



## USAID/India

Water Balance Tools to Support Water and  
Energy Decision-Making:

Overview and Application in  
Maheshwaram Watershed, Ranga Reddy  
District: Andhra Pradesh

October 6, 2003

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## Water Balance Tools to Support Water and Energy Decision-Making

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### Introduction

Use of water and energy for agricultural purposes has boomed in India over the past three decades. Groundwater in particular has become the preferred source of irrigation water for millions of farmers across the country; the growth in its use has largely been fueled by rural electrification. Over two-thirds of India's irrigation pumps are driven by electrical power, enabling larger-capacity pumps to draw water from greater depths.

The groundwater boom could be considered the pillar of India's food self-sufficiency since it brought unparalleled benefits to its farmers. However, the agricultural sector's rapidly rising demand for power is threatening the financial sustainability of the electricity boards and supplying utility companies. In an effort to shore up the utilities' bottom line, initiatives have been launched to reduce demand, improve pump and irrigation efficiency, increase revenue, etc.

Although such initiatives were aimed at addressing the problems faced by the energy sector, similar attention to protecting sustainability of the groundwater resource itself has been largely inadequate. Aquifers with various hydrogeological conditions under a range of cropping sequences are under threat. The alluvial aquifers of the Indo-Gangetic plain (Punjab, Haryana, and Western Uttar Pradesh) are experiencing serious overdrafts – resulting primarily from irrigation pumping demand – despite the significant recharge that occurs from the Himalayan river inflows and *bhabbar* (intermontane) zone groundwater influx. At the same time, large areas associated with canal irrigation command areas are subject to waterlogging that is linked to both primary salinity (naturally saline) and secondary salinity (induced by irrigation with poor-quality water or inadequate drainage of salts).

Groundwater overdrafts are particularly severe in the hardrock regions of Western India, the Deccan Plateau and much of South India (with the exception of coastal deltaic areas). This is primarily because water availability and recharge processes are highly variable from location to location. It is widely accepted that groundwater pumping is the primary force behind groundwater overdraft in these regions. Concerns have been raised about scanty and irregular rainfall, land use changes that alter recharge-runoff relationships, inter-basin water transfers, inter-sectoral water competition, and water quality deterioration. All these undoubtedly complicate the groundwater picture, particularly in heterogeneous aquifers. Nevertheless, the sheer volumes of groundwater pumped – India has the world's largest groundwater sector, measured in terms of annual volumes or hectares under groundwater irrigation – leave ***no doubt that groundwater pumping is the single-most important factor behind the groundwater crisis in India.***

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A series of crucial initiatives are underway to rationalize groundwater and energy use in India. The Water-Energy Nexus in Agriculture (WENEXA) program, supported by the United States Agency for International Development (USAID), is being implemented on a pilot basis in Andhra Pradesh (Maheshwaram watershed, Ranga Reddy District) and Uttar Pradesh (Noida) to devise and test pilot approaches to water and energy co-management. Similarly, nascent efforts are underway in Karnataka, Orissa, Madhya Pradesh, and Gujarat (to name just a few) to collectively manage rural power supply and groundwater. These projects, along with food security and agrarian prosperity efforts based on groundwater, are doomed to fail unless groundwater overdraft is tackled.

Groundwater assessment methods are not new, although important scientific innovations continue to be made. Computational models have been developed that are spatially and temporally explicit; however, these require inordinate amounts of data and may be based on the same simplifying assumptions as the more crude water balance approaches.

This paper presents and applies a simple yet robust water balance that is intended to serve as the basis for decision-making related to water and energy co-management. We consider the watershed to be the appropriate physical unit for water balance assessments, in principle because aquifer delineation in heterogeneous hardrock conditions is itself time- and data-intensive and fraught with inaccuracies. Further, throughout most of India, watersheds have been delineated and in fact are already taken as the unit of management and investment for several government and non-government programs related to natural resources. Finally, based on the recognition that accurate historical data on groundwater levels may either be non-existent or prohibitively difficult to access for a number of institutional and political reasons, the water balance approach presented here derives monthly changes in the reference static groundwater level, i.e., the water level in a representative well not currently being pumped. It is not intended to be a spatially explicit model, for instance, that would provide information on where to site new wells. Instead, it should serve as a first-cut method with acceptable accuracy to support decision-making on agricultural water demand, aggregate pumping volumes, and the influence power supply and management may have on groundwater.

### **The Water Balance as a Water Accounting Tool**

In general, the water balance accounts for the stocks and flows of water in a geographic area. Surface flows (rainfall, evaporation, runoff, etc.) are accounted for separately from sub-surface flows (percolation, recharge) and stocks (moisture stored in the soil, water stored in the underlying aquifer). While the water balance is a mass balance model, temporal variability is the basis for the approach: water balances are extremely useful in examining inter-seasonal and inter-annual trends in water availability. A robust water balance should be descriptive of the primary processes of interest to the non-scientific community (e.g., the influence of rainfall on runoff or the impact of land use change on groundwater levels). It should strive to optimize accuracy with limited data or detailed knowledge of the physical processes. Finally, it should be a “gray box” that functions as a simple input-output model for the untrained user, while at the same time containing the basic data relations and calculations in an accessible format for the trained (but non-expert) user.

Spreadsheets are well suited for water balances – they can store input data in tabular form, cross-reference cells with formulas that describe the essential physical processes, and calculate, tabulate and graph output data. Above all, they can be stored and exchanged on

diskettes, and opened and used with conventional software on virtually any PC. Based on its ease of operation and clarity of output (tabular and graphical display), the water balance is ideal for scenario development and exploration. Once up and running (its data and configuration requirements are described below), the water balance can be used to demonstrate, for example, how pumping behavior affects groundwater levels or how crop choice influences irrigation water demand. In this sense, it is a good decision support tool.

### Water Balances vs. Models

There are two main differences between these tools. First, advanced hydrological and water resources models (for watershed, river basin and groundwater processes) rely on many of the same relationships as water balances; however, the models strive for accuracy, and spatially and temporally explicit output data. As a result, more sophisticated models are significantly more data-intensive than the basic water balance described here. The two should not be confused: a water balance is not designed or capable of generating the types of outputs that a model is, and a model cannot be set up as quickly as a water balance. Each has its own application and utility. Second, surface water and groundwater balances have tended to be developed and applied separately (this is primarily a result of scientific disciplinary specialization). Coupled surface and groundwater balances make a number of simplifying assumptions, for example, that percolation below the vegetation root zone goes directly to the aquifer, or that where the aquifer discharges to a stream or open water body, it does so at a constant rate or logarithmically at a rate proportional to the volume stored in the aquifer. In the final analysis, the water balance of the type described below certainly achieves accuracy acceptable for and commensurate with the complexity of decision making required to address groundwater and energy management.

The approach applied here accounts for changes in groundwater storage resulting from rainfall, crop and natural vegetation evapotranspiration (ET), and runoff out of the watershed. The residual term in the mass balance is the net change in aquifer storage, expressed as:

$$\Delta S = R - (ET_c + ET_v + E) - Q_{ro}$$

where:  $\Delta S$  is net change in aquifer storage  
R is rainfall  
 $ET_c$  is crop evapotranspiration  
 $ET_v$  is vegetation (non-crop) evapotranspiration  
E is open water surface evaporation (tanks and ponds)  
 $Q_{ro}$  is surface runoff

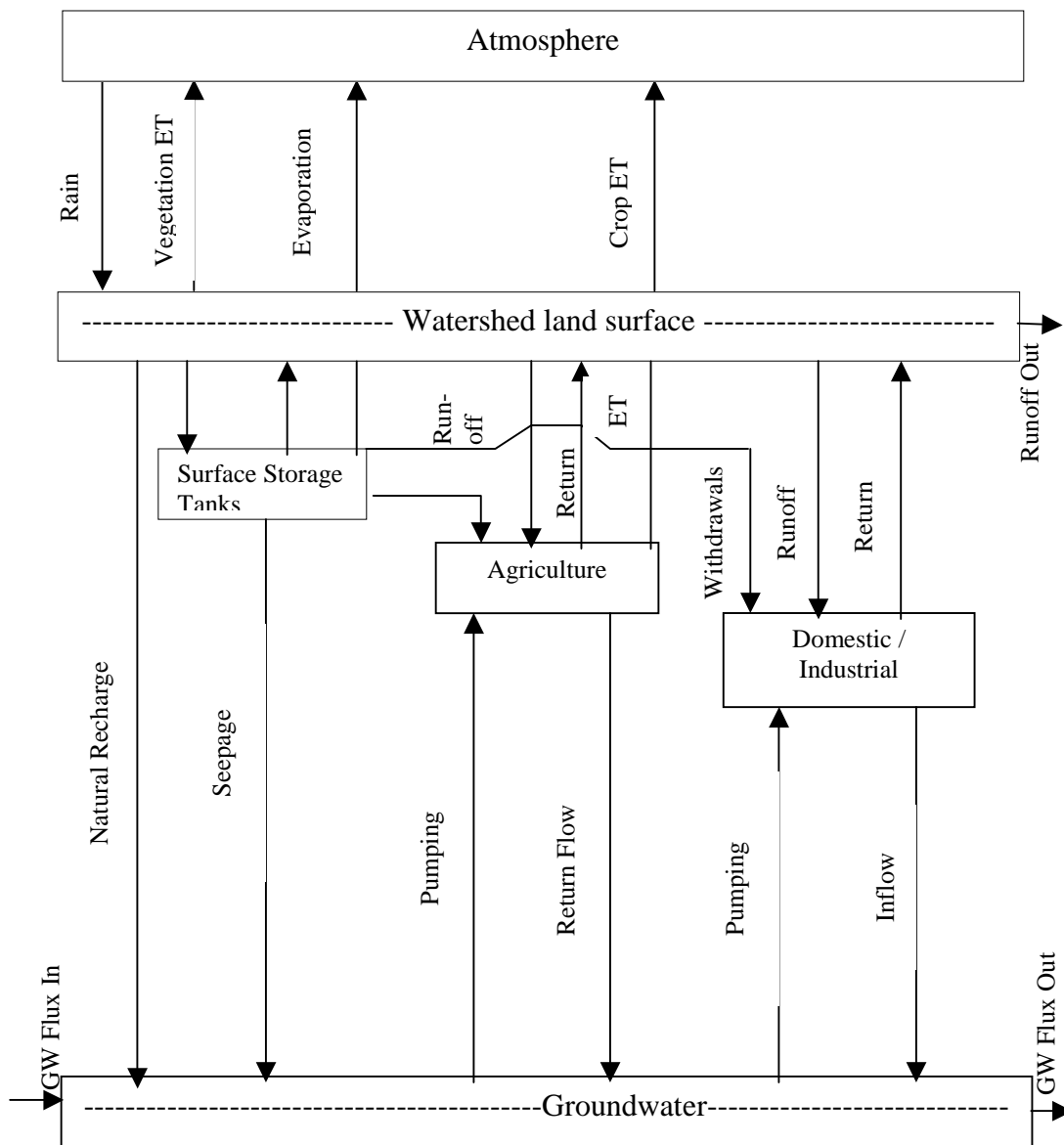
The change in static water level is calculated as:

$$\Delta h = \frac{\Delta S}{A k}$$

where:  $\Delta h$  is the change in static water level  
 $\Delta S$  is as defined above, including net groundwater flux from outside the watershed  
A is the aquifer area  
k is the aquifer storage coefficient

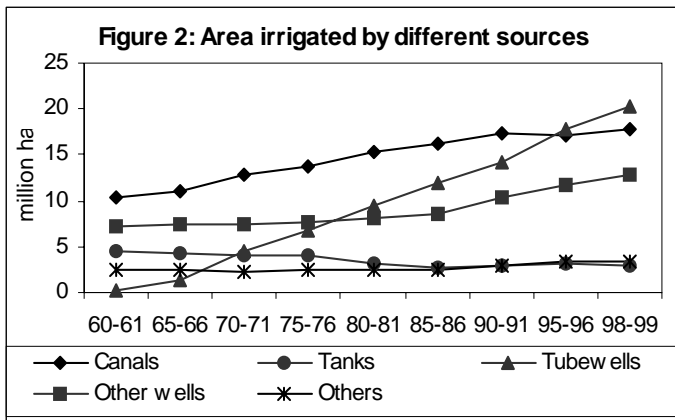
Figure 1 presents a schematic of the water balance. The system boundaries have been defined as the spatial limits of the watershed. We recognize that pumping for domestic and residential water supply places additional demand on the aquifer; however, because of high return rates (in the range of 70%), this is not considered in the water balance, except as ET loss from gardens, etc.

**Figure 1. Water Balance Schematic Diagram**

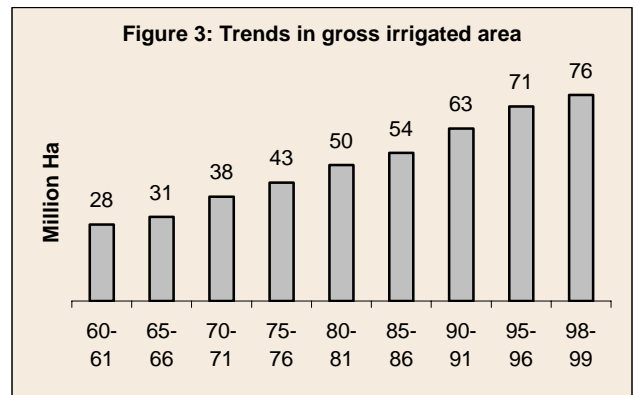


### Groundwater and Energy Use in India with an Emphasis on Andhra Pradesh

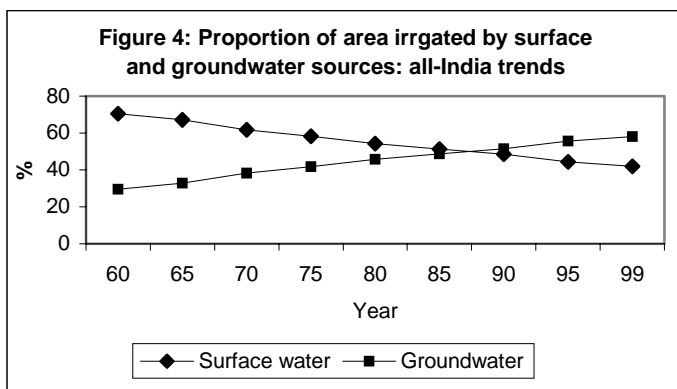
This section briefly describes the context of groundwater and energy use. In India, the gross irrigated area was 76 million ha in 1998-99, up from 28 million in 1960-61, representing a compounded annual growth rate (CAGR) of 2.2% (Ministry of Agriculture and Cooperation as cited in [www.agricoop.nic.in](http://www.agricoop.nic.in)). Much of this growth is accounted for by groundwater (see Figures 2, 3 and 4).



Source: [www.agricoop.nic.in/statistics/sump2.htm](http://www.agricoop.nic.in/statistics/sump2.htm)



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**Table 1: Change in area irrigated by source (1960-99)**

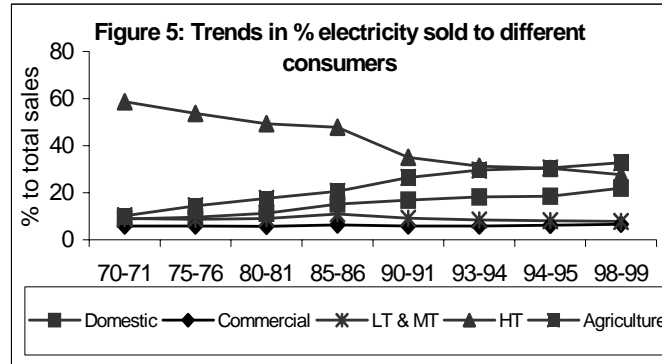
Irrigation Source	CAGR (%)
Canals	1.4
Tanks	-1.1
Tubewells	13.7
Other wells	1.5
Other sources	0.8
<b>Total irrigated area</b>	<b>2.2</b>

Source : [www.agricoop.nic.in/statistics/sump2.htm](http://www.agricoop.nic.in/statistics/sump2.htm)

From the perspective of the energy-water nexus, tubewell irrigation registered the highest growth of the different sources of irrigation (see Table 1). There are several reasons for this. First, the area irrigated by canals is limited by the designed command area. Second, there are great inequalities in canal supplies at the heads and tails of command areas. In some systems, the head reaches take over 150% of the allocated supply while the tail gets less than 33% (Sivamohan et al., 2003). Research has also shown that in many areas, the system efficiency is actually much less than designed, thus limiting water availability (Sehgal et al., 1997). On the other hand, extracting groundwater through wells and tubewells offers flexibility and ease, and is relatively reliable (Sharma, 2002). Virtually all of the country’s groundwater development has resulted from private investment (albeit with some government support in the form of subsidies). Thus, the share of the total area irrigated by canal water declined

during 1970-95 from 62% to 46%, while the share of groundwater irrigated area increased from 38% to 54% (Sharma, 2002).

Such trends in groundwater-irrigated area have direct ramifications for energy use. Figure 5 shows the growth in power consumption by the agriculture sector compared to other sectors.



Source: Center for Monitoring Indian Economy (CMIE), Energy, 2000

Table 2 shows that while overall power sales in the country grew at a CAGR of 9.1%, sales to the agriculture sector grew at a whopping 16.5%. Such high growth in agricultural power consumption is due to the growth in tubewell irrigated area.

Table 2: CAGR of the different energy consumer sectors (1985-90)

Consumer segment	CAGR (%)
Domestic	13.1
<b>Agriculture</b>	<b>16.5</b>
HT Industry	4.1
MT/LT Industry	6.9
Commercial	8.9
Aggregate	9.1

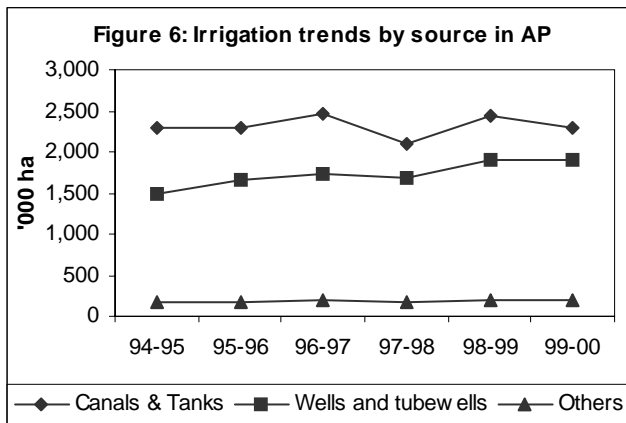
Source: Center for Monitoring Indian Economy (CMIE), Energy, 2000

At current levels of groundwater extraction, it is estimated that out of the total 7,034 administrative blocks in India, the annual groundwater draft has exceeded the annual available recharge in 428 blocks, with 38 districts and 2 states being classified as over-exploited (Sharma, 2002). Table 3 shows the overexploited blocks in India.

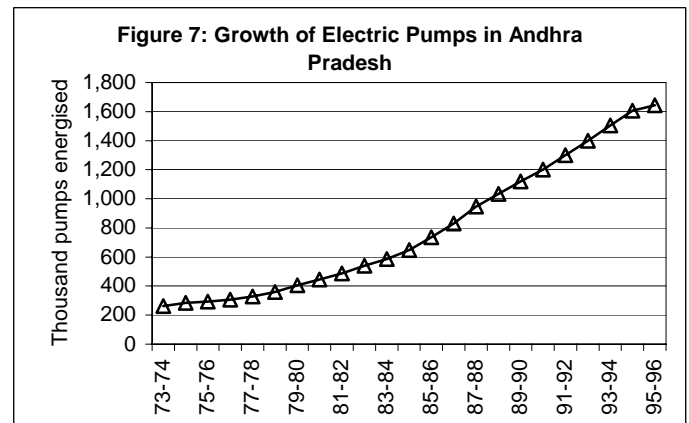
State	Over-exploited	
	Blocks	Districts
Andhra Pradesh	30	-
Gujarat	26	4
Haryana	51	10
Karnataka	18	3
Kerala	1	-
Madhya Pradesh	3	-
Maharashtra	34	-
Orissa	70	6
Punjab	56	9
Tamil Nadu	97	6
Uttar Pradesh	41	-
<b>Total</b>	<b>428</b>	<b>38</b>

Source: Central Groundwater Commission, 2000

Thirty of the over-exploited blocks are located in Andhra Pradesh. Here too, groundwater irrigation usage has been increasing and has surpassed the surface water irrigated area (Figure 6). This increasing groundwater irrigated area is being supported and sustained by steadily increasing numbers of electric pumps in the state (Figure 7).

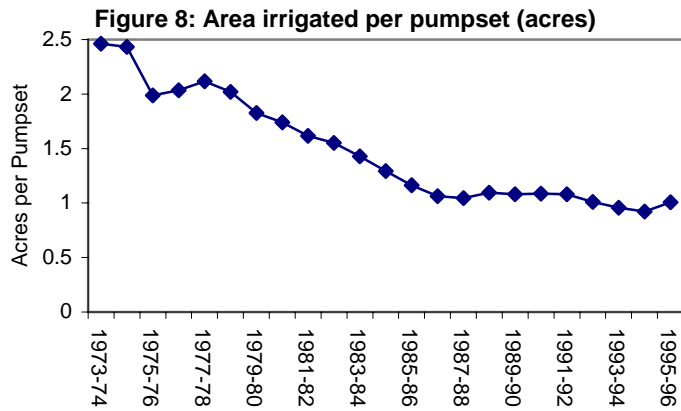


Source: Center for Monitoring Indian Economy (CMIE), Energy, 2000

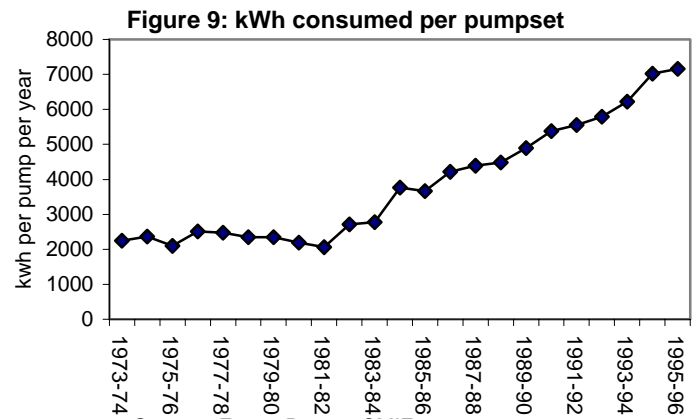


Source: Center for Monitoring Indian Economy (CMIE), Energy, 2000

The number of pumps swelled from an estimated 200,000 in 1973-74 to 1.8 million in 1995-1996. Recent estimates of the energized pumps in Andhra Pradesh puts this number at 2.2 million (APERC, 2001-02), growing at 8% CAGR. Combined with declining water levels, this growth represents a 13.3% CAGR increase in power supplied to agriculture (APERC). While this was caused in part by an increase in energy consumed per pump, there has been a steady fall in area irrigated per pump (Figures 8 and 9).



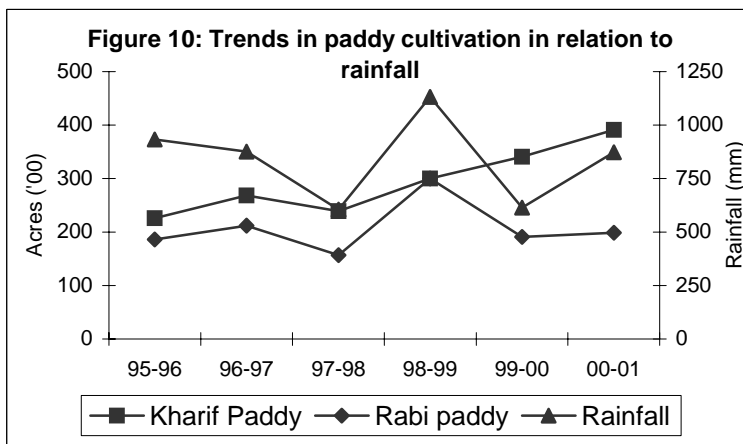
Source: Enezy Report, CMIE, 2000



Source: Enezy Report, CMIE, 2000

As the use of energy in agriculture is primarily for pumping groundwater for irrigation purposes to meet specific crop water requirements, the prevailing cropping pattern plays a determining role in agricultural energy consumption. Based on APTRANSCO's meter readings of agricultural transformers in 26 villages for a period of 76 days (July 7 to September 21, 2001), village energy use coincided with area under paddy (Narayana, 2001). In Ranga Reddy District, paddy area has been growing at 5.7% CAGR, which is the highest across all crops. Pulses at 2.3% are in second place, while the rest of the crops show declining trends (Narayana, 2001). Interestingly, paddy is cultivated twice a year here, although this district is categorized as drought prone.

The trends show that *Kharif* paddy has been increasing, irrespective of rainfall, while the *Rabi* paddy area follows rainfall trends. This means farmers' decisions to plant *Rabi* paddy is determined by the rainfall in the preceding monsoon, while they generally take a chance and plant *Kharif* paddy every year in larger areas (see Figure 10). Thus, when rains do not occur at normal levels, there would be heavy pumping of groundwater. Further, because the rains do not conform with the crop-water requirements and occur depending on other factors, farmers are likely to pump up groundwater to meet their additional water requirements, if any. This means that increasing trends in paddy area, even in *Kharif* season, would increase dependence on groundwater. Additional area under paddy during *Rabi* season (when much of the crop water requirements are met from groundwater sources) means further pressure on groundwater resources.



Given that such uncontrolled exploitation of groundwater only adds to the number of over-exploited blocks, it is necessary that appropriate measures be initiated such that neither groundwater extraction exceeds sustainable levels nor energy use surpasses the utilities' capacity to supply power. There is a need to establish a clear understanding of groundwater availability and recharge processes, which would

help in identifying the appropriate interventions required to stem over-use of both water and energy.

### **Water Balance for Maheshwaram, Ranga Reddy District, Andhra Pradesh (A.P.)**

Ranga Reddy District is located in the plains and Deccan slopes regions of northwestern A.P. and forms part of three separate river basins. The Musi basin (a tributary to the Krishna River) accounts for over 65% of the total geographic area, while the Kagna and Manjira basins (part of the Godavari basin) drain the northern part of the district. Irrigation is banned in the western Musi basin because of the municipal water rights held by Hyderabad for the Osmansagar and Himayatsagar reservoirs and irrigation rights in the downstream Nalgonda district. There is some scope to develop additional irrigation in the Kagna and Manjira basins; however, with increasing water demand to meet Hyderabad and Secunderabad's municipal supplies (and pipelines and tanker trucks already servicing that demand), it is certain that irrigation development from surface water supplies will cease due to water scarcity.

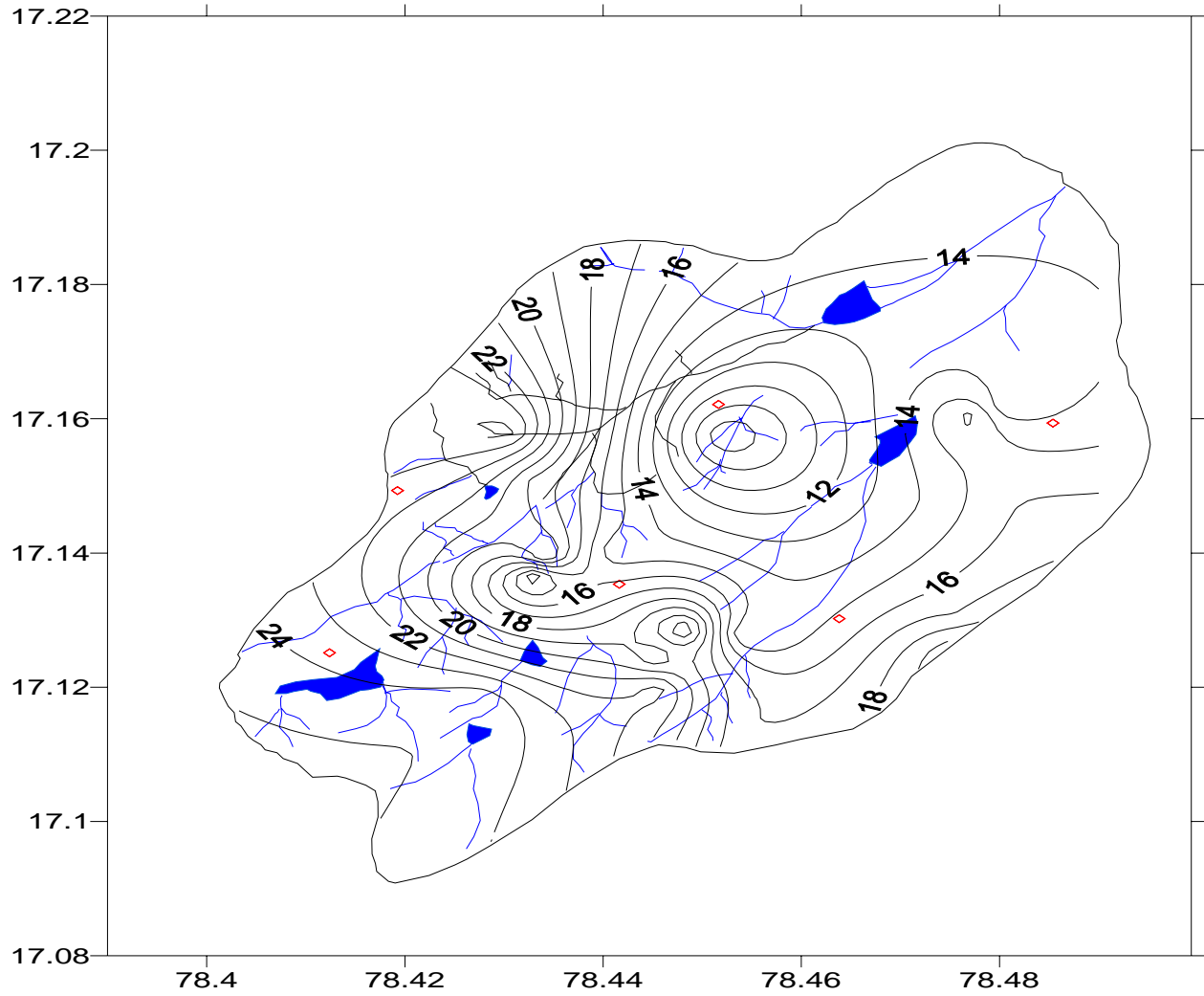
Watershed development and management under a range of government programs – loosely coordinated under the Neeru Meeru scheme – aim to improve soil and water conservation and groundwater recharge. The official statistics show that in nearly 250 of the district's 985 inhabited villages, watershed development has been or is being implemented. According to the internal evaluation reports of the DPAP, watershed development has been linked to increases in groundwater levels, in some cases, increases of over 2.0 m.

The dynamic and charismatic Chief Minister of A.P. has correctly linked the success of watershed management to increases in groundwater levels, and in his periodic real-time video conferences with officials across the State, he regularly rewards mandals and districts that show favorable trends and reprimands those who do not. This partly explains the difficulty in obtaining official groundwater statistics. The rise in groundwater levels results from the extensive construction of runoff harvesting structures, which create "groundwater mounds" that are not continuous across the entire watershed area but are localized in the immediate vicinity of the recharge structure. However, subsequent to watershed development activities and a general rise in water levels, in most of the villages there is an increase in the number of pumpsets; in some villages over 100 additional bore wells were drilled after groundwater recharge programs were implemented (Narayana, 2000).

Maheshwaram mandal is located in Ranga Reddy District to the south of Hyderabad, bordering the adjoining district of Mahboobnagar. This mandal has 33 villages, 3 of which are uninhabited, at elevations ranging from 600 to 700 m above mean sea level. The area is underlain by granites with dolerite dykes intruding in the northern parts of the watershed. The topography is undulating with sub-dendrite type drainage with a number of gullies leading into streamlets with eroded banks. The upper part of the watershed drains into Mankhal tank, which ultimately drains into the Musi River. The drainage density is about 640m/km<sup>2</sup>.

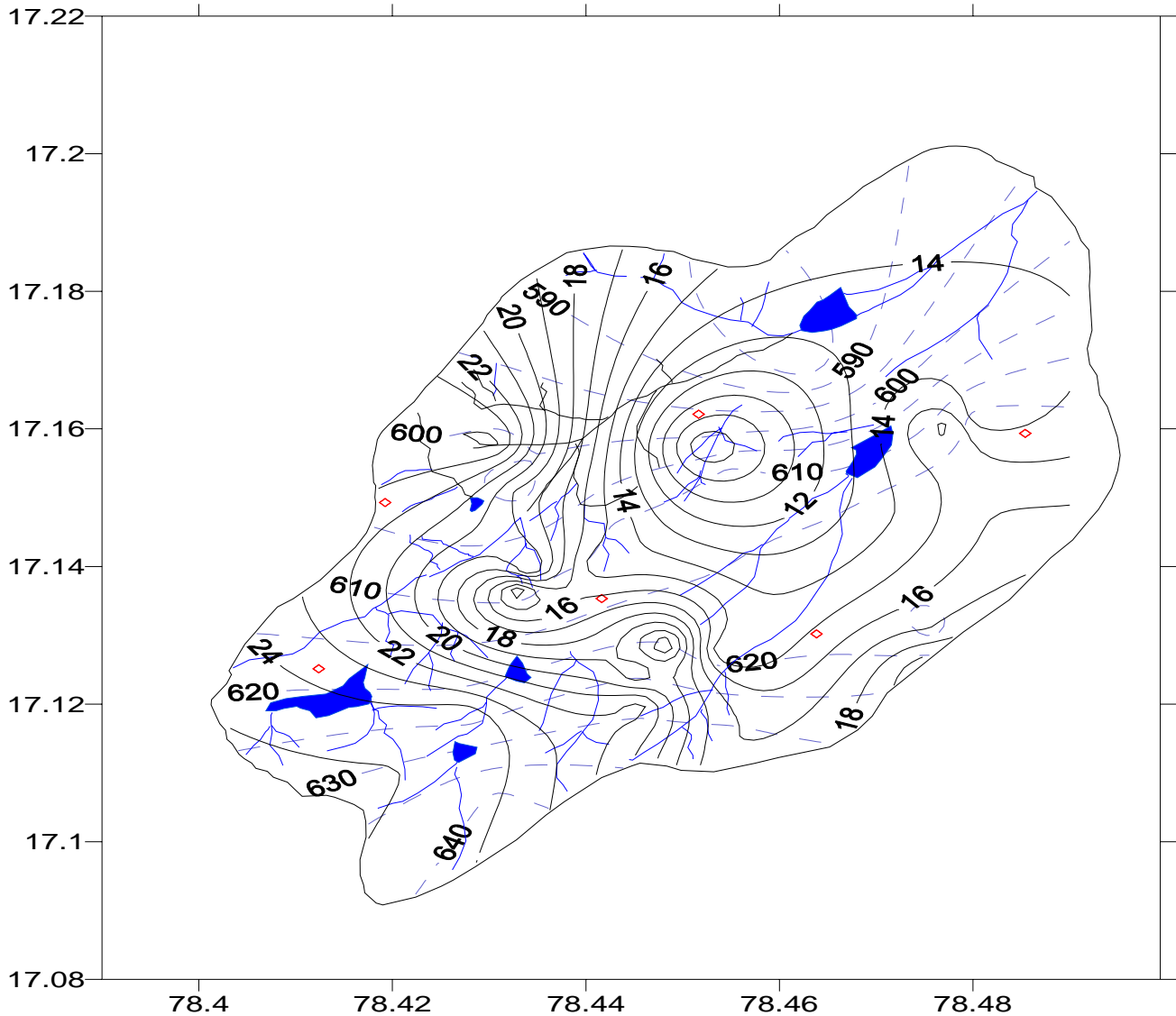
The Indo-French Center for Groundwater Research (IFCGR), located at the National Geophysics Research Institute in Hyderabad, is undertaking a series of independent investigations into the groundwater resources in Maheshwaram watershed. Time series and spatially distributed data have been collected and deterministic modeling of groundwater processes has been carried out.

**Map 1: Groundwater contour of Maheshwaram watershed (Pre monsoon: May 2001)**



Source: Indo French Center for Groundwater Research

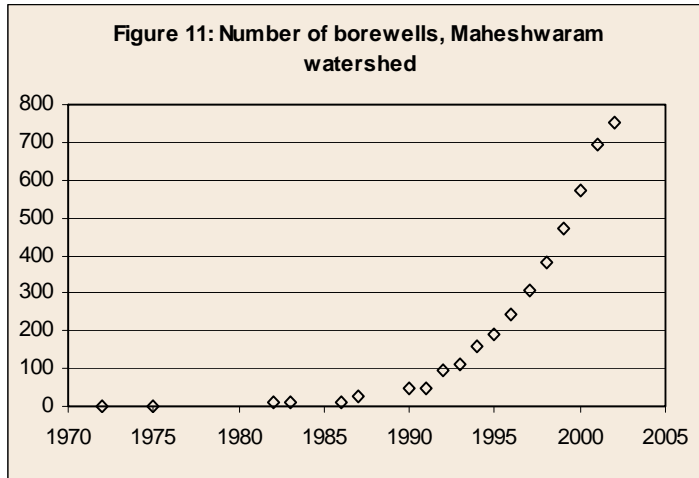
**Map 2 Groundwater contour of Maheshwaram watershed (Post monsoon: 2001)**



Source: Indo French Center for Groundwater Research

Maheshwaram, with its typical hard rock geology, increasing agricultural intensification, and rising urbanization, presents a representative case of groundwater development in the Telangana and Rayalseema regions of western Andhra Pradesh. Surveys by IRDAS (an NGO) have shown that the groundwater levels have been declining rapidly. Discussions with the farmers revealed that the cost incurred for getting a borewell drilled has more than quadrupled in the past 10 years. In spite of this, the number of borewells has increased from

397 about 10 years ago to 1219 currently (including 346 unauthorized connections, 28% of the total). Similar trends are reported by IFCGR (see Figure 11).

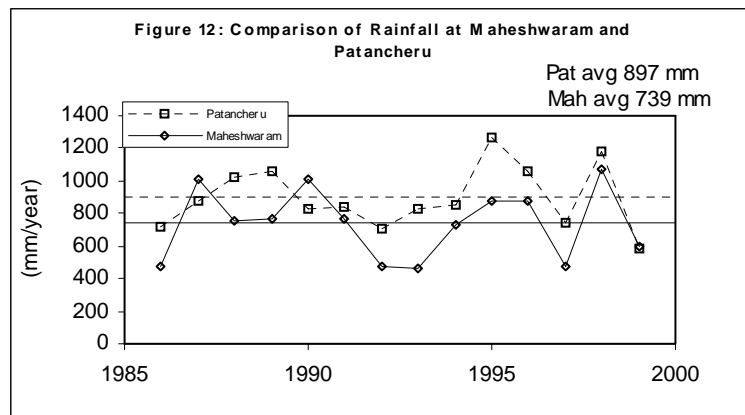


Simultaneously, the profile of the borewell owners has also undergone a significant change. As opposed to the past when mostly large landowners were investing in wells, the present trends show that small landholders (1 to 2 ha) currently account for the majority of wells. This has resulted in heightened competition for groundwater and as a result, there has been a steady fall in the water levels. In addition, due to the hard rock geology of the region, the well yields have also shown notable fluctuations. Wells yield good discharge for about half an hour after pumping starts and then as the flow rate exceeds inflow to the well, the discharge falls to a sporadic trickle. In terms of energy management, this means power is being under-utilized during these periods of low discharge. There has been a general complaint that due to the fluctuations and restricted hours of power supply, farmers are not able to apply adequate irrigation to their crops, particularly paddy.

**Water Balance**

Rainfall data from Maheshwaram mandal were used. However, the most accurate full meteorological data (daily rain, evaporation, max and min temperature, relative humidity, radiation and wind speed) in the area are collected by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Patancheru, some 40 km from Maheshwaram. Reference evapotranspiration values were derived for Patancheru and applied to Maheshwaram. This assumption is valid given that climatic conditions (max, min temperature, relative humidity, radiation and wind speed) are less likely to vary over a 40 km distance than rainfall, which is strongly influenced by convective storms. It should be noted that the 1986-99 (14-year) average rainfall at Maheshwaram is lower than Patancheru by 17.6% (see Figure 12), while the coefficient of variation of annual rainfall at Maheshwaram (29.2%) exceeds that at Patancheru (21.7%). 85% of Maheshwaram’s rainfall occurs in the monsoon months of June – October. Rainfall at 75% (477 mm) and 25% (878 mm) probability of exceedance was calculated for Maheshwaram (Table 4 and Figure 12).

Table 4: Rainfall at 75% and 25% probability of exceedance					
n	Exceed Prob	Year	Ann Rain	Exceed Prob	Use Year
14	93.33%	1993	466.4	75%	1997
13	86.67%	1992	468.9		
12	80.00%	1986	472.7		
11	73.33%	1997	477		
10	66.67%	1999	591.6	50%	1988
9	60.00%	1994	725.7		
8	53.33%	1988	757		
7	46.67%	1989	771.1	25%	1995
6	40.00%	1991	772.6		
5	33.33%	1996	871.7		
4	26.67%	1995	878.1		
3	20.00%	1990	1009.9		
2	13.33%	1987	1010.5		
1	6.67%	1998	1071.2		



Land use from the reference years 1999-2000 and 2000-01 were used for Maheshwaram, and detailed crop calendars were put together to determine the evapotranspiration loss coefficients by crop and by growth stage. Land use in Maheshwaram is presented in Table 5.

Category	Area in (Ha) 1999-2000	%	Area in (Ha) 2000-2001	%
Geographical area	26841	100.0	26841	100.0
Forests	2736	10.2	2736	10.2
Barren and uncultivable land	1207	4.5	1207	4.5
Land put to non-agricultural uses	2720	10.1	2720	10.1
Permanent pastures and other grazing lands	75	0.3	75	0.3
Miscellaneous tree crops & groves not included in net area sown	182	0.7	182	0.7
Culturable waste	478	1.8	478	1.8
Other fallow lands	3469	12.9	3336	12.4
Current fallows	5777	21.5	6102	22.7
Net area sown	10198	38.0	10005	37.3
Total cropped area	11949	44.5	11282	42.0
Area sown more than once	1751	6.5	1277	4.8

Source: District Statistical Abstract, Ranga Reddy District, 2001-02

The cropping pattern in Maheshwaram has undergone changes, adjusting to changes in groundwater resources as well as market conditions. Earlier studies show that there was a predominance of castor, vegetable and *jowar* cultivation (Sivamohan, et al, 1982). Until about five years ago, paddy was the predominant crop (this was responsible for the rapid growth in the number of groundwater draft structures); however, the consequent fall in groundwater levels and low discharge of the wells has caused farmers to begin the shift to other crops in the past two years.

Table 6 shows the detailed cropping pattern in the mandal. The data show that in the year 1999-2000, paddy accounted for over a fourth of the gross cropped area. This fell to less than 19% in the following year. Since the rains were quite erratic, the area sown decreased twice between the two years presented. This is important to note given that in this district (as in most other districts of Andhra Pradesh), paddy is the preferred crop for the second season. More than one decline in the area sown would indicate that there is a fall in the *Rabi* paddy.

Crop	Cropped area in 1999-2000 (Ha)			Cropped area in 2000-01 (Ha)		
	<i>Kharif</i> area	<i>Rabi</i> Area	Total area	<i>Kharif</i> area	<i>Rabi</i> Area	Total area
Rice	2114.5	955.6	3070.2	1454.4	597.6	2052.0
Jowar (sorghum)	2773.0	11.7	2784.7	2981.9	9.7	2991.5
Wheat	0.0	8.9	8.9		4.8	4.8
Bajra (millet)	10.9	0.0	10.9	6.5		6.5
Maize	849.6	146.0	995.6	1062.9	60.9	1123.8
Ragi (finger millet)	20.2	0.0	20.2	20.2		20.2
Green Gram	4.0	0.0	4.0	4.0		4.0
Red Gram	688.7	0.0	688.7	747.6		747.6
Bengal Gram	0.0	0.0	0.0		2.0	2.0
Chilies	60.1	0.0	60.1	38.3		38.3
Sugarcane	0.0	0.0	0.0	0.8		0.8
Vegetables	1254.0	548.8	1802.8	1332.7	510.5	1843.1
Fruits	781.5	0.0	781.5	881.5		881.5
Cotton	773.0	0.0	773.0	733.0		733.0
Groundnut	15.3	5.2	20.6	20.2		20.2
Sesamum	4.0	0.0	4.0	5.6		5.6
Safflower	0.0	16.9	16.9		10.9	10.9
Sunflower	10.5	15.7	26.2		1.6	1.6
Castor	532.3	0.0	532.3	460.5		460.5
Flowers	97.2	11.7	108.9	146.0	17.3	163.3
Total	9988.7	1720.6	11709.3	9895.9	1215.3	11111.2

Source: District Statistical Abstract, Ranga Reddy District, 2001-02

Table 6 shows that paddy registered a decline, both in *Kharif* and *Rabi*, and there was a consequent increase in area under *jowar* and maize. Incidentally, this seems to be a reversal in cropping trends, wherein a few years ago paddy had all but replaced these two otherwise prominent crops. With rains being erratic and less than normal, the farmers appear to have reverted to some of their earlier cropping practices.

In estimating the water balance, a monthly mass balance time step was used to simulate watershed and aquifer response to existing and historical meteorological data and land use. The following parameters were calculated or estimated:

- Monthly reference  $ET_0$  (based on corrected pan evaporation data for the area from ICRISAT in Patancheru)
- Evapotranspiration coefficients for crops, trees, and fallow (uncultivated) land based on CROPWAT (FAO, 1996)

- Runoff coefficient to compute total runoff out of the watershed, varied (0.025 – 0.2) by month to increase as the monsoon progresses then recedes taking account of antecedent soil moisture conditions
- Aquifer storage coefficient,  $k = 0.1$

Land use and cropping data (Tables 5 and 6) were combined with rainfall and reference ET data to calculate the water balance. Net groundwater flux was assumed to be zero given that adjoining watersheds are pumping at roughly the same rate. Using the crop coefficients for different crop growth stages, ET was computed as follows (Table 7):

**Table 7: Estimated crop ET**

Crop	1999-02		2000-01	
	Crop Area %	ET %	Crop Area %	ET %
Rice	26.2	34.3	18.5	24.8
Jowar	23.8	16.2	26.9	18.9
Wheat	0.1	0.1	0.0	0.1
Bajra	0.1	0.1	0.1	0.0
Maize	8.5	6.3	10.1	7.8
Ragi	0.2	0.1	0.2	0.1
Green Gram	0.0	0.0	0.0	0.0
Red Gram	5.9	3.2	6.7	3.8
Bengal Gram	0.0	0.0	0.0	0.0
Chillies	0.5	0.4	0.3	0.3
Sugarcane	0.0	0.0	0.0	0.0
Vegetables	15.4	13.3	16.6	14.8
Fruits	6.7	13.3	7.9	16.3
Cotton	6.6	7.5	6.6	7.7
Ragi	0.2	0.0	0.2	0.0
Sesamum	0.0	0.0	0.1	0.0
Safflower	0.1	0.1	0.1	0.1
Sunflower	0.2	0.2	0.0	0.0
Castor	4.5	3.6	4.1	3.4
Flowers	0.9	1.1	1.5	1.8
Total	100.0	35.4	100.0	33.4

Table 7 shows that agriculture alone accounts for about a third of the total ET demand and much of it comes from paddy. This crop, which accounted for less than a fourth of the cropped area in 1999, contributed to a third of the total ET demand. In the following year, when this crop fell to 18% of the gross cropped area, the ET demand accounted for about a fourth.

Table 8 presents the total water balance in the mandal for the years 1999 and 2000. It can be seen that for both years, rainfall had been less than normal and consequently there had been a net fall in groundwater levels. It is important to note that since rainfall is the only source of water inflow into Maheshwaram, when rainfall is less than normal, there would be heavy pumping of groundwater to meet ET demand.

Description	1999	2000
Area (ha)	26730	26730
ET (million m3)	1915.2	187.5
ET (mm)	714.0	701.3
Rainfall (mm)	590.6	626.1
Rain (million m3)	158.4	167.4
Runoff (million m3)	13.0	14.1
Net rechg (million m3)	-46.1	-34.2
Aquifer stor coeff	0.1	0.1
GW rise (m)	-1.7	-1.3

In 2001-02, the Indo-French Center for Groundwater Research (IFCGR) undertook a series of measurements in selected piezometers to study the groundwater balance. Even during this year, rainfall had been less than normal at 603 mm. As a result, even in this year the groundwater balance registered a deficit of 10.5 mm/year, equivalent to a static groundwater decline of 1.18 m/year (see Table 9).

Flows	Value (mm/yr)
Infiltrations	+ 94.5
Return flows	+ 119.0
Horizontal inflows	+ 10.9
Pumping	- 230.7
Evaporation	- 1.7
Horizontal outflows	- 2.6
Total	- 10.5
Net change in groundwater level (m)	- 1.18
Rainfall	603.0
Source: IFCGR, Hyderabad	

It is critical to note here the difference between a generalized water balance comprising both surface and groundwater interactions and the more detailed groundwater balance presented in Table 9. In the former, the storage coefficient (0.1) is for the subsurface geological formation but also the fractured upper zone. For the former, a lower value (0.01) is used for the hard rock.

The water balance was verified using observed static water levels and farmer recall in the study area. For the 1987-2000 simulation period, the average simulated decline was 0.56 m/year (yearly results are presented below with the cropping scenarios). The simulated decline is somewhat higher than the average measured decline of 0.34 m/year in the 1987-2000 pre-monsoon levels in an observation well in adjoining Mankhal mandal (long-term data were not available for Maheshwaram). The total simulated drop of 9.9 m over the 1987-2002 period also compares favorably with farmers' recall that open wells (typically 10-12 m deep) have dried up.

**Groundwater Balance under Different Levels of Rainfall Exceedance**

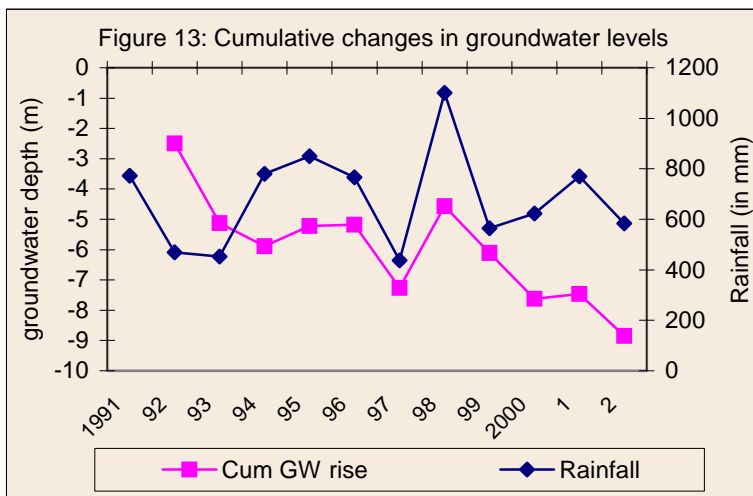
The tables above demonstrate that groundwater is registering a negative balance when rainfall is less than normal. Table 10 presents the water balance for the historical years most closely corresponding to the 75%, 50% and 25% probability of rainfall exceedance, i.e., 1997 (477 mm), 1988 (757 mm), and 1995 (878 mm), respectively.

**Table 10: Water balance under different rainfall conditions**

Description	At 75% probability of rainfall (1997)	At 50% probability of rainfall (1988)	At 25% probability of rainfall (1995)
Area (ha)	26731	26731	26731
ET (million m3)	187.5	187.5	187.5
ET (mm)	701.3	701.3	701.3
Rainfall (mm)	477.0	757.0	878.6
Rain (million m3)	127.5	202.4	234.9
Runoff (million m3)	9.3	19.2	17.1
Net rechg (million m3)	-69.2	-4.4	30.3
Aquifer stor coeff	0.1	0.1	0.1
Net gw rise (m)	-2.6	-0.2	1.13

As Table 10 shows, at the 75% probability of exceedance, there would be a net drop in the groundwater levels of 2.6 m. At 50% probability, the drop would be marginal at 20 cm. However, at 25% exceedance levels, there would be a net increase in the groundwater levels of up to 1.13 m.

Given this variation, an attempt was made to determine the cumulative effect of such an impact on groundwater over a ten-year period. For this analysis, it is assumed that the land use and cropping patterns would remain constant at 2000 levels. Figure 13 presents the findings.



Year	Cum GW rise	Rainfall
91		773
92	-2.5	469
93	-5.1	453
94	-5.9	780
95	-5.2	850
96	-5.2	766
97	-7.3	437
98	-4.6	1101
99	-6.1	564
00	-7.6	623
01	-7.5	770
02	-8.8	584

This figure shows that groundwater levels had been steadily registering a negative balance, dipping at an average rate of about 88 cm each year. Thus, groundwater resources in the mandal as a whole are experiencing severe pressures and immediate remedial measures need to be taken. A host of solutions exist to address this problem, including cropping pattern changes (with associated forward and backward linkages), watershed development, and power supply management to ration power supply so that farmers would be further dissuaded from cultivating paddy and other water-intensive crops.

## ***APPENDIX A: REFERENCES***

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- Alam, Anwar and Ashwini Kumar, 2001, "Status and Strategies to Develop Groundwater Management Policy in India."
- Bhatnagar, P.R. and A.K. Sikka, 2002, "Energy and Groundwater Utilization for Agricultural Production in India," ICAR, Patna.
- Andhra Pradesh Electricity Regulatory Commission (APEREC), Tariff Order 2001-02.
- Center for Monitoring Indian Economy (CMIE), *Energy Report*, 2000.
- Food and Agriculture Organization (FAO), 1998, FAO Irrigation and Drainage Paper No: 56: *Crop Evapotranspiration* (guidelines for computing crop water requirements). FAO, Rome, Italy.
- Food and Agriculture Organization (FAO). 1996. *CROPWAT software package*. FAO, Rome, Italy.
- Gulati, Ajit S., 2002, "Energy Implications of Groundwater Irrigation in Punjab," paper presented at the IWMI-ICAR-Colombo Plan Secretariat-sponsored Policy Dialogue on Forward Thinking Policies for Groundwater Management: Energy, Water Resources and Economic Approaches, organized at the India International Center, New Delhi, September 2-6, 2002.
- Institute of Resource Development and Social Management (IRDAS), 2003, "Findings of Farmers' Survey in Maheshwaram," paper presented at the Policy Dialogue on Energy-Water Co-management in Andhra Pradesh, organized at the Hotel Grand Kakatiya, Hyderabad, January 21, 2003.
- Institute of Resource Development and Social Management (IRDAS), 2003, "Maheshwaram Watershed: Communication and Outreach Material."
- Marechal, J.C., Galeazzi, L., and Dewandel, B., 2003, "Spatial groundwater balance of Maheshwaram watershed using GIS," paper presented at the Policy Dialogue on Energy-Water Co-management in Andhra Pradesh, organized at the Hotel Grand Kakatiya, Hyderabad, January 21, 2003.
- Narayana, P., 2001, "Establishing linkages for energy and water co-management," STEM, paper presented at IWMI-TATA partners meeting, Anand.
- Narayana, P., 2002, "Economics of the supply of power to agriculture," paper presented at the IWMI-ICAR-Colombo Plan Secretariat-sponsored Policy Dialogue on Forward Thinking Policies for Groundwater Management: Energy, Water Resources and Economic Approaches, organized at the India International Center, New Delhi, September 2-6, 2002.
- Palanisami, K. and Suresh D. Kumar, 2002, "Power Pricing, Groundwater Extraction, Use and Management: Comparison of Tamil Nadu and Andhra Pradesh States," paper

A: References...

presented at the IWMI-ICAR-Colombo Plan Secretariat-sponsored Policy Dialogue on Forward Thinking Policies for Groundwater Management: Energy, Water Resources and Economic Approaches, organized at the India International Center, New Delhi, September 2-6, 2002.

Penkova, N. and V. Shiklomanov, 2002, *Water Balance Methodology for Indirect Assessment and Prediction of Basin Water Yield under Human Induced Landuse Changes*. State Hydrological Institute, St. Petersburg, Russia.

Rao, M.V.K. and G.R.K. Reddy, 2003, "Energy Management, Supply and Reliability Implications for Pump Irrigation," paper presented at the Policy Dialogue on Energy-Water Co-management in Andhra Pradesh, organized at the Hotel Grand Kakatiya, Hyderabad, January 21, 2003

Sehgal Manmohan, 'Study on cropping pattern changes in the command area of Indira Gandhi Nahar Pariyojana (IGNP), ORG, research supported by Command Area Development Authority – Indira Gandhi Nahar Pariyojana (CADA-IGNP), 1997

Sharma, B.R, "Improved Policies for Groundwater and Energy Use for Sustainable Agriculture Production in India," paper presented at the IWMI-ICAR-Colombo Plan Secretariat-sponsored Policy Dialogue on Forward Thinking Policies for Groundwater Management: Energy, Water Resources and Economic Approaches, organized at the India International Center, New Delhi, September 2-6, 2002.

Siva Mohan MVK, 'Pro-poor intervention strategies in irrigated agriculture in Asia – Indian Context, IWMI, ADB supported research, 2003

Siva Mohan MVK, 'Moving towards the concept of "Partnerships" in irrigation management in India' paper published in "India: Irrigation Management Partnerships, Booklinks, edited by Dr MVK Siva Mohan, 1982