GROUNDWATER EXPLORATION AND AUGMENTATION EFFORTS IN RAJASTHAN

- A REVIEW -

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Summary

In Rajasthan water harvesting for groundwater recharge is the lead activity for many non-governmental organization (NGO) programs and is also central to government investments in watershed treatment. Organizations such as Tarun Bharat Sangh, which works in Alwar District, have received global attention for their water harvesting and recharge initiatives.

The high level of attention being given to water harvesting and groundwater recharge in Rajasthan reflects both the aridity of the state and increasing concerns regarding groundwater overdraft. In recent years, drought conditions have had a major impact on rural livelihoods, particularly in regions where decades of extensive groundwater development have already caused long-term declines in groundwater levels. Although integrated management of the resource base has been recommended for several decades, most responses have focused on water harvesting and groundwater recharge. Such recharge initiatives are extremely popular, and between 1974 and 2002, the state government alone invested 8,534,930,000 rupees (approximately U.S. 190 million) in watershed treatment.

Despite the huge investment and concerted attention being given to water harvesting for groundwater recharge, the author of this report has been unable to locate any systematic scientific evaluation regarding the effectiveness of recharge techniques. Existing technical reports identified by IDS-Jaipur and reviewed here do not provide a systematic or quantitative basis for evaluating the impact of investments in water harvesting on groundwater conditions. This should not be interpreted as indicating that water-harvesting efforts themselves have had little impact. Rather, it simply indicates that available technical evaluations are inadequate to reach any conclusion.

Acknowledgements

This report has been prepared as a contribution to a project entitled - Augmenting Groundwater Recharge through Artificial Recharge – AGRAR. The British Department for International Development – DFID, commissioned the British Geological Survey – BGS, to undertake this project, which runs from July 2002 to July 2005, through a programme of collaborative studies with IDS Jaipur and other NGOs and universities in India and Nepal. The aim of the project is to assess the effectiveness of managed aquifer recharge in a variety of environments, both physical as well as socio-economic, and to produce guideline for effective implementation. Thanks are due to Marcus Moench of ISET and Ian Gale of the BGS for comments on the document. Sonam Bennett-Vasseux of ISET provided extensive editorial support.

Introduction

Rajasthan's economic growth is largely dependent on water, more specifically on groundwater. 71% of the irrigation and 90% of the drinking water supply source is groundwater (Rathore 2003). Presently, there is tremendous pressure to exploit groundwater by State and private users, i.e. by those who have access and control over this limited resource. The resulting consequences are also well known - in 2001, out of 236 groundwater zones, only 20.8% were categorized as safe. The rest reached the stage of being categorized as semi-critical (8.9%), critical (33.9%) and over-exploited (36.4%). The causes of groundwater depletion and pollution are rooted in population growth, economic expansion, decline in groundwater recharge and over-abstraction caused by the rapid increase in the number of wells and tubewells and the progress in pumping technology.

In response to this grave groundwater situation, numerous efforts were initiated by the State government, NGO's and civil society, such as the construction of dams, tanks and traditional water harnessing systems, and, the most important initiative: the watershed management program. What is lacking is any scientific evaluation of these interventions in terms of their impact on groundwater augmentation. In this study, an attempt has been made to review the status of groundwater in Rajasthan and document the results of groundwater augmentation studies in the State.

In the first part of this study, the historical background of groundwater in the State is discussed followed by a description of the geology, geohydrology, rainfall and other relevant factors affecting groundwater that are helpful in understanding the present situation. The next section presents a review of studies documenting the impacts of groundwater augmentation efforts in the State. Finally, some recommendations are given for future activities to improve the groundwater situation in the State.

Historical Background

The surface water resources of Rajasthan are meager and the entire state is principally dependent on groundwater for its water needs. The hydrogeologic environment controls the occurrence, distribution and movement of groundwater. Over the years, the study of groundwater has focused singularly on understanding the occurrence and movement of water is these environments in order to develop and manage the resource. Besides understanding the hydrogeological framework in which groundwater occurs and assessing its utilizable component, an equally important concern is assessing its quality. If groundwater is to play a lead role in development, then it will have to be protected from increasing threats of depletion and contamination. The growth of population, industry and agriculture coupled with increasing urban development has, for the first time in history, resulted in over-abstraction of groundwater and production of enormous quantities of waste. The management of groundwater is a complex job that must be efficiently handled, given the concerns of the economic impacts of groundwater development and allocation amongst competing users. Groundwater management should be done in a systematic manner rather than the focus on individual pump capacity that has been the trend in the past.

Rajasthan is a landlocked state of 342,239 km^2 situated between latitudes $23^o3`$ to $30^o12`$ N and longitudes 69^o 30` to $78^o$ 17` E. It experiences varied climatic conditions ranging from extreme aridity in the northwestern parts (Jaisalmer) to sub-humid conditions in the southeastern parts (Jhalawar and Banswara) and humid conditions in the isolated Mount Abu region. However, most of the state (94.0%) falls under arid and semi-arid conditions with low and erratic rainfall patterns. Physiographically, western Rajasthan is covered in sand and dunes while the eastern, southern and southeastern parts are rocky and hilly with very few alluvial plains. Surface water sources are meager and the entire state has always been principally dependent on groundwater for its water needs.

During British India, almost the entire state of Rajasthan belonged to a large number of autonomous or semi-autonomous princes. Consequently, comprehensive efforts to cope with the urgent need for water were impossible, despite the rapid progress in groundwater exploration and exploitation. Efforts to exploit groundwater were made by individuals who dug deep wells by hand in rocky and alluvial/sandy areas to obtain small quantities of water. Throughout Rajasthan, especially in the western districts, dug wells and open wells were few and sparse, and most yielded very small quantities of water. Water was encountered at depths up to of 122 m belowground with saturation depths of not more than one to one-and-a-half meters. The wells were dug by hand and the groundwater finally obtained was saline. Rural inhabitants had to travel long distances to fetch drinking water. The drinking water situation in eastern Rajasthan was different because of hilly terrain and higher rainfall, which made collecting water easier, but even there wells yielded quantities too low to meet agricultural requirements.

After the advent of railways, in a few places water was supplied by train tanker, especially in desert areas. The first scientific exploration of groundwater in Rajasthan occurred in 1921 by G.H. Tipper who investigated the water supply for the Jodhpur-Bikaner Railways (Taylor *et al.* 1955).

After independence in 1942, the Government of India and the State Government of Rajasthan undertook groundwater exploration, exploitation and management programs through various central and state agencies. These were the:

- i Geological Survey of India
- ii Exploratory Tubewells Organization
- iii Central Ground Water Board
- iv Central Arid Zone Research Institute, Indian Council of Agriculture Research
- v Ground Water Department, Government of Rajasthan
- vi Public Health Engineering Department, Government of Rajasthan
- vii Sanitation, Water and Community Health Project
- viii Rajasthan Jal Vikas Nigam Ltd.
- ix Other NGOs and private individuals.

Various development programs were supported with funding made available by financial institutions for drilling and mechanizing wells and with professional assistance for locating the best sites for them. The number of open wells and tubewells increased dramatically from 1957/58 to 1999/2000 (see Table 1). The density of wells increased from 1,489 wells per 1,000 km^2 in 195/57 to 3,944 in 1999/2000.

The first groundwater potential estimates were made during 1983/84 and were repeated in 1987, 1990, 1992, 1996, 1998 and 2001. Despite an increase in the area of groundwater potential due to more exploratory studies, there has been a total decline of 39.89% in the groundwater potential. As a result, ‘safe’ water zones, i.e. those safe for exploitation, declined from 86% in 1984 to 20.7% in 2001, and in 2001, 70.3% of all groundwater potential zones were classified as ‘dark’ and ‘gray’ (Tables 2 and 3).

Categorization of areas for groundwater development

Groundwater development can be categorized based on the stage of development and the long-term trend of pre- and post-monsoon groundwater levels. The following categorization is adopted by the Ground Water Department in Rajasthan:

Safe areas with potential for development

(a) Areas where groundwater resource assessments show the stage of groundwater development to be 70% or lower and where there is no significant long-term decline of pre- or post-monsoon groundwater levels.

(b) Areas where groundwater resource assessments show the stage of groundwater development to be more than 70% but less than 90% and where both pre- and post-monsoon groundwater levels do not show a significant long-term decline. However, in these areas, caution should be exercised in plans for future development with regard to quantities of additional groundwater withdrawn.

Semi-critical areas for cautious groundwater development

Areas where groundwater resource assessments show the stage of groundwater development to be more than 70% but less than 90% and where either pre- or post-monsoon groundwater levels show a significant long-term decline.

Critical areas

(a) Areas where groundwater resource assessments show the stage of groundwater development to be more than 90% but less than 100% and where either pre- or post-monsoon groundwater levels show a significant long-term decline.

(b) Areas where groundwater resource assessments show the stage of groundwater development to be less than 100%, but where both pre- and post-monsoon groundwater levels show a significant long-term decline.

(c) Areas where groundwater resource assessments show the stage of groundwater development to be more than 100%, but where either pre- or post-monsoon groundwater levels do not show a significant long-term decline.

Over-exploited areas

Areas where groundwater resource assessments show the stage of groundwater development to be greater than 100% and where both pre- and post-monsoon groundwater levels show a significant long-term decline.

Stage of groundwater development

The stage of groundwater development, indicated as a percentage, is defined by:

$$\frac{\text{Existing gross groundwater draft x 100}}{\text{Net annual groundwater availability}}$$

Table 1 District-wise density of wells/1,000 km^2 in Rajasthan, 1956-2000

Districts	Density of wells (all types) /1,000 km2					
	1956–57	1961–62	1971–72	1981–82	1999–2000	1999–2000 (tubewells only)
WESTERN REGION						
Barmer	64	137	154	300	653	25
Jaisalmer	1	9	12	54	12	1
Bikaner	19	28	43	–	45	27
S. Ganganager	2	–	2	66	0	566
Churu	2	5	18	125	345	48
Nagaur	427	440	508	883	2,602	267
Jodhpur	188	259	300	432	850	475
Pali	1,964	2,129	2,092	2,620	4,007	98
Jalore	768	994	1,106	2,272	5,281	76
Hanumangarh	–	–	–	–	55	1,310
NORTHEASTERN REGION						
Sikar	2,145	1,771	1,919	2,984	6,936	21
Jhunjhunu	765	838	940	2,602	6,957	0
Alwar	2,360	2,363	3,566	5,590	9,299	3,170
Jaipur	5,051	5,113	5,800	7,047	11,928	48
Ajmer	3,366	4,919	5,363	5,903	8,860	45
Tonk	2,954	3,275	3,638	4,786	7,042	35
S. Madhopur	2,598	2,324	2,918	3,859	6,396	282
Bharatpur	3,414	2,326	3,359	1,301	4,374	6,352
Dholpur	–	–	–	–	5,480	2,430
Dausa	–	–	–	–	13,075	1,366
Karauli	–	–	–	–	6,116	1,013
SOURTHEN REGION						
Bhilwara	6,495	6,845	7,539	7,820	11,862	46
Chittorgarh	4,028	4,365	5,317	6,322	9,729	639
Udaipur	3,858	4,090	4,545	4,921	5,315	39
Sirohi	1,443	1,557	1,723	2,221	3,645	0
Banswara	821	772	1,456	2,026	4,331	22
Dungarpur	738	938	2,051	2,429	7,712	50
Bundi	2,480	2,428	2,346	2,960	4,538	407
Kota	1,503	1,376	1,690	2,717	3,530	729
Jhalawar	3,400	3,737	4,732	6,625	11,435	148
Rajsamand	–	–	–	–	12,903	65
Baran	–	–	–	–	4,890	605
Rajasthan total	**1,489**	**1,558**	**1,722**	**1,822**	**3,944**	**395**

Source: State and Central Ground Water Board reports for various years, Government of Rajasthan and Government of India, Jaipur; Chatterji, P.C.(1993), 'Status of Ground Water in Rajasthan – Retrospect and Prospect', Institute of Development Studies, Volume III, pp. 500.

Table 2 Groundwater resource estimation in Rajasthan (mcm)

Item	Year				
	1984	**1990**	**1995**	**1998**	**2001**
Gross groundwater recharge	16,224	12,708	13,157	12,602	11,159
Net groundwater draft: (1) Irrigation (2) Domestic & Industrial	4,929.7 2,109*	5,423 1,994*	9,085 696	11,036 983	10,454 1,181
Gross draft (1) + (2)	7,039	7,417	9,916	12,019	11,635
Groundwater balance	8,799	5,239	4,535	3,894	– 476
Stage of groundwater development (%)	36	54	59	69	104

Source: Ground Water Department and Central Ground Water Department, Report of the Group on the Estimation of Ground Water Resources of Rajasthan (as on 1/1/2001), April 2002.
* Draft for drinking and industrial use is around 15% of gross water resources.

Table 3 Status of groundwater in Rajasthan

Year	Block (area unit)	Number of zones (figures in brackets are %)			
		Safe (White)	Semi-critical (Semi Gray)	Critical (Gray)	Over-exploited (Dark)
1984	236	203 (86.0)	10 (4.2)	11 (4.7)	12 (5.1)
1988	226	122 (54.0)	42 (18.6)	18 (8.0)	44 (19.5)
1990	236	148 (62.7)	31 (13.1)	13 (5.5)	44 (18.6)
1992	236	149 (63.1)	19 (8.1)	15 (6.4)	53 (22.5)
1995	236	127 (53.8)	35 (14.8)	14 (5.9)	60 (25.4)
1998	233	135 (57.9)	34 (14.6)	23 (9.9)	41 (17.6)
2001	236	49 (20.8)	21 (8.9)	80 (33.9)	86 (36.4)

Source: Ground Water Department and Central Ground Water Department, Report of the Group on the Estimation of Ground Water Resources of Rajasthan (as on 1/1/2001), April 2002

Geohydrology of Rajasthan

Rajasthan lies over some of the oldest rock formations in India. The State has a heterogeneous assemblage of geological formations ranging from the oldest Archean to recent alluvium and blown sand (Heron 1936, 1953; Sharma 1992). All of the lithological units have some groundwater potential; however, the water potential of these formations depends on their hydrogeological characteristics and structural control. The groundwater potential areas in Rajasthan are not widespread and homogenous, but found as isolated basins with unique hydrological parameters. Also, the quality of the groundwater depends entirely on the site-specific physical properties of the formation, the extent and nature of weathering, and other specifics.

There is considerable knowledge of the regional geological formations and mega-structures, and of the extent of weathering. However, the information generated is inadequate to correlate with the groundwater potential of any specific area.

Geomorphological Characteristics

According to Singh *et al.* (1990), the geomorphological characteristics of Rajasthan can be broadly divided into four major geomorphic regions. These are, from west to east, (1) the Rajasthan desert, (2) the Aravalli Mountains, (3) the east Rajasthan plains and (4) the southeastern plateau.

Hydrogeological Conditions

Hydrogeological characteristics of the various lithological formations, such as depth of groundwater, yield, etc., are of vital importance in studying the groundwater potential in any area. The State Ground Water Department (SGWD), in 1977/78, identified 28 types of aquifer and grouped them into 13 hydro-geological zones. Subsequently, better data and information on hydrological properties of various aquifers and their extent were generated and these groups were reclassified (Chatterji 1993). Based on detailed information of these 13 aquifer types, the SGWD divided the State into seven provenances, each with similar groundwater characteristics, including water quality (Figure 1). These provenances are: hard crystalline rock, consolidated sedimentary rock, semi-consolidated cavernous rock, semi-consolidated sedimentary rock, basaltic, unconsolidated to poorly consolidated sedimentary rock and alluvial. However, despite good data, water yield data is based on water lifting devices installed in the wells. There is a gap in information and precise hydrogeological characteristics such as optimum yield, drawdown, recovery rate, porosity, permeability and transmissivity have not been adequately determined.

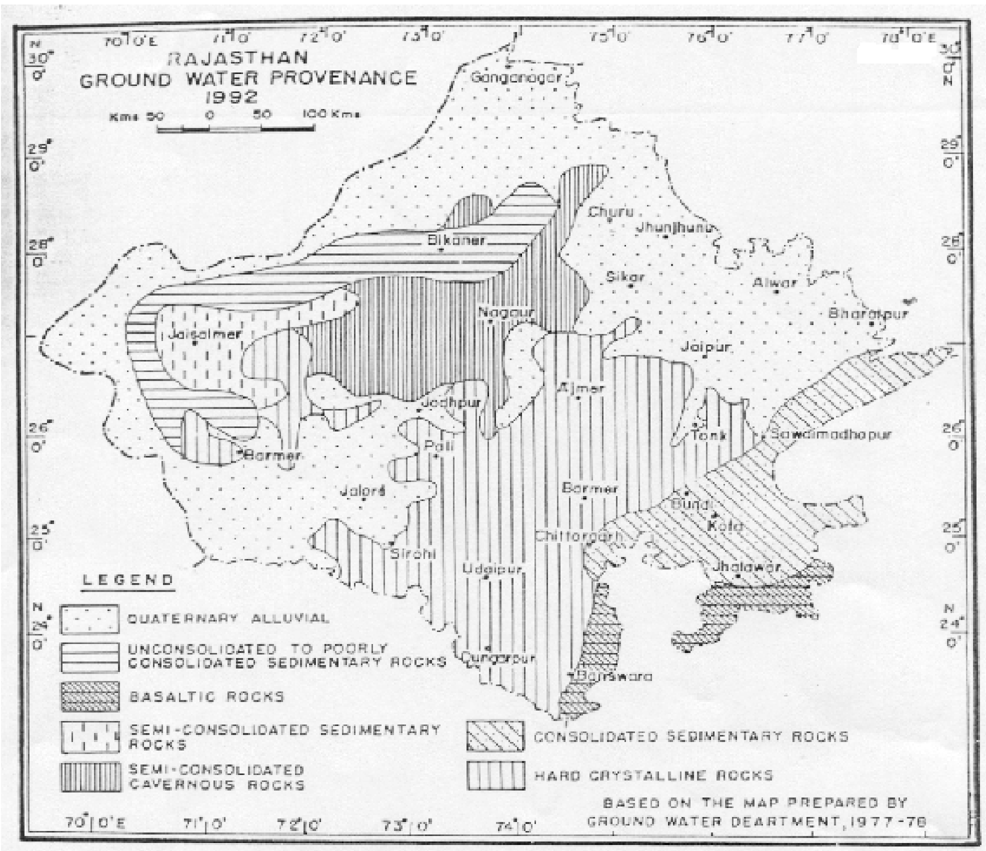


Figure 1 Groundwater Provinces in Rajasthan

Systematic hydrological investigations in the State of Rajasthan were initiated in 1965 and completed in 1972. From preliminary investigations, regional maps depicting the hydrogeology, depth to water, chemical quality of the groundwater and groundwater potential zones (phreatic) were prepared. These maps divided the State into 90 basins.

Semi-detailed hydrogeological surveys to estimate the dynamics of groundwater resources and approximately quantify the groundwater potential of the State were initiated in 1972 on a block basis. These were short-term, one-year studies, completed in 1976. The findings of these surveys proved helpful in launching systematic groundwater development programs such as the Minor Irrigation Scheme, Rural Electrification Scheme/SPA Scheme, Cattle Drinking Water Supply Scheme and the construction of wells for individuals.

From these and subsequent, more detailed, hydrogeological surveys and drilling programs, groundwater potential zones able to receive recharge and transmit water were delineated. These zones were categorized into thirteen groups. Hilly and inaccessible areas and areas with saline water or poor yield potential are not included. A total of 766 groundwater potential zones were identified and demarcated in 1977/78. The number of groundwater potential zones has since been reduced to 583 by merging zones of 50 km^2 or less with the neighboring zone. Groundwater potential zones are periodically revised based on further surveys and exploratory drilling programs.

Table 4 Revised groundwater potential zone

Formations	Number of				Notation
	Zone	Sub-zones	Sub-sub-zones	Total	
GROUP I – UNCONSOLIDATED					
Younger alluvium	32	16	2	50	A
Older alluvium	71	48	20	139	Ao
GROUP II – TERTIARY FORMATIONS					
Tertiary sandstone and gravel	–	–	–	–	T
Tertiary formations (mixed aquifer)	3	13	–	16	T
GROUP III – CONSOLIDATED SEDIMENTARY FORMATIONS					
Parewar formations	–	2	–	2	P
Bhadesar formations	–	3	–	3	Bh
Lathi formations	1	8	–	9	L
Sandstone (M.SG/Vindhyan's)	35	8	27	70	SS
Shale (M.SG/Vindhyan's)	9	8	–	17	Sh
Limestone (M.SG/Vindhyan's /Aravallis/Delhi etc.)	17	8	16	41	LS
Slate (M.SG/Vindhyan's/ Aravallis etc.)	2	–	–	2	SL
GROUP IV – CRYSTALLINES – IGNEOUS FORMATIONS					
Basalt	14	–	–	14	B
Rhyolite (Malani)	5	–	–	5	R
Granite (Malani/ post-Delhi/Aravallis)	14	20	–	34	Gr
Ultra basic (Dalorite/Diorite)	1	–	–	1	Ub
GROUP V– METAMORPHICS					
Quartzite (Delhi/Aravalli)	24	2	–	26	Q
Schist/Phyllites (Calc/Mica/Biotite)	72	16	–	88	Sc/Ph
Gneisses/B/G.C.	46	20	–	66	Gn.

Source: Anonymous 1972.

For greater clarity of classification, groundwater potential zones have now been divided into five groups, 15 zones, 13 sub-zones and 94 sub-sub zones (see Table 4). The sub and sub-sub zones are based on variation in discharge and quality of water (Table 5). The first and second estimates were made during 1984 and 1988 but the area determined during 1990 increased by 10.67% and 14.14% over 1984 and 1988 years, i.e., the coverage improved in the subsequent years of estimation.

Detailed, long-term hydrogeological investigations for delineating aquifers, studying their geometry and hydrological parameters, and identifying the dynamic and static groundwater resources were undertaken in 1976. These studies investigated hydrogeological, hydro-geochemical, hydro-meteorological and geophysical aspects over at least one hydrologic cycle and involved exploratory drilling. Shortage of funds prevented these studies from being undertaken in a large number of basins simultaneously. The studies in western Rajasthan were mainly financed under the Desert Development Programme (DDP)/Drought Prone Area Development Programme (DPAP), whereas in eastern Rajasthan they were financed under the State Plan Scheme.

Hydro-geomorphology and Groundwater Development/ Recharge

Besides rainfall and lithological characteristics, the development of groundwater aquifers and recharge to such aquifers is largely determined by the geomorphic properties of the land, especially slope, drainage patterns and the nature and thickness of the unconsolidated/semi-consolidated layers over the bedrock formations. A good correlation exists between the hydrogeological properties of non-hard rock areas and the geomorphic properties of the land. Since geomorphic features can easily be identified through visual interpretation of remote sensing products and field traverses, it is possible to identify potential aquifers and to locating areas suitable for groundwater recharge (Table 6). However, very few studies on the relationship between geomorphic properties and groundwater characteristics have been done in Rajasthan, and most of these have been carried out in universities in the arid western part of the State.

Table 5 Characteristics of groundwater potential zones

Code	Zone	Sub-code	Aquifer	Nature of Aquifer	Suitable for
A	Unconsolidated Aquifer	A1	Younger alluvium	Intercalated clay layers, moderately permeable	Tubewells
		A2	Younger and old alluvium	Appreciable clay contents, low permeability	Tubewells
		A3	Older alluvium	Dominantly argillaceous, calcareous, poor permeability	Ring wells, dug wells
B	Semi-consolidated to consolidated Aquifer	B1	Tertiary sandstone	Medium to coarse grained arenaceous, moderate permeability	Tubewells
			Occasional limestone		Tubewells
		B2	Vindhyan sandstone	Medium grained intercalation of shales, moderate to low permeability	Tubewells
		B3	Vindhyan sandstone	Fine grained, compact, poor permeability	Dug well, tubewell
		B4	Vindhyan limestone	Partly cavernous, moderate to low permeability	Tubewell, dug well
C	Consolidated Metamorphic Aquifer	C1	Quartzite/ Sandstone/ Phyllite/ Schists/ Granite and acid intrusive	Moderate secondary permeability due to extensive weathering and fractured zones	Wide diameter, tubewells/ dug wells
		C2	Quatzite/Gneisses/ Slate/Shale/Basic & Ultra basic intrusives	Low secondary permeability due to limited fractured zones	Tubewells, wide diameter
					Dug-cum-bore wells
		C3	Quartzite/ Gneisses/Slate/ Shales/Basic & ultra basic intrusives	Compact poor permeability	Revitalization of dug wells by blasting, lateral drilling, etc.
D	Detailed hydrological investigations are in progress				
E	Area not suitable for further groundwater development due to meager potential, unsuitable water quality and inaccessibility				
F	Hills				

Source: Ground Water Department Map, “Ground Water Potential Zones”, 1977/78

Table 6 Potential area (km^2) capable of receiving recharge

District	District size	Potential recharge area	Potential area as a % of the district	Unproductive recharge area	Unproductive area as a % of the district
Ajmer	8,481	7,466.76	88.04	1,014.24	11.96
Alwar	8,380	6,843.81	81.67	1,536.19	18.33
Banswara	5,037	4,289.42	85.16	747.58	14.84
Barmer	28,387	13,492.32	47.32	14,894.68	52.47
Bharatpur	5,100	3,412.52	66.91	1,687.48	33.09
Bhilwara	10,455	9,354.84	89.48	1,100.16	10.52
Bikaner	27,244	11,561.00	42.43	15,683.00	57.57
Bundi	5,550	4,240.18	76.40	1,309.82	23.60
Chittorgarh	10,856	8,277.87	76.25	2,578.13	23.75
Churu	16,830	6,440.34	38.27	10,389.66	61.73
Dholpur	3,000	2,231.35	74.38	768.65	25.62
Dungarpur	3,770	2,649.00	70.26	1,121.00	29.74
Jaipur	14,068	12,623.29	89.73	1,444.71	10.27
Jaisalmer	38,401	9,027.76	23.61	29,373.24	76.49
Jalore	10,640	7,520.64	70.68	3,119.86	29.32
Jhalawar	6,219	6,106.16	98.18	112.84	1.82
Jhunjhunu	5,728	5,153.22	89.96	574.78	10.04
Jodhpur	22,850	16,606.51	72.68	6,243.49	27.32
Kota	12,436	12,015.38	96.62	420.62	3.38
Nagaur	17,718	15,106.28	85.26	2,611.72	14.74
Pali	12,387	7,362.54	59.44	5,024.46	40.56
S.Madhopur	10,527	8,670.05	82.36	1,856.95	17.64
Sikar	7,732	6,957.04	89.97	774.96	10.63
Sirohi	5,136	4,075.71	79.35	1,060.29	20.65
S. Ganganagar	20,634	2,078.16	10.07	21,555.84	89.93
Tonk	7,194	6,525.71	90.71	668.29	9.29
Udaipur	17,279	12,467.86	72.15	4,811.14	27.85
Rajasthan total	**342,039**	**212,555.72**	**62.14**	**129,488.28**	**37.86**

Source: Chatterji, P.C. (1993), 'Status of Ground Water in Rajasthan – Retrospect and Prospect', Institute of Development Studies, Volume I, pp. 96.

Rainfall and Groundwater

While recognizing the importance of the factors discussed above in understanding the status and potential of groundwater, ultimately it is the rainfall distribution and quality that determines groundwater availability. Rajasthan can be divided into three rainfall zones: arid, semi-arid and sub-humid (Figure 2). The total area classified as arid is 196,149 km^2 (58% of the state), as semi-arid is 121,016 km^2 (36%), and as sub-humid is 21,248 km^2 (6%). Rainfall distribution is highly variable, both in time and space. Annual rainfall across the state varies from more than 900 mm in the southeastern part to less than 100 mm in the west (Tables 7 and 8). Only the Mount Abu region receives more than 1,593 mm of rain a year due to its elevation, but this localized heavy rainfall over such a small region is not considered to influence the climatic conditions of the neighboring regions, which are sub-humid to semi-arid. The Mount Abu region is therefore often not included in the regional climatic classification.

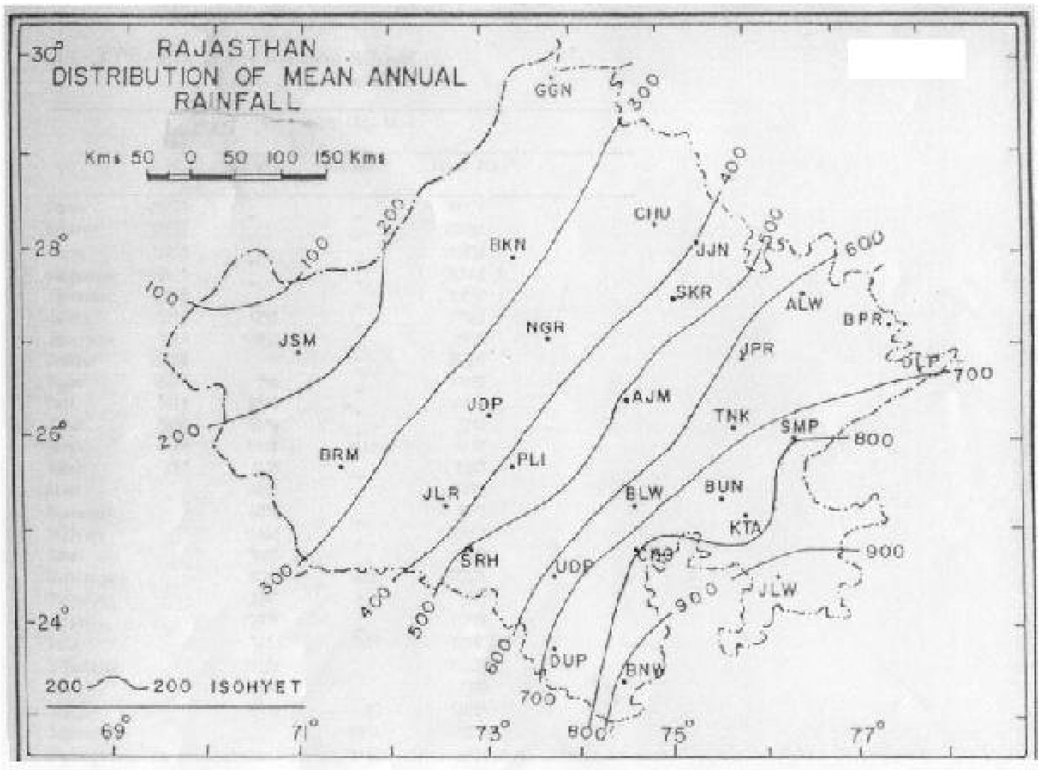


Figure 2 Distribution of mean annual rainfall in Rajasthan.

The current practice to estimate recharge through rainfall assumes various natural factors. These factors are always site-specific and depend on the physiographic setting, soil type, natural vegetation and geological formation. Rajasthan has a heterogeneous assemblage of soil types and its geological formations have varied physical and chemical characteristics. Unless these parameters are scientifically determined, assessment results will not be of practical use. Even the classification of zones as “white”, “gray” or “dark” may not depict the true picture.

Impact of Rainfall Variability on Water Resources

Rainfall is the most vital input in the hydrological cycle and fluctuations in quality and distribution strongly influence surface and sub-surface water sources. Often the impact of rainfall variability is clearly evident on surface water sources within a short time, but its impact on sub-surface sources is complex and long-lasting, often with a time lag between incidence and effect. Groundwater occurs under diverse climatic, physiographic and geological conditions and the sub-surface medium through which water filters plays an important role in building-up groundwater reserves. A careful understanding of the terrain and recharge conditions and long-term studies on variations in rainfall patterns and water exploitation are needed in order to interpret changes in groundwater storage. Table 9 shows the changes in water level over time by district.

Table 7 Rainfall variability in different regions of Rajasthan

Station	Normal rainfall (mm)	Average # of rainy days	Greatest annual rainfall (mm)	Greatest annual rainfall as a % of normal	Year of greatest rainfall	Greatest 24-hr rainfall (mm)	Date of greatest 24-hr rainfall
Arid							
Barmer	288.0	14.1	940.0	326	1944	285.7	13.8.1944
Bikaner	289.8	19.0	758.2	262	1917	165.6	25.9.1945
Churu	356.5	20.7	783.8	220	1917	146.1	5.9.1942
Ganganagar	248.4	19.5	674.0	271	1983	251.7	31.8.1928
Jaisalmer	186.2	12.5	583.1	313	1944	129.5	25.6.1961
Jalore	377.2	18.3	1039.4	276	1990	279.4	11.9.1905
Jhunjhunu	399.2	25.5	777.8	195	1956	121.9	14.7.1908
Jodhpur	365.2	20.0	1180.5	323	1917	215.9	12.9.1924
Nagaur	329.9	19.6	1259.0	382	1975	285.0	17.7.1975
Pali	418.3	19.0	1047.0	250	1990	200.0	6.8.1990
Sikar	455.8	29.7	1093.0	240	1977	184.4	25.8.1964
Semi-arid							
Ajmer	537.5	31.0	1226.8	228	1917	164.6	31.8.1928
Alwar	667.4	36.0	1260.3	189	1917	289.3	24.9.1904
Bharatpur	651.5	35.8	1382.8	212	1986	228.6	11.8.1916
Bhilwara	682.5	32.0	1304.0	191	1956	216.4	18.9.1950
Bundi	758.6	35.9	1546.6	204	1942	370.3	6.9.1947
Chittorgarh	862.9	33.5	1533.7	178	1944	274.3	20.7.1943
Dungarpur	738.0	36.8	1800.6	244	1937	486.4	30.6.1937
Jaipur	614.4	35.3	1317.0	214	1917	353.6	19.7.1981
Kota	760.9	37.9	1586.5	209	1917	249.2	13.7.1945
S. Madhopur	872.9	37.7	2445.0	280	1942	301.0	16.7.1942
Tonk	669.1	33.0	1513.6	226	1945	246.4	18.8.1945
Udaipur	640.1	34.4	1223.3	191	1917	183.9	18.9.1950
Sirohi	574.2	26.7	1571.6	273	1973	362.7	14.8.1941
Sub-humid							
Banswara	952.3	41.9	1977.0	210	1977	558.8	23.7.1957
Jhalawar	975.8	47.8	1708.2	175	1942	252.0	29.6.1945
Humid							
Mt. Abu	1593.8	52.9	3990.3	250	1944	484.9	14.8.1941

Source: Chatterji, P.C. (1993), 'Status of Ground Water in Rajasthan – Retrospect and Prospect', Institute of Development Studies, Volume II, pp. 321.

Table 8 Average number of rainy days in Rajasthan (1997–2001)

Name of Districts	1997	1998	1999	2000	2001
Jaipur/ Dausa	43	35	55	51	69
Tonk	-	-	27	26	29
Bharatpur	37	-	34	28	34
Alwar	44	-	31	26	36
Dholpur	36	-	31	28	36
Sikar	36	-	20	19	29
Jhunjhunu	41	35	24	22	27
Churu	34	27	15	13	22
Jodhpur	28	19	12	12	21
Jaisalmer	15	15	8	6	15
Barmer	22	17	11	22	15
Pali	32	21	16	16	24
Sirohi	32	28	16	21	31
Jalore	27	17	12	14	19
Udaipur/ Rajsamand	68	67	50	37	64
Banswara	Na	43	32	23	29
Dungarpur	39	39	27	32	30
Chittorgarh	37	33	32	24	29
Kota/Baran	96	-	72	51	68
Jhalawar	-	-	42	27	34
Sawai Madhopur/ Karauli	82	-	67	52	65
Bundi	38	36	28	26	27
Ajmer	31	20	16	17	24
Bhilwara	34	-	25	21	28
Nagaur	36	24	-	18	23
Bikaner	29	18	11	12	17
Ganganagar/ Hanumangarh	56	34	25	15	36
Average # of rainy days	**35**	**26**	**24**	**20**	**28**

Source: Ground Water Department, Jaipur

Because of the increased overdraft of groundwater from all the potential regions of western Rajasthan, recharge to the aquifer during normal rainfall periods is inadequate, especially because of the sporadic rainfall distribution patterns and the terrain characteristics, with a major portion of the precipitation being lost as runoff or through evaporation. It is therefore important to identify the potential aquifers so that the limited surplus rainwater received in the region is conserved efficiently for use during drought years and to meet the ever-increasing demands on underground water resources.

Table 9 Changes in pre-monsoon water levels, 1984–2001

District	Average rise/decline			Average annual rise/decline			
	1984–2001	1998–2001	1984–1998	1984–2001	1984–1998	1998–2001	2001
Ajmer	–6.29	–5.59	–0.7	–0.37	–0.05	–1.86	–0.7
Alwar	–6.72	–4.2	–2.52	–0.4	–0.18	–1.4	–1.79
Banswara	–1.66	–2.22	–0.556	–0.1	–0.04	–0.74	–1.63
Baran	–2.83	–3.01	0.18	–0.17	–0.01	–1.03	–2.06
Barmer	–1.8	–1.51	–0.29	–0.11	–0.02	–0.5	–0.48
Bharatpur	–2.66	–1.97	–0.69	–0.16	–0.05	–0.66	–1.6
Bhilwara	–6.19	–5.11	–1.08	–0.36	–0.08	–1.7	–1.4
Bikaner	1.74	1.29	1.45	0.1	–0.1	0.1	–0.2
Bundi	–5.04	–4.5	–0.54	–0.3	–0.04	–1.5	–1.35
Chittorgarh	–5.58	–3.02	–2.56	–0.33	–0.18	–1.01	–1.23
Churu	0.09	–0.53	–0.62	0.005	–0.04	–0.18	0
Dausa	–4.46	–2.99	–1.47	–0.26	–0.11	–1	–1.75
Dholpur	–2.72	–1.43	–1.29	–0.16	–0.09	–0.48	–0.87
Dungarpur	–3.75	–3.5	0.15	–0.22	–0.01	–1.3	–1.7
Hanumangarh	-	-	-	-	-	-	-
Sri Ganganagar	-	-	-	-	-	-	-
Jaipur	–6.68	–2.33	–4.35	–0.39	–0.31	–0.8	–1.15
Jaisalmer	0.27	–0.33	0.6	0.015	–0.04	–0.11	–0.09
Jalore	–8.66	–3.94	–4.22	–0.51	–0.34	–1.31	–0.77
Jhalawar	–2.42	–3.54	1.12	–0.14	–0.08	–1.18	–1.34
Jhunjhunu	–7.67	–3.9	–3.77	–0.45	–0.27	–1.3	–1.21
Jodhpur	–7.57	–3.3	–4.47	–0.45	–0.32	–1.1	–1.02
Karauli	–4.65	–1.83	–2.82	–0.27	–0.2	–0.28	–1.79
Kota	–2.87	–3.46	0.62	–0.17	–0.04	–1.15	–2.72
Nagaur	–7.07	–2.63	–4.44	–0.42	–0.32	–0.88	–1.08
Pali	–7.19	–6.25	–0.94	–0.42	–0.07	–2.08	–1.47
Rajsamand	–5.95	–5.06	–0.89	–0.35	–0.43	–1.69	–1.12
Sawai Madhopur	–3.8	–2.82	–0.98	–0.22	–0.27	–0.94	–2.31
Sikar	–5.72	–2.58	–3.14	–0.34	–0.41	–0.86	–0.72
Sirohi	–6.69	–5.56	–1.13	–0.39	–0.48	–1.85	–0.88
Tonk	–5.6	–3.99	–1.61	–0.33	–0.4	–1.33	–1.98
Udaipur	–3.3	–3	–0.8	–0.23	–0.27	–1	–1.03

Impact of Drought

Apart from the periods of drought which limit recharge and lead to a lowering of the water table, the increase in number of wells and area irrigated also increase the rate of withdrawal of groundwater. The rate of withdrawal is greater than the recharge rate and leads not only to a decrease in the water level but also to a deterioration of the water quality.

With this pattern of water use in various regions of the state, the impact of even a mild drought would have long-lasting effects on the water resources of the region. Prolonged droughts caused adverse effects experienced over all of Rajasthan during 1984–88 and 1997–2002. As a consequence of low rainfall and associated drought conditions, the groundwater reserves in most parts of the state were not sufficiently replenished. The groundwater level has dropped from 1 m to 6 m in about 90% of the state.

To assess the hydrogeological conditions of various aquifers, the Central Arid Zone Research Institute carried out a study on the water balance from 1977 to 1980. 42 key wells were selected at which rainfall and static water levels were recorded every day from June to March of the following year (Chatterji 1988). Similarly, a study of the water balance of the Luni Basin (32,805 km^2) was carried out from 1979 to 1983 for which 141 key wells were selected and 250 rain gauging stations were set up. Such studies need to be conducted across the state on a continuous basis and the information generated used for managing the groundwater resource.

Groundwater Resource Assessment

All resources, whether non-renewable or renewable, have their limitations for exploitation or use. This holds true for groundwater too. Although rain or surface water replenishes groundwater, the quantity of recharge is dependent on both natural and artificial parameters which vary across space. Spatially sustainable use of groundwater requires equilibrium between all waters entering and leaving the basin. Determining the safe yield of a groundwater basin requires knowledge of; (i) the water supply available to the basin, (ii) the economics of pumping within the basin, (iii) the quality of the groundwater, and (iv) user rights in and around the basin.

Quantifying the groundwater available can be done using two concepts based on the existing hydrological situations: (i) the quantity concept for an unconfined aquifer, and (ii) the rate concept for confined aquifers. These are explained below.

Unconfined (Water Table) Aquifers

Groundwater is essentially a dynamic resource that is recharged by various sources. The most important mode of recharge to the aquifer is the direct infiltration of rainwater, which varies according to climate, topography, soil and sub-surface geological characteristics. Depending on the efficiency of the irrigation system and the soil characteristics, a portion of applied irrigation water also reaches the groundwater. Influent streams recharge the groundwater body too, depending on the drainage density, width of stream and texture of the riverbed material. Other sources of recharge include percolation from canal systems, reservoirs, tanks and other bodies of water. An estimation of these sources of recharge can give an estimate of safe yield.

Confined Aquifers

Confined aquifer resources can be quantified using the rate concept. In confined aquifers, water is released by decompression of the aquifer, unlike in an unconfined, water table aquifer where de-saturation takes place. The quality of groundwater transmitted through deeper zones can be computed and development of the resource be planned accordingly.

For a scientific assessment of groundwater resources, the Ground Water Over Exploitation Committee was created in 1977 by the Agriculture Refinance and Development Corporation (ARDC), now known as the National Bank for Agriculture and Rural Development (NABARD). Following a detailed study, the committee made recommendations in 1979. Its methods used were later considered flawed, however, and in 1982 the Government of India created the Ground Water Estimation Committee. This committee, after consultation with various central and state organizations, universities, research and financial institutions, prepared a set of guidelines for assessing groundwater resources. A modified version of these guidelines is used by the SGWD today to calculate groundwater extraction and recharge (Vijay *et al.* 1986).

Various organizations have suggested different methods for assessing groundwater potentials and rainfall recharge. However, as Chatterji (1993) argues, adopting any of these methods requires knowing various natural parameters, such as the hydrological characteristics of geological and lithological formations, recharge through surface water resources, etc. Without knowing these parameters for a specific area, values have to be assumed. Chatterji pointed out shortcomings to the proposed methods and tried to develop a more accurate one for western Rajasthan based on detailed information of these parameters.

The major shortcomings Chatterji listed were:

(i) The lack of information on rainfall in various terrains and their sub-surface characteristics, which require more rain gauge stations;

(ii) That besides the area of the potential aquifer, the physiographic conditions of the area must be considered in order to estimate the groundwater resource;

(iii) That water balances should be reported for drainage basin rather than district;

(iv) That current observations of key wells - twice a year by the SGWD and four times a year by the Central Ground Water Board - seems inadequate given the state's geohydrological conditions. The number of observation days and the number of wells observed must be increased;

(v) That currently, specific yield is used for estimating groundwater potential, but aquifer porosity would give better results;

(vi) That more experiments need to be done on seepage and recharge through old tanks rather than using ad hoc estimations.

Augmentation of Groundwater Resources

Groundwater is a renewable, finite resource; annual recharge is governed by several natural factors. The stored capacity of groundwater reservoirs combined with small flow rates provides a large, extensive distribution of water supply.

In order to augment the natural groundwater reserve, artificial recharge of groundwater basins/bodies has been attempted. Artificial recharge can be defined as augmenting natural infiltration of precipitation or surface water into underground formations by altering natural conditions of replenishment. In other words, surplus water, which would otherwise flow out of an area, is retained for a longer period, thus enabling more infiltration than runoff. Artificial recharge is attempted in order to:

i Restore supplies to an aquifer depleted from excessive draft or augment supplies to aquifers lacking adequate recharge;

ii Store excess surface water underground for future use;

iii Improve the quality of the groundwater or prevent its deterioration, or to create a freshwater layer;

iv Remove sediment, bacteriological and other impurities from sewage and waste water effluent;

v Store energy in aquifers or obtain cool water of a relatively constant temperature;

vi Arrest or reduce land subsidence by increasing hydrostatic pressure.

Government Initiatives

The Department of Soil Conservation and the Department of Public Works are constructing artificial recharge structures such as anicuts, bunds, khadins, rapats and percolation tanks and devising water spreading methods in order to reduce soil erosion and gulley formations, conserve soil moisture and provide causeways. These activities are being carried out in a sectoral approach. As a result, the effects of these activities on the groundwater regime are not known, mainly because these constructions were not designed with water resource exploitation in mind. Structure built in connection with artificial groundwater recharge or conjunctive utilization need to have certain pre-requisites, and hydrological and hydrogeological observations must be made over long periods after their construction to assess their effectiveness and benefits.

The Ground Water Department initiated artificial recharge studies in 1990. The construction of recharge structures has been undertaken by the department with some reservation as there is no provision for comprehensive pre-feasibility or post-construction evaluation studies. The State Government’s present effort in watershed development is a major intervention in natural resource regeneration and groundwater recharge. The budgetary allocation, which is the largest with any department, is given in Table 10.

However, given the rainfall distribution pattern, the hydrogeological characteristics of the aquifer, the non-availability of silt-free surplus water at regular intervals and the variable quantities of water, it seems that adopting artificial recharge methods may not yield meaningful results to compensate for the overdraft. So far, very few scientifically designed experiments have been done to assess the suitability of various methods for different terrains, soils and rainfall zones. Their impacts on water resources and socio-economic development are therefore as yet unknown.

Table 10 Watershed development in Rajasthan – physical and financial achievements between 1974 and 2002

Year	NWDP*		Special Plans		Outsider Helping Plans		Total	
	Area (ha)	Rs. ('000)	Area (ha)	Rs. ('000)	Area (ha)	Rs. ('000)	Area (ha)	Rs. ('000)
1974–75	–	–	59681	6.27	–	–	59681	6.27
1975–76	–	–	54582	48.58	–	–	54582	48.58
1976–77	–	–	18248	0.7	–	–	18248	0.7
1977–78	–	–	8299	6.72	–	–	8299	6.72
1978–79	–	–	16303	67.3	–	–	16303	67.3
1979–80	–	–	35649	92.76	–	–	35649	92.76
1980–81	–	–	32356	236.31	–	–	32356	236.31
1981–82	–	–	46530	219.45	–	–	46530	219.45
1982–83	–	–	41840	315.66	–	–	41840	315.66
1983–84	–	–	36086	375.08	–	–	36086	375.08
1984–85	–	–	17368	124.28	–	–	17368	124.28
1985–86	–	–	29677	581.08	–	–	29677	581.08
1986–87	1329	8.43	66249	1669.07	–	–	67578	1677.50
1987–88	11597	90.77	30870	877.8	–	–	42467	968.57
1988–89	9645	90.20	26638	1023.56	–	–	36183	1113.76
1989–90	11763	120.99	31460	1091.35	–	–	43223	1212.34
1990–91	9000	833.64	24057	1420.74	–	71	33057	2325.38
1991–92	24633	750.82	22485	1110.16	1407	365.12	48525	2226.10
1992–93	95555	1464.01	28281	1378.83	5431	872.07	129267	3714.91
1993–94	104882	2086.87	46942	1284.98	14146	1271.89	165970	4643.74
1994–95	77879	2452.00	38581	2430.69	25568	1397.99	142028	6280.68
1995–96	96087	3500.50	97468	2360.52	25614	2515.68	219169	8376.70
1996–97	116015	3548.27	36355	1183.66	29700	2906.41	182070	7638.34
1997–98	75950	2578.7	26459	2667.15	36105	2400.15	138514	7646.00
1998–99	89459	3814.49	79872	4080.24	13500	1473.79	182831	9368.52
1999–00	85792	3932.71	69910	4262.27	1102	182.34	156804	8377.32
2000–01	119518	3895.82	51463	5748.89	247	82.09	171228	9726.80
2001–02	60783	3654.88	25576	4323.66	–	–	86359	7978.54
Total	**989887**	**32823.10**	**1099285**	**38987.76**	**152820**	**13538.53**	**2241992**	**85349.39**

Source: Watershed Rajasthan Annual Report 2001–2002, pp. 16–17.
*National Watershed Development Programme

NGOs’ Efforts in Groundwater Augmentation

People in the arid and semi-arid regions of Rajasthan practice innovative methods of harvesting rainfall runoff for drinking and agriculture by building embankments. Several NGO’s have initiated programs aimed at reviving these traditional water harvesting systems with community participation. Some popular NGO’s are Tarun Bharat Sangh, Gramin Vikas Vigyan Samiti (GRAVIS), Social Work Research Centre (SWRC), Center for Community Economics and Development Consultants Society (CECOEDECON), Seva Mandir and Pradhan. They focus on watershed management, natural resource management, drought mitigation, improving drinking water supply, soil conservation, etc. A range of activities was undertaken to harness rainwater runoff. The structures range from earthen field bunds to cement concrete structures, and from plugging water flow in small streams to structures to harness the flow from whole watersheds or sub-river basins. Funding varies from government to international rural-support organizations. With all these interventions, the main objective was to check surface runoff, impound water and recharge groundwater. Most of the NGOs’ activities are participatory and address immediate local needs, but little consideration is given to impacts downstream and at the watershed scale.

The design and location of the structures are guided by local conditions, especially the topography of the area, and built with traditional and/or modern knowledge. These NGO interventions are so varied and location-specific that in most cases it is difficult to replicate, either because of geographical conditions or the prevailing socio-economic and political conditions. Even when models are followed, as in the case of watershed development, their implementation varies across the State. However, one common element in all these interventions is groundwater recharge. As groundwater recharge depends on geohydrological parameters, it becomes difficult to assess their actual impact. This becomes even more difficult when the intervening agency is not aware of these technical parameters. What is known, from the existing literature and field visits, is that NGOs are good at mobilizing and motivating communities for such works, economizing on costs and ensuring, to a degree, the utilization and sustainability of the system. But the NGOs do not know the exact nature of the benefits derived from these recharge structures. Even when they attempt to evaluate their benefits, they invariably either ignore or give a low priority to the technical parameters. It is not that NGOs are not interested in such evaluations, but they lack the necessary information and expertise to do so with any accuracy.

Technical Review of Recharge Impact Reports

The technical review presented here summarizes all the technical evaluations of water harvesting and groundwater recharge activities that the Institute of Development Studies in Jaipur was able to identify through an extensive literature search. Before going into detail, however, it is important to emphasize that, while the published literature on water harvesting and groundwater recharge in Rajasthan is huge, very little of it contains any technical information.

Despite the scale of emerging groundwater overdraft problems and the large amounts of time and money invested in addressing the problem, and despite extensive reviews of available literature, the Institute of Development Studies in Jaipur was only able to locate three semi-technical analyses that address the impacts that water harvesting and groundwater recharge activities may be having. These technical analyses were each undertaken by the International Water Management Institute, the Government of Rajasthan, and by Dr. Agrawal from IIT Kanpur (Agrawal 1996; H.D.D. Directorate 1999; Bagider, Sakthivadivel *et al.* 2002).

The first of these studies, by the IWMI team, focused on the 'Paal' system of water harnessing in Alwar district of Rajasthan. In their study, they documented the benefits of water harvesting as an increase in the water table and in agriculture production by participating households. The second study, by Agarwal (1996), pertains to the large number of traditional rainwater harnessing structures called 'Johads' that were revived and constructed by Tarun Bharat Sangh in Alwar district. The third study was done by the Irrigation Department, Government of Rajasthan, to investigate the impact of Johads on the Sainthal Sagar Dam[1]. The information and limitations of these three analyses is summarized here. This is not intended to be an evaluation of the impact of the water harvesting activities themselves but rather an evaluation and summary of the technical information contained in these reports.

General Approach of Existing Evaluations

Before discussing the individual reports, two points are important to recognize with regard to the information they contain. *First*, the analyses are largely empirical; they report observed relationships between recharge activities, groundwater levels, stream flows, etc. As far as can be determined, no attempts were made to estimate key hydrological parameters or model hydrologic dynamics in the reports. *Second*, the reports contain little baseline data and relatively little indication of the sources for the data they do use. As a result, it is impossible to cross check the accuracy of the relationships they report in most cases.

The Reports

Preliminary Assessment of a Traditional Approach to Rainwater Harvesting and Artificial Recharging of Groundwater in Alwar District, Rajasthan

This report, conducted by a team from the International Water Management Institute (Bagider, Sakthivadivel *et al.* 2002), uses data from four micro-watersheds in the Mewat region of Alwar district.

While the main focus of this report was to evaluate the livelihood and economic impacts of traditional 'paal' water retention systems (cascading systems of small dam structures within a farmer's field), attempts were also made to evaluate groundwater recharge. 42 wells located at varying distances from the line of recharge in paal areas and in small stream areas identified as having significant natural recharge were monitored weekly over a two-year period. In theory, recharge should be higher along the cascading waterline where paals had been constructed.

Data in the report indicate that water levels at distances of 0 m to 500-600 m beyond the line of recharge are highly variable and display no regular pattern relating to the presumed line of recharge. The report attributes this high variability to the heterogeneous, highly fractured nature of the underlying hard-rock aquifer. Furthermore, despite similar levels of

[1] Rather than documenting the benefits of Johads, a committee of irrigation engineers with the State Government initiated an inquiry to document their negative impact – the decline in water flow in the Sainthal Sagar Dam. For details see, 'Government of Rajasthan, A Study of the impacts by the small water harvesting structures in the catchment area of Sainthal Sagar Dam, 1999'.

pumping and a smaller irrigated area, water level declines between August 2000 and April 2001 in wells within 200 m of paals were greater (3.52 m) than in wells further away (2.89 m). The statistical significance of this difference was not reported.

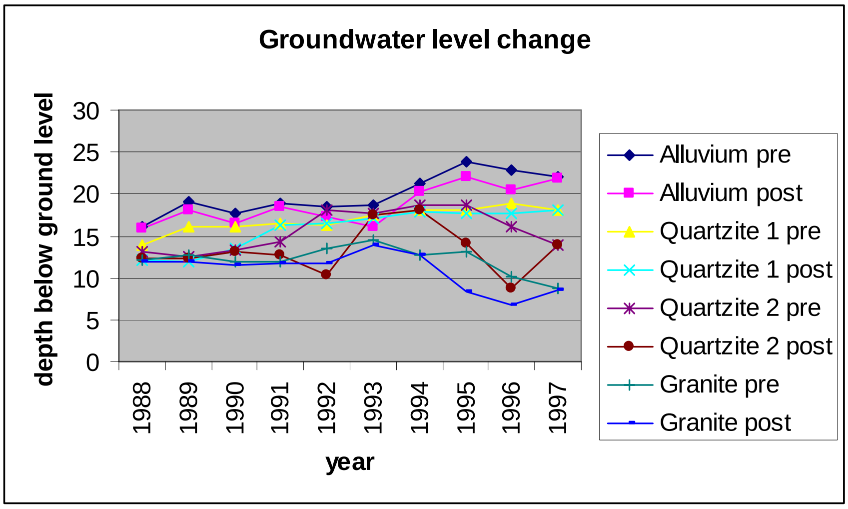
In addition to the above results, natural recharge was estimated using empirical relationships developed from tritium studies for granite and gneissic aquifers by the National Geophysical Research Institute, or NGRI (Rangaran and Athavale 2000). Additional recharge due to the construction of paals was estimated to be between 3% and 8% of total rainfall. This estimate was derived at using another water balance method for which details were not given. As a result, the accuracy of this estimate cannot be evaluated. The report does, however, note that the estimated value is critically dependent on assumptions made regarding the specific yield of the aquifer. In addition, the water balance approach used probably depends on the accuracy of natural recharge estimates made using the empirical equation developed by NGRI (Rangaran and Athavale 2000). In general, the reliability of such empirical approaches depends on the degree to which local conditions match the conditions under which they were originally developed. Given the heterogeneous nature of soils, granite and gneissic aquifers, rainfall patterns, etc., there is substantial uncertainty regarding the reliability of the reported natural recharge estimate.

Overall, while the authors conclude that the paal system results in additional groundwater recharge of between 3% and 8% of rainfall, their conclusion is not supported by the data contained in their report. While the paals may well contribute to recharge, the data presented provide little proof of their actual impact.

A Study of the Impacts by the Small Water Harvesting Structures in the Catchment Area of Sainthal Sagar Dam. (H.D.D. Directorate 1999)

This report uses data collected by the Rajasthan State Government from the monitoring of wells, rain gauges and inflows to the Sainthal Sagar Dam as a basis for evaluating the impact of water harvesting activities undertaken by Tarun Bharat Sangh on groundwater levels and dam inflows. Groundwater data used for the report cover the period 1988 to 1997. The report concludes that water-harvesting activities have had no impact on dam inflows but may have contributed to rises in groundwater levels observed after 1992.

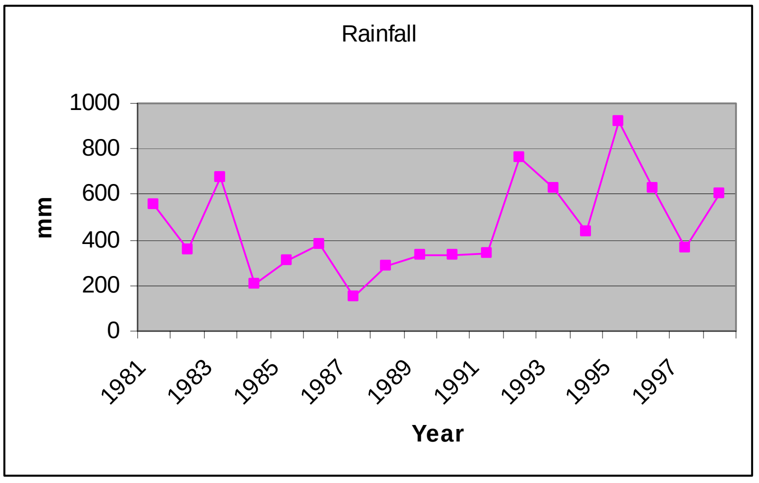
Graph 1 Pre- and post-monsoon groundwater level changes, Rajasthan 1988-1997



According to the report, groundwater levels in monitored wells have increased since 1992 following the initiation of water harvesting activities by Tarun Bharat Sangh. This conclusion is only partially supported by the groundwater data presented. As Graph 1 shows, pre- and post-monsoon water levels have increased in monitored wells in some formations but not in others. Increases appear in granite formations and possibly some of the quartzite areas but not in alluvial areas.

In addition to the high variability in pre- and post-monsoon water levels, as the chart below indicates, rainfall levels between 1992 and 1998 presented in the report have generally been substantially higher than in the period from 1988 to 1992 when groundwater levels were declining.

Graph 2 Rainfall levels between 1981 and 1997, Rajasthan



Overall, the report presents little information that suggests any definitive impact of increases in water harvesting on groundwater recharge. Increases in water levels in monitored wells could simply be due to higher rainfall levels and may have little relationship to water harvesting activities.

Evaluation of Water Conservation Efforts of Tarun Bharat Sangh in 36 Villages of Alwar District. (Agrawal 1996)

Of the three reports, this one represents the most systematic effort to evaluate the impact of water harvesting on groundwater conditions. The Spearmans Rank-order Coefficient of Correlation was used to correlate changes in groundwater levels with the extent of water conservation efforts undertaken in sample villages. The study used data collected during 1995/96 from 36 villages in Alwar district where Tarun Bharat Sangh had been working.

Data input consisted of village rankings based on the storage capacity of recharge structures per hectare of cultivated area in the village and changes in groundwater levels based on levels reported by villagers before and after the construction of water harvesting structures (known as johads). The resulting correlation was quite strong (0.77) and reported to be statistically significant. The report concluded that: “For all practical purposes, the high value of R shows that the groundwater table rise is a direct impact of the conservation effort.”

The above conclusion should be taken with caution. In evaluating it, several points are important to recognize:

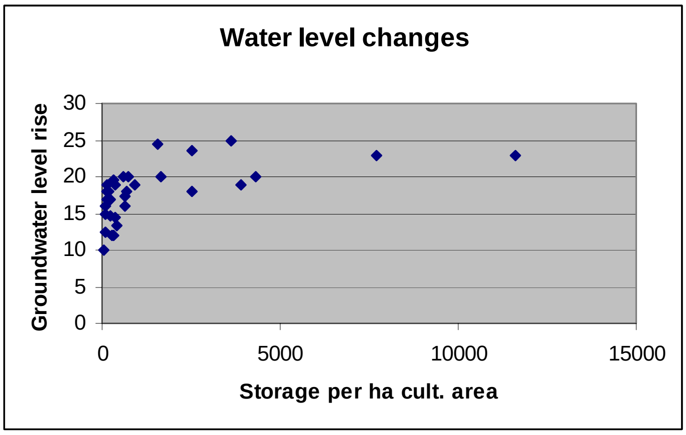
1. As noted in the evaluation of the preceding report, rainfall levels during the period 1992-1996 were substantially higher than in preceding years. As a result, overall changes in groundwater levels could be related to this rather than conservation efforts.

2. Changes in groundwater levels were estimated using the villagers' memories. While this method is often essential in the absence of more direct measurements, it can be misleading. In many situations, responses are known to be influenced by perceptions and the attitudes of those conducting the interviews. In this case, villager responses could have been systematically biased by the level of TBS involvement in the village (they built lots of recharge structures so the groundwater level *must* have come up – and where more work was done, the tendency would be to recall more of a rise). The potential for this type of bias is inherent in most surveys using recall techniques.

3. Changes in water levels could be due, not to increases in recharge, but to declines in pumping as more surface water became available as a result of water harvesting structures. The report does not present any information regarding changes in the use of surface and groundwater sources following TBS investments, so this is impossible to evaluate.

4. Other measures of the potential relationship between groundwater level changes and storage in water harvesting structures do not show as strong a correlation as the method used in the report. A straight correlation between the storage created per hectare of cultivated area (m^3/ha) and the reported rise in groundwater level returns, for example a correlation of 0.565 and an r^2 of 0.32. A graph of this data (below) does suggest a relationship, but the correlation is not as strong as that produced using a ranking method as was done for this report.

Graph 3 Correlation between storage created per hectare of cultivated area (m^3/ha) and the reported rise in groundwater level (data from Agrawal 1996)



Overall, while the data contained in this report do suggest that investments by TBS in water harvesting structures have had a positive impact on groundwater levels, they do not conclusively demonstrate this. Furthermore, the report contains no data for evaluating recharge quantities or their relationship to extraction levels.

Conclusions from the Evaluations of the Technical Reports

The existing technical reports identified by IDS-Jaipur and reviewed here do not provide a systematic or quantitative basis for evaluating the impact of investments in water-harvesting on groundwater conditions. This should not be interpreted as indicating that water-harvesting efforts themselves have had little impact. Instead, it simply indicates that available technical evaluations are inadequate to reach any conclusion.

Overall Conclusions and Recommendations

One of the largest challenges in evaluating the viability of groundwater harvesting for recharge is the lack of accessible technical information on the overall groundwater context in Rajasthan. As a result, the first step in planning and the development of groundwater resources in the State should be detailed mapping of the resource base. In addition, to asses and plan optimum utilization of groundwater resources, precise determination of all the hydrological parameters under different geomorphic and rainfall conditions for the same lithological unit is required. Even the river basin boundaries should be demarcated more precisely – something that can be achieved with the help of advanced remote sensing techniques. In areas where basin boundaries cannot be identified, we suggest that the area of the basin be classified into "Donor" and "Receptor" zones or as "Index Catchment".

Assessment and exploitation of groundwater resources should be restricted to Receptor Zones only in order to derive maximum benefit of the recharge, whether natural or artificial. Geomorphic mapping of the State on a 1:50,000 scale depicting all structural controls such as lineaments, present and prior drainages, flood and alluvial plains, existing wells/tubewells, donor and receptor zones for the areas covered with sand and sand dunes having no defined drainage system, groundwater potential basins, etc. will provide a better understanding for further exploration, exploitation and correlation of results in order to better manage the groundwater resources. It is of paramount importance to understand the interrelationship between the drainage pattern and lithological formations and the groundwater potential and recharge.

To better understand rainfall patterns, the World Meteorological Organization has suggested that rain gauging stations be installed on a 10-km grid in the plains and a 5-km grid in hilly areas of arid and semi-arid regions. Though unproductive areas do not directly contribute to the groundwater resources of the state, they do contribute to generating surface runoff and/or sub-surface flow to the potential aquifer.

In Rajasthan, the India Meteorological Department has 30 observatories, the Revenue Department has 268 rain gauging stations, the Irrigation Department has 223 rain gauging stations and the Central Water Commission has 14 rain gauging stations - a total of 535 rain gauging stations already exist in the state. Besides these, there are many rain gauging mechanisms installed on Dak Bungalows and Circuit Houses under the control of the Public Works Department. If an observation well is within one or two kilometers of on of these rain gauging stations, he data being generated by them should be used to assess groundwater changes.

The Ground Water Department has identified 583 groundwater potential zones in 26 districts of Rajasthan. Although Rajasthan already has one of the largest state networks of piezometers and key wells where groundwater levels are monitored, the links between these wells and other hydrologic parameters are often unclear. We believe it would be desirable to have one monitoring station consisting of one key well and one rain gauging station in each zone for regular observations. In larger zones, more monitoring stations need to be selected. However, for a better understanding of the behavior of variation in water level in the more heterogeneous groundwater potential zones, two wells per rain gauging station would give better results.

The Ground Water Department is already monitoring 6,708 key wells and the Central Ground Water Board is monitoring 1,095 key wells. As far as possible, existing key wells should be used for establishing monitoring stations. Monitoring procedures for both groundwater and rainfall must be coordinated to evaluate the relationship between precipitation and recharge. This can be achieved by establishing a proper rain gauging station network, as suggested by the WMO, and linking it with piezometers that are equipped with data loggers to frequently record groundwater level changes. This will allow for an evaluation of rainfall intensity-duration relationships and the time lag between rain spells and any recharge generated.

The ionic composition of groundwater in relation to the mineralogical assemblage and weathered products of aquifers as well as the changing patterns and behaviors of various ions in the groundwater needs to be investigated and analyzed to monitor water quality. So far, no such information is available.

Because the intensity and duration of rainfall plays a vital role in the generation of recharge, it is suggested that 10% of the monitoring stations be equipped with self-recording rain gauges and water level recorders. These could be installed in colleges, higher secondary schools, tehsils, Block Development Officer (BDO) headquarters or other government offices where responsible people are available to handle the equipment. At other monitoring stations, water level is to be recorded before the exploitation of an aquifer starts and rainfall is to be recorded according to standard practice at 8.00 every morning during the monsoon period.

Feasibility studies on groundwater recharge techniques, their relative merits and economics under different terrain, rainfall and socio-economic conditions are essential. This would help in standardizing more suitable artificial recharge methods for Rajasthan.

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Appendix 1

Table 1: Hydrograph network station in Alwar District

District	Stations monitored during August 2002	Total number of network stations, August 2002
Alwar	44	57
Rajasthan total	1,002	1,337

Table 2: Water level data for national hydrograph network stations, Alwar District, August 2002

Well No.	Village	Depth to water level (mbgl)				Fluctuation		
		May 02	Aug 01	Aug 02	Mean Aug 92–01	May 02–Aug 02	Aug 01–Aug 02	Mean Aug (92–01)–Aug 02
54A–2C2	Alwar	–	20.05	22.24	16.46	–	–2.19	–5.78
54A–1A1A	Anantpura	51.54	51.62	52.01	50.82	–0.47	–0.39	–1.19
54A–2D4	Bagar	8.22	7.53	8.26	7.11	–0.04	–0.73	–1.15
54A–2B1A	Bansur	12.97	12.05	13.87	10.35	–0.90	–1.82	–3.52
54A–3C2A	Baran	11.77	10.75	12.37	9.90	–0.60	–1.62	–2.47
54A–3D1	Barodamev	14.39	13.60	14.87	11.80	–0.48	–1.27	–3.07
54A–1C6	Bas Kirpalnagar	21.11	17.76	21.04	16.97	0.07	–3.28	–4.07
54A–1B4A	Behror	45.35	38.08	45.67	34.11	–0.32	–7.59	–11.56
54A–1C8	Bhindusi	13.08	11.92	13.17	10.93	–0.09	–1.25	–2.24
53D–4C2A	Bolni	17.70	16.60	17.91	16.57	–0.21	–1.31	–1.34
54A–2B3A	Chattarpura	17.06	17.00	17.32	15.37	–0.26	–0.32	–1.95
54A–2C5	Dalalpur	12.12	11.23	12.41	8.16	–0.29	–1.18	–4.25
54A–1C10	Darbarpur	13.78	12.19	13.98	–	–0.20	–1.79	–
54A–4D3	Gadi Swairam	28.55	30.13	28.97	18.55	–0.42	1.16	–10.42
54A–1B7	Gangwali Dhani	21.52	20.77	22.02	17.02	–0.50	–1.25	–5.00
54A–2D3	Ghansoli Kuri	19.77	17.75	19.93	16.00	–0.16	–2.18	–3.93
54A–4B3	Ghata Mordi	12.88	5.35	12.48	5.63	0.40	–7.13	–6.85
54E–2A6	Govindgarh	8.06	6.85	8.17	–	–0.11	–1.32	–
54A–1C2A	Harsauli	9.97	9.38	10.32	6.72	–0.35	–0.94	–3.60
54A–1D2	Hasanpura	21.27	21.54	21.47	21.17	–0.20	0.07	–0.30
53D–4D2	Jagmal Heri	15.12	13.56	15.68	–	–0.56	–2.12	–
54A–3D3	Jhaladala	33.19	28.37	33.19	18.25	0.00	–4.82	–14.94
54A–1B8	Josai	14.73	14.06	14.92	14.08	–0.19	–0.86	–0.84
53D–4B3	Kanhawas	32.63	32.40	33.96	30.01	–1.33	–1.56	–3.95
54A–1C9	Kishangarh Bas	15.61	14.50	16.24	12.94	–0.63	–1.74	–3.30
54A–3D2	Lachmangarh	6.99	8.02	5.37	5.54	1.62	2.65	0.17
54A–3D2A	Laxmangarh	7.43	5.78	4.05	–	3.38	1.73	–
54A–1B5	Majrikalan	18.29	18.10	18.57	17.32	–0.28	–0.47	–1.25
54A–1D5	Motuka	12.63	10.60	12.78	–	–0.15	–2.18	–
54A–1D3	Nimli	4.35	3.80	4.67	3.38	–0.32	–0.87	–1.29
54A–1B6	Nimrana	40.65	40.50	41.07	37.89	–0.42	–0.57	–3.18
54A–2D2	Nogaonwa	9.04	7.42	9.42	5.55	–0.38	–2.00	–3.87
54A–3A2	Partapgarh	10.82	7.44	10.97	6.40	–0.15	–3.53	–4.57
54A–2D1A	Ramgarh	12.04	8.57	12.41	4.21	–0.37	–.384	–8.20
54A–2D1	Ramgarh	6.72	5.92	7.13	6.72	–0.41	–1.21	–0.41
54A–3D5	Sahajpur	9.66	–	9.69	–	–0.03	–	–
54A–1B3	Sodawas	11.85	11.57	11.96	9.91	–0.11	–0.39	–2.06

53D–4D1A	Tapukara	17.18	17.02	17.42	15.03	–0.24	–0.40	–2.39
54A–1C1	Tatarpur	33.60	32.54	33.65	31.02	–0.05	–1.11	–2.63
54A–4B1	Tehla	14.40	11.80	14.67	8.74	–0.27	–2.87	–5.93
54A–1D4	Tijara	18.12	17.72	18.29	15.70	–0.17	–0.57	–2.60
54E–3A4	Titpuri	10.69	9.10	10.87	8.95	–0.18	–1.77	–1.92
54E–3A4A	Titpuri	9.27	9.30	9.44	–	–0.17	–0.14	–
54A–4B2	Torikabas	13.84	12.60	14.48	9.75	–0.64	–1.88	–4.73

Table 3: Categorization of water levels for 44 wells in Alwar District, Rajasthan - August 2002

Number of Hydrograph Network Stations and Percentage		
Water Level	**No. of wells**	**%**
0–2 m	0	0.00
2–5 m	2	4.55
5–10 m	7	15.91
10–20 m	24	54.55
20–60 m	11	25.00
>60 m	0	0.00
Range: Maximum 4.05, Minimum 52.01		

Table 4: Fluctuation in water levels measured in 43 hydrograph network stations and 37 wells of Alwar district, Rajasthan

Hydrograph network stations	Water Level		
	0–2 m	**2–4 m**	**>4 m**
May 2002 vs. August 2002			
Number of stations with a fall in water level	38	0	0
% of total number	88.4	0	0
Number of stations with a rise in water level	4	1	0
% of total number	9.3	2.4	0
August 2001 vs. August 2002			
Number of stations with a fall in water level	27	9	3
% of total number	62.8	20.9	7.0
Number of stations with a rise in water level	3	1	0
% of total number	7.0	2.3	0
Wells: **Mean August 1992–2001 vs. August 2002**			
Fall			
Number	10	14	12
%	27.0	37.8	32.4
Rise			
Number	1	0	0
%	2.7	0	0
Range: Fall 0.3-14.94; Rise 0.17-0.17			