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WATERLOGGING AND CONJUNCTIVE USE

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SYNOPSIS

This paper describes, the phenomena of waterlogging, its status and how it can be controlled and removed through Conjunctive Use of Groundwater with Surface Water. Relevant case histories have been described.

I. DEFINITIONS

1. Water logging has been defined as per Report of the National Commission on Agriculture Report (1976), as follows "An area is said to be waterlogged when the water table rises to an extent that the soil pores in the root zone of a crop become saturated in restriction of the normal circulation of air, decline in the level of oxygen and increase in the level of carbon dioxide." The water table which is considered harmful would depend upon the type of crop, type of soil and the quality of water. The actual depth of water table, when it starts affecting the yield of crop adversely may vary over a wide range from zero for rice to about 1.5 metres for other crops".

Some of the states have different criteria for waterlogging as shown in Table 1.

Latest definition given by Working Group on problem identification in irrigated areas with suggested remedial measures, Dec. 1991 is as below:-

i. Waterlogged area - Water table within 2 metres of land surface

ii. Potential areas for water-logging - Water table between 2-3 metres below land surface

iii. Safe areas - Water table below 3 metres of the land surface

Table 1 : Criteria for Water logging in Different states

State	Water table (below ground level) in metres
Uttar Pradesh (Sharda Sahayak Project)	
i. Worst Zone	less than 1
ii. Bad Zone	1 - 2
iii. Alarming Zone	2 - 3
iv. Safe Zone	More than 3
Punjab	
i. Very critical	0 - 1.5
ii. Critical	0 - 2.0
Haryana	
i. Critical Waterlogged	0 - 1.5
ii. Critical	1.5 - 3.0
Karnataka	
i. Tungbhadra Command	0 - 2.0
Maharashtra	
i. Fully water logged	Water at surface
ii. Waterlogged	0 - 1.2

2. Conjunctive Use specifies not merely development of groundwater resources in addition to surface water resources, but the optimal development of the two considering, the land and water, the matrix of a dynamic ecological system taking into account the

specific spatial and temporal availability and variability of each, considering total river basins or even their interlinkages and the economics of development of the total water resources to satisfy the multifarious and often conflicting demands with due consideration of technological and socio-economic aspects.

3. The National Water Policy (1987) has mentioned that in the planning and operation of systems, water allocation priorities should be broadly as follows:

- Drinking water
- Irrigation
- Hydropower
- Navigation
- Industrial and other use

This is with reference to water and so shall apply both to Surface Water and Ground Water. In respect of Conjunctive Use, the National Policy says:

"Integrated and coordinated development of surface water and ground water and their conjunctive use should be envisaged right from the project planning stage and should form an essential part of the project".

There is no mention of waterlogging problem in the document of National Water Policy.

II. PROBLEM OF WATERLOGGING - HISTORICAL REVIEW

The waterlogging problem is mainly an adverse direct effect of large scale canal irrigation. Waterlogging can also be caused by excess soil moisture due to periodic flooding, overflow by runoff, seepage, artesian water and obstructed sub-surface drainage. These conditions affect the growth and yield of crops. In course of time, such land turns saline or alkaline and ultimately becomes unfit for cultivation. Waterlogging and its attendant adverse effects in the areas irrigated by the Western Yamuna Canal (Haryana) first received attention around 1850. In the Deccan, the Nira Irrigation project was opened for irrigation in 1884, it caused serious waterlogging and salt affliction in the deep black soil of the project area, with 6 to 7% area being damaged annually. By 1907, waterlogging problem appeared in canals of Punjab (old undivided). In 1925, Punjab Waterlogging Board constituted a waterlogging enquiry committee to study and report on the extent and causes of waterlogging which had assumed serious proportions in the irrigated areas and to indicate preventive measures. The Chakkanwali Reclamation farm and the Punjab Irrigation Research Institute at Lahore were established to investigate all the problems associated with irrigation, drainage and salinity. About the same time the Baramati Experimental Station was set up in Deccan canal area for a similar purpose. In 1972, Irrigation Commission classified as a similar purpose. In 1972, Irrigation Commission classified as waterlogged all areas where the depth of water table varies from 0 to 1.5 m. On the terms of replies received from the states, the flowing statewise picture emerged:

Punjab

The state had the largest area, approximately estimated as 1.09 mha in 1958. Since then, a number of drainage schemes have been carried out and waterlogging has been brought under control.

Haryana

According to an estimate made in October 1966, 0.65 mha was affected by waterlogging, 0.62 mha in the Western Yamuna Canal area and 31,000 hectares in the Bhakra Canal tract. The State has also reported that about 142,000 ha under some branches of the Western Yamuna Canal have been affected by salinity and alkalinity, that soil surveys done before the introduction of irrigation in the Bhakra Canal area had indicated salinity or alkalinity over an area of 344,000 ha and that salts were usually met with at varying depths over the entire state.

Uttar Pradesh

No reliable records of the extent of waterlogging area were available but it was estimated that about 0.81 mha were affected. The state also does not appear to have made any reliable assessment of land affected by salinity or alkalinity.

Bihar

Because of the flat nature of the country, large areas of north Bihar suffer from inundation due to floods in the various rivers. Even after the floods recede, water stagnates in a large number of depressions, known as 'chaurs'. The state had not furnished any precise figures for the area that suffers from waterlogging.

West Bengal

More than 2590 sq. km in Midnapur district were reported to be subject to waterlogging. In addition, another 1295 sq. km in districts like the 24 Parganas, Howrah and Hooghly were also reported to be affected.

Maharashtra

The total damaged area in the old Deccan Canals was reported to be 27,800 ha, out of which 26.200 ha had been been damaged due to salts and the rest from waterlogging. The extent of waterlogging in other areas of Maharashtra had not been reported.

Rajasthan

Waterlogging have been reported in the Chambal command and the extent of it could be gauged from the fact that the water table which had been between 0 to 3 m. below ground had increased from 88,050 ha in June 1967 to 347,600 ha in October 1968. Even prior to irrigation, a soil survey indicated that 40,000 ha had salts and alkalis in the soils. The effect of irrigation on the soils was still to be assessed.

Madhya Pradesh

Waterlogging was being experienced in the Chambal command in much the same way as in Rajasthan. The extent of it could be gauged from the fact that 57,465 ha had a subsoil water table between 0 to 3m below ground level in October 1968.

Karnataka

It was reported that the extent of waterlogging under the Ghataprabha, Gokak, Tungabhadra and Bhadra Projects was 6,600 ha, out of a total irrigated area of 430,000 ha.

Waterlogging was not a serious problem in the States of Assam, Orissa, Andhra Pradesh, Tamil Nadu , Kerala and Gujarat. Though replies could not be received from Jammu & Kashmir, Nagaland and Himachal Pradesh, it was not a serious problem in these states also, except for some areas in the Kashmir Valley.

Agriculture Commission (1976) also made a study of waterlogged areas. Based on the depth of watertable below ground level as an index, 6.0 mha was identified as water logged out of which 3.6 mha was due to surface flooding and 2.6 mha had high water table. The commission suggested that: "Based on the depth of water table below ground level as an index, estimates of waterlogged area were prepared by various agencies. Of the total waterlogged area of 6 mha. 3.4 mha are subject to surface flooding, mostly in the states of West Bengal, Orissa, Andhra Pradesh, Punjab, Uttar Pradesh, Gujarat, Tamil Nadu, Kerala. The remaining 2.6 mha have high water table. In irrigated areas it is desirable to keep the average water table well beyond the capillary range, say, around 5 metres if not deeper. Apart from the risk of increasing soil salinity, a high water table is wasteful for groundwater resource as it contributes to unproductive evaporation. Also, a low water table provides more space for groundwater recharge during the rainy season and thus helps in increasing the groundwater resource. In the canal irrigated areas of flat plains of northern India, waterlogging occurs in about one million hectares. The problem of waterlogging is very serious mainly in the irrigated areas of Haryana, Punjab, Rajasthan and Uttar Pradesh. In Punjab and Haryana alone, the area thus affected through faulty irrigation is about 8 lakh hectares".

The report also says that waterlogged areas in Punjab were 1.6 mha in 1962 when the water table rose to its peak. Large scale drainage works were taken up as also sinking of shallow tubewells. The development of a ground water resources (conjunctive use) on the wake of the introduction of high yielding varieties of wheat helped a great deal in lowering the water table. Between 1966 and 1972, about 4 lakh tubewells were installed, which caused water table to go down steadily and bring improvement in the lands which were earlier affected.

After National Commission of Agriculture (1976), Govt. of India, Ministry of Water Resources constituted a Working Group in 1986 with following terms of reference.

i. To identify the problem areas affected by water logging/salinity/ alkalinity in existing irrigation projects in the country based on available data with different Ministries/Departments/Institutes.

ii. To undertake prioritisation of the problem areas and suggest adoption of suitable remedial measures for their reclamation.

iii. To suggest suitable priorities in future plan allocation for tackling the problem.

iv. The group will submit its report within six months.

The group submitted its report in 1991. It gave a set up of figures for area waterlogged which are given in Table 2. Recommendation made relate to drainage and efficient use of water and completely ignore the conjunctive use aspect.

Central Ground Water Board, Govt. of India also carried out for 1982 on the basis of water table depth of 2 metres the areas for different periods in the years. These are given in Table 3.

III. PRESENT STATUS OF WATERLOGGING

All the present estimates of waterlogged area relate to water table depths criteria and as such are not correct estimates. Crops have

Table 2: Extent of Waterlogged Area as estimated by various Agencies (in lakh hectares)

State	As per irrigation Commission (1972)	As per National Commission on Agriculture (1976)	As estimated by Ministry of Agriculture (1984 85)	As per estimation collected by CWC (due to rise in water table)
1	2	3	4	5
Andhra Pradesh	N.R	3.39	3.39	2.664
Assam	N.R	N.R	4.50	N.R
Bihar	N.R.	1.17	7.07	3.627
Gujarat	N.R	4.84	4.84	0.894
Haryana	6.5	6.20	6.20	2.30
Jammu & Kashmir	N.R	0.10	0.10	0.015
Karnataka	0.07	0.10	0.10	0.245
Kerala	N.R	0.61	0.61	0.116
Madhya Pradesh	0.57	0.57	0.57	0.043
Maharashtra	0.28	1.11	1.11	0.060
Orissa	N.R	0.60	0.60	1.963
Punjab	10.0	10.90	10.90	2.000
Rajasthan	3.48	3.48	3.48	1.795
Tamil Nadu	N.R	0.18	0.18	0.018
Uttar Pradesh	8.10	8.10	19.80	0.352
West Bengal	18.5	18.50	21.80	N.R
Delhi	N.R	0.01	0.01	N.R
Total	47.50	59.86	85.26	16.092
mha	4.75	6.00	8.53	1.61

N.R = Not Reported
(Source : Report of Working Group on problem identification in Irrigated Areas - 1991)

Table 3: Extent of area with water table within 2 m of ground surface in different months, during 1982

	Name of State	Depth to water table within 2 m (lakh ha)				
		Aug.	Nov.	Jan.	April	June
1.	Punjab	3.337	2.550	3.150	2.508	0.400
2.	Haryana	2.733	0.765	1.225	0.820	0.020
3.	Uttar Pradesh	41.643	17.260	7.230	3.513	4.142
4.	Bihar	9.700	7.275	1.995	1.785	2.150
5.	Rajasthan	4.970	2.705	1.422	1.238	0.185
6.	Gujarat	8.885	2.820	7.880	1.506	1.055
7.	Madhya Pradesh	142.283	7.316	1.980	0.288	0.136
8.	Karnataka	-	-	-	-	-
9.	Andhra Pradesh	20.000	22.350	18.530	7.250	7.270
10.	Maharashtra	19.136	12.540	3.616	2.732	13.940
11.	West Bengal	16.473	9.146	1.873	1.515	3.375
12.	Orissa	77.700	21.220	11.720	3.720	10.590
13.	Tamilnadu	3.07	5.315	12.510	0.510	-
14.	Kerala	0.014	0.014	0.010	0.014	0.014
15.	Delhi	-	-	-	-	-
16.	Jammu & Kashmir	0.100	0.775	0.581	1.780	1.180
17.	Assam	12.982	6.808	3.058	4.450	23.472
18.	Arunachal Pradesh	0.520	0.280	-	0.380	0.484
19.	Mizoram	-	-	-	-	-
20.	Manipur	-	-	-	-	-
21.	Meghalaya	-	0.372	0.440	0.568	0.685
	Grand Total	363.602	119.51	77.212	34.225	69.099

(Source: Central Ground Water Board)

different tolerance to water logging. Wheat and sugarcane are affected when the watertable is within 0.6 metre, maize, bajra and cotton are sensitive to water table within 1.2 metre and gram and barley within 0.9 metre. For rice it is zero. For example in case of Sarda Sahayak Project, different concepts and agencies gave vastly differing figures given in Table 4.

In this case author has also the opportunity to see the situation physically and it was noticed that water logging is confined to about 1 km on either side of main canal and branches in filling reaches. It may be stated here that drainage conjusted areas and low wet lands should not be confused with waterlogging due to canals. In a similar case of Tawa irrigation command area, it was seen that physical condition show a very small extent of actual waterlogging compared to figures working out on the basis of water table depth contour. Similarly in case of North west area of country comprising Punjab, Haryana and Rajasthan, water table depth criteria show an extent of 2.9 lakh ha area waterlogged even though in Punjab & Haryana large scale conjunctive use is there. All these factual examples strongly suggest that:

1. Waterlogging definition should be changed from waterlogged depth concept to crop concept. The area should be termed as water logged only if it is not able to grow any crop through out the year.

2. There should be field to field survey of the extent of area waterlogged in all major-irrigation project commands. This is not difficult or costly. Most of the states have

Table 4 : Total area affected by water as given by various organisations for Sarda Sahayak Project, U.P.

	Name of Organisation	Area reported to have gone out of Rabi cultivation/Waterlogged in hectares	
1.	Irrigation Dept., UP	7418	Out of Rabi cultivation as in Nov. 1983
2.	District/Revnue Authorities	16156	"
3.	Ground Water Investigation Organisation UP	31371	Waterlogged
4.	Sarda Sahayak Command Area Development	69642	"
5.	Remote Sensing Application Centre, Lucknow	35226	"
6.	Central Ground Water Board	422700	Area having water level less than 2m in November 1983

(Source : Report of Working Group to study waterlogging problem in Sarda Sahayak Canal Command, U.P., Ministry of Irrigation, Govt. of India.)

a system of charging water rates for area irrigated. The official recording of area for water rates should be given some honorarium to note the field numerous which are actively water logged. Thus, infact, there should be some sort of census of waterlogged lands in India.

3. There is no recent or survey available of the extent of conjunctive use of groundwater in the commands of surface water irrigation projects. This is essentially required to know the effect on waterlogging through conjunctive use.

IV. MEASURES TO PREVENT AND CONTROL WATERLOGGING

1. Irrigation Commission (1972) has made the following recommendations:

   - Improvement of drainage as the most effective answer to water logging is a properly designed drainage system. Greater attention need to be paid to this item.

   - Construction of Field Drains, in area waterlogged or prone to water logging, field drains to drain individual fields will be necessary. But as their construction and maintenance is to be done by farmers, technical advice has to be given to farmers which should be done after research and experiments have been carried out in this respect.

   - Borrow Pits: Indiscrimate excavation of barrow pits should not be allowed for excavation of canals, roads, and rail embankments.

   - Use of Ground Water for Irrigation (Conjunctive Use) : Adequate provision for such use should be done in the planning of new projects, because it helps to keep waterlogging under control. Farmers should also be encouraged to dig wells and sink shallow tubewells, for which necessary technical and financial assistance should be given.

   - Lining of Canals: If lining is done at the initial stage, it will cost less and help to keep waterlogging in control in the areas susceptible to waterlogging.

- Crop Pattern: In areas susceptible to waterlogging, it will be desirable to introduce only those crops which need light irrigation.

- Water Management: Land shaping is necessary to prevent the accumulation of water in the fields. Sound water management methods should be demonstrated and introduced right from the time that irrigation commences. This will not only lead to economy in the use of water but also avoid the danger of water logging.

- Post Irrigation Observations: The behaviour of ground water levels after the introduction of irrigation has to be studied, alongwith quality of groundwater. A continuous rise in the water table should be viewed seriously and investigated and suitable remedial measures taken.

2. Agricultural Commission (1976) has recommended following Anti-Waterlogging Measures.

i) Experience of the past 70-80 years in regard to waterlogging prevailing in the Indo-Gangetic plains caused either by monsoon rains and/or irrigation suggests following methods of remedy, used singly or in combination according to the situation, these are:

a) Drainage - either surface or sub-surface or both to remove surplus water

b) Lining of canals - to prevent seepage and rise of water table

c) Sinking tubewells and utilising water for irrigation, lowering water table and augmenting recharge of ground water.

d) Connecting, where posible high water table tracts with low water table tracts.

e) Combination of measures such as drains and tubewells can effectively eradicate waterlogging. Actually drains should be designed as drainage cum irrigation channel to use drainage water.

f) Even inspite of taking all the necessary anti waterlogging measures, there would still be areas which remain waterlogged and are liable to flooding. These areas should be identified and for their economic, exploitation should be brought under suitable crops avoiding flood periods.

3. Working Group on Problem Identification in Irrigated Areas with suggested Remedial Measures (Dec. 1991), made following recommendations:

i) In view of lack of proper infrastructure in the country both at the state and centre level to deal with the problems related to water logging and salinity, there should be a three tier organisational set up for the purpose.

ii) Since construction of drainage possible network is a costly proposition, as far as possible preventive measures should be initiated in all the major and medium irrigation projects at the very beginning of the commissioning of the project like Command Area Development (CAD) approach, effective water management etc.

iii) Correction of system deficiency : To increase the irrigation efficiency, the irrigation network must be in a proper condition with proper and adequate measuring and control structures, proper maintenances and lining in vulnerable reaches.

iv) Monitoring of Ground Water level and Excess Salt Concentration.

v) The Irrigation Department should be made responsible for maintenance of conducive soil environment for proper growth for which proper preventive measures may be planned, executed in advance.

vi) Water utilisation should be given more importance even if it means slowing down the construction of new works. There is a need to have the cadre of Water Utilisation Experts.

vii) There is a need to have the proper discipline in the irrigation management among the farmers.

viii) To avoid the use of excess water to the crops, water supply should be made through volumetric system at least at the Govt. outlet level.

ix) The water utilisation and operation of the canal network should find dueplace in the academic course of the Engineering Institutes and Agricultural Universities so that the students could be tought from the vary beginning the importance of scientific water utilisation.

x) Funds have been constants in the past, they should be earmarked. A centrally sponsored scheme for irrigation projects should be initiated for the purpose.

xi) Since there are the gigantic problems, a full fledged committee of experts is recommended to tackle and decide the organisational structure in the country for these areas, in the irrigation projects and outside the irrigation commands for suggesting Anti Waterlogging Measures.

A perusal of above recommendation would indicate that these are either repetition of recommendations made by Irrigation Commission and Agriculture Commission earlier or totally not relevant to problem of water logging but to the irrigation sector as a whole, already manifest in Command Area Development programme being implemented in more than major medium irrigation projects in the country.

V. ANTI WATERLOGGING MEASURES

The most effective measures to prevent, check and remove water logging are:

i) Drainage
ii) Conjunctive Use of Groundwater
iii) Improvement in Irrigation Water Application
iv) Efficient Irrigation Water Management

The drainage whether surface or sub surface if designed and constructed properly, and maintained adequately, is the most effective method to remove the excess water from the fields and maintain the health of root zone. But it is costly to construct the drainage and most difficult to maintain it in proper shape so that it is able to perform its function. For construction sometimes finance are available like World Bank loan assistance to construct drainage in 1,67,00 hectares of Rajasthan Chambal command area but for maintenance it is rather impossible. Moreover whatever little money is available for maintenance it becomes insignificant due to an adequate supervision and inspection of drainage channels by the project staff. The result has been that drainage constructed in Rajasthan Chambal Command Area deteriorated as year after year passed after construction. In so many projects like Sarda Sahayak, Gandak in U.P., Ghataprabha Malaprabha, Tungabhadra in Karnataka, Nagarjunasagar, Sriramsagar in Andhra Pradesh, Gandak in Bihar, Ukai, Kakrapur, Mahi, Kadana in Gujarat, Jayakwadi in Maharashtra etc. no effective drainage network could be provided so far. And finally to sum up, it can be said that in no major irrigation project of country effective drainage network is in operation.

Similarly for bringing improvement in Irrigation Water Application efficiency, elaborate and high sounding programme like National Water Management Programme (NWMP), development of Institution of Water and Land Management (WALMI) have been taken up with World Bank assistance, under USAID and centrally sponsored scheme of command area development but effective improvement has not been noticed although good results have been reported in case of pilot studies.

Lastly Conjunctive Use is the most effective practical and economical method for prevention, control and removal of waterlogging and as such it is discussed in more details:

VI CONJUNCTIVE USE

As already defined judicious use of Surface Water and Ground Water in any area maintaining watertable at a depth adequate to keep the health of soil in good condition and to have maximum yield, so as to keep away waterlogging and salinity from the land, is called Conjunctive Use.

Examples of Conjunctive Use:

The first planned conjunctive use for removal of waterlogging was in the Punjab province of Pakistan. The area selected was

Central Rachna Doab comprising 1.2 million acres of land. Before the construction of perennial canals in 1892, the general direction of ground water movement was from the rivers downstream and towards the central axes of doab. The water table reached depth of more than 100 feet below ground level near the centre of Rachna doab. After introduction of irrigation, the water table rising gradually and in about 70 years it rose to 80 feet (1959) and in 50% area of Rachna doab, water table was between 0 to 10 feet below ground level. It was observed that out of 1,140,676 acres of culturable area, 425,000 acres (37%) had wholly or partially gone out of cultivation. As a measure of planned conjunctive use, about 2000 deep tubewells were constructed with capacity of 2 to 5 cusec and depth of drilling varying from 225 to 360 ft. Original water depth was 3 to 6 ft which declined to 8 feet 3 inch after 5 years of pumping. However these tubewell started giving trouble and it was noticed that within a short period of 4 years problem of incrustation, corrosion, fall in discharge arose. Ultimately installation of shallow tubewells in large number could come to rescue in controlling the problem of water logging. In 1964 when the ground water development stated, number of shallow tubewell was 23,140 which increased to 2,42,160 by 1986.

In India ground water development as a conjunctive use is taking place as a supplementary source of water in canal commands, tank commands and the commands of deep tubewells by installation of shallow tubewell in their command area. A census of Minor Irrigation (1987) was carried out all over India, it revealed the extent of this supplementary irrigation by ground water as follows:

Above ground water development has helped to keep in check the waterlogging problem.

Conjunctive Use in CAD Projects

CAD Authorities are working since 1973-74 in various states. Although conjunctive use is one of the main objective under CAD, no serious efforts have been made to know the status of conjunctive use in commands of these major-medium irrigation projects. Author using districtwise Major irrigation census data has made an effort in this direction. The results obtained are given in Table 5, which would indicate that large number of GW structures are doing supplemental irrigation in these CAD Projects, which in turn helps to keep waterlogging problem in check.

Table 5: Supplemental Irrigation by Ground Water in Surface Water Irrigation commands

Area in 1000 ha

Name of State	Utilised potential of SW projects	Area under supplemental irrigation by GW	Percentage
Andhra Pradesh	3091	12	0.4
Gujarat	873	33	4.1
Haryana	1785	400	22.1
Karnataka	1188	42	3.5
Madhya Pradesh	1403	120	8.6
Maharashtra	935	365	39.0
Punjab	2498	1056	42.3
Tamil Nadu	1245	250	20.0
Uttar Pradesh	5703	986	17.3
West Bengal	1524	145	9.5

Status of Conjunctive Use in Tank Irrigation

Irrigation through surface water tanks plays an important role in Southern States particularly those of A.P., Karnataka, Maharashtra and Tamilnadu. According to M.I. Census (1987) there are about 500,000 tanks doing irrigation in the country. To meet the inadequacy of water in these tanks, farmers have gone for large scale G.W. extraction structures in the registered ayacut of these tanks. No data in this respect is available vide Table 6. However, in case of Tamilnadu some data has been collected for tanks modernised under externally aided projects. For some tanks the details are given in Table 7.

A study of above table would reveal that command area being irrigated both by tanks and wells varies from 9.5% to 43.5%.

VII CONJUNCTIVE USE MODELLING

In any area which has already been waterlogged or has become prone to waterlogging, for brining down the water table to safe level, the number of tubewells, type of tubewells whether shallow or deep, spacing, time and duration of pumping has to be decided. It is very difficult to undertake this exercise through conventional methods, recourse will have to be taken to mathematical modelling techniques using computers having large memory.

There are two types of models used for groundwater simulation: (1) lumped model, (ii) distributed model.

i) Lumped Model

In the lumped model the basin is treated as one unit and the water balance equation is evolved for the basin. The equation can be written as:

Inflow - Outflow = storage change.

Here, Inflow = $R_r+R_c+R_i+I+S_i$

Outflow = $S_c+O+T_p+E_t$

Storage change = ΔS.

where

R_r = Recharge to groundwater from rainfall

R_c = Recharge from canal seepage

R_i = Recharge from irrigation water

I = Inflow into the basin from adjoining basins

S_i = Influent seepage from streams

S_c = Effluent seepage from streams

O = Outflow from the basin to other basins

E_t = Evapotranspiration from the region in direct contact with the aquifer

T_p = Pumpage of groundwater

ΔS = Change in storage of the aquifer.

This balance equation is solved for the whole basin region assuming it to be one unit and computing various elements of inflow and outflow. The solution of this equation on lumped basis involves inaccuracy and may not be used for aquifer simulation.

ii) Distributed Model

To know the detailed picture of the groundwater levels with respect to time and space, the groundwater flow equation is solved throughout the basin. The equation is given as :

$$\frac{\partial}{\partial x}\left(T_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_y \frac{\partial h}{\partial y}\right) + Q = S \frac{\partial h}{\partial t}$$

where

h = head of water (L)

Q = Flux (L^3)

S = Storativity

T_x & T_y = Transmissivity (L^2/T) in X and Y direction respectively.

There are several methods to solve the above equation in the basin with defined boundary conditions. These methods can broadly be categorized as: (1) analogue models and, (ii) mathematical models.

1) Analogue Model

The most commonly used analogue model is the Resistance Capacitor (R.C) network model.

Table 6 : Status of Conjunctive Use in Some Major Irrigation Projects

S.No.	Name of Project	C.C.A. in ha	Ultimate Potential in ha	Nos. of G.W. Dugwells	Structures Command Shallow Tubewells	Potential created by G.W. in ha.	GW development as percent of Ultimate Potential by S.W.
	ANDHRA PRADESH						
1.	Nagarjunasagar	8,95,000	8,95,000	1,45,704	19.992	2,25,672	25.2%
	GUJARAT						
2.	Mahi	2,00,000	2,74,490	1,41,602	702	1,44,410	52.6%
3.	Ukai-Kakrapar	3,48,000	3,80,910	73,191	1866	80,658	21.2%
	HARYANA						
4.	J.L.N. Lift Canal	2,50,000	1,55,000	26,459	41,128	1,00,971	65.1%
	JAMMU & KASHMIR						
5.	Tawi Lift Irrigation	12,880	17,980	51	712	2,899	15.6%
	KARNATAKA						
6.	Ghataprabha	3,17,430	3,17,430	90,900	4,430	1,08,380	34.1%
7.	Malaprabha	2,14,980	2,14,980	98,768	9,426	1,36,380	63.4%
8.	Tungabhadra	5,29,000	3,49,100	23,557	1,736	30,381	8.7%
9.	Upper Krishna	4,24,910	4,24,910	55,585	850	58,985	13.9%
	MADHYA PRADESH						
10.	Chambal	2,20,000	2,73,200	25,990	292	27,158	9.9%
11.	Tawa	2,47,000	3,33,000	15,699	770	18,770	5.6%
	MAHARASHTRA						
12.	Jayakwadi	2,27,200	2,27,200	2,66,375	408	2,68,007	118.0%
13.	Puna	61,500	57,300	58,363	761	61,407	107.2%
14.	Krishna	74,000	1,11,720	1,10,343	57	1,10,571	99.0%
	ORISSA						
15.	Hirakud	1,53,240	2,51,150	64,979	1	64,983	25.9%
16.	Mahanadi	1,79,410	3,00,100	27,205	3,030	28,125	9.4%
	UTTAR PRADESH						
17.	Gandak	4,11,000	3,08,000	13,251	1,01,899	4,18,350	135.8%
18.	Ramganga	18,97,000	13,72,000	39,650	3,22,515	13,29,710	96.9%
19.	Sarda Sahayak	20,00,000	19,23,000	40,669	4,18,359	17,14,005	89.1%
	WEST BENGAL						
20.	D.V.C.	3,91,970	5,15,000	8,503	73,561	2,92,717	56.8%
21.	Kangsabati	3,49,750	4,01,460	34,440	80,303	3,55,652	88.6%
22.	Mauyu Rakshi	2,26,630	2,50,860	1,104	1,04,407	2,18,832	87.2%

NOTE:

1. The figures for G.W. structures have been taken from M.I. Census (1987) on districtwise basis for this purpose whole district has been assumed in the command.

2. Irrigation potential created by G.W. structures has been estimated on the basis of the 1 ha for wells and 4 ha for shallow tubewells.

Table 7: STATUS OF CONJUNCTIVE USE IN SOME TANK PROJECTS OF TAMILNADU

(Area in ha)

S.No.	Name of Tank	Taluk/ District	Registered Ayacut (command)	Irrigation Area	Irrigated by Tank only	No. of Wells	Area ha	Percentage of Well Irrigation
1.	Latheri	Gudlyatham North Arcot	118.74	115.65	8.56	67	50.58	43.7%
2.	Samudram	Thrumayam Puddu Kottal	124.315	101.89	82.29	36	17.61	13.3%
3.	Periyurkulam	Sankaran Koil Tirunelvdi	196.770	156.230	105.666	90	48.064	31.1%
4.	Aliyalmangalam	Pohar-Tiru-vanna malai	112.88	93.06	70.80	78	22.26	23.9%
5.	Periasadayareri	Sivagiri Tirunelveli	161.29	129.80	99.02	56	30.78	23.7%
6.	Velur	Kulathar Pudukkotkai	131.20	105.32	95.32	81	10.00	9.5%
7.	Manalur Periyakulan	Sanakaran Koil Trinunelvi	110.67	92.73	63.390	40	29.34	81.6%
8.	Annamputhur	Tindivanam South Arcot	107.12	88.09	72.245	24	8.845	10.1%

The model consists of regular array of resistors and capacitors. The registors are inversely proportional to the hydraulic conductivity of the aquifer and capacitors store electrostatic energy in a manner analogus to the storage of water within aquifer. The electrical network is a sealed down version of the aquifer.

2) Mathematical Model

A mathematical groundwater model is a mathematical expression or a group of expressions that describes the aquifer functioning. These models are applied to specific aquifers using specific aquifer coefficients and boundary conditions. The boundary condition describe the hydraulic conditions and the geometric conditions of the boundaries of aquifers and their variation with time. These models mostly use finite difference, finite element technique for obtaining numerical solution.

Conjunctive Use Model for North West Region

In this region comprising part of Punjab, Haryana and Ganganagar there are large areas waterlogged due to poor quality of groundwater with limited exploitation and inadequate surface drainage, creating conditions of waterlogging and salinity in several areas. Waterlogged areas includes areas in the district of Hissar, Sirsa, Jind, Bhiwani, Rohtak, in Haryana and districts of Ferozpur, Faridkot, Bhatinda, Sangrur in Punjab and Sriganganagar in Rajasthan. The canal system in the area are (a) Bhakra Canal System (ii) Western Yamuna Canal, Gang Canal and Indira Gandhi Canal. A small part of area drain into Yamuna (Ganga Basin) and rest drains through Ghaggar and Sutlej (Indus basin). Earlier in a UNDP study carried out for Central Ground Water Board a two dimensional model was prepared for Ghaggar basin. The flow eqautions was solved through a finite difference approach. This model was modified for this region to calculate depth to groundwater and to allow percentage variations of input data of each mode independently. The model has been validated using input data for 1977-89 situation. The results were compared with actual observed data of water for this period. The critical areas, those corresponds to water table depth of 3 meter were taken. Water logged area was taken with depth upto 1.5 m, and critical areas with depth upto 3 metres below ground level.

The present scenerio and future as predicted by model are given in Table 8.

Table 8 : Ground Water Regime present and projected in some districts of Haryana, Punjab and Rajasthan.

S.No.	District	Waterlogged area (1989)	Critical areas (1989)	Critical areas (2000)	Area in ha
	Haryana				
1.	Jind	121 (76)	434	-	124300
2.	Sonepat	- (10)	102	-	-
3.	Rohtak	2 (13)	67	-	37000
4.	Hissar	74 (53)	276	-	249600
5.	Sirsa	49 (96)	186	-	133200
6.	Bhiwani	- -	-	-	-
	Punjab				
7.	Ferozpur	130 (234)	528	-	231400
8.	Faridkot	215 (360)	792	-	201600
9.	Bhatinda	- (89)	46	-	88400
	Rajasthan				
10.	Sriganga-	170 (NA)	498	-	181600
		760 -	2932	-	1336200

(Source: North West Drainage Project Report - WAPCOS, 1993)
(Figure in brackets indicates the average extent of waterlogged area.

This clearly shows that if no drainage or conjunctive use measures to pinpoint the surplus drainable groundwater are taken the waterlogging problem will increase very fast.

Linear Programming Model for Conjunctive use

For a major irrigation project, this simple technique can be used to work out the weekly/fortnightly/monthly surface water release and ground water pumping in the command area, so that both the surface and ground water is utilised fully and there is no water logging. The objective function in such a case would be:

Maximise Z =

$$\sum_{j=1}^{n} (P_j . q_j - C_j)\ A_j - P.\ L - C_1\ .\ L - C_o\ .S/\mu$$

$$- C_y\ .\ Y - C_m\ .\ M - C_z\ .Z - \sum_{i=1}^{m} C_s . S_1$$

where,

Pj = market price of jth crop in Rs/Kg.

q_j = average yield of jth crop in kg/hec.

C_j = cost of production of jth crop in Rs./hect.

A_j = area under the jth crop in hect.

P = average economic value of production for unirrigated land in Rs/hect.

L = area to be irrigated in hec.

C_1 = Annual cost and maintenance expenses of land preparation is Rs./hect.

C_y = Annual cost and maintenance expenses of canal system in Rs/hect.

C_z = Annual cost and expenses of surface drainage

C_o = Annual cost and maintenance expenses of tubewells in Rs/cumec.

C_m = Annual cost of dam in Rs/hec.m.

C_s = Unit power cost of well operation in Rs/ha.m.

S = Total delivery capacity of tubewells in cumecs.

μ = Capacity of individual tubewell in cumecs.

Y = Delivery capacity of canal system in cumecs

M = Useful storage reservoir capacity in ha.m.

Z = Total capacity of surface drainage works in cumecs.

S_i = Amount of tubewell water supplied in ith period in ha.m.

The objective function is to be maximised subject to the following constraints:

i) Crop area in Rabi and Kharif should not exceed the total area

$$\sum_{i=1}^{n} A_j \leq \text{Total area in Rabi}$$

$$\sum_{i=1}^{n'} A_j \leq \text{Total area in Kharif}$$

Where, n and n' are the number of crops in Rabi and Kharif respectively.

ii) Crop water requirements must be met

$$\sum_{i=1}^{m} \sum_{j=1}^{(n+n')} S_j A_j \leq \sum_{i=1}^{n} (Y_1+S_1) + Y'_1$$

Where m is the number of decision periods in an year, S_j is the depth of water in metres required for the jth crop, Y_i, S_i, Y_i are the releases in the ith decision period from storage reservoir, ground water reservoir and existing canal respectively.

iii) Total releases from the storage should not exceed the storage capacity of the reservoir.

$$\sum_{i=1}^{m} Y_i \leq \text{Storage capacity}$$

iv) Release from wells and tubewells not to exceed the total availability of groundwater.

$$\sum_{i=1}^{m} S_i \leq \text{Ground water potential of the area.}$$

v) Periodic maximum releases from the wells and tubewells not to exceed their capacity

$$S_i \leq \text{Maximum capacity for the ith period.}$$

vi) Area under each crop not to be less than the present area and not to exceed the maximum allowable area.

$$\text{Present Area} \leq A_j \leq \text{Maximum Allowable Area}$$

Crops can be considered and set of equations can be solved using as many as possible fast computer with large memory.

IX CONCLUSIONS

1. It is proved beyond doubt that for control and removal of waterlogging in any area conjunctive use of ground water with surface water is most effective solutions provided that ground water quality is suitable for crop production. In all future surface water irrigation projects to check the twin problem of waterlogging and subsequent salinity, the conjunctive use of groundwater should be included at the planning stage itself.

2. There should be a close and regular monitoring of water table in all the irrigated areas to know groundwater behaviour. Based on this monitoring the groundwater response models of aquifer system should be prepared and kept up date.

3. The irrigation water rate for surface water are negligible compared to groundwater. This acts as a big deterrent for conjunctive use. Rationalisation of irrigation water rates is to be done as quickly as possible by state governments.

4. Groundwater development in private sector should be implemented in a scientific planned manner, so that it is effective as a conjunctive use measure for control and prevention of water logging specially in canal irrigated areas.

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