

Sustainable Groundwater Management Lessons from Practice

Case Profile Collection Number 22

A Hydrogeologic and Socioeconomic Evaluation of Community-based Groundwater Resource Management – The Case of Hivre Bazaar in Maharashtra-India

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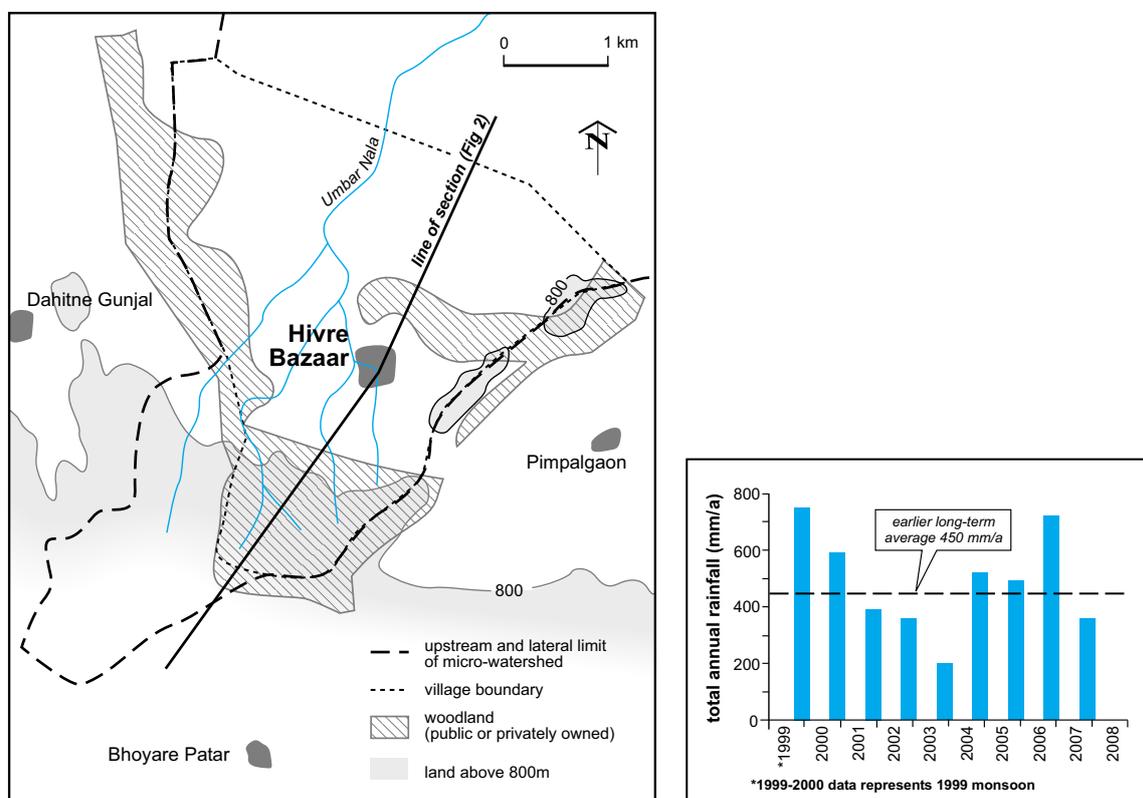
In the hard-rock terrains of Peninsular India groundwater resource management cannot be generally achieved through policy and regulatory actions by government, given the extremely large numbers of individually small users and the limited institutional capacity which needs to be focused on that small proportion of critical aquifers at risk of irreversible degradation. There are, however, just a few examples of long-standing community self-regulation of groundwater resource use for agricultural irrigation, which need to be understood and replicated by any available mechanism. Hivre Bazaar (1,140 population), in the drought-prone part of the elevated Deccan Traps country of Maharashtra State, is one such example and has received particular attention because of its apparent success at increasing farmer incomes and social well-being. It is the subject of this study to assess its socio-economic dynamics, agricultural evolution and hydrogeological sustainability, which was carried out by GRASP in coordination with GW-MATE and with advice from GSDA-Maharashtra State.

GENERAL CONTEXT AND APPROACH OF COMMUNITY ACTION

Historical Perspective of Study

- The central objective of the study was to generate sufficient data to make an independent and impartial analysis of the effectiveness of village-level community management of groundwater resource use at Hivre Bazaar (Ahmednagar District) in terms of resource status, agricultural revenue and socio-economic welfare. Critically also the study needed to assess the 'self-regulation mechanisms' adopted by the village community, since this should also provide insights into the sustainability and replicability of the initiative.

Figure 1: Sketch map and recent rainfall data for the Hivre Bazaar micro-watershed



- In Hivre Bazaar the concerted effort on groundwater resource management (as one foundation stone for sustainable social development) really commenced with the implementation of a comprehensive 5-year plan from 1994, under the Maharashtra Ideal Village Scheme (*Adarsh Gaon Yojana*) and with formation at village-level of Yashwant Agricultural, Rural & Watershed Development Trust as implementing agency, as a result of the leadership of the Village Council Chief (*Gram Panchayat Sarpanch*) Mr Popatrao Pawar – who was first elected in November 1989 (after obtaining a Master of Commerce degree from Pune University) and had already been seeking ways to make progress the expressed priorities of the villagers for secure drinking water-supplies, increased employment opportunities and improved agricultural production through irrigation.
- These initiatives took place against a long history of drought propensity and progressive land degradation. From 1850-1950 large-scale deforestation of the Hivre Bazaar watershed occurred to supply timber and firewood to nearby Ahmednagar City with its military cantonment – resulting in increasing hill-slope erosion, flash run-off and sedimentation of water-storage structures. Subsequently the village was devastated by the severe drought of 1970-73. Then, and in the years that followed, farmers struggled to maintain even the kharif crop against prolonged dry spells and were unable to do any significant rabi cropping. Few were able to see their crops through to harvest, to feed their families and cattle, and most had to leave the village periodically or permanently to search for paid work in Pune or Mumbai.

Hydrogeological Setting of Hivre Bazaar

- Hivre Bazaar is situated in a low rainfall drought-prone area of Maharashtra State – ‘quoted average rainfall’ of about 450 mm/a but with high variability (Figure 1). Its physiographic setting is the hilly part of the Deccan Traps country (Figure 1), at the foot of an escarpment and head of a local watershed (Figure 2), with elevation mainly in the range 710-740 m ASL.
- Around Hivre Bazaar the weathered zone of the Deccan Traps Basalt reaches to about 10-12 m bgl (and has a low hydraulic conductivity (K) of 1-2 m/d and moderate drainable storage (Sy) of 5-6%) and is underlain by 5-10 m of well-fractured basalt (with very variable K = 1-5 m/d and low Sy = 1-2%) (Figure 3). The ‘weathered zone aquifer’ is tapped by dug wells for irrigation, which reach the most highly-fractured bedrock – many are relatively deep (20-25 m) in part because their construction pre-dates watershed conservation. The weathered and fractured sequence is underlain by massive (and only sparingly fractured) basalt with occasional ‘red bole beds’, which do not play any role in transmitting groundwater to dug wells but can provide limited additional flows to deeper bore wells used for domestic water-supply.
- The study was carried out using systematic and quantitative rapid assessment techniques in three main stages : collection of secondary data, design of field investigations and collection of primary data through field survey (Figure 3). The design of the field investigations was undertaken by a ‘core team’ of a sociologist, hydrogeologist and agricultural economist – and they were supplemented by 8 more personnel (with basic training in social or geological sciences) for the actual field survey.
- Secondary data were collected from the Gram Sabha office, the main rural banks, government offices and voluntary organizations on land-use types, cropping patterns, livestock populations, and demographics (including population, employment and farmer land holdings) – with 35 families being selected for field interview. For the hydrogeological evaluation existing data were compiled on rainfall from nearest stations, water well listings and inventory – with 27 wells being short-listed for field inspection.

Figure 2: Simplified hydrogeological section of Hivre Bazaar micro-watershed methodology of study

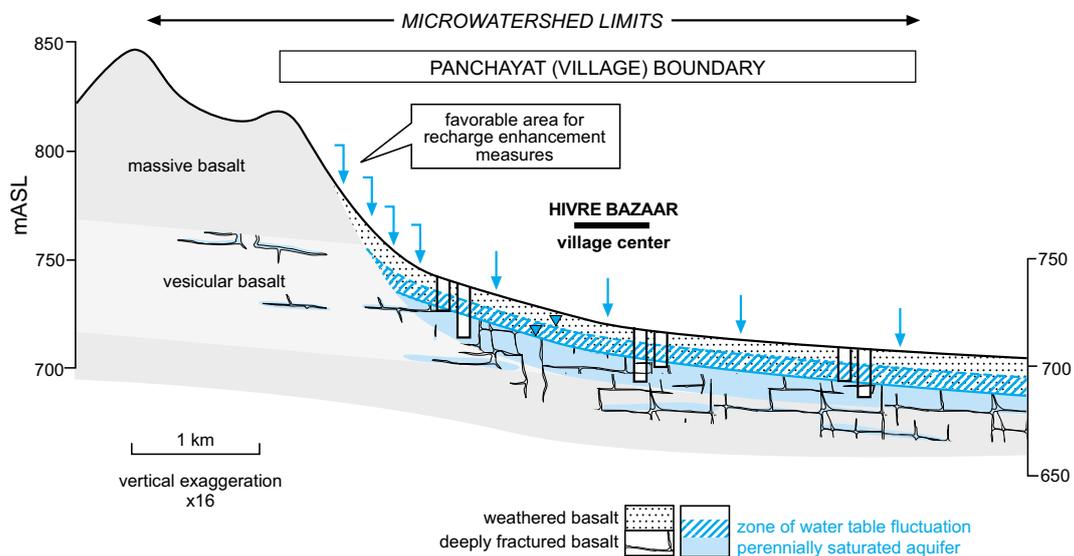
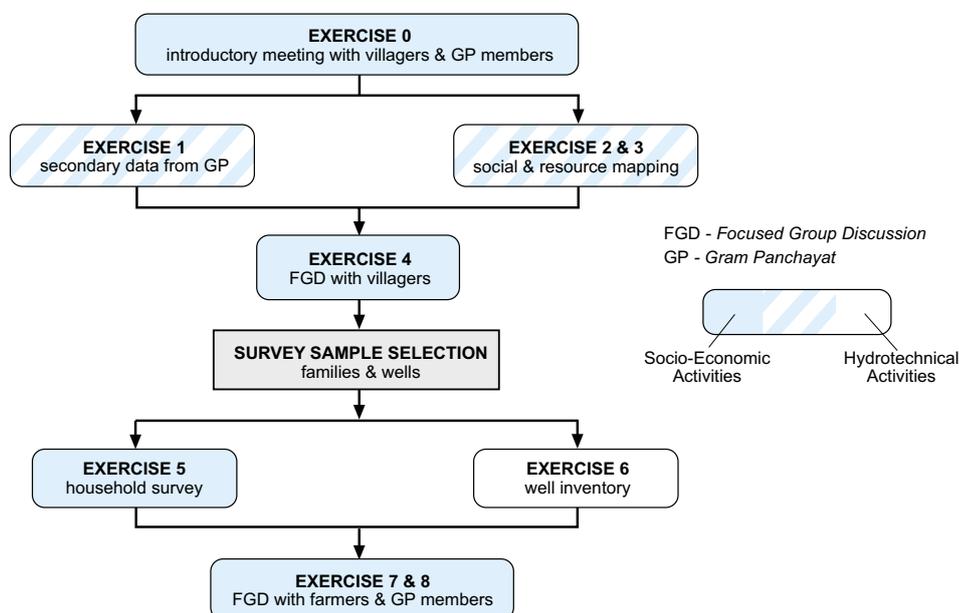


Figure 3: Organizational summary of field investigation methodology


Social Characteristics & Dynamics of Hivre Bazaar

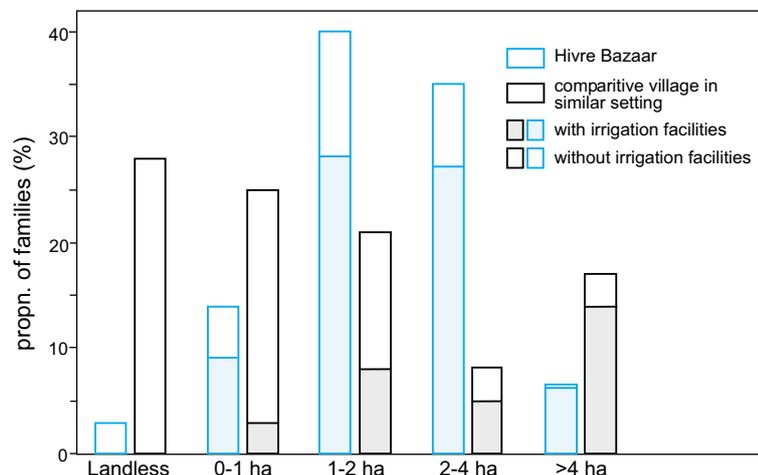
- Today the total population of Hivre Bazaar is around 1,140 (52% male and 17% under 14 years) – these are divided amongst 226 families (of which 100% have a ‘kitchen garden’, 53% use biogas and 35% have some remittance income). Some 14% of the families are categorized under Union and/or State Government criteria as ‘socially-disadvantaged communities’, while less than 2% of families are led by artisans. Almost all families live in Pacca houses (*walls of cement/lime with masonry/concrete floor and tin/asbestos roof*), and many families have both a house in the village and another dwelling on their farmland. There is 100% coverage of domestic water-supply by hand-pumps and sanitation by latrines.
- The land-holding pattern is significantly asymmetric – only 7% of families are in the large farm (>4 ha) category and 20% in the marginal and small farm (< 2 ha) category. But with 73% in the medium (2-4 ha) and small (1-2 ha) farm category it is significantly more equitable than many neighboring villages (Figure 4) and is noteworthy in terms of its ‘equity and livelihood position’ (*Priya Sangamaswaran / Indian Economic & Political Weekly / 27 May 2006*).
- Hivre Bazaar has no recorded ‘distress’ migration in last 10 years, and in fact has seen the return of 40 families who left in the early 1970s. Indebtedness of households is not a major issue – most having been able to access credit from formal lending institutions (especially the Multi-Purpose Cooperative Society) and also no case of ‘farmer suicide’ has been reported.
- Hivre Bazaar is very strong on community participation – its Gram Panchayat (like most in this part of India) is elected every 5 years, has 7 members (2 of which are female) and meets monthly. The Village Council Leader (Sarpanch) has now held the position for 18 years – such continuity being an important issue for sustainability of community projects. Gram Sabha (village meetings) are held on a

mandatory basis at least 5 times per year – with a male and female from each family expected to attend and contribute to any community project decided upon. The issues discussed at Gram Sabha can be of a holistic social nature with far reaching consequences, extending well beyond groundwater use (discussed below) to family planning, bans on alcoholic liquor production and selling land to outsiders. Incidentally no topics of irreconcilable conflict have been reported in recent years.

Groundwater-Related Community Management Measures

- The critical groundwater-related decision of the Gram Panchayat (on advice of the Sarpanch) was to prohibit the use of bore wells (and the drilling of vertical bores in the base of dug wells) for agricultural irrigation in 1993. This had the major benefit of moving farmers’ minds and resources away from ‘competition for deeper groundwater’ to ‘cooperation on maximizing benefits from groundwater to which they nearly all had access’ (that is from ‘supply-side measures’ to ‘demand-side management’). Social control is exerted to enforce the agreed ‘irrigation water well rules’ – and although there has been a substantial overall increase in dug wells (from 97 to 245 over 18 years) the rate of well digging is now much reduced. Moreover, the agreement is not too restrictive (since it allows driving of horizontal radial bores to increase effective dug well diameter), but nevertheless serious water-table depletion has been avoided and bore well yields adequate for drinking water are always available.
- From the early 1990s the watershed was also subjected to comprehensive soil conservation, reforestation and water harvesting measures (notably hill contour-trenching and many Nalla bunds in streams). Such arid foot-hill terrain is more favorable for recharge enhancement than further out on the pedepain – with heavy showers favouring recharge or runoff to water harvesting structures. Today the village sees little runoff during the monsoon (with the main percolation tank remaining dry for most of the year) but the observed dry-season water-table is usually a few metres higher than pre-1990.
- Other groundwater-related community management measures discussed and agreed by the Hivre Bazaar Gram Panchayat during the 1990s were :
 - prohibition of deforestation and use of axes (dung replacing timber for domestic heating)

Figure 4: Histogram of land ownership in Hivre Bazaar



- ban on livestock grazing to reduce soil erosion (with scythes being hired to allow hand-cut-fodder collection from communal forest areas for animal stall feeding)
- ban on sugar-cane cultivation (given its high water requirement and other implications).
- Most importantly, village-level water-resource budgeting was introduced in 2002 – with assistance from the state Groundwater Surveys & Development Agency (Ahmednagar District Office). After the monsoon availability of soil-water and groundwater are estimated from the data of 3 rainfall gauges and 6 observation wells. Human and livestock water requirements (taken as 50 and 30 lpd/capita) are given first priority and, using previous experience with crop irrigation and ‘simple rules of thumb’, the amount available for irrigated cultivation is calculated. This is compared to the aggregate of villagers’ proposed kharif, rabi and jayaad cropping – and in drought villagers are asked to reduce their proposed irrigated area and/or to give preference to low-water demand crops. The Gram Sabha agrees the pro-rata adjustments and mutual surveillance is usually enough to achieve compliance – since all farmers are assumed to be responsible members of the ‘village family’. (*Urbashi Narain/BNWPP Watershed Window Report /June 2008*).
- It is noteworthy that no change in groundwater abstraction rights per se (which at village-level still tend to be directly related to land ownership) is implied by the above arrangements – the community merely imposes a control on form of access to groundwater and on which crops can be irrigated. This is probably the rationale behind one other long-standing Gram Sabha agreement – namely that outsiders are not allowed to purchase land in the village.

SOCIOECONOMIC EVALUATION OF GROUNDWATER RESOURCE USE

Current Agricultural Production in Hivre Bazaar

- The village of Hivre Bazaar has an administrative area of some 975 ha, of which approaching 60% could potentially be irrigated in the most favorable years, and somewhat over 10% is now forest and rough land (mainly situated on the higher ground).
- The main crops cultivated are shown in Table 1 (for 2007-08 cropping year in which rainfall was about 80% of ‘long-term average’ with the area of rabi-wheat and the summer crops thus somewhat reduced) – indicative values or best estimates for the related unit production costs, net incomes generated and consumptive demands for irrigation water are also given. Staple food crops are grown primarily for home consumption but surpluses are sold at market (with crop residues serving as livestock fodder, or in the case pigeon-pea stalks domestic fuel). On the other hand most pulses, onions, vegetables and flowers are sold at market.
- Livestock rearing has increasingly become an important agricultural activity for numerous families in Hivre Bazaar, and in such drought-prone terrain is considered to be a robust alternative to the considerable investment needed for vegetable, flower and fruit production. In 2007-08 there were 530 bovine animals (cows, bullocks and buffalo), 480 goats and 1,600 poultry – with both commercial milk and chicken production.

Investment in Irrigation-Related Water Infrastructure

- Water well characteristics were evaluated by reviewing the inventory of 247 wells and selecting 27 (11%) for more detailed study – to give an indication of groundwater usage, groundwater levels and their fluctuations, pump types and sizes, well depth and yield, well ownership and age, as well as the amount of water used

Table 1: Main Crops Cultivated, Incomes Generated & Irrigation Demand in Hivre Bazaar *

| SEASON (crop) | CROPPED AREA (ha) | PRODUCTION COST (1 rps/ha)** | NET INCOME (1 rps/ha)** | ESTIMATED CONSUMPTIVE DEMAND FOR IRRIGATION WATER (mm in crop season) (total Mm ³ for cropped area) | |
|---|-------------------|------------------------------|-------------------------|--|-------------|
| PERENNIAL/PERIODIC CROPS incl. SUMMER/JAYAAD (hot dry season) (130ha cultivated) | | | | | |
| <i>vegetables+</i> | 60 -120 ^ | 5,200 | 177,800 | 500 - 650 | 0.27 - 0.36 |
| <i>onions</i> | 60 -120 ^ | 8,900 | 39,400 | 320 - 400 | 0.26 - 0.32 |
| KHARIF CROPS (hot-wet season) (430 ha cultivated) | | | | | |
| <i>Pearl Millet</i> | 90 | 2,100 | 2,900# | | |
| <i>Pidgeon pea</i> | 110 | 800 | 3,500# | 0 - 50 | 0 - 0.15 |
| <i>Peas</i> | 40 | 1,600 | 25,800# | | |
| RABI CROPS (cool-dry season) (390 ha cultivated) | | | | | |
| <i>Sorghum</i> | 120 | 2,700 | 4,200# | | |
| <i>Wheat</i> | 70 | 1,500 | 16,300## | 120 - 180 | 0.29 - 0.43 |
| <i>Chickpea</i> | 40 | 1,800 | 14,400 | | |

* 2007-08 data from local records adjusted by primary field survey data
 ** US \$ 1 = 1 rps 45 approximately at time of survey

^ cropped area varies significantly with season
 # 50-70% ## 30-50% of total production respectively reported to be used in farmers' homes

for the various crops grown, and the frequency of irrigation within each season – a brief partial summary is given in Table 2. There are no ‘local markets’ in groundwater for irrigation as such in this area, although water is sometimes shared by co-owners (mostly from the same family) in return for shares in crops.

- Water wells have long been the basic ‘irrigation infrastructure investment’ in Hivre Bazaar, and new wells are still appearing with some 20% having been constructed since intensive watershed conservation in 1993-95. The corresponding investment is estimated to be I rps 4.0 million (Table 3) – which reflects to large degree investment made in replacement and new wells by the current generation of farmers. Replacement of irrigation pump sets and pipes is required once every 10-15 years, and thus almost all farmers have made this investment in the last decade and at an estimated total cost of I rps 3.87 million (Table 3).
- Significant investment has also been seen on :
 - well deepening especially in the 1990s at costs of I rps 30,000-40,000 per well
 - horizontal boring to increase effective well diameter, by around 30% of well owners at cost of I rps

Table 2: Summary of Waterwell Characteristics in Hivre Bazaar

| WATER WELL CHARACTERISTICS | WATERSHED LOCATION | | |
|--|--------------------|---------|---------|
| | upper | middle | lower |
| <i>depth range (m)</i> | 5 - 25 | 7 - 27 | 10 - 18 |
| <i>maxm summer water-table (m bgl)</i> | dry | 16.6 | 15.5 |
| <i>minm summer water-table (m bgl)</i> | 10.0 | 7.1 | 9.0 |
| <i>maxm winter water-table (m bgl)</i> | 5.0 | 11.1 | 14.5 |
| <i>minm winter water-table (m bgl)</i> | 1.0 | 4.0 | 8.0 |
| <i>summer recuperation (hours)</i> | 96+ | 20 - 24 | 24 - 48 |
| <i>winter recuperation (hours)</i> | 5 - 8 | 4 - 7 | 4 - 6 |

Table 3: Summary of Irrigation Water Well Investments in Hivre Bazaar

| COST COMPONENTS (in 1 rps) | TOTAL | PER WELL |
|-------------------------------------|-----------|----------|
| <i>no. of pre-1993 water wells</i> | 196 | (80%) |
| <i>no. of post-1993 water wells</i> | 49 | (20%) |
| <i>water well digging</i> | 3,970,000 | 81,000 |
| <i>water well deepening</i> | 700,000 | 35,000 |
| <i>irrigation pumpset + pipes</i> | 3,870,000 | 16,000 |
| <i>'horizontal boring' in well</i> | 620,000 | 7,000 |
| TOTAL | 9,160,000 | 139,000 |

7,000 per well (Table 3) (of 27 dug wells surveyed 13 had horizontal bores with 10 constructed prior to 1993 – but the trigger for this technology is not understood).

Thus the total investment in irrigation water wells is estimated to be just over I rps 9.0 million.

- A significant number of farmers have introduced sprinkler or drip irrigation technology at a reported average corresponding cost of I rs 45,000/ha and I rs 25,000/ha, in many cases availing themselves of a government subsidy – 61 and 17 ha respectively of horticultural production are currently under sprinkler and drip irrigation. A few farmers are also planning to invest in greenhouse construction. Most farmers have all the basic implements for land preparation and cultivation, but combine harvesters were occasionally deployed as a hired service and only a few have invested in tractors and threshers.
- Water well pumping for irrigation is done using electric motors (with negligible presence of diesel-engined pump sets). Although the State Government has initiated a drive to convert existing electricity connections for agriculture to metering, most electricity connections were of 'fixed tariff type' with an average tariff of I rps 2,400/a and I rps 7,000/a for a 3 HP and 5 HP connection respectively – equating to less than I rps 500 /crop/ha. However, obtaining an electric connection from the State Electricity Distribution Company is problematic.

CONCLUDING DISCUSSION OF HIVRE BAZAAR EXPERIENCE

Assessment of Groundwater Resource Status

- Evaluation of the groundwater resource balance is complicated by the inherent variability of rainfall recharge and agricultural use, and further constrained by lack of detailed long-term field monitoring of groundwater levels – Table 4 is the best that can currently be attempted. Specific assumptions underlying the estimation of each component are given as footnotes – with the underlying approach being to assume a quasi-steady water-table situation in which 'consumptive irrigation use + natural subsurface outflow must be balanced by vertical groundwater recharge' (the former two are significantly easier to estimate than the latter).
- This evaluation of the groundwater balance (Table 4) leads to the following observations:
 - the estimated rates of groundwater recharge (from locally-infiltrating rainfall and runoff) are on the high-side of typical CGWB estimates for the Deccan area (which are based on a standard indirect estimation methodology calibrated from well-monitored watersheds and normally indicate local

recharge as 10-15% of local rainfall)

- this suggests that comprehensive watershed conservation, which has been successful in avoiding soil erosion and land degradation, has also been successful in recharge enhancement (given the favorable hydrogeological setting)
- it is also evident that the watershed area extends well beyond the village boundary to include a substantial area of upland ‘run-off zone’ and contiguous ‘government forest’ (Figure 1) – furthermore it is just possible that it benefits from percolation tank infiltration above the adjoining village of Dahitne Gunjal (not allowed for in the calculation).
- Hivre Bazaar has a weathered zone with capacity to store monsoon recharge and a relatively favorable ‘hill-front’ setting for recharge enhancement, but the average rainfall is very low – and thus the level of irrigated agriculture production with sustainable groundwater resources represents a remarkable feat. Proactive groundwater resource management has resulted in a marked contrast with the majority of villages in drought-prone Maharashtra – with as many as 32 dug wells producing important revenue in the summer season from irrigated onion, vegetable and flower cultivation, and only a few in the upper watershed drying-out.

Key Factors in the Success of Hivre Bazaar

- The ‘household-level benefits’ of community intervention on land and groundwater management in Hivre Bazaar are large (Table 5), with average household income having risen markedly (to over I rps 20,000/a) and the land-values appreciating many-fold in the past 10-15 years. This potential ‘household-level benefits’ should not be overlooked when designing other schemes of village participation in voluntary programs – and could be used in a similar way to which other ‘payments for environmental services’ operate by rewarding small land holders for good resource use behavior providing benefit to others.
- The key factors, in terms of groundwater resource management, in the success of sustainable and productive irrigation in Hivre Bazaar appear to be:
 - only permitting the use of dug wells for irrigation, which made sound hydrogeological sense in terms of groundwater extraction efficiency and also facilitated a spirit of water-use cooperation (rather than water-supply competition) – it being a ‘traditional egalitarian technology’ (despite the fact dug wells are 5-10 times more expensive than bore wells
 - putting a variable but intelligent ceiling on total village irrigated cropping area in the dry seasons

Table 4: Estimation of Indicative Groundwater Resource Balance for Hivre Bazaar Micro-Watershed (average year)

| ESTIMATE RANGE | CONSUMPTIVE USE BY IRRIGATED CROPPING* (Mm ³ /a) | SUBSURFACE OUTFLOW# (Mm ³ /a) | IMPLIED VERTICAL RECHARGE RATE ^ | | |
|----------------|---|--|----------------------------------|--------|------------------|
| | | | (Mm ³ /a) | (mm/a) | (propn rainfall) |
| <i>minimum</i> | 0.90 | 0.05 | 0.95 | 68 | 14% |
| <i>maximum</i> | 1.38 | 0.08 | 1.46 | 104 | 22% |

* derived from Table 1 but with 10% increase to allow for increased crop area in average rainfall year

based on ‘downstream flow frontage’ estimated from Figure 1, inferred aquifer properties at high and low water-table and ‘downstream hydraulic gradient’ approximately equal to slope of land surface (typical for weathered hardrock (shallow low permeability) aquifer systems)

^ assumes quasi-steady state water-table and negligible surface runoff from micro-watershed (in accordance with local observation except in very exceptional monsoon years) - unit recharge rates expressed as average over entire micro-watershed (area about 14 km²), although in practice recharge will be concentrated in most permeable hill-slope and hill-foot soils.

Table 5: Indicators of Socio-Economic Improvements* in Hivre Bazaar related with Improved Land and Groundwater Resource Management form 1993 onwards

| YEAR | 1992 | 2003# |
|--|------|--------|
| <i>Summer/Jayaad Irrigated Area (ha)</i> | 7 | 72 |
| <i>Land in Horticultural Production (ha)</i> | 7 | 54 |
| <i>Pulse Cultivation (ha)</i> | 54 | 188 |
| <i>No. of Milk-Producing Livestock</i> | 19 | 476 |
| <i>Household Income (1 rps/a)</i> | 830 | 11,900 |
| <i>Families below Poverty Line (%)</i> | 92 | 1 |

* based on State Government survey data of corresponding years

considerable further improvements appear to have occurred by 2007-08 (year of current survey)

(rabi and jayaad) informed by precedent – and persuading farmers to adapt their individual cropping plans to this constraint.

- The demand-management measures have been implemented within the framework of an effective Gram Sabha (allowing good communication between villagers) and a Sarpanch (acting as leader, motivator and problem solver) who has been very effective in liaison on behalf of farmers with government schemes and in maximizing opportunities for financing, implementing and maintaining watershed conservation and recharge enhancement. Beyond this (and of more indirect benefit in water terms) the Sarpanch has done much by way of mobilizing investments and procedures for agricultural diversification and risk reduction (such as the introduction of high-value crops, improved agronomics and product marketing).
- Hivre Bazaar is an example of a situation where a charismatic village leader has been able to mobilise community awareness and to influence villagers to change both their social and resource use behavior. As difficult as it is to replicate such leaders – well-designed policy mechanisms could take their place and help coordinate the activities of farmers and overcome failures that might otherwise result in decreased overall benefits. By constructing a model of agricultural production and groundwater use it has been demonstrated that the gains to forgoing immediate benefits, such that the groundwater table remains at a higher overall level avoiding water well failure, are considerable. This leaves scope for locally-active NGOs to educate farmers, so that they understand and internalize these trade-offs. The gains that are computed can be interpreted as the value of good resource management.

Publication Arrangements

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