water through water saving technologies.

Third: the skewed pattern of operational holdings (toward marginal and small farmers) become major constraints for farmers in adopting sustainable agricultural practices from a socioeconomic point of view in Mehsana and Gandhinagar districts. At the same time, the existing local institutions provide opportunities for mobilizing social action for producing biomass in the command property land in the whole region. In districts such as Banaskantha, Sabarkantha and Ahmedabad, opportunities exist for adoption of horticultural crops due to the presence of large number of semi-medium and medium operational holdings.

6.0 Conclusions

Following inferences can be drawn on the technical feasibility and socioeconomic viability of the local groundwater management strategies vis. a vis., the geographical locations and target groups, on the basis of the above analyses.

First: check dams are likely to be effective in increasing the supplies in the groundwater supplies in the hilly terrains of North Gujarat. If constructed downstream of the existing reservoirs, they will have least ecological impacts. In the alluvial plains of North Gujarat, especially in Rupen basin, Saraswati river basin and the lower plains of Banas and Sabarmati river basins, percolation tanks will recharge tube wells can be constructed for recharge of deep aquifers. Analysis shows that the amount of water that can be harnessed through local water harvesting structures will be quite substantial in some of the high rainfall years. Along with physical structures, wasteland re-vegetation (grasses) has to be taken up. This will enhance the life of the structures, check the rate of and improve natural recharge rates. The village communities in this region need to be educated about this critical linkage between water, forest and land.

The socioeconomic viability of adopting organic farming practices is high in Banaskantha district due to the presence of larger number of farming having medium and large sized holdings. The most immediate concern with regard to adoption of organic farming practices in this region is to increase the efficiency of utilization of the available biomass for production of organic manure. The pressure on biomass such as dung and crop residue needs to be reduced, by providing alternate sources of cooking fuel. The inputs have to be in the form of training and education through demonstrations and field trials. The second concern will be to motivate farmers to take up tree plantation in private and common land to generate surplus biomass. Community-level action is required for taking up plantation in wasteland and fodder plots.

The conventional water saving technologies (pressurized irrigation systems) will find takers among the farmers who have poor water sources. Therefore, they need to be targeted for promotion of these technologies. Those who have tube wells and have sufficient supplies to irrigate their own land and for sale are least likely to adopt them due to the lack of clear economic incentives. So is the case with the shareholders of partnership wells and water buyers. In the case of water buyers, the constraint is physical in nature. The water saving technologies that do not require pressure head are likely to find more takers, among all categories of farmers and well owners. Field trials and demonstrations of the new water-saving technologies, such as sub-surface irrigation and the micro-tube drips need to be carried out for crops such as alfalfa, potato, castor, cotton and fennel.

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