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ARTICLES

Groundwater Depletion in Punjab: Measurement and Countering Strategies

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The important studies on the water resources of Punjab show it to be deficit in water, for which it has been over-exploiting the groundwater, more than the recharge. The total available water estimated at 3.82 million hectare metres (mHaM) has 3.12 mHaM of good quality and another 0.24 mHaM as only marginally fit water.[1] These are short by 1.54 mHaM (15.4 km^3) of the normative requirement estimated at 4.90 mHaM (Prihar *et al.*, 1993).[2] Thus in terms of water balance, the deficit in Punjab was found to be very serious even in 1990. A later study, making adjustments in the demand/supply coefficients, estimated the demand at 4.40 mHaM (Hira *et al.*, 2004), and reported the deficit of 1.27 mHaM (Arora *et al.*, 2008). The *State Water Policy-2008* document gives the total supply at 3.939 mHaM out of which 1.795 mHaM is the river water allocation and 2.144 mHaM is the replenishable groundwater;[3] the total draft from groundwater is 3.116 mHaM,[4] which implies the rate of depletion of groundwater of 0.989 mHaM (Government of Punjab, 2008).[5]

One of the major concerns often voiced is the increase in the area under rice, the major water-consuming crop. The rice area occupied less than 0.4 million ha (mha) in 1980 which increased to 2.8 mha in 2010. The central part of the State is the rice belt, 100 per cent irrigated, extensively through groundwater withdrawal and partially with canals. Over the years, the canal water from this sub-region has been diverted to the South West Punjab where the groundwater is unfit for agriculture.[6] Thus, there had been serious fall in the water table in the central Punjab; from 4-5 metres in 1973 to more than 14 metres in 2005. The rate of decline in water table in this region increased over time; being 9, 20 and 65 cms per year during 1974-85, 1986-97 and 1998-2005 respectively (Singh, 2006). In contrast, in many parts of the South Western region, the ground water rose from too deep in 1970s to too shallow and even as water-logging (Singh, 2006; Singh, 2007). This study examines the annual water table situation from 1973 to 2005 in the three agro-climatic regions of the state, derives the estimates of depletion/deficit and examines the strategies to meet the deficit. The objectives of the study are: (i) To scan the behaviour of water table in Punjab in its three agro-climatic regions. (ii) To estimate the total underground water that has been withdrawn in excess of the recharge, i.e. the total water depletion. (iii)

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To approximate the excess withdrawal as equivalence of the rainfall, which is the major source of recharge and (iv) To short-list the strategies and policy regimen needed to meet the deficit.

Data and Methodology:

The data on water level is monitored by the Hydro-geological wing, Department of Agriculture, Government of Punjab, from around 600 selected locations since 1973. The observations (depth of water level) from the selected open wells are recorded at two points of time, viz., June (pre-monsoon) and October (post-monsoon), any day during the 10th to 25th of the month. When a particular well dried up, another well in the same village was selected, and it also carried on for some years, when finally, it came to installing the Piezometer tubes (PZ meters).

The Department of Agriculture has been estimating the area under various water table depths. In 1973, the area under water table depth of more than 10 metres was 3.7 per cent only, which increased to 26.7 and 84.6 per cent in 1990 and 2004, respectively. Likewise, the area with more than 15 and 20 metres deep water table, increased from 0.56 and 0.39 to as much as 36.57 and 12.47 per cent in 2004, respectively (Government of Punjab, 2008). The groundwater statistics from the Directorate of Water Resources and Environment, Punjab also show that as many as 103 out of 137 blocks were over-exploited, where the withdrawal was more than the recharge (Arora *et al.*, 2008). The underground water in Punjab is being overdrawn, where rice is extensively grown, by the farmers because of its relative profitability ensured by the nation through various continuous policy initiatives such as more remunerative minimum price support, an effective procurement system, etc., for its food security.

The original data on water table was used to measure the balance of water,[7] i.e., how far the groundwater, which is the most precious reservoir source, an accumulation over the centuries, has been, withdrawn in relation to its recharge, year-after-year. The monsoon season, June to September, is the main recharging season. Accordingly the groundwater table rises towards the end of the season and gradually goes down to be the lowest by about the beginning of the monsoon. Thus, the following parameters were worked out:

(i) The change in water level from October-over-October and June-over-June over the years. It captures the effect of yearly rainfall and other variables. The fall shows that the yearly withdrawal has been more than the yearly recharge.

(ii) The change during October-over-June gives the net recharge by monsoon during the rice season.[8] This captures the effect of monsoon rainfall, the rice area, which is the major water-requiring crop and other variables like water-management and its use-efficiency.

(iii) The change during June-over-Octobe r (previous year). Due to very low rainfall during October-May, there is always a fall. It shows the net withdrawal during the *rabi* season.

The three regions are broadly as follows:[9]

Region (1)	No. of Blocks (2)	Per cent area (3)	Characteristics (4)
North Eastern	31	18.1	Sub-mountainous, high rainfall = +80 cms.
Central	86	50.7	Main rice belt, 100 per cent tubewells coverage, medium rainfall = Around 60 cms.
South Western	21	31.2	Lowest rainfall range = Around 40 cms, marginally fit or even unfit underground water, extensive canal water supply.[10]

The situation regarding underground water became precarious since the early 1990s. Thus the trend in water table since 1990 was used to estimate the water balance, i.e. excessive withdrawal of the underground water than its recharge in case of falling water table, and accordingly the re-supplementation or accumulation in case of rising water table. This was done for each region and the state, with focus on the central region in particular. It may be noted that this approach does not work out the demand and supply per se; rather it centers on estimating the deficit of water through estimating the decline in water table. Thus the assumptions about the demand and that of the supply remain in the background, i.e., these are, as whatever these are, the actual ones.

Agriculture is the major source of demand for water, including the underground water. The crops can be grown as rain-fed or on rain and surface water only and thus the actual evapotranspiration is usually no greater than precipitation, with some buffer in time depending upon the soil's ability to hold water. But assured irrigation withdrawing ground water increases the productivity and lowers the risk of crop failures. And on the other extreme, the crops can be kept flooded even for long periods, such as the rice crop, which attained the status from 'zero to hero' in Punjab (Singh and Sajla, 2002), and is the major crop requiring most of the water, and where the management system plays a significant role as a determinant of water required.

Declining Water Table in Punjab

During the month of June, which is pre monsoon,[11] the water table in 1973 was at a shallow depth of 5.7 and 6.7 metres in the Central and North Eastern regions respectively, whereas in the South Western region, it was at an average depth of 12.1 metres (Table 1). By June 2005, the water level in these regions was at 14.6, 9.4 and 7.1 metres depth respectively.

In the North Eastern region, the water table in June 1988 was also at 9.2 metres and it came up to 7.4 metres in 1997. Again by 2005, the water level in this region was at 9.4 metres. Thus the closest paradigm of the water table behaviour in this region is that it is almost static though fluctuating, with relatively more recharge during excessive rains and floods (as in 1988 when by October it rose to 5.6 metres) and declining somewhat in low rainfall years.

TABLE 1. WATER TABLE BEHAVIOUR IN PUNJAB, REGION – WISE, 1973-2005

Region → (1)	North Eastern (2)		Central (3)		South Western (4)		Punjab (5)	
Blocks	31		86		21		138	
Obs wells:(AV)	162		362		92		616	
All over time	419		1185		238		1842	
	Average water table level (metres)							
Year ↓	June	October	June	October	June	October	June	October
1973	6.686	5.095	5.693	4.801	12.066	11.727	6.827	5.900
1974	6.480	6.134	5.617	5.656	10.837	10.801	6.643	6.594
1975	7.010	5.284	6.408	5.004	10.613	9.994	7.234	5.870
1976	6.180	4.825	5.820	4.501	9.970	9.434	6.562	5.362
1977	6.381	4.691	5.655	4.371	9.468	9.040	6.418	5.174
1978	6.881	5.745	5.457	4.456	8.966	8.330	6.301	5.307
1979	6.645	6.614	5.274	5.535	8.610	8.381	6.064	6.200
1980	7.726	6.725	6.364	5.517	8.513	7.919	6.995	6.139
1981	7.373	6.984	6.109	6.105	8.241	7.967	6.706	6.588
1982	7.403	7.117	6.221	6.348	8.005	7.616	6.761	6.716
1983	7.368	6.676	6.247	5.434	7.659	7.256	6.716	5.980
1984	7.536	6.822	6.485	5.683	7.150	6.773	6.832	6.109
1985	8.490	6.984	6.849	5.865	6.911	6.536	7.250	6.234
1986	8.558	7.502	6.769	6.400	6.560	6.383	7.178	6.675
1987	8.340	8.361	7.059	7.606	6.818	7.208	7.356	7.742
1988	9.203	5.607	8.471	6.004	7.106	7.098	8.487	6.023
1989	7.789	7.228	7.430	7.107	6.767	6.851	7.437	7.105
1990	8.047	5.982	8.031	6.329	6.814	6.392	7.871	6.233
1991	7.767	6.688	7.456	7.124	6.197	6.280	7.366	6.877
1992	8.124	7.118	8.038	7.722	6.399	6.272	7.812	7.305
1993	8.870	7.564	8.958	7.992	6.433	6.459	8.507	7.606
1994	9.207	7.060	9.525	8.436	6.860	6.578	9.013	7.724
1995	8.424	6.156	9.679	7.845	6.452	6.070	8.815	7.049
1996	7.563	5.770	8.970	7.908	5.976	5.773	8.118	6.933
1997	7.413	6.195	9.336	7.996	5.955	5.786	8.279	7.143
1998	7.416	5.900	9.304	8.035	5.454	5.093	8.213	6.990
1999	7.722	6.649	9.439	9.047	5.419	5.553	8.336	7.839
2000	8.087	7.119	10.217	9.864	5.736	5.707	8.916	8.440
2001	8.656	7.269	11.228	10.185	5.745	5.870	9.622	8.745
2002	8.984	8.313	11.276	11.240	6.304	6.641	9.834	9.616
2003	9.572	8.042	12.093	11.616	6.656	6.521	10.456	9.726
2004	9.568	8.942	13.501	13.407	6.784	7.322	11.122	10.937
2005	9.351	8.424	14.591	14.062	7.138	7.039	11.552	10.964

Note: The regional classification here is slightly different than in Singh (2006).

In the South Western region, with large areas of unfit ground water, large supplies of canal water, and the water table, which was too deep in 1973 (12.1 metres), came up to 6.8 metres in 1990 and was at the shallowest level of 5.4 metres in 1999 creating waterlogging conditions in many parts of the region; but declined thereafter due to the concerted measures/investment in drainage. And it went down again to 7.1 metres by 2005, which is about the same as in 1990.

It is the Central region of the state, which is the largest, where rice is the predominant crop during *kharif* season, and the water table has been consistently declining, from 5.7 metres in 1973 to 6.4, 8.0, 10.2 and 14.6 metres in 1980, 1990, 2000 and 2005 respectively. The region has the underground water fit for irrigation and most of the approximately one million electricity operated tubewells of the state, about half of which are the submersible ones, are in this region.

The long-term rate of fall in water table shows there was a serious fall @ 23 cms per year in the Central region; and, a quick rise in the South Western region @ 14 cms per year (Table 2). The gravity of fall in water table in the central region increased over time; the fall was at the rate of 14, 20 and 82 cms per year during, 1973-1990, 1990-1999 and 1999-2005, respectively. Worse still, even the river beds, which mostly lie in this region, are not immune from this malaise of depleting the underground water resource, *albeit* gradually in the major parts of these belts. (Singh, 2007).[12] The area under rice was less than 2.3 mha in 1997 and increased sharply to more than 2.5 m ha in 1998; and has stayed beyond this level with slow increases since then. The water table in the South Western region increased to @ 29 cms per year during 1973 to 1990. The water level in this region during 2005 was about the same as in 1990 (the rate being only 0.1 cms per year during 1990-2005); but it increased @ 13 cms per year during 1990 to 1999 and thereafter fell sharply @ 29 cms per year during 1999 to 2005. The field observations show that there is again a reverse trend, i.e., the rise in water table since then.

TABLE 2. RATE OF FALL IN WATER TABLE IN PUNJAB, REGION-WISE, 1973-2005

(cms per year)

Region	North Eastern		Central		South Western		Punjab	
Period ↓	June	October	June	October	June	October	June	October
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1973-2005	7.5	6.6	23.1	23.3	-14.3	-12.5	12.8	12.8
1973-1990	13.3	11.3	13.7	12.8	-29.0	-26.7	7.4	6.3
1990-2005	8.1	13.5	38.0	43.5	0.1	2.9	22.1	27.2
1990-1999	-8.3	-6.3	19.6	19.0	-13.2	-12.6	6.7	7.1
1999-2005	31.3	34.8	81.7	84.1	29.2	29.8	53.2	54.8

Estimating the Groundwater Depletion

For estimating the quantum of groundwater depletion from the behaviour of the water table in a region, an estimate of soil porosity (per cent of soil void of material or the air space between the soil particles which can be filled with water) is needed (Groundwater depletion = Fall in water table *multiplied by* soil porosity *multiplied by* area of the region). The porosity of sandy loam soils is 0.2 (Hira and Khera, 2000); it is higher as the sandy part increases, and vice versa when the clay component increases. The estimates of water depletion, during June 1990-June 2005, in this study are based on the soil porosity of 0.20, as was done in other studies (Table 3).

TABLE 3. ESTIMATES OF TOTAL WATER DEPLETION, REGION-WISE, PUNJAB, JUNE 1990 - JUNE 2005

(km^3)

Year (1)	North Eastern (2)	Central (3)	South Western (4)	Punjab (5)
1990-91	-0.510	-2.934	-1.219	-4.663
1991-92	0.651	2.972	0.398	4.021
1992-93	1.360	4.698	0.069	6.126
1993-94	0.615	2.897	0.841	4.352
1994-95	-1.426	0.786	-0.805	-1.445
1995-96	-1.571	-3.622	-0.938	-6.130
1996-97	-0.274	1.868	-0.042	1.552
1997-98	0.006	-0.162	-0.989	-1.145
1998-99	0.558	0.690	-0.068	1.181
1999-2000	0.664	3.972	0.625	5.261
2000-01	1.039	5.161	0.018	6.217
2001-02	0.597	0.248	1.102	1.947
2002-03	1.072	4.168	0.695	5.935
2003-04	-0.008	7.193	0.252	7.437
2004-05	-0.396	5.564	0.697	5.865
Total of the positive net recharge years*	- 4.184 (6)	- 6.718 (3)	- 4.060 (6)	- 13.383 (4)**

Notes: Figures in parentheses is the number of years with positive net recharge, i.e. water accumulation.

* That is, the years with negative water depletion.

** The sum of the three regions in this row (-14.962), will be an over estimate of the total net recharge for the state because the years of net recharge need not be necessarily the same in all the regions, and thereby cancel out for some years.

The total water depletion during 1990-2005 was estimated at 36,5 km^3 out of which 33.4 km^3 was from the Central Punjab, where tubewells and the rice area are the maximum (Table 4). The rate of ground water depletion during the period in the state was 2.43 km^3 per year; it reached a high of 6.1 km^3 during as early as 1992-93 (June-over-June) and was the maximum at 7.44 km^3 in 2003-04. The rate of depletion per year was the maximum in the Central region at 2.23 km^3. It was only 0.16 and 0.04 km^3 in the North East and South West respectively. It may also be noted that during 1990-2005, there were 6, 3 and 6 years when the water resource rather accumulated as much as 4.18, 6.72 and 4.06 km^3 in the North East, Central and South West Punjab, respectively.[13]

In the South Western region, the total depletion during June 1990-June 2005 was only 0.64 km^3 whereas the total depletion during the last 6 years (June 1999-June 2005) was relatively more than 4.5 times being 3.39 km^3. In fact the rate of fall in water table during 1999-2005 was the same as the rise in water table during 1994-99 as shown below:

Depletion (Falling water table) :: June 1991 to June 1994 = 0.436 km^3 per year
Addition (Rising water table) :: June 1994 to June 1999 = 0.568 km^3 per year
Depletion (Falling water table) :: June 1999 to June 2005 = 0.565 km^3 per year

TABLE 4. ESTIMATES OF TOTAL DEPLETION OF GROUNDWATER IN PUNJAB, JUNE 1990 - JUNE 2005

(km^3)

	1990 – 2005		1990 – 1999		1999 – 2005	
Region (1)	Total (2)	Av/year (3)	Total (4)	Av/year (5)	Total (6)	Av/year (7)
North Eastern	2.377	0.158 (6)	-0.591	-0.066 (4)	2.969	0.495 (2)
Central	33.497	2.233 (3)	7.193	0.799 (2)	26.305	4.384 (0)
South Western	0.638	0.043 (6)	-2.752	-0.306 (6)	3.389	0.565 (0)
Total Punjab	36.513	2.434 (4)	3.849	0.428 (4)	32.663	5.444 (0)

Notes: 1. The figures in the table are derived ones.

2. The estimate of total depletion for each region was based on the area, which was 18.1, 50.7 and 31.2 per cent in North East, Central and South Western region, respectively.

3. Figures in parentheses is the number of years when the recharge was more than the withdrawal.

4. The total of Punjab is the sum of the three regions. It will be slightly different, if worked out directly from the average water table behaviour in Punjab because the relative weights of different regions in this case varied from year to year depending upon the number of observation wells, which changed on account of drying up, etc.

The depletion of water was particularly high during 1999-2005, which was estimated at 2.97, 26.31 and 3.39 km^3 in the North East, Central and South West Punjab respectively. In the North East and South West regions, it was even more than the total depletion during 1990-2005, because the net result of year-to-year variation in accumulation and/or depletion during 1990-99 was in favour of net accumulation in these regions. The average rate of water depletion in the Central region was 0.80 km^3 during 1990-99, which increased to 4.38 km^3 during 1999-2005; for the Punjab, it was 0.43 and 5.4 km^3 during the respective periods.

The quantum of water deficit estimated at 2.43 km^3 for Punjab, out of which 2.23 km^3 is from Central Punjab, per year during 1990-2005, using the actual monitored fall in water table approach, is much lower than the earlier estimates of 15.4 km^3 (Prihar *et al.*, 1993), 12.7 km^3 (Hira *et al.*,2004) and 9.9 km^3 (Government of Punjab, 2008). Even the peak depletions of 6.13 km^3 in 1992-93, 6.22 km^3 in 2000-01 and 7.44 km^3 in 2003-04 for Punjab are lower than the earlier estimates.[14]

The rate of depletion during the latest six years of the study (June 1999-June 2005) estimated at 4.39 km^3 per year at the soil porosity of 0.2 translates to about 4 $\pm$ 0.5 km^3 per year. It is a huge gap, noting that the India's largest reservoir dam (Bhakra) in the region has the gross storage capacity of 9.34 km^3, with live storage capacity of 6.91 km^3. This indeed is alarming. The total water depletion during June 1999-June 2005, estimated at 26.3 km^3, from the Central Punjab, which constitutes only 5.8 percent of the total area but accounts for about 24 per cent of the total depletion as estimated by NASA for the entire region of Punjab, Haryana, Delhi and Rajasthan region, (also over the six year period of August 2002-October 2008) of 109 km^3 (Rodell *et al.,* 2009).[15]

Deficit as Equivalence of Rainfall

Meeting the groundwater deficit means no change in water table. The equation of groundwater depletion, as given earlier, can be transposed to estimate the requisite rainfall, which is the prime additional source of water recharge. It was estimated for the central Punjab, where the water table has been falling seriously due to excessive groundwater depletion. Again, this was done for 1990 to 2005 for each of the years (Table 5).

TABLE 5. ESTIMATES OF RAINFALL FOR MAINTAINING WATER BALANCE, CENTRAL PUNJAB, 1990–2005

	Change in water level						
	June-over-June	Oct-over-October	Net monsoon recharge	Net rabi withdrawal	Monsoon rainfall Jun-Sep	Annual rainfall Jun-May	Additional rainfall/water for balance
Year	Metres	Metres	Metres	Metres	mms	mms	mms
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1991	..	-0.795	0.333	1.127	603.9	756.8	159.0
1992	-0.582	-0.599	0.316	0.914	397.9	552.7	119.8
1993	-0.920	-0.270	0.966	1.236	381.7	486.2	54.0
1994	-0.567	-0.444	1.09.0	1.533	566.9	644.7	88.8
1995	-0.154	0.590	1.834	1.244	543.3	685.6	-118.0
1996	0.709	-0.063	1.062	1.125	615.0	747.0	12.6
1997	-0.366	-0.088	1.340	1.428	499.5	609.7	17.6
1998	0.032	-0.039	1.269	1.308	509.9	718.9	7.8
1999	-0.135	-1.013	0.392	1.405	268.5	452.1	202.6
2000	-0.778	-0.816	0.354	1.170	313.2	385.1	163.2
2001	-1.011	-0.322	1.042	1.364	316.0	409.2	64.4
2002	-0.049	-1.054	0.037	1.091	367.9	418.6	210.8
2003	-0.816	-0.376	0.477	0.853	264.7	372.6	75.2
2004	-1.409	-1.791	0.094	1.886	350.2	436.5	358.2
2005	-1.090	-0.655	0.529	1.184	249.3	428.7	131.0
Average	-0.508	-0.516	0.742	1.258	416.5	540.3	103.1

* Soil porosity = 0.2. The average additional rainfall required for water balance at soil porosity of 0.20, 0.18 and 0.16 is estimated at 103.1, 92.8 and 82.5 mms respectively.

Notes: 1. The water level recharge and withdrawal are based on all the observation wells during different years for which the data were available; these were about 250 to 400.

2. Monsoon rain is from June to September; the total rain is from June to May. These data are derived from the Statistical Abstracts of Punjab. There are some variations in the rainfall data as given above and the one released by the India Meteorology Department on its website. The State data is, on the average, was lower by about 38 mms monsoon rainfall for 2004-07. Nonetheless, the additional rainfall / water for balance, which is derived from the fall in water table will be unaffected by this variation. However, the following correlations, which is just academic, might differ somewhat.

3. Correlations: Additional water / rainfall with annual rainfall (June-May) = -0.509, with monsoon = - 0.460 *Kharif* recharging with monsoon rain = 0.522; Rabi withdrawal with *rabi* rain = - 0.010.

The average additional water/required to meet the deficit during 1990-2005 was estimated at about 103 mms (at soil porosity of 0.2) and it was not very sensitive to the soil porosity; it being 93 and 83 mms at soil porosity of 0.18 and 0.16 respectively. Although the entire rainfall does not translate into groundwater recharge, the model here implicitly considers the rainfall as a substitute to withdrawing the equivalent amount of ground water. Thus about 10 cms of rain-water deficit needs to be contained through managing the demand for water, mainly from the agricultural management systems and practices (Table 6).

TABLE 6. ESTIMATING THE RAINFALL EQUIVALENCE FOR MAINTAINING THE WATER BALANCE, CENTRAL PUNJAB, AVERAGE OF 1990 TO 2005

(cms)

Parameter ↓ Soil porosity → (1)	0.20 (2)
Change in water level	- 51.2*
Net monsoon recharge (October-over-June)	74.2
Net rabi withdrawal (June-over-October)	125.8
Estimated rainfall deficit for maintaining water balance	10.3

Notes: 1. Starting with October 1990, when the water level was at 6.329 metres, which went down to 14.062 metres by 2005 (Annex 1). It gives the rate of fall as 51.6 cms. Likewise, the average rate of fall during June 2005 over June 1991 comes to 50.9 cms.

2. The difference in the rates of monsoon recharge and rabi withdrawal is also 51.6 cms.

However, it could be different, because of the difference in the periods involved.

The fall in water table and the additional water required for maintaining the water balance is a complex phenomenon; two or more consecutively better or lower rainfall years enlist the response to adjust accordingly in different modes. There were 5 consecutively better rainfall years (1993-94 to 1997-98) when the average annual rainfall was 681 mms,[16] and overall there was a water balance; the cumulative difference in the rainfall and the water required was only 8.8 mms. These were followed by 7 consecutively lower rainfall years with an average annual rainfall of 415 mms and the additional rainfall required for water balance was 172 mms; thereby making the total water demand to be 587 mms, which is almost 100 mms less than when the rainfall was better. It shows that there are adjustments to crisis-laden scenario to contain the effective demand for water. Nonetheless, the higher the annual rainfall, the lower the additional water requirement for restoring the balance between the demand and supply, the correlation being negative at -0.509, which was significant at 0.05 probability level.

Variation in Crop Water Demand (ET)

Evapotranspiration (ET) is the sum of evaporation (movement of water to the air from the soil, canopy interception and water bodies) and transpiration (movement of water within a plant which is subsequently lost as vapours through stomata). It is expressed in terms of depth of water. Potential Evapotranspiration (PET) is the amount of water that could be evaporated and transpired if there was sufficient water available. It is important to note that the ET varies from crop to crop and year to year depending upon rainfall, temperatures, humidity, wind speeds, etc.

Different crops have different ET rates (Table 7). The crops, which require/applied standing water at some stage of growth, as rice, have higher ET. Further, the crops like rice with marginal productivity to water tending to close at zero, i.e. rarely negative, and the cost of using water is fixed, i.e. the marginal cost is zero, the farmers would tend to apply as much water as they can, which increases the ET. Again, the period and the timings of growth, such as how long during the summer months or so, also determine the ET. Thus, a short duration variety would have lower ET. Likewise, manipulating the growth period to delay from the extreme summer would reduce the ET. The ET for rice transplanted on May 1, May 30 and June 30 is 84, 67 and 52 cms respectively (Hira *et al.,* 2004). The changed transplanting pattern of rice also affects the sowing pattern of wheat, which would reduce the ET of wheat.[18] And the rice and wheat are the two most important crops of the state covering about 80 per cent of the total cropped area.

TABLE 7. EVAPOTRANSPIRATION (ET) OF DIFFERENT CROPS, PUNJAB

(*cms*)

Crop (1)	Prihar *et al.,* (1993) (2)	Hira *et al.,* (2004) (3)	Arora *et al,* (2008) (4)
Rice	73	73	65
Cotton	65	71	60
Maize	60	46	48
Sugarcane	180	160	135
Groundnut	50	51	-
Wheat	50	35	38
Gram	40	-	32
Rape seed and mustard	35	35	28
Lentil	40	-	-
Sunflower	-	65	55
Moong	-	41	-

Above all, some other cultural practices of the crops determine the ET.[19] Such practices can be manipulated to contain the major component of demand for water for crops. Using happy seeder, which cuts the paddy straw, spreads on the sides (synonymous to mulching during October-November), and sows wheat directly would reduce the ET. Its impact on water saving vis-à-vis burning of paddy straw need to be studied.[20] Mulching during summer, using the surplus crop residues, has been extensively reported to be conserving the moisture/saving the water applied and even improving the yields (Sandhu *et al.*, 1980; Prihar *et al.*, 1996; Jalota and Prihar, 1998; Arora *et al.*, 2008). Similarly, the trench/ridge planting of crops like sugarcane help to save the irrigation water application up to 25 per cent as well as improve the yield, which could be as high as 50 per cent (PSFC, 2009). So does the laser leveler. The precise laser-land leveling and proper plot size increase the irrigation efficiency at a field scale, which saves 25-30 per cent of irrigation water application (Sidhu *et al.*, 2007). All such technologies, which save water, must be promoted.

Crop substitutions also determine the total ET. Sugarcane has high ET of around 160 cms compared with its substitutes, rice and wheat in Punjab, which have ET of about 60-65 and 35-40 cms respectively. Thus the decline in area under sugarcane by 1 hectare substituted by rice + wheat would save about 50 cms of water. This explains that when the area under sugarcane, which follows a cyclical pattern, declines, even a significant increase in the rice area by 118 and 240 thousand hectares during 1997 and 1998 respectively (the decline in sugarcane area was 48 and 23 thousand hectares), the water table declined by 8.8 and 3.9 cms only as compared with the average decline of 51.2 cms during 1990-2005.

Act to Save Underground Water

The farmers had started planting paddy beginning from the first week of May for convenience as the research results indicate that paddy crop transplanted from 10th June onwards has the same productivity (PSFC, 2009). Thus, to delay the transplanting to save lot of water, as the evapo-transpiration is much less compared to May, at the initiative of the Punjab State Farmers Commission, 'the Punjab preservation of sub-soil water Act, 2009' was promulgated as an Ordinance in 2008. It has been effectively implemented and ensured that the 'sowing of paddy nursery was not before May 10' and the 'transplanting of paddy nursery was not before June 10'. During 2008, the combined effect of more (than normal) rainfall and the Act led to improvements in water table, estimated as almost equal contribution to total at 80 to 100 cms; and is within the range of provisional estimates from the monitored data (Singh, 2009). The press reports beamed on June 5, 2009, 'A year into new Act, water table up, power bills down' (Kaur, 2009).[21]

It has been estimated that about 10 cms of the additional monsoon rainfall would restore the long term balance. The Act saves about 5 cms. In a low rainfall year, the savings could be higher because due to the Act, the transplanting is further staggered as the expectation of rain enters the decision process, like in 2009 with the lowest monsoon rainfall of the decade (Singh, 2009). The higher savings on this account and the lower water-equivalent net area under rice (with substitution from the decline in area under sugarcane) at about 2440 ha, which is about the same (2460 thousand ha) in net water-demand terms as of 1998, impacted the water deficit/table/depletion to be far lower than it would have been otherwise. Again during 2010, when the monsoon and the rainfall following *rabi* season was close to normal, the fall in water table did not make any news.

Will There be Water Balance?

Yes, ultimately, for, if it continues to be depleted, a stage would reach when it would be uneconomical and/or even technically impossible to deplete further.[22] But the crisis would unfold earlier; the decreasing supply of water would cause the production to decline, and that is when the 'conflicts and sufferings' would begin to generate the 'suicidal tensions'.

The estimates of the available supply of water in the long run are somewhat more thoroughly monitored and therefore more precisely known; these are somewhat static but for annual variations of rainfall and seasonal flows; the latter also having been maneuvered by the 'political shifts' from one region/ area to another one. However, shifting the excessive flow of canal water to areas, where the underground water is brackish and 'not fit for use', the recharge is the 'net loss' (for it cannot be pumped out for use). It also ultimately leads to other problems like water-logging, etc. for which the public investment in drainage systems becomes necessary. This is what has happened precisely and silently over the last few decades by inter-linking the rivers and large-scale diversion of surface water supply from recharging the sweet-water zones to the brackish ones. This makes a strong case of 'mandating to recapture the excessively recharged sweet water, due to canal water supply as per demand, from the shallow layers for reuse before it is lost to deeper layers and mixes with the unfit groundwater'. The equity considerations do demand the management of given scarce water resources in a way, that allocates more to the relatively more disadvantaged regions, but nonetheless not in the above fashion. The cost of such policies needs to be weighed against the policies and incentives to make the South West region highly concentrating on low-water requiring crops like cotton (Singh, 2009).

This leaves the onus on managing the demand side of water for agriculture, where numerous possibilities do exist, but require the needed investments and incentives. The long run deficit is about 10 cms height of water (rainfall), of which about half has been resolved, though too late (read it crisis-laden situation, which compelled and/or had educated the user farmers to accept and act accordingly in one go) with the 'preservation of sub-soil water act', since 2008 in Punjab and since 2009 in Haryana. It was long overdue.

Various 'water-use-efficiency' possibilities have also been discussed earlier; more need to be researched. The evaluation of the technology-investment options like happy seeder, laser leveler, ridger/trencher, etc. from the perspective of savings in water and other benefits is needed. A 20 to 25 per cent reduction in irrigation water applied, especially in case of high ET crops like sugarcane and rice means an equivalence of 4 to 5 irrigations, which means the savings in electricity (and subsidy).[23] Although, considered judiciously, these technologies could be economical from the farmers' point of view too, but the heavy initial investment and low use during the year makes these out of the reach of majority of the farmers, particularly the smaller ones. But the state should be more concerned with the real savings in water. This aspect, is recommended, must be considered in the state and federal budgets for providing the additional support to the agriculture sector. It might work out to be providing it totally free, though a highly subsidised system and ensuring effective utilisation would work out to be better proposition. Providing these to the majority of Primary Agricultural Co-operative Societies enabling them to work as Agricultural Service Centres at working cost to the individual farmers is still better. For substantial coverage to be effective, the amount in the annual budgets has to be large, but it would be substantially recovered indirectly through the positive impact on water balance bringing the savings of subsidy and the check on environment pollution, etc.; for instance, Rs. 250 crores worth of nitrogen fertilisers[24] is burnt (lost) annually through rice straw burning in 80 per cent of the rice fields (PSFC, 2008) before wheat sowing by the Punjab farmers, and if the entire practice is substituted by the happy seeders, it would also be saving about 1-1.5 cms of water on some 2 million ha, which is equivalent of about 0.25 km^3 of water. This is 25000 ha metres of water, i.e., 250 million cubic metres, i.e., 8825 million cubic ft, which means a flow of more than 10000 cusecs for 10 days.[25]

SUMMING UP: THE POLICY REGIMEN TO MAINTAIN THE WATER BALANCE

Agricultural development in Punjab started around the water management, whether it was the enthusiastic land mark of achieving the consolidation of the fragmented holdings upto mid-1960s, i.e., even prior to the high-yielding varieties era or during the era through the complementary policies of institutional credit and electricity supply (and others) that facilitated the private/farmers investments in tubewells (Kalkat *et al.,* 2006).[26] As of today there are more than a million electric tubewells in Punjab, of which more than half have been replaced over time with the submersible ones in search of water from the deeper layers underground; and almost every one is with a standby availability of a diesel engine/generator set, in case of scarce electricity supply.[27] The area irrigated by tubewells is 3 million hectare, which is about 71 per cent of the net cultivated area of the State, and is cropped twice a year, irrigated many times throughout the year. Some concerted policy initiatives and capital investments need to be channelled judiciously, for it would be unaffordable to let the story of development end with its mismanagement that had been depleting the underground water, which had accumulated over the centuries, at the rate that the crisis showed up in a quarter century, and, which even worsened over the next quarter century.[28]

The depletion rate of groundwater resource from the central region of Punjab, where most of the rice is grown, and supplied to the food security of the country, is 4 $\pm$ 0.5 km^3 per year for the period June 1999-June 2005. The deficit has been of a crisis-laden, considering that the gross storage capacity of India's largest reservoir dam (Bhakra) in this region is 9.34 km^3, with live storage capacity of 6.91 km^3. Thus effective measures need to be taken to manage the deficit, still meeting the needs of the food-security of the country and save the groundwater from "diminishing to the point at which farmers and residents of the region are forced to react. Severe shortage of potable water, reduced agricultural productivity, conflict and suffering surely would accompany the supply-limited solution" (Rodell *et al.,* 2009).

The demand for water from the agriculture sector, which is the major claimant to produce food and fibre for the mankind, responds to a variety of factors, and can be efficiently managed to restore the water balance to a significant extent. The response to the concerted appeals by the scientists and other policy measures like limiting electricity supply hours during May to early June, delayed entry of procurement agencies, etc. yielded only little impact on delaying the transplanting of rice. But the same in response to the 'Punjab preservation of sub-soil water Act, 2009' has been a significant land mark. There have also been some improvements in water use efficiency, through techniques like laser leveling of fields and trench/ridge planting of crops like sugarcane; and the use of happy seeders for wheat sowing, which not only saves moisture, organic matter and nitrogen fertilisers from burning, but also further acts as a mulch to save more water. These need be extended to the maximum possible coverage. The economic evaluation of such technologies, accounting for their role in restoring the water balance, the crucial long-term natural resource, and other impacts, need be considered in the fiscal budgets of the state and federal governments for providing additional support to agriculture.

At the same time an appropriate 'policy for groundwater use in the urban sector' is needed, where there is uncontrolled criminal exploitation and wastage of groundwater.[29] The utmost priority is to conserve the groundwater, whatever are the means, measures and policies necessary; and it is the key word.

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NOTES

1. The marginally fit and unfit water refers to the underground source, to be used for either crops or domestic.

2. These estimates, however, are on the higher side. For instance, the water requirements of rice alone (for the 1989-90 area of 1.924 million ha) were estimated at 1.40 mHaM, which implies that even if there were no rice, no crop and no evaporation during the rice-period from that area either, still there would have been deficit of good water.

3. The total demand given in the report is 50 million Acre Feet (6.172 mHaM), which implies that the deficit is even higher at 2.233 mHaM, i.e. 22.3 km^3 (Government of Punjab, 2008). Note that the demand-driven-deficit and depletion may vary.

4. The overdraft is depletion but not necessarily the deficit, which may be higher.

5. Other important studies include those by the Indian Ministry of Water Resources (Central Groundwater Board, 2006), which estimated the annual deficit (difference between annual available recharge and annual withdrawal) of 13.2 km^3 per year in the Punjab, Haryana (including Delhi) and Rajasthan region. The findings of the study by NASA using the Gravity Recovery and Climate Experiment (GRACE) sounded more alarming in the Press (Mohan, 2009). The concluding lines are, "Depletion is likely to continue until effective measures are taken to curb groundwater demand or until

the supply or quality of the resource is diminished to the point at which farmers and residents of the region are forced to react" (Rodell *et al.,* 2009).

6. The net irrigated area by canals, during 2006-07 over 1970-71, declined by about 100 thousand ha in central Punjab, but increased by 134 thousand ha in the South Western Punjab. In percentage terms, the share of South Western region in the net area irrigated by canals increased from 61 per cent in 1970-71 to 77 per cent in 2006-07. This is in terms of area; the field observations point to more quantity of water supplied per acre / diverted to this region.

7. In terms of actual water withdrawn / recharge, the adjustment with the soil porosity, explained later, is needed. The soil porosity is 0.2 for sandy loam soils and is lower for the clay soils. A value of 0.2 means a 20 cm fall in water table is equivalence of 4 cm of water withdrawn and vice versa.

8. It is rare for the net monsoon recharge to be negative, but it did happen during very poor monsoon years (Singh, 2006; also see Annexure I).

9. The classification of blocks into three regions varies slightly by different authors according to the parameters considered; and a new block is created by re-demarcating every now and then (Singh, 2006).

10. In areas where underground water is unfit, the recharging with canal water supply is not utilisable, and the water table rises, thereby implying that rising water table does not mean that utilisable water supply exceeds the demand for water in such areas.

11. June to September are considered as monsoon months as per India Meteorology Department; the monsoon in Punjab is usually received towards the end of June onwards.

12. Based on the ground water behaviour mapping, the state was demarcated into 13 regions; 3 in the North East, which are mainly sub-mountainous and undulating, 3 in the South West and the remaining 7 in the Central Punjab including the 3 river beds, one each for Ravi, Beas and Satluj (Singh, 2007).

13. The sum of the three regions (-14.962), will be an over estimate of the total net recharge for the state because the years of net recharge need not be necessarily the same in all the regions, and thereby cancel out for some years.

14. Even the maximum depletion in each region irrespective of the year, which was 1.4, 7.2 and 1.1 km^3 from the North East, Central and South West regions in 1992-93, 2003-04 and 2001-02, respectively, adds up to 9.7 km^3 only.

15. The depletion would be mainly from the areas where underground water is used for irrigation. Punjab constitutes 11.5 per cent area of the entire region, but its underground water resource exploiting area is 33 per cent of the region (2914 out of 8952 thousand ha). The underground water resource exploiting area in Punjab is about 58 per cent of its (Punjab) area, thus the Punjab over-exploits more than Haryana and Rajasthan. Based on our estimate of rate of water depletion at 5.44 km^3 from 33 per cent of the water-exploiting area of the region (Punjab, Haryana, Delhi and Rajasthan), the rate of depletion for the region would be 16.74 km^3 (1999-2005) as compared with 13.2 km^3 (up to 2004) of CGWB estimate and 17.7 km^3 (2002-2008) of NASA estimate. However, the estimate for the region, based on the Punjab one, possibly could be little overestimate because tubewells (Punjab) exploit more than the wells (Rajasthan), which irrigate 2914 and 2538 thousand ha area in the respective states.

16. As per the Government of Punjab data in *Statistical Abstracts of Punjab*, used in this study, the average rainfall during 1990 to 2005, was 417 and 540 mms as monsoon rainfall and total rainfall, respectively. The normal rainfall as per India Meteorology Department (50-year average) for Punjab is 502 and 649 mms for monsoon and annual rainfall, respectively. However, the estimates of depletion, and accordingly the additional rainfall required remain the same.

17. The variety-wise difference in the yield/productivity of a crop depends, other factors notwithstanding, mainly on the seed-to-seed duration of the variety; the longer the duration, the higher the yield. Thus there is a trade-off between saving water through forcing the short duration genes vis-à-vis the productivity.

18. Again the limiting factor would be how to manage the sowing of wheat in a shorter period with minimal delay so that the productivity of wheat is least affected.

19. For a more comprehensive review of this aspect, see, Arora *et al.* (2008); Singh (2008).

20. The water savings through reduced evaporation, from the relevant experiments, could be placed as 1 mm per day during the initial periods of crop growth; the practice leads to the delay in the first irrigation from the 21st day (after sowing) to around the 40th day. This makes it to about 20 mm; a safe guess is 10 to 15 mms, the same as for the kharif season with similar practice (Personal discussion with S.K. Jalota, Professor, Department of Soils, Punjab Agricultural University Ludhiana).

21. The neighbouring state, Haryana, encouraged by the response to the Act in Punjab, also followed enacting the similar Act in 2009 (Khetri, 2009).

22. "Saudi Arabia is a good example of how unsustainable water use can eventually lead to a collapse in production. During the 1980s the Saudi government developed domestic wheat farming by pumping water from underground aquifers….. and even became the sixth largest wheat exporter by the early 1990s. But water began to run out …. Wheat production halved between 2000 and 2008 and it will end entirely by 2016" (ISU, 2011, pp. 9-10).

23. One irrigation means about 60 to 70 electricity units per ha; the cost is about Rs. 4 per unit (Singh, 2009).

24. The fertilisers, particularly nitrogenous, are subsidised by the central government, by about 40 per cent of the price at which it is sold to the farmers. Thus, it would amount to savings of fertilisers subsidy to the central government (for Punjab farmers alone) worth about Rs. 100 crores annually.

25. Compare this with about 20000 cusecs from Bhakra dam released normally by the end of September. During 2009 these are even down to 18570 cusecs as of September 21.

26. Water, as a stimulus and pre-requisite for development, has been in the limelight of inter-state and even inter-country sharing of river waters, a prime source of surface water supply including replenishing groundwater, often perennially, in its riparian area. For the one between the states of the region in this paper, see Khurana (2006). A special session of the Punjab Assembly (July 12, 2004) passed unanimously the 'Punjab Termination of Agreements Bill, 2004' terminating all agreements relating to sharing of waters of Ravi and Beas with Haryana and Rajasthan. It also abrogated the Yamuna Agreement of May 12, 1994 between Punjab, Haryana, Rajasthan, Delhi and Himachal Pradesh (which allotted 4.6 MAF of Yamuna water to Haryana to be further augmented by Satluj Yamuna Link canal) and all other accords for sharing water. The case is still pending in Supreme Court (Singh, 2008).

27. In 1960-61 there were less than 12000 tubewells, which increased to 192,000 in 1970-71 and to 600,000 in 1980-81; and less than 50 per cent were electrical ones, and hardly any as submersible.

28. Considering the emerging gravity of the situation, the Government of Punjab set up an Expert Committee on 'Diversification of Punjab Agriculture' in 1985 followed by a second one in 2002 and even therafter, the Punjab State Farmers Commission in 2005 (Kalkat *et al.,* 2006, pp .15-17).

29. To understand the scarcity value of water, consider the following: No one values water more than a village woman who has to walk miles to fetch a pot of water and tries to use it multiple times. No one values water less than the urban folk who, though pay for it, but let it flow endlessly at the turn of a tap and rarely bother to attend to the leaking tap.

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