STATE OF ART REPORT

Scientific Contribution
No.:INCOH/SAR-23/2000

CONJUNCTIVE USE OF SURFACE AND GROUND WATER

R.S. Saksena

INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247 667, INDIA

May, 2000

INDIAN NATIONAL COMMITTEE ON HYDROLOGY
(Committee Constituted by Minsitry of Water Resources, Govt. of India)

Scientific Contribution
No.:INCOH/SAR-23/2000

CONJUNCTIVE USE OF SURFACE AND GROUND WATER

R.S. Saksena
Chief Engineers (MI) (Retd.)
Ministry of Water Resources
Government of India

INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247 667, INDIA

May, 2000

The presentation of material throughout the publication does not imply the expression of any opinion whatsoever on the part of Indian National Committee on Hydrology (INCOH) or the publishers.

Published by :

Dr. K.K.S. Bhatia
Member Secretary, INCOH &
Scientist F
National Institute of Hydrology
Roorkee - 247 667, India

Printed by :

Ajay Printers & Publishers
19, Civil LInes (Centenary Gate),
Roorkee - 247 667 (India)
Phone : 01332-73140, 74740
Fax : 01332-74740

PREAMBLE

The water is one of the important natural resource available to mankind. Wtih the increasing pressure for rising population, there is a growing need for finding, developing and maintaining suitable water supply and for proper management of this natural resource. Water as a resource is available as surface water and ground water.

For an integrated planning of water resources both surface water and ground water have to be developed conjunctively. Both these represent two phases of occurrence of the total water potential of the basin and any intervention in one phase affects the other. The development of water resources has to be undertaken through integrated river basin development programmes.

In recent years, considerable interest has been generated regarding optimum and efficient utilization of the country's water resources for the benefit of entire nation, over-riding narrow regional considerations. A large number of rivers in the country are interestate in character and as such a national view is as necessary in planning, development and management of river basins. By adopting improved methodology of basin-wise development, by creation of additional storage reservoirs, conjunctive use of surface and ground water and by inter basin transfer of surplus water to needy areas, it is possible to an additional irrigation potential of 35 to 37 million hectares. As there is hardly any scope to increase the cultivated areas, as such conservation and efficient utilization for various purposes through storage reservoirs, conjunctive use and water transfer system have assumed importance.

The Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The committee is also effectively participating in the activities of Unesco and is the National Committee for International Hydrological Programme (IHP of Unesco. In pursuance of its objective of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the committee invites experts in the country of prepare these reports on important areas of hydrology.

The Indian National Committee on Hydrology with the assistance of its erstwhile Panel has identified this important topic for preparation of this state-of-art report and the report has been prepared by Saxena, Former, Investigation Department, UP and presently a consultant. The guidance, assistance and review etc. provided by the Panel are worth mentioning. The report has been finalised by Dr. K.K.S. Bhatia, Member Secretary and Sri R. Mehrotra, Scientist in charge of the Indian National Committee on Hydrology.

This state of art-report describes in detail the present status of conjunctive use of surface water of ground water and suggests recommendations for future. It is hoped that this report would serve as a useful reference material to practicing engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilization of the water resources of the country.

(S.M. Seth)
Director

(S.M. Seth)
Executive Member, INCOH
& Director, NIH
Roorkee

Table of Contents

ABBREVIATIONS

abc	:	Ambah Branch Canal
A.T.	:	Augmentation Tubewell
CAD	:	Command Area Development
CGWB	:	Central Ground Water Board
CWC	:	Central Water Commission
Cfs	:	Cubic Foot per Second
Cm	:	Centimetre
d	:	day
dia	:	diameter
EEC	:	European Economic Commission
GW	:	Ground Water
ha	:	hectare
ID	:	Irrigation Department
lps	:	litre per second
m	:	metre
m/day	:	metre per day.
m^2day	:	Square metre per day.
m^3day	:	Cubic metre per day.
m ha	:	million hectare
NABARD	:	National Bank for Agriculture and Rural Development
SW	:	Surface Water
SGWO	:	State Ground Water Organisation
TW	:	Tubewell.

INTRODUCTION

India having a geographical areas of 329 m.ha and supporting a population of one billion (2000) is a land of climatic contrasts. The season and weather conditions range from extreme cold to dry spell to extreme humidity and from drought conditions to torrential rains and floods. The rain takes place largely during the monsoon season, but of about 1200 mm of annual average rainfall, 80% is recorded in four months from June to September and the remaining 20% during the winter months. If, for certain reasons, monsoon is too much late or if it is not evenly distributed over rainy season, or if the rainfall is to little or too much, then the whole agriculture sector is put in a tight corner. To ensure against the risk of vagaries of rainfall, irrigation has to be provided through systematic means. Rainfall has to be stored as much as possible, and the portion of it which percolates below ground has to be pumped out in a planned and scientific manner. Water flowing in the rivers the year round can also be diverted or lifted for irrigation. Thus, irrigation is provided by tanks, canals, wells and tube-wells. Each of these means of irrigation has its own role and uses in various regions of the country and it is well advised to develop in a planned and scientific manner the type of irrigation in a region for which it is most suited. It is only by developing assured and regular irrigation facilities so as to protect the country side from economic disasters and develop the agriculture which is the backbone of the ecnomy. Both surface and groundwater resources are being used for irrigation purposes. It is reported that by end of 1996-97, an irrigation potential of 89.44 m.ha. has been made available out of which 38.84 m.ha. is through Ground Water Development. Presently, however, ground water irrigation is contributing about 1.4 m.ha. of additional irrigation potential against 1.1 m.ha. from surface water. The Utilimate water resource avialble for irrigation is officially reported as 73 m.ha. for Surface Water and 40 m.ha. for Ground Water. However, Central Ground Water Board (CGWB) has tentatively revised the figure for ground water as 64 m.ha. (Refer "Ground Water Resource' of India" by CGWB 1995).

The planning of two resources viz. surface and ground water is done separately and in an isolated way. The agency, organisation and implementation of two programmes is quite separate. However, inadequacy of irrigation water to meet the need of farmers in space and time has lead to large scale utilisation of ground water through wells and tube-wells in the command of irrigation projects. And so the conjuctive use becomes a necessity. Nevertheless some efforts have been made to utilise ground water in conjunction with surface water. This paper describes in detail the present status and gives recommendations for future for the conjuctive use of surface and ground waters.

DEFINITIONS

GROSS COMMAND AREA (G.C.A.)

It is the total area which can be physically irrigated from a scheme without considering the limitation of the quantity of water available.

TURABLE COMMANDED AREA (C.C.A.)

It is the gross command area, less the area of unculturable land (including habitation areas, ponds and land otherwise unfit for cultivation) included in the gross area.

INTENSITY OF IRRIGATION

The sum total of the area irrigated under different crops in a year expressed as a percentage of the C.C.A. is called the intensity of irrigation.

NET IRRIGATED AREA

This is the area irrigated during a year, counting the area only once even if two or more corps are irrigated on the same land.

GROSS IRRIGATED AREA

This is the total irrigated area under various crops during a year, counting the area irrigated under more than one crop during the same year as many times as the number of crops grown.

INTENSITY OF IRRIGATED CROPPING

The ratio of the difference of the gross irrigated area and net irrigated area to the net irrigated areas expressed as a percentage is called intensity of irrigated cropping.

ULTIMATE IRRIGATION POTENTIAL

The ultimate irrigation potential is the gross area that can be irrigated from a project in a design year for the projected cropping pattern and assumed water allowance on its full development. The gross irrigated area will be the aggregate of the areas irrigated in the different crop seasons the areas under two seasonal and perennial crops being counted only once in the year.

IRRIGATION POTENTIAL CREATED

The irrigation potential created by a project at a given time during of after its construction is the aggregate gross area that can be irrigated annually by the quantity of water that could be made available by all the connected and completed works upto the end of the water courses or the last point in the water delivery system upto which the Government is responsible for construction.

IRRIGATION POTENTIAL UTILISED

The irrigation potential utilised is the total gross area actually irrigated by a project during the year under consideration. the figures relating to the stabilisation of old areas should be furnished separately in this case also since these will not be additive to the gross area irrigated.

MAJOR IRRIGATION PROJECTS

All irrigation projects which have a culturable area commanded (CCA) more than 10,000 ha.

MEDIUM IRRIGATION PROJECTS

All irrigation project having CCA more than 2000 ha but less than 10,000 ha.

MINOR IRRIGATION PROJECTS

All projects having CCA less than 2000 ha. All Ground Water Development is under Minor Irrigation Sector.

CONJUCTIVE USE OF SURFACE AND GROUND WATER

This specifies not merely development of ground water 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 the variability of each, considering total river basins or even their interlinkages and the economics of development and transportation of the total water resources to satisfy the multifarious and often conflicting demands with due consideration of socio-economic technological considerations.

LAND AND WATER RESOURCES

LAND RESOURCES

According to Land Utilisation of statistics for 1994-95, the land classification is as follows :

		Million ha
1.	Geographical are...	328.73
2.	Reported Area for land utilisation Statics...	304.58
3.	Forests...	68.39
4.	Area of unculturable land...	18.77
5.	Area put to Non-Agricultural use...	22.51
6.	Permanent Pastures and other grazing lands...	11.24
7.	Land under misc. crops & groves not included in net area sown...	3.63
8.	Culturable waste land...	14.21
9.	Fallow land...	23.30
10.	Net Area Sown...	142.82
11.	Total cropped Area...	188.15
12.	Net irrigated Area...	53.00
13.	Gross irrigated Area...	70.64

The Soil Conservation Wing of Department of Agriculture, Ministry of Agriculture has indicated that there is about 47.55 million ha. of degraded land on which restorative activities can be taken up immediately.

Degraded lands	Million ha
Water logged areas...	8.53
Ravine & gullied land...	3.97
Alkali Soil...	3.58
Saline Sandy Areas...	5.50
Total...	**21.58**

Degraded lands	Million ha
Net Properly Used Land	
Culturable waste land..	16.41
Fallows other than current fallows...............................	9.56
Grand Total..	**47.55**

It may also be pointed out that there is hardly any increase in Net area sown as would be revealed from following figures:

Year	Net Areas shown in m.ha
1980-81	140.00
1989-90	142.34
1994-95	142.82

This also indicates that programe for reclaiming waste and has not made little dent because whatever may be increase in net area shown, it has been offset by increased urbanisation. It can be concluded that non-expandable land resources have to accommodate the competing demands of agricultural and non-agricultural use. Whereas in 1951 per capita availability of land was 0.94 ha.

Larger part of the country has a monsoon type of climate. The rainy season generally runs from June not September. The rainfall varies from 400 mm to 3000 mm during the monsoon, the country average being about 1200 mm. Rainfall in the remaining part of the year is negligible in greater part of the country. Depth of Rainfall is not an accurate indicator for secured rainfed farming. Dry spells often do occur during the monsoon and there are drought years when there is scanty rainfall.

To meet the ever increasing demand for food, fodder, fibre and fuel, production will have to expand. In view of limited availability of land resources, vertical expansion is imperative. Land has to be used and managed more efficiently and intensively. At the same time to overcome the vagaries of climate, application of irrigation water is essential for increased agricultural production.

Conjunctive Use of Surface and Ground Water

WATER RESOURCES

According to National Commission on Agriculture, the total precipitation is 400 million hectare metre. Out of this 115 m.ha.m. is the surface water and 50 m.ha.m. is the ground water. 20 m.ha.m. of surface water has been shown as flow from outside India and thus the total annual basic water resources of the country has been estimated as 185 m.ha.m. Ultimate usable potential for irrigation is 70 m.ha.m. for surface water and 26 m.ha.m. for ground water. The area figure being adopted by Planning Commission so far are :

Ultimate Irrigation Potential

1.	Surface Water-Major-Medium Irrigation	=	58 m.ha.
2.	Surface Water-Minor Irrigation	=	15 m.ha.
	Total	=	**73 m.ha.**
3.	Ground Water	=	40 m.ha.
	Grand Total	=	**113 m.ha**

The basin wise surface water flow as assessed by different agencies and compiled by CWC (!987) comes to as follows :

Average Annual Flow	=	1801.123 km^3 (180 m.ha.m.)
Utilisable Flow	=	684.1 km^3 (68.4 m.ha.m.)

Details are given in **Appendix I**

In case of Minor Irrigation, Ministry of Water Resources has indicated a revised figure of 64 m.ha. for ground water. A state wise estimate of the Ground Water Potential is given in **Appendix II.**

PHYSIOGRAPHIC AND HYDROGEOLOGICAL DIVISIONS

India has seven distinct physiographical divisions viz; (1) The Northern Mountains (2) The Great Plains (3) The Central Highlands (4) The Peninsular Plateau (5) the East Coast Belt (6) The West Coast Belt and (7) The Islands.

The Himalayan range, 2500 km in length and 250-400 km in width, with a mean elevation of 6000 meters in the Central axial range, is the dominant geographical feature of India. It is a complex of several parallel and converging ranges intersected by a number of valleys and plateaus. The location of the great Himalayas has an important role in the water resources of India. From the Pamirs in the North-West to the tri-junction of India. China and Burma (now MYANMAR) in the East, the great Himalayan range is drained by a multitude of streams and river. The great Indo-Gangetic plains have been built up in the west by the Indus and its tributaries, and in the Centre and East by the Ganga and its tributaries. The Central Highlands lie between the great plains of North India and the plateau of the Deccan. They form a compact block of mountains, hills and plateaus intersected by valleys and basins largely covered by forest and account for one-sixth of the total area of India. The peninsular plateaus lie between the Bay of Bengal in the east and the Arabian Sea in the West. It is the largest of the physiographic divisions of India. The peninsular plateaus consist of five physiographic sub-division viz. the Western Ghats, the North Deccan Plateau, the South-Deccan Plateau, the Eastern Plateau and the Eastern Ghats. The East coast belt is washed by the waters of the Bay of Bengal. It extends for a distance of 1000 km from Kanyakumari northward to the united delta of the Krishna and the Godavari with an average width of 100-130 km. The West coast belt is washed by the waters of the Arabian Sea runs more or less straight from Kanyakumari to Bharauch, for a distance of 1500 Km. The coastal plains are confined to a narrow belt 10-25 Km wide between the Western Ghats and the sea. The islands of India lie in the Bay of Bengal. In the Arabian Sea, are the coral Islands of the Lakshadweep, and in the Bay of Bengal, the Andaman and Nicobar Islands which are formed by the elevated portions of submarine mountains rising above the sea.

CLIMATE & RAINFALL

India has a very great diversity and variety of climate, and an even greater variety of weather conditions. The climate ranges from continental of oceanic, from extremes of heat to extremes of cold, from extreme aridity and negligible rainfall to excessive humidity and torrential rainfall. The climatic condition influences to a great extent the water resources utilisation of country. Rainfall in India is dependent in differing degrees on the South West and North East monsoons, on shallow cyclonic depressions and disturbances and on violent local storms which form in regions where cool humid winds from the sea meet hot dry winds from the land and occasionally reach cyclonic dimensions. Most of the rainfall in India take places under the influence of south-West Monsoon between June to September, except in Tamil Nadu where it is under the influence of North East Monsoon during October and November. The rainfall in India shows great variations, unequal seasonal distribution, still more unequal geographical distribution and the frequent departures from the normal. It generally exceeds 1000 mm in areas to the east of longitude 78°E. It extends to 2500 mm along almost the entire West Coast and Western Ghats and over most of Assam and Sub Himalayan West Bengal. On the West of the line joining Porbandar to Delhi and then to Ferozpur the rainfall diminishes rapidly from 500 mm to less than 150 mm in the extreme West. The peninsula has large areas of rainfall less than 600 mm with pockets of even 500 mm. The estimate of a real average rainfall is subjective depending on the method adopted.

HYDROGEOLOGICAL DIVISIONS

CGWB has evolved following categories to describe the Hydrogeological characteristics of various rock types occurring in the country.

1. Porous Formation
   a. Areas underlain by unconsolidated formations.
   b. Area underlain by semi-consolidate formations.
2. Fissured Formation
   a. Areas underlain by consolidated formation.

POROUS FORMATION

a. Unconsolidated Formations :

The Quanternary sediments comprising recent alluvium, older alluvium and coastal alluvium are by and large the important repositories of ground water. These are essentially composed of clays, silts, sands, gravels, pebbles, cobbles, boulders, ferruginous nodules, kankar (calcareous concretions),etc. The beds of sand and gravel and their admixtures from potential aquifers. The aquifer materials vary in particle size and rounding and in their degree of sorting. Consequently, their water yielding capabilities vary considerably. The coastal aquifers show vide variation in the water quality both laterally and vertically.

The piedomont zone of the Himalayas is skirted by artesian belt under free flowing conditions extending from Punjab to Assam. The hydrologeological environment and ground water regime conditions in Indo-Ganga-Brahmaputra basin indicate the existence of enormous fresh ground water reservoir atleast down to 600 m or more below land surface, for large scale development through heavy duty tube-wells. Bestowed with high incidence of rainfall, this ground water reservoir gets replenished every year. The alluvial aquifers to the explored depth of 600 m or have transmissivity values from 250 to 400 m^2 / day and hydraulic conductivity from 10 to 800 m/day. The well yields range upto 100 lps and more but yields of 40-100 lps are common.

b. Semi consolidated Formations :

The semi consolidated formations belong to Paleozoic Mesozoic and cenozoic group of rocks extending from Carboniferous to Mio-Pilocene in age. These are chiefly composed of shales, sandstones, limestones, flyasch and molasse beds. The terrestrial freshwater deposits belong to Gondwana system of the peninsular shields are also included under this category. The sandstones in them form highly potential aquifers, locally, particularly in Peninsula. Elsewhere they are moderately potential and in places they yield meagre supplies. These sediments normally occur in narrow valleys or structurally faulted basins. Though these formations have been identified to possess moderate yield potential, the Physiography of the terrain, normally restricts exploitation. Under favourable situations , these sedimentaries give rise to flowing conditions as in parts of Godavari vallar basin, Combay basin and parts of west coast. Potential semi consolidated rock aquifers particularly those belonging Gondwana and Tertiaries in the Peninsula have transmissivity values from 100 to 2270 m 2/d and the hydraulic conductivity from 0.5 to 70 m/day. Generally the well yields in productive areas range from 10 to 40 lps.

FISSURED FORMATION

a. Consolidated Formations :

The consolidated formations occupy almost two-third of the country. Most consolidated rocks, except vesicular volcanic rocks containing porous layers between successive lava flows and pyroclastic rocks associated with lava flows, have negligible primary porosity. From the hydrogeological point of view, the fissured rocks are broadly classified into the following four types.

1. Igneous and metamarphic rocks excluding volcanic and carbonate rocks.
2. Volcanic rocks
3. Consolidated sedimentary rocks excluding carbonate rocks.

4. Carbonate rocks.

The nature, occurrence and movement of ground water in them are described below:

The Deccan Trap lava flows are mostly horizontal but occasionally are very gently dipping. Ground water occurrence in the Deccan Traps is controlled by the contrasting water bearing properties of different flow units. The topography, nature and extent of weathering, jointing and fracture pattern, thickness and depth of occurrence of vesicular basalts are the important factors which play a major role in the occurrence and movement of ground water in these rocks. Basalts or Deccan Traps have usually medium, to low permeabilities depending on the presence of primary and secondary porosity. Pumping tests have shown that under favourable conditions, borewells could yield about 250-500 m^3/day of moderate drawdowns. Transmissivity values of Deccan Trap aquifers vary from around 25 m^2/day and the bulk hydraulic conductivity varies from 0.05 m/day to 15 m/day.

CONSOLIDATED SEDIMENTARY ROCKS EXCLUDING CARBONATE ROCKS

Consolidated sedimentary rocks occur in Cuddapah and their equivalents. The formations consist of conglomerates, sandstones, shales, slates, quartzites, apart from limestones dolomites. Locally they contain phyllities and schists. The Cuddapahs and their equivalents were subjected to low grade metamorphism in place while the Vindhyans and their equivalent do not show any evidence of metamorphism. The occurrence and movement of water in them is governed by bedding planes., cleavages, fracture, joints, faults, contact zones, degree and magnitude of weathering, topography and climate. They yield limited to moderate supplies wherever favourable conditions exist.

CARBONATE ROCKS

Carbonate rocks include limestone, marble and dolomite. Among the carbonate rocks, limestone have the greatest distribution. In the carbonate rocks solution cavities develop due to circulation of water. This process leads to widely contrasting permeability within short distances. Potential karstified aquifers are found to occur in Rajasthan and Peninsular India in which the yields range from 5 to over 25 lps. Large springs exist in the Himalayan region in limestone formations.

Igeneous and Metamorphic Rocks Excluding Volcanic and Carbonate Rocks

According to their modes of origin these rocks can be divided into plutonic and hypabyssal (igneous) rocks and metamorphic rocks. The most common rocks types are granite, slate etc. These rocks posses negligible primary porosity but are rendered porous and permeable due to the formation of secondary openings by fracturing and weathering.

Ground water yield also depends on rocks types (e.g. granite, khondalite and biolite, gneiss are better sources than charnockite) and possibly upon the grade on metamorphism. The ground water studies carried out in the crystalline rocks revealed the existence, along certain lineaments of deeply weathered and fractured zones, locally forming potential aquifers. These lineament zones are found to be highly productive for construction of borewells.

In areas underlain by hard crystallines and metasedimentaries viz. granite, gnesis, schist, phyllite, quartzites charnockite etc., occurrence of ground water in the fracture system has been identified down to a depth of 60 metres and even upto 200m locally. In most of the granite gneiss country the weathered residium, serves as an effective ground water connected with the weathered saturated residium. The yield potential of the crystalline and metasedimetary rocks show wide variations. Through 10 cm to 15 cm diameter bored wells, the fracture systems generally yield from less than 1 lps to 5 lps and more 25 lps in the vicinity of structurally disturbed areas. The transmissivity values of the fractured rock aquifers vary from 25 to 500 sq.m./day and the bulk hydraulic conductivity varies from 0.1 to 10 m/day.

DEVELOPMENT OF IRRIGATION

Importance and need of irrigation is already explained in para - I earlier. The planning Commission has classified the Irrigation Schemes in Major-Medium and Minor,. Before 1978, all projects costing less than Rs. 25 lakhs were classified under Minor Irrigation. Since April 1978, the new classification has been done and all projects having culturable Command Area (CCA) less than 2000 ha. were put under Minor Irrigation. However, in the Planning Process the financial allocation are being made under two categories :

i. Major Medium irrigation and

ii. Minor Irrigation

All the ground water development schemes are included under minor irrigation. Thus, Minor Irrigation has two components :

(1) Surface Water and

(2) Ground Water schemes

Starting from an investment of Rs. 380 crores in the First Plan, the Plan-wise investment of major and medium irrigation rose to Rs. 21,838 crores in the VIII Plan. The all India position of expenditure incurred and potential created in each Plan is reflected below :

Table 5.1 Development of Major-Medium Irrigation

Plan Period	Outlay Expenditure (Rs. in Crore)	Potential Created (in m.ha.) During	(Rs. in Crore) Cumulative
Pre-Plan	N.A.	9.70	
First Plan	376	2.50	9.70
IInd Plan	380	2.13	12.20
IIIrd Plan	576	2.24	14.33
Annual Plan (1966-69)	430	1.53	16.57
IV Plan (1969-74)	1242	2.60	18.10
V Plan (1974-78)	2516	4.02	20.70
Annual Plan (1978-80)	2079	1.89	24.72
VI Plan (1980-85)	7369	1.09	26.61

VII Plan (1985-90)	11107	2.22	27.70
Annual Plan (1990-92)	5459	0.82	29.92
Eighth Plan (1992-97)	21838	2.22	32.96
Annual Plan (1997-98)	8403	1.04	(Target)
Total (excluding pre-Plan)	**26222**	**23.43**	

Source : Annual Plan Report 1998-99 Ministry of Water Resources.

Thus, during the Plan period of 46 years (1951-1997), additional irrigation potential created through major and medium irrigation sector will be 32.96 million ha.

UTILISATION OF POTENTIAL IN MAJOR MEDIUM PROJECTS

The position of creation of potential and its utilisation at the end of each Plan is as under :

	Potential (Cumulative)	Million ha Utilisation	%of Utilisation
At the beginning of I Plan	8.6	8.6	100
At the end of I Plan (1951-56)	11.1	9.9	89.2
II Plan (1956-61)	13.2	12.0	90.0
III Plan (1961-66)	15.5	14.1	91.0
Annual Plan (1966-69)	17.0	15.7	92.4
IV Plan (1969-74)	19.6	17.6	89.8
V Plan (1974-78)	23.6	20.1	85.2
Annual Plain (1978-80)	25.5	21.6	84.7
VI Plan (1980-85)	27.6	23.8	86.3
VII Plan (1985-90)	30.8	26.6	86.4
VIII Plan (1992-97)	32.96	28.47	86.3

(Source : Working group on Major-Medium Irrigation (1989)

Causes for lag in utilisation of the created potential can be divided into following categories) :

(i) Over reporting of potential at source.

Data base inaccuracies.

(iii) Inadequate development of land and poor water management

SURFACE WATER MINOR IRRIGATION AND GROUND WATER DEVELOPMENT

Minor Irrigation Schemes include all ground water schemes and surface water schemes (both flow and lift) which individually have culturable command area upto 2000 ha. These schemes are quick maturing and labour intensive by nature and hence increasing emphasis is made on the development of minor irrigation.

Private ground water schemes comprise of dugwells, dug-cum-borewells, bore-wells, filter points, shallow tube-wells and individual boring. The culturable command area of such works varies from 1 to 4 ha. on an average. The government assistance in installation of these schemes is confined to technical guidance, custom services subsidies and arrangement of credit at reasonable rates of interest. The construction, operation and maintenance of deep tube-wells with culturable command areas varying from 40 to 100 ha. are being handled by the State Governments or Minor Irrigation Tube-wells Corporations.

Minor surface water flow irrigation projects comprising of storage and diversion works occupy a conspicuous place particularly in the undulting areas and hilly regions of the country. These provide the only means of irrigation in the chronically drought affected areas. The storage scheme also help recharging ground water in the hard rock areas in addition to irrigation. In certain areas where irrigation facilities cannot be provided through flow irrigation schemes due to typographical limitation, the lift irrigation schemes are playing an important role.

Development of minor irrigation is primarily achieved through individual and cooperative efforts with the help of institutional finance or investment by the farmers from their own saving and resources. The bulk of institutional finance is mobilised through the Land Development Banks, Commercial Banks, State Co-operative Banks with refinance from NABARD. Public Sector outlay are limited to public tube-wells surface water schemes, survey and investigation work and giving subsidy to the farmers for installation of minor irrigation works. The primary responsibility for planning and implementation of minor irrigation programme is that of State governments, centre provides assistance under various Centrally Sponsored Schemes for accelerating the development of minor irrigation. Generally, a number of departments/organisations are implementing minor irrigation programme under different developmental sectors such as Agriculture, Rural Developments, Welfare, Cooperation etc.

The plan wise outlays and potential created is given in the table below. For ground water development no separate plan-outlays are given. It is included in overall plan-outlay for minor irrigation. As such, the figures given for ground water are purely estimated and adhoc.

Table 5.2 Development of Minor Irrigation

Plan Period	Irrigation Potential Cumulative in m.ha.			Investment made (Rs. Crores)		Approx. Share of Ground Water	
	Surface Water	Ground Water	Total	Plan Outlays	Institu tional finance	Total	*
1. Pre Plan	6.4	6.5	12.9	-	-	-	-
2. Ist Plan (1951-56)	6.43	7.63	14.06	66	-	66	20
3. 2nd Plan (1956-61)	6.45	8.30	14.75	142	19	161	60
4. 3rd Plan (1961-66)	6.48	10.52	17.00	328	115	443	200
5. 1966-69	6.50	12.50	19.00	326	235	561	300
6. 4th Plan (1969-74)	7.00	16.50	23.50	513	661	1174	760
7. 5th Plan (1974-78)	7.50	19.80	27.30	631	780	1411	990
8. 1978-80	8.00	22.00	30.00	497	490	987	590
9. 6th Plan (1980-85)	9.70	27.80	37.50	1802	1438	3240	1730
10. 7th Plan (1985-90)	10.98	35.62	46.60	3228	3312	6540	4270
11. Upto end of (1991-92)	11.46	38.89	50.35	N.A.	N.A.	N.A.	N.A.
12. Upto end of (1996-97)	12.2	45.7	51.9	N.A.	N.A.	N.A.	N.A.

* Institutional Finance 90% + Plan outlay 30% upto VI[th] plan and 40% during the VIIth plan.

Development of Ground Water Structures
(000 Nos.)

Sr. No.	Plan Period	Dug Wells	Shallow Tube-wells	Deep Public Tube-wells	Electrical Pumpsets	Diesel pumpsets
1	2	3	4	5	6	7
Ultimate feasible						
1.		12200	4076	60	12000	5000
Revised Comulative						
2.	1950-51	3860	3	2.4	21	66
3.	1960-61	4540	22	8.9	200	230
4.	1968-69	6100	360	14.7	1090	720
5.	1973-74	6700	1138	22.0	2430	1750
6.	1977-78	7435	1749	30.0	3300	2350
7.	1979-80	7786	2132	33.3	3965	2650
8.	1984-85	8742	3359	48.2	5709	3550
9.	1989-90	9487	4754	63.6	8226	4355
10.	1990-Onwards		DATA NOT AVAILABLE			

Note : Figure are estimated & provisional. (Source : Working group Report on Minor Irrigation, 1989.

In the case of privately owned works, the standard of irrigated agriculture including land levelling and preparation of fields is usually better since the farmer himself owns the source of irrigation. As such, the utilisation of irrigation potential from these private structures is almost immediate and the potential from these structures is fully utilised, while in the case of State Minor Irrigation Surface water schemes and Public Tube-wells, the irrigation potential created from these works is not fully utilised. During the course of discussions with the state officers during the annual plan discussions in the Planning Commission and also in the meetings convened by the Union Ministry of Water Resources from time to time, it has been observed that the potential utilisation from surface water schemes ranges from 50-70% and particularly, the utilisation during kharif season from lift irrigation scheme is negligible. Similarly, in the case of Public Tube wells the major constraint in utilising the full potential is non-availability of adequate power. Public Tube-wells are designed to run for about 3000 hours in a year but nearly in all the States due to imposition of power cuts, the performance of tube-well has not been satisfactory. The largest number of Public Tube-wells are in the State of Uttar Pradesh where the utilisation is hardly 40%. It will therefore, be evident from the above that greater attention is required for stepping up the utilisation from Surface Water Schemes as well as Public Tube-wells.

The potential created and its utilisation figures under Minor Irrigation were being reported as the same till the end of VIth plan. The Public Accounts Committee in its 141st (1982-83) report did not accept the practice of reporting 100% utilisation from Minor Irrigation Schemes as the basis of compilation of statistics. The working Group on Minor Irrigation for the formulation of 7th plan proposal recommended that during 6th plan utilisation figures may be reported as per the current practice but the base level for the year 1984-85 should be worked out both for potential created and potential utilised and during the 7th plan separate figures for the potential created and utilised should be given. Accordingly, the planning commission after having discussion with the State Government has fixed up the base figures for 1984-85 for the potential created and potential utilised as 37.52 m.ha. and 35.25 m.ha thereby showing a gap of 2.27 m.ha. at the end, of 1984-85. For the subsequent years also, potential created and potential utilised are being worked out separately.

The plan wise figures for potential created and utilised in respect of Minor Irrigation are as follows :

Cumulative Irrigation Potential in m.ha.

	Plan period	Potential created			Potential utilised		
		G.W.	**S.W.**	**Total**	**G.W.**	**S.W.**	**Total**
1.	1950-51 (Pre-plan)	6.5	6.4	12.9	6.5	6.4	12.9
2.	1960-61 (IInd Plan)	8.3	6.45	14.75	8.3	6.45	14.75
3.	1968-69	12.5	6.5	19.0	12.5	6.50	19.0
4.	1973-77 (IVth Plan)	16.5	7.0	23.5	16.5	7.0	23.5
5.	1977-78 (Vth Plan)	19.8	7.5	27.3	19.8	7.5	27.3
6.	1979-80	22.0	8.0	30.0	22.0	8.0	30.0

7.	1984-85 (VIth Plan)	27.8	9.7	37.5	26.2	9.0	35.2
8.	1989-90 (VIIth Plan)	35.62	10.96	46.6	32.5	10.1	42.6
9.	1992-97 (VIIIth Plan)	45.9	12.2	57.9	42.0	10.8	52.8

STATUS OF GROUND WATER SURVEYS AND INVESTIGATIONS

In the country macro level survey is done by CGWB and the micro level by State Ground Water Organisation (SGWO). CGWB carried out following survey works :

- Systematic Hydrogeological Surveys.
- Reappraisal of Hydrogeological Surveys.
- Water Supply Investigations.
- Monitoring of waterable and quality at selected points throughout the country
- Exploratory Drilling
- Construction of Production wells.
- Pilot projects for Artificial Recharge like percolation tanks check dams and subsurface dams.
- Preparation of District and State reports
- Hydrogeological atlases of the State.
- Basinwise water balance studies etc.

It may be stated that under programme of Hydrogeological surveys an area of 299 million ha has been covered against geographical area of 329 m.ha. and it is hoped to completely cover the entire country by March, 1991. Water table and quality observation are being made regularly on 13,450 places. Finally CGWB has so far drilled 7710 wells and constructed 3330 water supply tube-wells. Eleven water balance studies have been completed.

SGWO's observe the water table behaviour more closely and carry out the quantitative assessment for each development block annually (there are 5153 such blocks in the country). This forms the basis for future Ground Water development in the states.

TYPE OF GROUNDWATER STRUCTURES

Following types of Ground Water structures are being constructed in the country.

1. Open Dug wells.
2. Repair of wells.
3. Boring of wells.
4. Deepening of wells.
5. Shallow Tube-wells.
6. Borewells.
7. Artesian wells.
8. Filter wells.
9. Deep public Tube-wells.

However these are grouped in 3 broad categories.

1. Dugwells

The cost in northern alluvium belt is about Rs. 5000 for a 1 m.dia and 10-15 m deepwell. The area irrigated is about 1 ha. in the hard rock areas the wells of 1 to 1.5 m dia cost Rs. 15,000 to Rs. 20,000 for a 10-15 m well. The area irrigated is 0.8 ha with indigenous lift and 2.0 ha with a pump. For increasing the discharge additional vertical and horizontal borings are done.

2. Shallow Tubewells

In alluvium these are 10 to 15 cm dia and 15 to 20 m deep and would cost Rs. 15,000 to Rs. 20,000 with pump set. The discharge is about $50 m^3/hr$. The area irrigated is about 3 to 4 ha. In hard rock areas, these are called Borewells and cost about Rs. 20,000 to 25,000. The area irrigated is also about 2 to 3 ha. only.

3. Deep Public Tubewells

These are about 100 to 150 m deep of 20 cm dia and gravel packed. The Discharge varies from 100 to 150 m^3. The area irrigated is 40 to 80 ha. and the cost is Rs. 5,00,000 to 9,00,000. These are constructed operated and maintained by Government Department or Corporation of the Government.

CONJUNCTIVE USE AND ITS IMPORTANCE

Surface waters and ground waters are two important sources for irrigation purposes. Both have been extensively used, as would be clear from the description given in earlier paras, but generally without integrated planning for coordinated development and maximum benefits. The conjunctive use is important because of :

MEETING THE INADEQUACY OF WATER IN SURFACE WATER IRRIGATION:

Inadequacy of water in the irrigation systems of the country, particularly in run off the river schemes is well known. These system fall in no small measure to provide assured and timely supplies to support high yielding crops. Moreover, the concept of protective irrigation has now changed to intensive irrigation. As such, in a command of irrigation project, both surface and ground water are to used in a planned manner to maximum agricultural production.

PREVENTION OF THE PROBLEM OF WATER LOGGING AND SALINITY :

The massive development of surface water resources and the process of intensification of irrigation and meeting the full water requirements of high yielding varieties combined with indiscriminate and unplanned irrigation from canals and high incidence of canal seepage has disturbed the underground hydrological balance through extensive recharging of ground water aquifers in commands of several irrigation projects. This has resulted in high water table rise resulting in Water Logging, accompanied with Salinity. The Working Group on C.A.D. of Ministry of Water Resources has identified atleast 24 Major Irrigation Projects in which 8,65,350 ha. of area has been water logged and 876350 ha. and 6,73,400 ha. respectively are suffering from the Salinity and Alkalinity problems. The state wise details of water logged areas are given in **Appendix III.**

It is here that integrated development of the two resources, surface and ground water and their conjunctive process of use is most effectively brought into play as much to rectify major deficiencies in surface water deliveries as to provide a fundamental safeguard to hold the ground water table at a safe depth by planned and judicious use of ground water.

CHECKING THE PROBLEMS OF OVER-EXPLOITATION OF GROUND WATER:

Indiscriminate pumping of ground water in area, not supported by required surface water input has resulted in serious problems of water table lowering accompanied by well going dry, lowering of pump in existing tube-wells and their discharge going down and finally resulting in serious water shortage even for drinking and irrigation. Monitoring of Ground Water table at 13450 stations all over the country by CGWB has revealed that there are only 13 states where fall of more than 5m has been recorded. However, due to uncontrolled development of groundwater in some areas particularly in the states of Haryana, Punjab, Gujarat, Tamil Nadu, U.P., Maharasthra and Karnataka decline in ground water level has been observed during the recent past. This is on account of the fact that the amount of resource having exploited in these area has exceeded the average annual replenishable recharge. According to CGWB, the State and Union Territories where stage of ground water over-development has reached are given below :

1.	Haryana	-	Karnal, Kurukshetra
2.	Punjab	-	Amritsar, Julandhar, Kapurthala, Ludhiana, Patiala, Sangrur
3.	Delhi	-	Mehrauli
4.	Chandigarh	-	Chandigarh
5.	Pondicherry	-	Pondicherry

Thus only 10 districts out of 424 districts in India have a true problem of over exploitation. However according to assessment made by SGWOS, about 300 blocks out of 5143 total blocks are approaching to over exploitation and about 400 another blocks are in critical stage. Both these studies present a satisfactory picture as far as over exploitation of Ground Water resources is concerned. However, the author has the opportunity of travelling throughout the country and it has been observed by the author that with in the command of irrigation project there is no problem of over exploitation of Ground Water resource but only out of commands area there is a general decline of water table and hydrograph show a definite declining trend, which would be clear from the examples given in the next para.

EXAMPLES OF THE OBSERVATION OF DECLINE OF GROUND WATER TABLE

Here the examples have been sited for a few typical States.

Madhya Pradesh :

This is a large state south of Gangetic plain. It is mostly hard rock with patches of alluvium. This State has got big irrigation systems also. District-wise long term trend of declining of water level from 0.10m to 1.93 m while the maximum decline varies from 0.55 to 13.05 m.

(ii) Tamilnadu :

It is the southern most state of India. Except for coastal area rest is all hard rock and undulating. The state has 1.6 million wells irrigating 1.2 m.ha. which is about 40% of total irrigated area . According to a study made by Dr. R.K. Shivappan, presently working as Consultant in the state, the Ground Water table has depleted from 10 m to 50 m in the last 40-50 years. The area of irrigation by each well has reduced from 1.5 ha. to less than 1.0 ha. in the last 20-30 years. In many talukas (subdivisions) of Pasumpron District water table has dropped to 20 to 30 m from ground water surface and large number of irrigation water have deep borewells inside to a depth to 60-70 m. According to Dr. R.K. Shivappan hundreds of wells in Chindambaranar district (Sathankulam block), Madhurai district (Chinnamanon) and Coimbatore district (Karamadai, Saber, Muadukkarai, Avinashi block) have been abondoned.

Uttar Pradesh :

This is the most populous state of the country and most of geographical area is fertile alluvium plains, substaining wells and tube-wells. It has a maximum ground water potential of 6.84 m. ha. m. out of 38.30 m. ha. m. for the country according to revised assessment of CGWB. In this state also several areas of serious decline of water table is taking place because of over exploitation and non-availability of recharge from canals. Observed data from 1975 to 1985 indicates following decline for some districts.

		Decline of water table in last 10 years in metres
1.	**Ghaziabad District**	
-	Loni blocks	0.84-3.02
-	Muradnagar	1.78-2.48
-	Bhojpur	2.97-5.37
-	Dadri	1.56-2.48
-	Bisrakh	2.4-5.59
-	Thaulare	0.70-4.15
-	Hapur	1.74-4.15
-	Garhmukteshwar	0.87-2.98
2.	**Bulandsahar**	
-	Bulandsahar blocks	0.80-1.49
-	Lakhavati	4.18-5.57

-	Siana	2.37-3.07
-	Bibinagar	4.47-5.47
-	Gulavathi	1.78-3.81
-	Anupshahr	1.83-2.86
-	Danpur	2.85-4.00
-	Dibai	2.46-5.90
-	Jahangirabad	1.83-3.36
-	Unche Goan	3.41-3.36
-	Dankor	0.79-4.02
-	Sikarapur	2.05
-	Khurja	2.23
-	Arnia	3.20-4.35
-	Pahansu	0.53-3.28

3. Saharanpur

-	Deband Blocks	0.40-2.34
-	Nagal	1.22-2.64
-	Baliakheri	0.45-6.65

In a study made by the Ground Water Department of U.P. titled "Conjunctive use of G.W. in Ramganga Command of U.P. in 1987". Contour of water table rise and fall from 1972 to 1985 were plotted. It indicates that atleast 20% area show a decline of water table upto 7 meters, naturally outside canal command and with large scale development of G.W. resource by tube-wells. The districts most affected are Aligarh, Agra and Mathura. This decline of water table could have been checked if the conjuctive use of surface and ground water could have been planned before taking up large scale Ground Water extraction.

PREVENTION OF SEA WATER INGRESS

The groundwater resource, once contaminated, is cost prohibitive to restore to its original condition. Coastal fresh water aquifers need to be managed to ensure that saline water does not intrude into them due to heavy withdrawals causing sea water to move inwards because of the disturbed hydro-chemical equilibrium. The National Water Policy has laid emphasis on avoiding the over exploitation of ground water near the sea coast to prevent ingress of sea water into fresh water aquifers. This problem has already taken place in the Saurashtra area of Gujarat, where the failure of the monsoon to provide normal rainfall during 1974 followed by repeated failures in the following years, lead to large scale energisation of dug wells in the coastal area, which in turn caused substantial increase in the ground water exploitation. Withdrawal of water in excess of natural recharge lead to intrusion of saline water. Cash crops grown in the area were found to give very poor yields and economy of the coastal area was badly hit by this salinity problem. The coastal areas of Tamilnadu, Kerala, Orissa and West bengal are also threatened with this problem. In all such cases, conjunctive planning is a must.

AUGMENTATION OF WATER RESOURCES

It has been observed that in some basin/areas, there is surplus ground water. Through construction of Augmentation Tube-wells this water can be transferred by existing or new canal system to water short basins or areas. This has already been tried in States like Haryana, M.P. etc.

USE OF SALINE WATER

In some states like Haryana, U.P., there are large tracts of land which have saline groundwater. Through conjunctive use of mixing this water with fresh canal water in tolerable limits can be used for irrigation purposes. Vice-versa in such tracts large scale induction of surface water if possible will help in creating a perched water table of fresh water which can be used for drinking or through pumping within limits.

PRESENT STATUS OF CONJUNCTIVE USE

As already described in earlier paras, Surface and Ground waters are being used in isolation and in unplanned way. Data is also not available as to how much supplemented irrigation is provided in commands of surface water Irrigation projects by Ground Water. In Minor Irrigation causes carried out in 1986-87, an effort has been made in this direction. The state-wise position is as below:

Supplemental Irrigation by Ground Water in Surface Water Irrigation Commands

Area in 1000 ha

S.No.	Name of State	Utilised potential of Surface Water projects	Area under Supplemented Irrigation by Ground Water	Percentage
1.	Andhra Pradesh	3094	12	0.4%
2.	Gujarat	873	33	4.1%
3.	Haryana	1785	400	22.4%
4.	Karnataka	1188	42	3.5%
5.	Madhya Pradesh	1403	120	8.6%
6.	Maharastra	935	365	39.0%
7.	Punjab	2498	1056	42.3%
8.	Tamil Nadu	1245	250	20.0%
9.	Uttar Pradesh	5703	986	17.3%
10.	West Bengal	1524	145	9.5%

CONJUNCTIVE USE IN COMMAND AREA DEVELOPMENT PROJECTS

Command Area Development (C.A.D.) Authorities are working since 1973-74 in various States. Although conjunctive use is one of the main objectives under C.A.D., no serious efforts have been made to know the status of conjunctive use in commands of these Major-Medium Irrigation Projects,. Author using district-wise M.I. Census data has made an effort in the direction. The results obtained are given in Table as below.

STATUS OF CONJUNCTIVE USE IN SOME MAJOR IRRIGATION PROJECTS

Sr. No.	Name of Project	C.C.A. ha	Ultimate Potential in	Nos. of G.W. in command Dug. wells	Structures shallow Tube-wells	Potential Created by G.W. in ha.
1	2	3	4	5	6	7
	ANDHRA PRADESH					
1.	Nagurjan Sagar	8,95,000	8,95,000	1,45,704	19,992	2,25,672
	GUJARAT					
2.	Mahi	2,00,000	2,74,490	1,41,602	702	1,44,410
3.	Ukai-Kakrapar	3,48,000	3,80,910	73,194	1,866	80,658
	HARYANA					
4.	J.L.N. Lift Canal	2,50,000	1,55,000	26,459	41,128	1,90,971
	JAMMU & KASHMIR					
5.	Tawi Lift Irrigation	12,880	17,980	51	712	2,899
	KARNATAKA					
6.	Gataprabha	3,17,430	3,17,430	90,900	4,430	10,838
7.	Malprabha	2,14,980	2,14,980	98,768	9,426	1,36,472
8.	Tungbahdra	5,29,000	3,49,100	23,557	1,756	30,581
9.	Upper Krishna	4,24,910	4,24,910	55,585	850	58,985
	MADHYA PRADESH					
10.	Chamba	2,20,000	2,73,000	25,990	292	27,158
11.	Tawa	2,47,000	3,33,000	15,699	770	18,779
	MAHARASHTRA					
12.	Jayakwadi	2,27,200	2,27,200	2,66,375	408	2,68,007
13.	Puna	615	57,300	58,363	761	61,407
14.	Krishna	74,000	1,11,720	1,10,343	57	1,10,571
	ORRISA					
15.	Hirakund	1,53,240	2,51,150	64,979	1	64,983
16.	Mahandi	1,79,410	3,00,100	27,205	3,030	28,425

1	2	3	4	5	6	7
	U.P.					
17.	Gandak	4,11,000	3,08,000	13,254	1,01,899	4,18,550
18.	Ramganga	18,97,000	13,72,000	39,650	3,22,515	13,29,710
19.	Sarda Sahyak	20,00,000	19,23,000	40,669	4,18,359	17,14,005
	WEST BENGAL					
20.	D.V.C.	3,91,970	5,15,000	8,503	73,561	2,92,747
21.	Kangsabati	3,49,750	4,01,460	34,440	80,303	3,55,652
22.	Mauyurakshi	2,26,630	2,50,860	1,104	1,04,407	2,18,832

N.B.

1. The figures for G.W. structures have been taken from M.I. Census (1987) on district wise 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 of wells and 4 ha for shallow tube-wells.

The above table would indicate that large number of G.W. structures are doing supplemental irrigation in these CAD projects.

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. However in case of Tamilnadu some data has been collected for tanks being modernised under externally aided project of E.E.C. For some tanks the details are given in Table as below

STATUS OF CONJUNCTIVE USE IN SOME TANKS PROJECTS OF TAMILNADU

Sr. No.	Name of Tank	Taluk/ Distt.	Registered Ayacut (Ha.)	Irrigation Area (ha)	Irrigated by Tank only	No. of wells	Area ha	Percentage of well Irrigation
1.	Latheri	Gudyathan North Arcot	118.74	115.65	8.56	67	50.58	43.7%
2.	Samudram	Thrumayam Pudu Kottai	124.315	101.89	82.29	36	17.61	13.3%
3.	Periyurkulam	Sankaran Koil Tirunelvdi	196.770	156.230	105.666	90	48.64	31.1%
4.	Aliya-Imangalam	Pohar Triuvanna malai	112.88	93.06	70.80	78	22.26	23.9%
5.	Perias-adayareri	Sivagiri Tirunelveli	161.25	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 Periyakulam	Sanakaran Kol Triunelvi	110.67	92.73	63.390	40	29.34	31.6%
	Annuam-uthur	Tindivanam South Arcot	107.12	88.09	72.245	24	8.845	10.1%

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

STATUS OF PLANNED CONJUNCTIVE USE

Very few projects have taken under this heading, some known cases are described in the following para.

AUGMENTATION TUBEWELLS IN HARYANA

In the face of limited surface water resources, tapping of ground water potential remained the only alternative for augmentation of irrigational water supplies. The Irrigation Department of Haryana, therefore, chalked out a scheme for the installation of deep tube-wells in the year 1969. Originally, it was planned to install 493 deep tube-well, with a total capacity of pumping out about 1000 cusecs of underground water in the Yamuna Ground Water Basin, extending from Dadupur in Ambala District to Panipat in Karnal District. Later in the year 1970, "The Haryana State Minor Irrigation (Tubewells) Corporation" was formed and the work relating to the exploitation of underground water resources was transferred to this body. As a result of detailed investigations and Ground water studies undertaken by the Minor Irrigation Tube-wells Corporation, it was revealed that 3300 cusecs of ground water could be safely exploited form Yamuna Basin without causing any appreciable fall in the water table in the region. On the basis of these studies it was also decided to construct a lined channel from Jagadhari to Munak in order to save absorption losses and augment canal supplies from ground-water resources through deep tubewells. Thus, the "Augmentation Canal/Tube-wells Project" was conceived. Haryana was the pioneer State in India which had ventured to make conjunctive use of ground water and surface water resources for irrigation.

The main objective of the "Augmentation Canal/Tube-wells Project" was to increase water supplies at Munak canal head to the tune of 969 cusecs and thereby improve the supply position of the entire Western Yamuna Canal System. This was envisaged to be achieved through exploitation of 500 cusecs of ground-water by 160 tube-wells and saving of absorption losses of 469 cusecs in the lined Augmentation Canal, off-taking from Western Jamuna Canal at RD 68038 of mainline lower near Yamuna Nagar and out-falling into it at Munak at RD 125515, with a capacity ranging from 3240 cusecs to 3941 cusecs.

The work of the installation of deep tube-wells and Augmentation Canal Project was started in October, 1971 and completed in December, 1972, at a cost of Rs. 12.69 crores. The tube-wells/canal was commissioned on 31st December, 1972. An evaluation of this project revealed that the objective of increasing canal water supplies at the Munak head of Western Yamuna Canal had almost been achieved. However, the lowering of water table has been observed within 1-2 km from the canal and lowering of pumps in case of private tube-wells had to be done. Subsequently, the Haryana government took construction of about 1000 Augmentation tube-wells on Western Canal System to directly feed the canal.

AUGMENTATION TUBEWELLS IN U.P.

In Gandak Canal CAD Project of U.P., about 150 augmentation tube-wells were drilled about 7 years back. However due to no-demand these have not been used so far.

AUGMENTATION TUBEWELLS IN CHAMBAL COMMAND OF M.P.

The Chambal Irrigation System serves areas in the State of M.P. and Rajasthan. A series of dams have been constructed on the river and finally at Kota Barrage, the water is diverted into two canals respectively Right Bank Canal serving M.P. and Left Bank Canal serving Rajasthan. Due to several deficiencies in the system hardly 50% proposed area could be irrigated. As such to augment supplies in the system, a project on one of the distributary namely Ambah Branch canal for intensive development was taken with World Bank assistance in 1982. It includes construction of 175 augmentation tube-wells for conjunctive use of ground and canal water. The total installed pumping capacity would be about 47,000 m^3/hr (13 m^3/sec). It is assumed that power supply limitations will restrict pumping in peak demand priods to 16 hour/day, giving a peak 15-day production of 11.2 Mm^3 at the well heads, equivalent to a continuous discharge of about 8.7m^3/Sec. The proposed cropping pattern would require approximately 2,300 hours of groundwater pumping during the period October through March.

The wells will discharge into various parts of the canal conveyance system including the ABC. distributaries, minors and subminors down to 6 cusec capacity. They will be distributed through the conveyance system so that the augmentation well head capacity represents approximately half the water supply at full supply level at any point in the system.

Each individual AT complex will consist of the well, pump, prime mover, rising main, automated switch gear, starter relay and motor protection relay. The wells will range in depth from 100 to 160 m and their discharge will be within a range of 150 to 350 m^3/hr. Pumping water level will be in the range of 15 to 45 m below ground surface. The wells will be equipped with submersible electric motor powered turbine pumps. The main switch gear for groups of wells will be centralized at selected points on the transmission system.

The augmentation wells will be operated and maintained by the Madhya Pradesh Lift Irrigation Corpcration (now closed) on behalf of the Irrigation Department (ID). Directives for activating the wells will be given by the ID. Telephone communication networks will operate between operation decision levels in ID and the points on the 11 KV transmission where the operator, each operating a group of wells and the switch gear controlling such groups of wells will be located. Arrangements would be made for these operators of work on a 3 shift/ 24 hour day basis to maximize utilisation of the water points at periods of peak demand for irrigation water.

The project has since been completed. It performance needs evaluation.

MONSOON CANALS IN THE STATE OF U.P.

In several regions of the State specially Western District, there is heavy drawal of ground water through tube-wells for Rabi Irrigation. The rivers also do not carry much of discharge. During rainy season, these rivers carry enormous water which can be used for construction of Monsoon canals to provide irrigation for Paddy and at the same time perform the important function of recharging ground water aquifers. Several such canals have been planned and under construction viz., (i) Eastern Ganga Canal (ii) Madhya Ganga Canal Stage I and II, (iii) Parallel lower Ganga Canal. these are fine examples of including surface water to meet the shortage of Ground Water. Sixteen such canals are feasible in the State.

CONSTRUCTION OF PERCOLATION TANKS

This type of conjunctive use is now being implemented in a planned manner in several south Indian states like Andhra Pradesh, Karnataka, Maharashtra and Tamilnadu. These are very effective in recharging G.W. aquifers and increase of yield of wells downstream of tanks. A study of some tanks done in the State of Maharashtra indicates that for five tanks under Study, 100 new wells have come up and increase in irrigated area is 355 ha.

GROUND WATER DAMS

A ground water dam obstructs the flow of ground water and stores water below the ground surface. It may also serve as a collecting structure that diverts ground water flow to recharge adjacent aquifers or to raise the ground water table in an aquifer with a limited flow of ground water, making it accessible for pumping. The need to dam ground water for water supply purposes is caused basically by erraticity of rainfall. In monsoon climate area the total amount of rainfall would generally be sufficient to cater to the needs of people and agriculture, but here the seasonality means that during some part of the year water is not available. Damming ground water is thus a mean of bridging over the seasonal dry periods. The purpose of the sub-surface dam is to arrest the movement of ground water out of a sub basin. The method of storing under ground water have received considerable attention during last few year. Damming ground water for conservation purposes is not a new concept. Ground Water Dams were constructed on Islands of Sardinia in Roman times and structures in Tunisia show that damming of Ground Water was practicised by old civilisation in North Africa. Most recently various small scale ground water damming techniques have been developed and adopted in many parts of the world, notably in India, southern and eastern Africa, Brazil and Japan.

Small scale structures constructed for storage of ground water are presently in practice in various parts of India and oldest one is Ottapalam in Palghat District constructed during 1962-64. The Central Ground Water Board has also constructed two sub-surface dams one at Government Seed Farm, Ananganadi in Palghat District and Ottapalam in Agriculture University Farm, Kerala.

DEVELOPMENT OF MICRO WATERSHEDS

This programme is now being taken up in large measures by State Agriculture and Soil Conservation Departments. In a Micro-Water-Shed, the run-off generated from rainfall is checked and stored by construction of small tanks, check dams, contour bounding etc. The surface water stored in the tanks and additional ground water recharge is used for irrigation in the watersheds. To site a case-study, in a small water-shed of 8.4 hectares near Agra, the annual runoff out of a total precipitation of 624 mm in 1962 was 54 mm, which represents a percentage of 8.7. This water-shed which is situated in the ravines of the Yamuna and is under agriculture to the extent of 80% was treated for soil and water conservation by appropriate physical and biological measures in the early sixteen. Observations made in 1981 showed that out of a total of 863 mm of precipitation in that year, the runoff amounted to only 8.5 mm which represents a percentage of just about 1. In other words, thanks to effective land managements, the amount of run-off was reduced during the intervening years by a factor of 86%.

METHODOLOGY FOR CONJUNCTIVE USE

Conjunctive Use of Surface and round Waters has not been given the extent of attention and consideration it deserves. None of the States have so far proposed an Operational Plan for conjunctive use in any of Irrigation Projects. There in an urgent need for developing it on more scientific lines in order to derive it full benefits. Irrigation supplies for developing it on ore scientific lines in order to derive its full benefits. Irrigation supplies from a single source, surface or ground water are often inadequate to meet the requirements of crops in time and quantity. This is particularly so in case of high yielding varieties of crops being raised in the project commands in the season. On account of their differing base period and critical stages of irrigation, it becomes more difficult to meet their water requirements from a single source. both the sources have therefore, to be integrated and used conjunctively in order to meet the irrigation requirements. The National Water Policy has also emphasised the need for conjunctive use. The following paras reproduced here are of great relevance.

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.

In the planning and operation of systems, water allocation priorities should be broadly as follows. :

- Drinking water
- Irrigation
- Hydro-Power
- Navigation
- Industrial and other uses.

However, these priorities might be modified if necessary in particular regions with reference to area specific considerations.

Keeping in view the National Water Policy, the following methodology for Conjunctive Use Planning in suggested.

i) Water Balance Studies

Central Water Commission has already divided water of the country into major river basins. As water is a state subject and all the irrigation projects are planned and implemented at the state level, each state should carry out the complete water balance study for each basin/sub-basin. In such studies a complete inventory of all water resources surface and ground should be made. For GW recharge and working out rainfall, runoff recourse should be estimated using mathematical modelling techniques. A strong data base for all type of data i.e. Hydrometeorological, hydrological and hydro-geological etc. will have to be built up so that models can give a realistic output and response. Status of consumptive use by crops, ground water pumpage is needed to be worked out on a more realistic manner. Since all community development blocks, the water balance studies carried out on basin/sub-basin wise should be used to work out the district and block wise availability and use of surface and ground waters.

ii) Agro-Climatic Zoning and Cropping Pattern

Next step would be to divide the basin/sub-basin into different Agro-Climate zones and for each zone to work out the optimal cropping pattern. Helping of Linear Programming Techniques can be taken up in this respect. Several such studies have already been done in the country in this respect.

iii) Master Plan for Integrated Development

Having worked out the Water Resources availability and fixation of Optimal Cropping Pattern Master Plan for basins/sub-basins should be proposed. These will also incorporate the use of water for other purposes like drinking, industry etc. The priority allocated shall be as laid down in para 8 of National water Policy reproduced as above. These Master Plans should also give break up of schemes, proposals and data, taking district as a unit also. both for S.W. and specially for G.W. development these plans should include schemes and proposals in Private sector i.e. individually owned by farmers like Dugwells, tube-wells, pumset etc. and incorporate sector owned and maintained bv community like S.W. Lift Irrigation Schemes and deep tube-wells.

iv) Credit and Subsidy Requirements

As practically, al the GW development is in private sector mainly financed by Credits from Banks and subsidies for weaker sections from the Government. Based on the Master Plan, on district the long term requirement for credit and subsidies should be worked out as Long Term credit Planning for Conjunctive Use of Ground Water.

v) Operational Plans for Conjunctive Use in S.W. Irrigation Projects

For all existing project, the operational Plan for conjunctive use should be prepared. As the task is huge and time consuming, to start with, it should be confined firstly to Major and Medium Irrigation projects which have been included in the centrally sponsored schemes of command Area Development. In case of M.I. Projects it should be attempted for Tank projects being implemented through external assistance.

vi) Consideration of Various Alternatives

In respect of groundwater use, the following alternatives can be considered;

(i) Dug-wells, dug-cum-borewells and shallow private tube-wells.

Direct irrigation deep public tube-wells.

(iii) Augmentation tube-wells for supplementing the canal supplies.

(iv) Monsoon canals for the dual purpose of providing Kharif irrigation and recharge to groundwater body for extensive use in Rabi period.

Depth at which groundwater table is to be maintained subject to economic and ecological conditions.

Use of saline groundwater by mixing it with canal waters.

(vii) Induced recharge from the rivers during floods.

These various alternatives are to be considered and the one which gives the maximum cost benefit ratio subjected to various constraints including the social and political ones, is to be selected for actual execution. Although conventional methods are available but for most optimal solution, recourse has to be taken to the modern methods of analog and digital modelling and optimisation procedures. The details of modelling efferts in ground water studies are given in **Appendix - IV.**

IRRIGATION WATER RATES FOR CONJUNCTIVE USE

An important problem associated with conjunctive use of surface and ground water is the matter of irrigation water tariffs. Widely divergent patterns of tariffs for canal and tube well irrigation water can complicate matters in no small measures.

Farmers cannot be expected to forego willingly their claims to cheaper surface irrigation, though inadequate, for the more expensive volumetric system from State tube-wells, even if assured in time and quantity.

It is not cost of tube-wells irrigation is so disproportionate that crops cannot sustain the charge-multitudes for farmers are thriving on it-the problem is of a commodity being so drastically cheaper in comparison, though inferior in quality, that farmers would automatically choose and adhere to canal irrigation as compared to State tube-wells. Yet Indian farmer, intelligent and progressive as he generally is, and endowed with sound common sense, can eventually be expected to adopt new systems and techniques. He cannot allow low productivity to persist and must, therfore, orient his operations to maximising his yields and obtaining the best from his holding and improve his economic position.

When suitably educated in the matter of economic of expenditure on the existing canal charges plus that of supplementation from a private tube-well put together to the charges for supplementing irrigation from Public tube-wells, he would be able to understand that the two bear a close comparison in cost.

In the existing circumstances, therefore, where State tube-wells are being constructed to supplement canal water to individual farmers the proposal to charge him for tube-well water by volume in addition to full canal rates or area basis would be reasonable. This would mean having inclusive command for surface and ground water supplies serving the same area. In Haryana, however, where batteries of tube-wells have been constructed to augment canal supplies the old pattern of irrigation tariffs on area-crop basis has not been disturbed.

In any case for an ultimate future pattern of possible irrigation tariffs in areas where canal and ground waters are conjunctively utilised on the same land, a thorough study into all the aspects of the matter may lead to evolving a system best suited to the pattern of combination adopted. In doing so the basic approach of volumetric system being more rational and economical in water use will have to be borne in mind. Side by side it would need special attention to provide adequate safeguards against any further slicing of the financial returns from irrigation projects which have already been strained almost to a breaking point. Presently the water rate in Public tube-wells are 15 to 20% of the economic water rates.

To make the concept of integrated development and conjunctive use attractive and acceptable to the farmer, and to achieve a break-through his prevailing prejudices against State tube-wells, it is of paramount importance that the management of State tube-wells, the service against break down and for their repairs, the system of appointment and conveyance of water, uninterrupted supply of electric energy and general assurance of continuous working during period of demand, must be guaranteed. It is only thus that the farmer will get convinced of the real utility of the system. It should besides be ensureds that command areas in such a system is not in excess of a reasonable limit for multiple cropping and for supply of irrigation water at proper time and in adequate quantities from either or both the resources.

REGULATION AND CONTROL OF GROUND WATER FOR CONJUNCTIVE USE

During the past three decades, ground water development has witnessed a massive acceleration. Though on the national scale there is still considerable potential for future development but when viewed at the micro-level, critical stages appear to have been reached in certain pockets with very high levels of development. Such areas require careful consideration before additional withdrawals are effected. To prevent situation leading to overdrawals and to maintain sustainability of the system and social equity it is necessary that ground water development is regulated on scientific lines to permit optimal development.

ADMINISTRATIVE MEASURES

The method of control presently for regulating the ground water development to some extent is in the form of administrative measures, namely, restrictions of flow of institutional finance for ground water development in areas with high stages of development. Institutional financing agencies require technical clearance for proposed programmes in such areas. However, in the absence of any law, these measures do not necessarily permit the ground water development on scientific lines to control over-exploitation/indiscriminate exploitation of ground water. There is also no restriction on private investments.

MODEL BILL FOR REGULATING GROUND WATER DEVELOPMENT

With a view of protecting the ground water regime, taking safeguards measures against hazards of over-exploitation and ensuring equitable distribution of this vital and finite resource, enactment of suitable legislation to regulate the exploitation of this resource is considered a must sooner than later. Deterious effects of over-drawl are already being felt in some parts and pose a grave danger in coastal areas.

Anticipating the dangers, in 1970 the Government of India has circulated a Model Bill to the State governments for adoption of suitable legislation keeping in view the prevailing ground water situation in the States. the salient provisions of the Bill were :

1. Creation of a State Government Authority to administer the legislation.
2. Empowering the State Government to regulate, in Public interest, the extraction or use or ground water in any form, in any area so notified, based on a report from the Ground Water Authority of the State.

3. Requiring permission from the State Ground Water authority for grant of permit for drilling a well in a notified area for any purpose other than exclusively for domestic use.

4. Registration of the existing user in the notified area.

5. Grant or refusal of permit by the Ground Water Authority based on certain criteria and after providing opportunity to the person concerned to express his views.

6. Regulation of drilling activity in the notified area.

7. Grant of license for sinking wells and tube-wells for modification of permit of license cancellation thereof under certain circumstances.

8. Provision for penalty and approval

While Gujarat had tried to enforce its ground water legislation in a limited area, the State Government of Karnataka, Tamil Nadu and Andhra Pradesh have prepared draft legislation for enactment.

Rajasthan and Maharastra are contemplating similar steps. Madhya Pradesh has enacted a law to protect domestic water supplies in scarcity areas. The Government of Tamil Nadu has also enacted the Madras Metropolitan Area Ground Water Act, 1987. Government of Pondicherry has issued a notification on guidelines for ground Water development.

A committee has been formed under the Chairman of CGWB to review the Model keeping in view the experience of the past two decades and the concerns expressed in National Water Policy, 1987.

CONCLUSIONS AND RECOMMENDATIONS

Out of ultimate SW irrigation potential of 73 m ha. already by end of 1989-90, an estimated potential of 44.5 m.ha has been created. In respect of ground water it is 34.5 m.ha. out of present official figure of 40 m.ha. In case of ground water CGWB has re-assessed the ultimate potential as 80 m.ha. which as been termed as Tentatively revised. Still lot of potential remains to be developed both for S.W. & G.W. It is strongly suggested that in future all irrigation potential should be developed in an integrated manner.

For feeding our growing population which has gone up from 361 million in 1951 to 685 million in 1981, and estimated as 1070 m in 2001, increased food grains production is needed. There is hardly any possibility to increase the net cultivated area of 140m.ha. However there is a considerable scope increasing the present double cropped area of 180 m.ha. Irrigation, one of the main input for increased agricultural production has to be extended from the present potential of 79 m.ha (1989-90) and actual gross irrigated area of about 55 m.ha. (1985-86) at an accelerated pace. At the same time, there is urgent need for plug big gap of about 14 m.ha. (difference in irrigation potential and actual irrigation in 85-89) for which conjunctive use can play an important role.

For planning of conjunctive use of scientific lines, there is inadequacy of micro level hydro meteorological data like rainfall, climate, evaporation, hydrological data like run-off and yield from the catchment, fair weather flow in rivers and streams, geohydrological data like infiltration, seepage, vertical and horizontal flow of ground water and hydro-geological data like transmissivity, specific yield, and other properties and aquifers. At the same time there is hardly any data available of the ground water pumped from different GW extraction structures, availability of electric power, cropping pattern, actual number of GW structures etc. Necessary infrastructure has to be erected for observation, reporting, compilation and analysis of such data.

Water Balance Studies for the major/minor river basins should be completed expediously preferably within a period of 2 years hence. Using these studies, district and block wise ground water balance should be revised and planning of GW development done accordingly in conjunction with surface waters.

All new S.W. irrigation projects should include conjunctive planning and an operational plan for the same. CWC, CGWB should issue the necessary guidelines in this respect. Planning Commission should not give clearance to any irrigation projects in future which do not incorporate conjunctive planning.

Conjunctive use does not merely envisage, canal irrigation to be supplemented by GW but vice-versa also which is of great importance in all drought management programmes. Micro-water shed planning is of great relevance in this respect.

For effective implementation of conjunctive use of surface and ground water there should be Integrated Organisational Structure for the use of all forms of water not only at the centre but also in the States, preferably in shape of Water Resources Departments/River Basin Development Authorities.

Presently monitoring and performance evaluation of conjunctive use is grossly inadequate. Data on regular basis in respect of ground water development structures, SW lift irrigation, small tanks and the areas irrigated by them is hardly available. Necessary organisational set up at State and central level is urgently needed.

Regulation and Control of Ground Water to check the adverse decline in water table and undermining of resource is of prime importance. Suitable GW legislation may be enacted. Till then it may be controlled through indirect measures like stopping of loan, electric connection etc. In addition, artificial recharge measures like construction of monsoon canals, percolation tanks, check dams and GW dams etc. may be taken in areas already suffering from continuous decline of GW table. Use of sprinkler/drip irrigation systems may also be encouraged in such areas.

To give an incentive to farmers for G.W. development in command area of Major-medium irrigation project liberal subsidies and other facilities should be given. At the same time, in case of public tubewells/Augmentation T.W.'s water rate disparity should be reduced.

In order to fully achieve the object of integrated and conjuctive use of surface and ground waters, a comprehensive unified Water Resources Law taking consideration both the sources should be enacted by each State. A draft already prepared by Tamil Nadu State can serve as a guide in the respect.

REFERENCES

1. **Agricultural Statistics at a glance** - Deptt. of Agriculture & Cooperation, Ministry of Agriculture, Govt. of India, New Delhi (Feb. 1990).

2. **Annual report 1989-90** - Ministry of Water Resources, Govt. of India.

3. **Annual Report 1989-90** - Ministry of Agriculture, Deptt. of Agriculture, Govt. of India.

4. **Annual Report 1989-90** - Ministry of Agriculture, Deptt. of Rural Development, Govt. of India.

5. **Agricultural Development by 2000 AD** - Proceedings, National Seminar on Agricultural Development, Ministry of Agriculture, New Delhi (December 1998).

6. **"BHUJAL"** - Journal of Central Ground Water Board, Govt. of India, New Delhi (Oct. 1998).

7. **Conjunctive use of Groundwater in Ramganga Command Area** - Ground Water Deptt. Lucknow India (1988).

8. **Conjunctive use of Surface and Ground Water** - by R.S. Saksena, Proceedings, Seminar on Irrigation Water Management Jan., Institution of Engineers, Roorkee

9. **Conjunctive use of Ground Water and Surface Water for Better Water-Management**, by R.S. Saksena, Irrigation and Power, New Delhi, July, 1987 issue.

10. **Current Status of Minor Irrigation and Ground Water for land resources management**, by R.S. Saksena. Proceedings, National Seminar on Conservation of Land of Water Resources for Food & Environmental Security, January 18-20, 1990 organised by Soil Conservation Society of India, New Delhi (India).

11. **Energy Saving Standards** - Bureau of Indian Standards, New Delhi, India (August, 1990).

12. **Evaluation Report on the working augmentation tubewells installed along the augmentation canal**, Evaluation wing, Planning Department of Haryana, Govt. of Haryana - May, 1976.

13. **Ground Water Development - Status and Monitoring** by Shri. R.S. Saksena, Proceedings, National Seminar on Assessment, Development and Management of Ground Water Resources, 29-30 April, 1983 Central Ground Water Board, Ministry of Irrigation ,Govt. of India, New Delhi.

14. **Ground Water Development in Fractured Rocks** by R.S. Saksena, Proceedings, International Workshop on Rural Hydrogeology and Hydraulics in fissured Basement Zones (1984). pp 179-190. Department of Earth Sciences, University of Roorkee, Roorkee.

15. **Ground Water Potential of India and Present Status of Developments** by R.S. Saksena, Proceedings Seminar on Ground Development - A perspective for the year 2000 A.D. (1983), Indian Water Resources Society, Roorkee.

16. **International Training Programme on Audit of Rural Development Programmes-** Selected Readings, International Training Centre, Office of Controller & Auditor General of India, New Delhi (Sept. - Nov. 1988).

17. **Policies & Planning Procedures for Conjunctive use projects** by Shri M.A. Chitale, Seminar on Conjunctive Use of Surface and GroundWater Resources, 10-13 February, 1986, New Delhi, India.

18. **Planning and Development of Ground Water in India** by Shri R.S. Saksena. Proceedings Vol. 1. Third Congress of the Asian and Pacific Regional Division of the Internation Association for Hydraulic Research (Aut. 1982), Bandurng, Indonesia.

19. **Present Status of Ground Water Management in India & Perspective for Future,** by Shri. R.S. Saksena, Workshop of Efficiency and Equity in Ground Water Use and Management, Institute of Rural Management Anand, Gujarat, Jan-31 - February, 1989.

20. **Minor Irrigation Schemes and their Impact of Rural Development,** by R.S. Saksena. Proceedings, International Training Programme on Audit of Rural Development Programmes Sept. 19-November 03, 1988, organised by International Training Centre, Office of the Controller and Audit General of India, New Delhi.

21. **Minor Irrigation for Rural India** by R.S. Saksena. Paper presented in 77th Indian Science Congress Session held on 4-9th Feb. 1990 at University of Science and Technology Cochin, India.

22. **National water policy** - Ministry of Water Resources, Govt. of India, New Delhi (Sept. 1987).

23. **Report of the Expert Committee on Integrated Development of Surface and Ground Water** of Government of India, Ministry of Agricultural Irrigation Department of Irrigation, New Delhi, May, 1976.

24. **Report of Working Group for VIIIth Plan** - Ministry of Water Resources, New Delhi (July 1989).

25. **Statistics Of Minor Irrigation Development** - Central Board of Irrigation and Power, New Delhi, 1989.

__. **Symposium On Integrated Development of Surface and Sub Surface Water Resources** (44th Annual Board Session Publication No. 113) Central Board of Irrigation & Power, New Delhi, 1971.

27. **Socio-Economic Evaluation of Public Tubewell (World Bank) Phase-II and Study on Water Related Charges, U.P. Development Systems** Cooperation Ltd. Lucknow, India (1988).

28. **Technical Aspects of Agricultural Project Vol. 1** - National Banks for Agriculture Rural Development, Bombay, India (Nov. 1989).

29. **Water Lifting Devices for Irrigation in India** - FAO, Bankok Report (December 1988).

30. **Variations in Ground Water Conditions and Exploitation in Different Districts of Eastern U.P.** by R.S. Saksena. Seminar organised by Agricultural University, Faizabad U.P., India, April, 2988.

31. **"Ground Water Resources of India"** - Central Ground Water Board, Govt. of India, Faridabad - 1995.

32. **"Agricultural Statistics at a Glance - 1998",** Discreate of Economics & Statistics, Dept. of Agriculture and Cooperation, Govt. of India, New Delhi, 1998.

33. **Annual Reports 1997-98 and 1998-99,** Ministry of Water Resources, Govt. of India, New Delhi.

APPENDIX - I

WATER RESOURCES POTENTIAL IN THE RIVER BASINS OF INDIA

Sl. No.	Name of the River Basin	Average Annual Surface Water Potential	Estimated Utilisable Flow Excluding Gr. water	Totat repleni-shable ground water resources	Population in 1991	Per Capita Available Surface Water	Per Capita Surface & Ground Water
		Km^3	Km^3	Km^3	Millions	m^3	m^3
1	2	3	4	5	6	7	8
1	Indus (up to Border)	73.31	46.00	26.49	41.90	1750	2382
2	a. Ganga	525.02	250.00	170.99	356.80	1471	1951
	b. Brahamputra, Barak & Others	585.60	24.00	53.91	35.24	16617	18147
	Godavari	110.54	76.30	40.65	53.98	2048	2801
4	Krishna	78.12	58.00	26.41	60.78	1285	1720
5	Cauvery	21.36	19.00	12.30	29.33	728	1148
6	Pannar	6.32	6.86	4.93	9.70	652	1160
7	East Flowing Rivers Between Mahanadi & Pennar	22.52	13.11	18.22	23.60	954	831
8	East Flowing Rivers Between Pennar and Kanyakumari	16.46	16.73	18.22	45.20	364	831
	Mahanadi	66.88	49.99	16.46	26.60	2514	3133
10	Brahamani & Baitarni	28.48	18.30	4.05	9.77	2915	3329
11	Subernarekha	12.37	6.81	1.82	9.46	1308	1500
	Sabarmati	3.81	1.93	18.42	10.58	360	1120
13	Mahi	11.02	3.10	18.42	10.48	1052	1120

1	2	3	4	5	6	7	8
14	West Flowing Rivers of Kutch Saurashtra including Luni	15.10	14.98	18.42	22.10	683	1120
15	Narmada	45.64	34.50	10.83	14.70	3105	3842
16	Tapi	14.88	14.50	8.27	14.80	1005	1564
[illegible]	West Flowing Rivers From Tapi to Tadri	87.41	11.94	17.69	25.80	3388	3744
[illegible]	West Flowing Rivers From Tadri to Kanyakumari	113.53	24.27	17.69	32.60	3483	3744
19	Area of Inland drainage in Rajasthan desert	NEG.			7.10		
20	Minor River Basins Draining into Bangladesh & Burma	31.00			2.10	14762	14762
	Total	**1869.35**	**690.31**	**431.44**	**842.62**	**2218**	**2731**

APPENDIX - II

...ATER POTENTIAL AND THE LEVEL OF GROUND WATER DEVELOPMENT IN RIVER BASINS OF INDIA (PRO RATA BASIS)

Sl. No.	Name of the Basin	Total Repleni-shable gr. Water resources	Provision for Dome-stic, Indus-trial and other uses	Available Ground water resources for irri-gation	Net Draft	Balance Ground Water Poten-tial available for Exploi-tation	Level of Ground Water Develop-ment %
1	2	3	4	5	6	7	8
1	Brahmani with Baitarni	4.05	0.61	3.44	0.29	3.16	8.45
2	Brahmaputra	26.55	3.98	22.56	0.76	21.80	3.37
3	Chambal Composite	7.19	1.08	6.11	2.45	3.66	40.09
4	Cauvery	12.30	1.84	10.45	5.78	4.67	55.33
	Ganga	170.99	26.03	144.96	48.59	96.37	33.52
6	Godavari	40.65	9.66	30.99	6.05	24.94	19.53
7	Indus	26.49	3.05	23.43	18.21	5.22	77.71
8	Krishna	26.41	5.58	20.83	6.33	14.50	13.39
9	Kutch & Saurashtra Composite	11.23	1.74	9.49	4.85	4.64	51.14
10	Madras and South Tamil Nadu	18.22	2.73	15.48	8.93	6.55	57.68
11	Mahanadi	16.46	2.47	13.39	0.97	13.02	6.95
12	Meghna	8.52	1.28	7.24	0.29	6.95	3.95
	Narmada	10.83	1.65	9.17	1.99	7.18	21.74
14	North-East Composite	18.84	2.83	16.02	2.76	13.26	17.20
15	Pennar	4.9[illegible]	0.74	4.19	1.53	2.66	36.60
16	Subarnarekha	1.82	0.27	1.55	0.15	1.40	9.57
17	Tapi	8.27	2.34	5.93	1.96	3.97	33.05
18	Western Ghat	17.69	3.19	14.50	3.32	11.18	22.88
	Total	**431.43**	**71.08**	**360.35**	**115.21**	**245.13**	**31.97**

APPENDIX - III

EXTENT OF WATERLOGGED AREA AS ESTIMATED BY VARIOUS AGENCIES

State	As per National	As per National	As estimated
Andra Pradesh	N.R.*	3.39	3.39
Assam	N.R.	N.R.	4.50
Bihar	N.R.	1.17	7.07
Gujarat	N.R.	4.84	4.84
Haryana	6.5	6.20	6.20
Jammu & Kashmir	N.R.	0.10	0.10
Karnataka	0.07	0.10	0.10
Kerala	N.R.	0.61	0.61
Madhya Pradesh	0.57	0.57	0.57
Maharashtra	0.28	1.11	1.11
Orissa	N.R.	0.60	0.60
Punjab	10.9	10.9	10.9
Rajasthan	3.48	3.48	3.48
Tamil Nadu	N.R.	0.18	0.18
Uttar Pradesh	8.10	8.10	19.80
West Bengal	18.5	18.50	21.80
Delhi	N.R.	0.01	0.01
Total	**48.40**	**59.86**	**85.26**

N.R. - Not Reported

APPENDIX - IV

GROUND WATER MODELS

The groundwater models are used to understand behaviour of groundwater systems and predict response of aquifer to any external changes such as extraction, recharge etc. The model can be used to select the best of several alternative management plans for a groundwater basin. If the models are properly planned and provided with adequate data they can be used to save reliable time and money besides giving reasonably accurate answer to the problems. Most commonly used in ground water models are simulation models. The essence of simulation is to reproduce the behaviour of a system in every respect. Simulating a groundwater basin involves all of the inherent characteristics of the aquifers constituting the ground water reservoir and probable responses of the system by a model that is mainly mathematical in nature.

The primary value of a groundwater basin model in water resources planning can be realized after the existing hydrogeological conditions have been simulated. It is then possible to impose on that model future conditions which may develop such as increased or redistributed pumping, increased or decreased recharge due to engineering surface structure, change in recharge patterns, or any other factors which may change the existing hydrologic conditions.

The main objective of engineers and planners of water resources systems is to make the decisions which formulate a management policy. Among such decision may be listed those related to the quantity, location and time of pumping form an aquifer and/or artificially recharging it with imported water. When making these decisions, one has to consider the need for additional pumping and recharge installation, the quality of pumped water, the dangers of quality deterioration and the level and quality of water to be maintained in water bodies connected to an aquifer.

Aquifer models are used for studying proposed management policies. Each such policy, comprising for example, a list of timing and location of new installations and specification of the temporal an spatial distribution of pumping and artificial recharge, can be tested for physical feasibility on a model. For each policy which is found to be physically and technologically feasible, one can compute the values of some criteria selected for evaluating the different policies. In this way the best policy can be found. This is simulation approach, it is rather straight forward but does not ensure an optimal solution.

Another approach is to seek an optimal policy using a management model. In this case the aquifer model becomes a set of constraints in the management model. To enable a solution of later the aquifer model should be sufficiently simple, yet not too approximate so as to allow solution which are feasible in reality.

There are a variety of problems which need to be studied in connection with groundwater forecasting and management. These are : (i) ground water balance, (ii) aquifer modelling, (iii) inverse problems, (iv) artificial recharge, (v) coastal intrusion, (vi) quality modelling, (vii) conjunctive surface and groundwater development. Computer based numerical methods are the major tools for solving these problems.

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

(i) Lumped Model

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

Inflow - Outflow = Storage Charge

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 seepage from streams
S_r	=	Influent seepage from streams
S_c	=	Effluent seepage from streams
O	=	Out flow from the basin to other basins
E_t	=	Evapotranspiration from the region in direct contact with the aquifer
T_p	=	Draft from groundwater
ΔS	=	Change in storage of the aquifer

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

(ii) Distributed Model

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

Where

h = Head of water (L)

Q = Flux (L^3)

S = Storativity

T_x = Transmissivity

and $T_y(L^2/T)$

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 categorised as : (i) analogue models and (ii) mathematical models.

Analogue Model

The most commonly used analog model is the Resistor Capacitor (R.C.). network model. The model consists of regular array resistors and capacitors. The resistors are inversely proportional to the hydraulic conductivity of the aquifer and capacitors store electrostatic energy in a manner analogous to the storage of water within aquifer. The electrical network is a scaled down version of the aquifer.

MATHEMATICAL MODEL

A mathematical groundwater model is a mathematical expression or a group of expressions that describe the aquifer functioning. These models are applied to specific aquifers using specific aquifer coefficient and boundary conditions.

The boundary conditions describe the hydraulic conditions and geometric conditions of the boundaries of aquifers and their variation with time. Groundwater models mostly use finite difference, finite element techniques for obtaining numerical solution.

APPLICATION OF MODELLING TECHNIQUE

Groundwater Modelling has been attempted for several river basins within alluvial and hard rock areas. The Central Groundwater Board has prepared the models for the following basing :

(i) Mehasan basin (Gujarat)

(ii) Ghaggar river basin (Himachal Pradesh, Punjab, Rajasthan, Haryana, Chandigarh).

Upper Yamuna basin (Himachal Pradesh, Haryana, Utter Pradesh, Delhi)

(iv) Vedavati river basin (Karnataka, Andhra Pradesh)

(v) Noyil river basin (Tamil Nadu, Kerala)

Noin river basin (Madhya Pradesh)

MEHSANA RIVER BASIN

An area of 11500 sq.km. comprising mostly plain fertile with some foot hill areas in northern part of Gujarat was modelled to ascertain the extent of over exploitation and requirement of artificial recharge. The two dimensional equation of flow was solved numerically using finite difference technique for multi-layer aquifer system. The boundaries of the model were chosen to cover the main portion of the project area and some areas beyond to reduce interference effects. The model suggested that in certain over exploited areas pumping should be reduced while in other areas (near the base of the mountains) more groundwater could be exploited, without producing adverse effects. Based on the finding of this model study, C.G.W.B. with U.N.D.P. assistance has taken up a pilot project for artificial recharge.

GHAGGAR RIVER BASIN

Ghaggar river basin of about 42,000 sq.km. mainly alluvium plain country is located in the north western part of India in the states of Punjab, Haryana, Rajasthan, Himachal Pradesh and Union Territory of Chandigarh. The area is drained by river Ghaggar. To cope with the increased intensity of floods, a carrier channel was made to divert the excess surface flow to 24 depressions in sand dune area south and southeast of Suratgarh. In this basin, to keep pace with the increasing demand, the management of available water resources is very essential. It was decided to study the entire system through a mathematical model. The primary objectives were prediction of future ground water levels under expected pumping patterns, requirement of artificial recharge over draft areas, possibility of using saline groundwater, surface and groundwater relationship with regard to various field irrigation requirement. The area was modelled using finite difference technique. Forecasting runs were taken to see the conditions by the end of year 2000. Thus with the help of the model, possible solutions to the problem posed could be obtained.

UPPER YAMUNA BASIN

The Upper Yamuna basin covering an area of about 25000 sq.km. is located in northern part of India and falls in the stages of Himachal Pradesh, Utter Pradesh, haryana and Delhi. Yamuna forms the main drainage of the basin. Ground water exploitation has been going-on a large scale and increase has been of the order of 300 percent in the period 1967-68 to 1976-77. In view of this large scale ground water development it was considered essential to have a detailed study for planning groundwater resources development and management. Further the water use rights of different states require minimum level supply to be maintained in the river around Delhi. The large scale groundwater exploitation could cause adverse effects on the regeneration in the river. Hence, it was equally essential to study the response of the groundwater system as a result of ground water withdrawal and the planned future development of safeguard established water use rights and ecological balance. This required a development of a stream aquifer interaction regional groundwater flow model.

A two dimensional finite element model was developed because it could be better suited to handle the irregular boundaries of the system and it could be converted into a three dimensional model and could incorporate the homogeneity of the aquifer system. In the finite element method the complete continuum constituting the study area is descretized into a large number of discrete finite elements. The different equation governing equation governing the flow of water through porous media based upon the continuity equations is approximated using the Galerkin's method.

The aquifer parameters and draft data from the basin were obtained through field surveys and discretised over the area. The node wise natural flux has been calculated by solving the inverse problem corresponding to solution of Poisson's equation.

The stream aquifer interaction was modelled by conceptual realization of the interface existing between stream and aquifer. As is known, the flow across the boundary between the natural stream and thé adjacent aquifer connected hydraulically may occur in the following conditions :

(i) Seepage form the aquifer into the stream

Seepage from the stream into the aquifer

The conditions of flow in both the cases motioned above are affected by the presence of a silt layer on the banks and the bed or river. The Upper Yamuna Model simulates both the above flow situations to be used appropriately.

The Upper Yamuna Model was calibrated and validated before using it for prediction purposes. The method adopted for this purpose was the subjective calibration. In this technique, a historical time period is chosen and all data relevant to that period are coded in the model. The computer generated responses (water feel and river flow in this case) are compared with actual observed historical records. The match is tested for its acceptability. In case of unacceptable departures, the are adjusted within reasonable limits, till an acceptable match is obtained.

The validated model was used to study the nature of response of the Upper Yamuna system as a consequence of large scale ground water development in the area. The results are summarised below :

Monthly river regeneration between Tajewal a and Wazirabad does not show any appreciable decline due to augmentation/other models of draft.

Augmentation drafts have local effects in declining the water table but it appears the same is being recouped by groundwater flow to a major extent.

(iii) Overall effect of augmentation and other modes of drafts on the water table aquifer in the area studies is negligible.

(iv) The present quantum of groundwater draft having little regulatory effect on the confined aquifer can be attributed to :

(a) Salvage of evaportranspiration losses, as large areas in Haryana were under water logging prior to augmentation pumpage.

(b) More induced flow to water table aquifer from various sources.

(v) Further augmentation draft may be permitted in the area without affecting the river regeneration but that draft must be from deeper aquifers and location of the augmentation draft must be further down the present augmentation canal project. Such a scheme may, however, create local depressions.

Continuance of the augmentation draft in future may generate decline in water table adjacent to river in U.P. area as well without appreciable declining river regeneration.

(vii) An large scale groundwater development above the present location of the augmentation canal project may effect river regenerations.

VEDAVATI RIVER BASIN

The basin covering an area of 24,196 sq. km. is located in South India covering parts of the states of Karnataka and Andhra Pradesh. The area mainly comprise of hard rock formation. The alluvium patches exist along major streams in the granitic terrain.

The aquifers in the area are located in the weathered, fractured and jointed zone of the hard rocks. The aquifers are semi-unconfined to leaky semi-confined. The thickness of the aquifers is largely varying in different sub-basin and different rock types. In general dug wells are 20-30 m deep, while bore wells are less than 60m deep except in lower Fagari sub-basin, where wells upto 130 m bgl. also exist.

The recharge into the groundwater is primarily due to rainfall. The Groundwater modelling was done with the following main objective.

(i) Prediction of the responses of the groundwater system for various operating conditions.

The conjunctive use of groundwater and surface water systems for optimal development.

The modified leaky aquifer model is used for this study. The modification from the classical approach lie in treating the entire saturated portion above the aquifer as a composite aquitard in which the is flow predominantly vertical and considering the variation of head in both the aquitard and aquifer by solving coupled partial differential equation for the aquifer and the aquitard.

The model was developed at the Indian Institute of science, Banglore. With the help of this model, it could be possible to work out the safe yield in the basin, the pockets of over exploitation, the effect of drought condition and finally the Taluka additional irrigation potential from the groundwater.

NOYIL RIVER BASIN

The basin are (3,150 sq.km.) lies in the state of Kerala and Tamil Nadu. The area is covered by soils, alluvial deposits and weathered bed rock. Deep seated fracture zones exist all over the area. The overburden and weathered rock together range in thickness from a few meter to about 100 m. Ground water occurs under phreatic and semi-confined condition.

The main objective of development of mathematical model in the basin was to predict the water level distribution over the area of the basin for various conditions of consumption and rainfall.

The first phase is to determine the storativity and transmissivity by developing a model and computer programe and solving the inverse problem i.e., by solving the finite difference approximation of the equation of the groundwater flow for transmissivity and storativity as unknown parameters by using observed water levels and optimization procedure.

The second phase is the prediction of water levels by using the recharge and discharge and properties of the aquifer as input data.

The alternating Direction Implicit (ADI) procedure was used to solve the finite difference form of the equations for all the nodes of the grid for water level elevation.

NION RIVER BASIN

The Nion basin is a sub-basin of the Betwa river Basin. It covers an area of about 863 sq.km. in M.P.

The shallow aquifer consists of some or all the layers commonly developed within the present day weathering. The weathered antic extends from the surface to a depth normally less than 30m. It covers most of the basin except the cistern part where more or less unweathered basalt is exposed at the surface.

The objective was to develop a technique for groundwater investigation and management and to test the conceptual model of the groundwater system suggested by field hydrologeologist.

Finite difference approximation to the groundwater flow equation is solved using the successive over relaxation technique.

OTHER MODEL STUDIES

In addition to the model studies done by C.G.W.B. as described above several other studies have been taken by other institutions.

UPPER GANGA CANAL MODEL

The National Institute of Hydrology Roorkee with the objective of conjunctive use of surface and groundwater in the upper Ganga Canal command U.P. calibrated a two seasonal Tyson-Weber model using mean year conditions and validated for 4 years of data. The main findings of the model are :

(i) There is a quick response of water table to charging and discharging factors. So the yearly variation of water table is small and ground water storage carry over is not feasible without bringing water table very low.

With construction of M.G.C.I. (Monsoon irrigation by canal and non-monsoon by state tubewells) the groundwater table shall be rising the MGC area with existing level of extraction from State tubewells and so additional groundwater extraction is needed.

About 1,200 Augmentation Tubewells located along Main Branches/Distributaries with 2.25 cusec capacity, can operate during monsoon/non-monsoon during peak demand and can supplement the canal flows. Thus, about 2,700 cuses can be available by operating the ATW at the time of peak demand for any crop.

CONSTITUTION OF INDIAN NATIONAL COMMITTEE ON HYDROLOGY

i.	Chairman Central Water Commission, New Delhi	Chairman	
ii.	Director National Institute of Hydrology, Roorkee	Executive Member	
iii.	Dy. Director-General Geological Survey of India, Calcutta	Member	
iv.	Chairman Central Ground Water Board, Faridabad	Member	
v.	Dy. Director-General India Meteorological Department, New Delhi	Member	
vi.	A Senior Scientist National Remote Sensing Agency, Hyderabad	Member	
vii.	Member (D&R) Central Water Commission, New Delhi	Member	
viii.	Director Research, Designs & Standards Organization, Lucknow	Member.	
ix.	Additional Director Indian Institute of Tropical Meteorology, Pune	Member	
x	Director Central Designs Organization, Gujarat, Gandhinagar	Member	
xi.	Chief Engineer (Design) Irrigation Department, U.P. Roorkee	Member	
xii.	Director Central Designs Organization, West Bengal, Calcutta	Member	
xiii.	Director BODHI, MP, Bhopal	Member	
xiv.	Chief Engineer & Director Water Resources Development Organization, Karnataka Bangalore	Member	
xv.	Chief Engineer Central Designs Organization, Maharashtra, Nasik	Member	
xvi.	Dr. B.V. Rao Indian Institute of Technology, Mumbai	Member	
xvii.	Dr. T. Prasad Director Centre for Water Resources Studies, Bihar College of Engineering, Patna	Member	
xviii.	Dr. N.V. Pandarikanthan Director Centre for Water Resources, Anna University, Chennai	Member	
xix.	President Indian Association of Hydrologists, Roorkee	Member	
xx.	Director (R&D&SA) Central Water Commission, New Delhi	Member	
xxi.	Senior Scientist National Institute of Hydrology, Roorkee	Member Secretary	