REPORT

OF

THE GROUNDWATER OVEREXPLOITATION COMMITTEE

AGRICULTURAL REFINANCE AND DEVELOPMENT CORPORATION

BOMBAY

1979

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CONTENTS

APPENDICES

Appendix I

Old guidelines for evaluation of groundwater resources in a region.

Appendix II

ARDC II — Statewise groundwater utilisation

Appendix III

ARDC II — Criteria for spacing and density of wells.

Appendix IV

Methodology adopted for groundwater evaluation in special projects of Central Ground Water Board.

Appendix V

Estimation of stage of groundwater development.

ABBREVIATIONS USED

mm	millimetre
cm	centimetre (s)
m	metre (s)
m^2	metre square
ha	hectare (s)
sq. km	square kilometres
ham	hecta metres
mcm/mm^3	million cubic metre
TCM	thousand cubic metre
cusec	cubic feet per second
cumec	cubic metre per second
ARDC	Agricultural Refinance and Development Corporation
CGWB	Central Ground Water Board
SGO	State Groundwater Organisation

CHAPTER I

INTRODUCTION AND TERMS OF REFERENCE

In accordance with section 3.08 of the ARDC II project agreement, ARDC was required to carry out on a sample basis under terms of reference acceptable to IDA a detailed study of over exploited areas as listed in the schedule for purpose of collecting accurate data on the extent of investment taking place in areas identified as problem areas. Earlier, under the first ARDC credit project, the Central Ground Water Board had identified certain areas as problem areas in regard to groundwater development. Fresh schemes for minor irrigation investment in these areas were to be cleared only after detailed investigations by the State Groundwater Directorates under the second ARDC Credit Project. IDA Funds were not be made available for reimbursement against loans for minor irrigation investments in the problem areas identified by CGWB and ARDC unless the State Government concerned has either instituted acceptable control over the sinking of new wells or has carried out further studies proving that there is no longer a problem in these areas and that such areas could at the discretion of ARDC be removed from the problem areas list. The proposed study of certain sample of over-exploited areas were in persuance of the above objective

As the proposed study was of an All India nature, ARDC considered it necessary to constitute a high level committee for carrying out the study. The composition of the committee to study the problem of over-exploitation was as under :

1. Shri J. K. Jain — *Chairman*
   Chairman
   Central Groundwater Board,
   Dept. of Agriculture,
   Krishi Bhavan, New Delhi.

2. Shri Y. S. Borgaonkar — *Member*
   General Manager
   ARDC, Bombay.

3. State Groundwater Directorates

   a) Dr. B. P. Radhakrishna — *Member*
      Chairman-cum-Managing Director
      Chitaldurg Copper Company
      and Groundwater Advisor to
      Govt. of Karnataka

   b) Shri B. S. Karkare — *Member*
      Director
      Groundwater Surveys and
      Development Agency
      Govt. of Maharashtra.

   c) Shri V. A. B. Sastri — *Member*
      Deputy Secretary
      Groundwater Cell
      Directorate of Agriculture
      Govt. of Haryana
      Chandigarh

   d) Shri M. D. Pathak — *Member*
      Managing Director
      GWRDC Gandhinagar

4. Shri Dinesh Chandra — *Member*
   Deputy Secretary
   Department of Economic Affairs
   Government of India
   New Delhi.

5. Shri V. S. Dabholkar — *Member*
   Deputy Chief Officer
   Agricultural Credit Department
   Reserve Bank of India
   Bombay 400 018

6. Shri L. Krishnan — *Member*
   Joint Chief Officer
   Department of Banking Operations
   and Development
   Bombay.

7. Shri V. V. S. Mani — *Member-Secretary*
   Deputy Director (Tech.)
   Agricultural Refinance &
   Development Corporation
   Bombay 400 018

In the first meeting of the committee held at New Delhi on 14-3-1978 it was decided to co-opt the following new members with a view to making the committee as broad based as possible.

a) Shri B. K. Baweja
Chief Hydrogeologist and Member
Central Ground Water Board
New Delhi.

b) Chief Engineer (Groundwater)
PWD — Govt. of Tamil Nadu
Madras.

c) Director
Water Resources Directorate
Punjab–Chandigarh.

Consequent to joining of Shri S. P. Sangal as Director (Technical) in ARDC he was appointed as a Member of the Committee during March 1979.

It was also decided to include a representative of the Agricultural Finance Corporation as a special invitee on a request from the Managing Director, AFC. Shri K. Roy, Project Executive attended the meetings on behalf of AFC. During the second meeting of the committee it was decided to make Director, Ground Water Investigation Organisation, Uttar Pradesh, as member of the committee. Shri R. S. Saksena, Superintending Engineer (MI) in the Union Department of Agriculture attended the meetings of the committee as a special invitee.

The final composition of committee was as under :

1. Shri J. K. Jain — *Chairman*
Chairman
Central Groundwater Board
Department of Agriculture
Krishi Bhawan
New Delhi. 11

2. Shri Y. S. Borgaonkar — *Member*
General Manager
Agricultural Refinance and
Development Corporation
Bombay 400 018.

3. Shri L. Krishnan — *Member*
Joint Chief Officer
Department of Banking Operations
and Development
Bombay.

4. Shri V. S. Dabholkar — *Member*
Deputy Chief Officer
Agricultural Credit Department
Reserve Bank of India
Bombay 400 018.

5. Shri B. K. Baweja — *Member*
Chief Hydrogeologist and Member
Central Groundwater Board
Jamnagar House
Mansingh Road,
New Delhi.

6. Shri S. P. Sangal — *Member*
Director (Tech.)
Agricultural Refinance and
Development Corporation
Bombay 400 018.

7. Shri Dinesh Chandra — *Member*
Deputy Secretary
Department of Economic Affairs
Government of India
New Delhi.

8. Dr. B. P. Radhakrishna — *Member*
Chairman-cum-Managing Director
Chitaldurga Copper Company
Groundwater Advisor to
Government of Karnataka
Bangalore.

9. Shri M. D. Pathak — *Member*
Managing Director
Gujarat Water Resources
Development Corporation
Gandhi Nagar.

10. Shri C. A. Srinivasan — *Member*
Chief Engineer (Groundwater)
Public Works Department
Government of Tamil Nadu
Madras.

11.	Shri B. S. Karkare Director Groundwater Surveys and Development Agency Government of Maharashtra Pune.	*Member*
12.	Dr. G. Goyal Director Water Resources Directorate Government of Punjab. Chandigarh.	*Member*
13.	Director State Groundwater Investigation Organisation, Uttar Pradesh.	*Member*
14.	Shri V. A. B. Shastri Deputy Secretary Groundwater Cell Directorate of Agriculture Government of Haryana Chandigarh.	*Member*
15.	Shri V. V. S. Mani Deputy Director (Tech.) Agricultural Refinance and Development Corporation Bombay 18.	*Member Secretary*

The IDA had indicated that 31-12-1978 should be the date before which the committee should submit its report. However, during April 1978, the World Bank technical experts desired that the time limit be extended upto June 1979 so that the study can be carried out over one Hydrological cycle. The IDA thereafter extended the date of final submission of the report till 31st October 1979. The overexploitation committee finalised its report in October 1979.

TERMS OF REFERENCE

According to the project agreement under ARDC II, the proposed sample study was to be carried out as per terms of reference acceptable to IDA. Accordingly ARDC had proposed the following terms of reference.

(i) to carry out a detailed study, on a sample basis, of the areas in the country which have so far been declared as critical areas by CGWB;

(ii) to indicate, on the basis of available data, further areas which are likely to be over-exploited in view of increasing investment for development of minor irrigation structures;

(iii) to indicate the role played by SGOs in regulating groundwater exploitation in areas mentioned in (i) and (ii) above;

(iv) pending appropriate legislation in this regard, to suggest suitable measures for adopting in such areas for conservation of ground water keeping in view the recharge from various natural sources and also major and medium irrigation projects likely to be taken up in these areas;

(v) to collect comprehensive and accurate data on the extent of investment from different sources taking place in areas (i) and (ii) above. The various sources may be land development banks, commercial banks with or without refinance assistance from ARDC, private sources of individual cultivators whether borrowed or own, government agencies or local authorities;

(vi) any other matter pertaining to groundwater exploitation relevant to the study.

These were forwarded to IDA for their concurrence. In January 1978 the IDA technical expert who visited India in connection with preparations for ARDC III expressed the view on behalf of the World Bank that the scope of studies as visualised in the original covenant was too limited in scope. The ARDC terms of reference correctly went beyond this but still had several limitations and needed modifications in order to yield the required information and detailed terms of reference indicating methodology for sample study was given.

The committee felt that to evaluate ground water resources under ARDC III, it was necessary to refine the existing norms which were finalised in the year 1972. The previous norms were evolved at a time when detailed studies on groundwater assessment were not available and ad hoc parameters were taken into consideration. However since 1972 the Central Ground Water Board, the SGOs and the Universities have carried out detailed water balance studies which have thrown much light on the various aspects of groundwater recharge. The new norms are given in Chapter IV of the report.

The terms of reference given to the committee covered 5 items, the 6th being of a general nature indicating that the Committee may consider any other item which it feels relevant to the study.

(i) The first item in the terms of reference pertain to detailed study on a sample basis of the area declared critical by the Central Ground Water

Board. The Committee selected a few of such areas and the results are given in Chapter III of the report.

(ii) The second item in the terms of reference pertain to indicating further areas which are likely to be over-exploited in view of increasing investment for development of minor irrigation structures. The committee felt that before such a study can be undertaken it was desirable to lay down new norms for evaluation of groundwater resources for different geological settings obtaining in India and thereafter the SGO can work out the water balance and stage of groundwater development on a blockwise basis and submit a list of blocks where the stage of development is over 80% as per ARDC III norms finalised with the world bank and submit it to ARDC by December 1979. These new norms were accordingly laid by the Committee and are given in Chapter IV of the report.

(iii) The third item in the terms of reference pertain to indicating the role played by SGOs in regulating groundwater exploitation in areas mentioned in (i) and (ii) above. The committee examined this aspect in detail. It was observed that the SGOs are playing a very effective role in regulating groundwater exploitation in areas which are in a comparatively higher stages of groundwater development. This work is being carried out by the various SGOs by exercising 3 main types of control. These are:

(a) The SGO give clearance for institutional financing in those areas only where adequate groundwater balance is available.

(b) The spacing stipulations are strictly followed to regulate financing of only economically viable schemes and thus avoiding over capitalization on minor irrigation works in an area.

(c) The SGOs continually monitor the water levels in those blocks which are in a comparatively higher stage of development besides such observations being carried out in other blocks as well.

(iv) The fourth item in the terms of reference requires that pending legislation the committee may suggest suitable measures for adopting in overdeveloped areas for conservation of groundwater keeping in view the recharge factors :

The committee examined this aspect in detail and recommends that the SGO should keep on continuous monitoring of water table behaviour in such critical areas and clear works in areas where no progressive decline of water table is noticed by them. The pumpage cleared should not also exceed the recharge at any stage of groundwater development. Besides, revised spacing norms as given in Chapter IV should also be observed by the SGOs.

(v) The fifth item in the terms of reference pertain to collection of comprehensive and accurate data on the extent of investment from different sources taking place in areas (i) and (ii) above.

The Committee felt that collection of yearwise data regarding investment for private and institutionally financed works under the various categories of minor irrigation works should be carried out by the various SGOs for the last 5 years and submitted to ARDC. This data should also be required by them to make future projections for groundwater requirement at year 5.

(vi) The sixth item of the terms of reference pertain to study of any other matter pertaining to groundwater exploitation. The Committee felt that the SGOs should continuously carry out further research to refine the norms laid down under ARDC III. The suggested fields of research are given in Chapter IV of the report.

CHAPTER II

REVIEW OF METHODOLOGY AND NORMS ADOPTED FOR GROUNDWATER EVALUATION IN INDIA

I. METHODOLOGY AND NORMS ADOPTED IN THE PAST

Before 1972 the technical appraisal of groundwater schemes on the basis of available geohydrological knowledge was by and large limited to only those areas which were covered under the schemes financed by ARDC. Subsequently steps were taken to rectify the situation and undertake similar scrutiny in case of other groundwater schemes which were financed by land development banks under their normal lending activities.

Keeping in view the three important points viz.

(i) inadequacy of existing state groundwater organisations to cope up with the groundwater surveys required, (ii) quality and exhaustiveness of the investigation, and (iii) flexibility of criteria to be adopted in computing recharge factors, drafts, spacing of wells etc; guidelines were prepared for an approximate evaluation of groundwater potential and these were circulated to all the State Governments, ARDC, LDBs, etc., vide Ministry of Agriculture, Government of India's letter No. 12-2-72/MIT dated the 23rd May 1972 (Appendix I).

The following norms were suggested :

(i) Recharge from Rainfall

(a) For Alluvial areas by Chaturvedi formula

$R_p = 2.0\ (R-15)^{2/5}$

Where R_p = Recharge in inches

R = Rainfall in inches

(b) In Hard Rock areas upto 7.5%.

(c) In project areas where authentic data is available about the rise of water table, rainfall contribution to groundwater recharge may also be calculated as a second check by multiplying rise of the water table with estimated average value of specific yield and making adjustments for the withdrawal of groundwater if any during the monsoon season and also for the seepage during the period from canals and other surface water sources which may exist in the area.

(ii) Recharge from other Sources

(a) Seepage from canals at 6 to 8 cusec per million sq. ft. of wetted area or 1.8 to 2.5 cumec/10^6 sq. meter of the wetted area.

(b) From storage tanks = 5% of storage

(c) Return flow from irrigation = 20% of the estimated average total water application – higher figures for paddy areas.

(iii) Spacing for Works

(a) The average spacing between dugwells, borewells and shallow tubewells may be determined by application of the following formula :

$$Sm = 1000 \sqrt{\frac{R \times A \times C}{r \times 1000}}$$

where R = Water requirement of crops in mm.

A = Area of command of well in hectares.

C = Cropping intensity.

r = Annual total groundwater recharge from all sources including rainfall, seepage from canals and tanks, return seepage from irrigation in the area.

(b) In case of medium and deep tubewells the criterion for spacing may be specified on the basis of radius of influence of wells to avoid mutual interference.

II. CRITERIA SUGGESTED UNDER ARDC II

The old guidelines were continued to be followed but areas where the risk of over-exploitation of water resources was high were separately listed for careful development in future (Appendix II). Minimum spacing between wells was considered essential to avoid over-exploitation of groundwater resources and interference between individual water wells. Guidelines for minimum spacing and permissible density of wells were specified as given overleaf.

Table 2.1

Well Spacing (Minimum Spacing in Mts.)

Aquifer and well type	Annual Rainfall in mm.			
	Upto 500	500–1,000	1,000–1,500	Over 1,500
Dugwells				
Without pumpset[1]	180 m	150 m	110 m	100 m
With pumpset[2]	250 m	200 m	150 m	100 m
Tubewells in Alluvium				
Shallow tubewells[3]	275 m	225 m	175 m	150 m
Deep tubewells[4]	1000 m	800 m	600 m	500 m
Tubewells in Sedimentary Rocks				
Medium Tubewells[5]	700 m	700 m	700 m	700 m

1 Typical annual withdrawal 5–6,000 m^3
2 Typical annual withdrawal 10–12,000 m^3
3 Typical annual withdrawal 15–25,000 m^3 at 25–40 m^3/hr.
4 Typical annual withdrawal 30–40,000m^3 at 150–200 m^3/hr.
5 Typical annual withdrawal 75–125, 000 m^3 at 75–100 m^3/hr.

These were however not applicable to farmers who could use their own resources to install wells/tubewells. As such it was recommended that suitable legislation shall be enacted by State Governments. The details of the norms are given in Appendix III.

III. REVIEW OF CURRENT WORK CARRIED OUT IN INDIA

Since 1972 a great deal of work has been carried out in India to refine the earlier guidelines and to base them on more scientific data and detailed analysis. In this respect significant contributions have been made by the following organisations.

A. Central Ground Water Board.
B. State Government Groundwater Organisations.
C. Universities and Research Organisations.

A. Work done by Central Ground Water Board (CGWB)

The CGWB carried out several special projects for detailed basin studies in the country. These projects were conceived as experimental basin studies and were carried out in limited representative areas covering different types of hydrogeological formations in the country so that the results may be applied to much wider areas. The following were the main objectives of these project studies :

(1) To evaluate the groundwater potential in the region.

(2) To construct a mathematical model and to work out with the help of this model a plan for optimum utilisation of the groundwater resources.

(3) To indicate the optimum design of the various groundwater structures (dugwells, dug-cum-bore wells, tubewells of various depths etc.) considered feasible for each lithological unit in the area.

(4) To establish and evolve relationships and norms which may be applicable to much larger areas with similar hydrogeological conditions. These studies pertained to the following main parameters.

   (i) Rainfall penetration
   (ii) Seepage from canals
   (iii) Return flow from irrigation
   (iv) Estimation of the effluent discharge during the rabi season.
   (v) Norms for density of exploratory drilling in experimental basins and for normal development.
   (vi) Evolving cheaper methodology for determination of aquifer constant —storativity and transmissivity.

(5) To identify areas in the country which have similar hydrogeological conditions and where the relationships/ norms established under the project can be considered as applicable.

(6) To provide on-job training to staff of CGWB and State Groundwater Organisations in sophisticated techniques of exploration and assessment including mathematical modelling.

So far CGWB has taken up nine such projects in different parts of the country and five out of these have been completed. The various norms arrived at under these projects are as below.

(a) UNDP Assisted Project In Arid And Semi-Arid Areas Of Western Rajasthan And Gujarat (Completed)

The project areas comprised part of Jodhpur and Bikaner districts of Rajasthan and Ahmedabad, Mehesana and Banaskanta districts of Gujarat. The result of these studies are given in the following tables and details of the methodology are given in Appendix IV.

Table 2.2

Rainfall Recharge In Rajasthan

Aquifer	Basin	Annual rain-fall (mm)	Mean water level fluc-tuation (cm)	Speci-fic yield %	Rech-arge (mm)	Percent of Rain-fall
Quaternary	Sikar	409	33	10	33	8
Quaternary alluvium	Luni	409	67	5	33	8
Palana sandstone	Bikaner & Luni Basins	409	19	7	13	3
Nagaur sandstone	Bikaner Basin	404	74	1	7	1.7
Precambrian basement	,,	404	122	0.5	6	1.5
Nagaur limestone	,,	404	81	1	8	2

Table 2.3

Rainfall Recharge In Gujarat

Sr. No.	Place	Annual Rainfall (mm)	Recharge (mm)	Percentage of Rainfall
1.	Ahmedabad	708	124	17.5
2.	Palana	495	42	8.5
3.	Idar	807	115	14.2
4.	Deesa	529	116	21.9

Depending upon soil type the return flow from irrigation was taken as 20 to 35% of water, applied in field.

(b) Canadian Assisted Groundwater Project (Completed)

The Project area comprised of 11,620 sq. km. and lies in parts of the Krishna and Godavary river basins covering parts of Hyderabad, Mahabubnagar and Medak districts of Andhra Pradesh and Bidar and Gulbarga districts of Karnataka State. The Project area is underlain by peninsular gneisses and granites of Archean age intruded by dykes of dolerite, reefs of quartzites and veins of quartz and pegmatite. Deccan Traps (Basalts) with infratrappean beds consisting of siltstones, claystones, limestones and laterites are capping the traps. As a result of these studies the following norms were arrived at :

(i)	Recharge due to rainfall in upland areas	=	15 to 20% of Rainfall
(ii)	Recharge due to rainfall in valley fills	=	5% of Rainfall
(iii)	Average annual recharge	=	8.3% of Rainfall
(iv)	Specific yield	=	0.5 to 4%

(c) Ghaggar Basin Project (Completed)

The project area covers the whole basin of Ghaggar river and extends over an area of approximately 42,000 sq. km. in part of the States of Haryana, Himachal Pradesh, Punjab, Rajasthan, and the Union Territory of Chandigarh in north western part of the country. Most of the basin area consist of flat alluvial plains. A small portion of the basin in the east is occupied by Sivalik hills and the narrow kandi belt of alluvial tracts.

As a result of these studies the following norms were arrived at :

(i) Recharge from Rainfall

The recharge is given here as percentage of yearly rainfall.

	Districts	Recharge
Haryana	Ambala	18.3%
	Kurukshetra	18.2%
	Karnal	11.3%
	Jind	13.8%
	Hissar	6.2%
	Sirsa	13.6%
Punjab	Ropar	35.3%
	Patiala	24.4%
	Sangrur	18.9%
	Bhatinda	11.0%
	Faridkot	2.3%
	Ferozpur	1.1%
Union Territory	Chandigarh	41.6%
Rajasthan	Ganganagar	5.3%

(ii) Seepage From Canals

Major canals = 3.37 to 6.43 m^3 per million sq. mt. of wetted area

Minor canals = 1.18 to 3.15 m^3 per million sq. mt. of wetted area

(iii) Annual Draft

(a) Tubewells with electric motor	=	2.5 to 3.2 ha. m.
(b) Tubewells with diesel engine	=	1.0 to 1.8 ha. m.
(c) Dugwells with persian wheels	=	0.25 ha. m.

(d) Narmada Valley Basin Project (Completed)

The project area includes part of Hoshangabad, Sehore, Raisen, Narsinghpur and Jabalpur districts of Madhya Pradesh, and covers 25,900 sq. km. out of which the alluvial area is 14,500 sq. km. Out of remaining the parts of Baroda, Broach and Surat districts of Gujarat form the Outfall Area covering 6,250 sq. km. which is essentially a compound deltaic plain of Narmada, Mahi, Dhadhar and Kim rivers. Of this, an area of 3,885 sq. km. is in the Narmada basin.

The prominent geological formations in the catchment area of the Upland Valley which range in age from the Pre-Cambrian to Recent and consist of granites, granitic geisses, schists, phyllites, quartzites, slates, sandstones, limestones, basalts and the conglomeratic beds. The rock types in the Outfall Area range in age from the Upper Cretaceous to Recent comprising the Deccan Trap along with the argillaceous, arenaceous and calcareous formations of the Tertiary Group and the sediments of the Pleistocene and Recent ages.

As a result of these studies the following norms were arrived at.

(i) Recharge due to rainfall (In upland alluvial valley)	=	10.5% of annual rainfall
(ii) Specific yield Average value	= =	5.5 to 10% 7%

Annual Groundwater Draft :

(i) Dug wells without pumpsets	=	0.37 ha. m.
(ii) Dug wells with pumpset	=	2.4 to 4.5 ha. m.
(iii) Tubewells	=	23 ha. m.

(e) Upper Jamuna Project (In Progress)

The project area comprises part of alluvial tracts of eastern Haryana and Western Uttar Pradesh. The project field work has been completed and analysis of the data is in progress.

(f) Vedavati River Basin Project (In Progress)

The project area covers part of hard rock areas of Karnataka and Andhra Pradesh. The work on the project is still in progress. Adopting the same methodology as in the case of Canadian assisted project the tentative findings are given below :

(i)	Specific yield	=	3%
(ii)	Recharge due to rainfall	=	10% of rainfall
(iii)	Recharge due to canal seepage	=	9 to 10% of total input
(iv)	Recharge due to applied irrigation	=	10 to 12%
(v)	Recharge due to percolation tanks	=	10 to 13% of storage.

Seepage from unlined main canal in Granitic and Schistose terrain was taken as 0.30 MCM per 10^6 m^2 of the wetted perimeter/day.

Some more studies as given below were carried out to estimate the contribution of rainfall to groundwater recharge in the project area.

The various components of the hydrogeological cycle were estimated in the Vedavati River Catchment as part of the hydrogeological and water balance studies under a time bound project. Three different methods using the water balance equation and one method analysing the rainfall that occurred during the period of rise in water levels was utilised in arriving at an estimate of the gross groundwater recharge. The values obtained range from 13 to 21% of the rainfall in normal rainfall years. However, in an year like 1976 when the annual groundwater reservoir suffered actually a loss of 3.4 per cent, the dynamic reserve was estimated at 7 per cent of the annual rainfall. This gave the ratio of recoverable recharge to gross recharge as 40 per cent. This result is however not of general applicability as it pertains to an year of low rainfall.

(g) Betwa Basin Project (In Progress)

Betwa project is a water balance study project in collaboration with the United Kingdom. Its main aim is to assess the groundwater recharge and thus the groundwater potential in the basin of Upper Betwa river and at the same time to develop techniques which may be applied to similar areas elsewhere.

The water balance of the basin has been worked out by considering the seasonal cycle as a single period of water recharge during the monsoon and single period of total pumpage during the reminder of the year. It becomes analogous to studying the response to a series of a single storm with uniform antecedent conditions. The studies gave the following results :

Annual rainfall	=	1138 mm.
Soil moisture recharge	=	175 mm. (15.4% of rainfall)
Groundwater recharge	=	75 mm. (6.6% of rainfall)
Run-off	=	339 mm. (29.8% of rainfall)

(h) Sida Assisted Groundwater Project (In Progress)

The project covers an area of 8145km² located in the states of Tamil Nadu and Kerala. It comprises of the Noyil river basin upper reaches of Ponnani river basin and Vattamalaikarai sub basin of Amaravathi river basin lying between latitudes 10°19′ and 11°20′N and longitudes 76°17′ and 77°56′E. The Noyil and Vattamalaikarai rivers flow towards east and Ponnani towards west. The rainfall in the area varies from about 500 mm on the east to 3500-mm on the west sides. The area is underlain by rocks of Archaean complex consisting of hornblende-biotitite gneiss, garnet–sillimanite gneiss, charno ckite, granitic calc granulite, crystalline limestone and magnetite quartzite besides minor occurrence of ultrabasic, basic and acid intrusives like pyroxenites, pyroxene granulite, amphibolite, dolerite pegmatite and quartz vein.

The work in the project is still under progress. Tentatively the following results have been arrived at :

Table 2.4

Hydrologic Parameters

Sr. No.	Item	Recharge as % of Rainfall			
		Vettamalai Basin	Noyil Basin	Ponnani Basin	Average in Project Area
1.	Surface run-off	0.05	0.91	28.18	19.14
2.	Moisture retained by soil	3.39	(—) 0.34	6.99	4.73
3.	Evapotranspiration	77.26	51.61	59.69	57.70
4.	Groundwater Recharge	19.28	47.83	5.13	5.13

(l) Sina And Man Project (In Progress)

The project covers an area of 16,680 sq. km. of Sina and Man sub-basins falling in parts of Ahmednagar, Bhir, Osmanabad, Sangli, Satara and Solapur districts of Maharashtra. The Sina and Man rivers are tributaries to Bhima river and this project covers 11,970 and 4,710 sq. km. of basin area for Sina Man rivers respectively.

The studies are in progress and results would be known at the completion of the project.

B. Work Done By State Government Organisations

In recent years several State Groundwater Organisations (SGO) have been strengthened under a centrally sponsored scheme to undertake sophisticated experimentation and ground water research work. In some of the States considerable amount of good quality work has been carried out. The important findings of work done and the norms established for various groundwater recharge parameters and unit draft for groundwater structures in the following States are given below.

1. Karnataka
2. Kerala
3. Uttar Pradesh
4. Rajasthan
5. Gujarat
6. Maharashtra
7. Tamil Nadu
8. Andhra Pradesh
9. Madhya Pradesh
10. Haryana
11. Punjab
12. West Bengal

Ta ble 2.5

Groundwater Recharge Parameters

Sr. No.	Name of State	Rainfall	Canal seepage	Return flow	Specific yield
1.	**Karnataka**	5% for areas having rainfall 500–700 mm 10% for areas having rainfall above 700 mm	25% of water applied	15% of water applied from wells	1.3% to 6.21% for granites & gneisses. 1.3 to 5.8% for traps. 2% average
2.	**Kerala**	20% for sandy flat coastal areas. 15% for laterite in mid-land tracts. 5% for hard rocks in easte-rn upland tracts	Not accounted	Not accounted	Not given
3.	**Uttar Pradesh**	On the basis of water table fluctua-tion and specific yield	1.8 to 2.5 cumec per 10^6 sq. m. of wetted area	0.1 m. depth of canal water, 30% of groundwater	Weighted average in zone of fluctuation
4.	**Rajasthan**	—do—	N. A.	N. A.	N. A.

Sr. No.	Name of State	Rainfall	Canal seepage	Return flow	Specific yield
5.	Gujarat	(i) Chaturvedi formula for alluvial areas (ii) 10% for hard rocks (iii) 12% for sedimentary formations	1.8 to 2.5 cumec per 10^6 sq. m. of wetted area	45% from surface water 35% from ground-water	11 to 16% in alluvial areas. 3 to 5% in hard rock areas
6.	Maharashtra	Water table fluctuation method	1.8 to 2.5 cumec per 10^6 sq. m. of wetted area and 0.6 cumec per 10^6 sq. m. from distributaries. 50% percolation, from tanks in C. A.	15% of Rabi and summer irrigation 20% of kharif	Actual in zone of fluctuation (Recoverable Recharge =25%)
7.	Tamil Nadu	Water table fluctuation method gives values from 30 to 50% but	For 90 days varies from 180 to 1170 mm depending upon soil type	53–81% for paddy, max. value adopted at 36″ for one wet crop	Alluvial soil = 20–25%, weathered charnc·onite, granite gneiss = 5-10 % &

Sr. No.	Name of State	Rainfall	Canal seepage	Return flow	Specific yield
		actual values adopted in hard rock areas — 10 to 20%			jointed & fissured rock =3–5%, Sparsely jointed & fresh rock=1–3%
8.	Andhra Pradesh	15 to 20% depending upon soil	30 to 40% of applied irrigation water from paddy fields	15 to 20%	N. A.
9.	Madhya Pradesh	Alluvial Areas = 15 to 20%, Hard Rock Area = 9%.			Alluvium = 10% Deccan traps = 3–5% Vindhyans = 2%.
10.	Haryana	Based on Chaturvedi formula	20% of applied irrigation water	20% of applied groundwater	N. A.
11.	Punjab	Based on Tritium studies = 20%	1.8 cumec/10^6 sq. m. for unlined canals and 0.45 cumec/10^6 sq. m. for lined canals	25% for surface water after outlet, 30% for Groundwater	N. A.
12.	West Bengal	Alluvial Areas = 20%, Hard Rock = 10 to 15%	1.8 cumec/10^6 sq. m. of wetted area	15–25%	10–15%

The values of annual estimated groundwater draft as evaluated by the various SGO's is given below :

Table 2.6

Estimated Annual Groundwater Draft
In ha. m.

Sr. No.	Name of the State	Dugwells without pumpsets	Dugwells With pumpsets	Private Tube-wells / Borewells	Deep Public Tubewells
1.	Karnataka	0.6	1.2	2.00	—
2.	Kerala	0.12	0.54	0.54	—
3.	Uttar Pradesh	0.14	1.9	2.2	21
4.	Rajasthan	0.60	1.20	1.8	5
5.	Gujarat	0.37	1.2 in hard rock 1.8 in allu-vial area	10.0	18 to 28
6.	Maharashtra	0.6	1.2	2.00	—
7.	Tamil Nadu	0.39	1.2	3.64	15 to 20
8.	Andhra Pradesh	0.37	1.23	2.4	30
9.	Madhya Pradesh	0.50	1.20	6.8	3 to 30
10.	Haryana	1.0	1.8	2.6 to 3.5	40
11.	Punjab	0.45	—	2.12	40

C. Work Done In Universities And Research Organisations

a. Physical Research Laboratory, Ahmedabad.

The Hydrology Group in the Laboratory was established in the year 1975 and since then the Group has been studying the groundwater resources and their management for the growing needs of the city of Ahmedabad and Sabarmati Basin using the various radio-isotop techniques available in the country. The salient findings of the research work carried out so far are given below :

(i) Vertical recharge to groundwater in Sabarmati river basin varies from 5–15% of water input with an average value of about 8%.

(ii) Groundwater recharge estimates for the two consecutive years are consistent within 30%.

(iii) The distribution of soil grains coarser than 45mm is fairly uniform throughout the basin. A contour map of the median grain size in top 50 cm of soil was also prepared.

(iv) The fractional recharge exhibits a negative exponential correlation with the average silt and clay percentage.

(v) Increasing salinity in the Mangrol-Chorwad areas was ascribed to intrusion of sea water in the coastal aquifers.

(vi) Groundwater effluent seepage to Sabarmati river between Dharoi and Badra as estimated to be about 7% of inflow from Dharoi.

The Laboratory have also taken up the long-term study in respect of estimation of groundwater recharge due to rain and return irrigation in the two command areas in the State of Gujarat. In addition the studies in respect of permeability characteristics of near surface soils and estimation of seepage through canals and field channels and studies on the effect of slope, soil type, vegetation etc., on infiltration are also in progress.

b. University of Roorkee, Roorkee.

In the University of Roorkee the research on the various aspects of Ground Water Hydrology is being done since 1972. The main emphasis has been placed on water balance study, mathematical modelling of groundwater basin, conjunctive use of ground and surface waters, inverse problem and induced recharge and the application of nuclear methods for the estimation of groundwater recharge. Studies carried out in various fields are described below :

Recharge From Rainfall

In this respect the following methods have been used to determine the recharge both directly and indirectly :—

(i) Tritium Tracer Method.

(ii) Gamma Ray Transmission Method.

(iii) Water Balance Study.

In respect of water balance method, the study was carried out both for monsoon and non-monsoon periods separately. The data for a number of years has been used to arrive at a realistic figure. The results using this approach in respect of some of the basins of the State of Uttar Pradesh are given overleaf.

Table 2.7

Recharge Coefficients of Select Doabs

Sr. No.	Name of sub basin	Recharge coefficient	Annual Rainfall
1.	Gomati Sai Doab	0.252	750.0 mm
2.	Gomati Kalyani Doab	0.354	592.5 mm
3.	Upper Ganga Canal Command of Ganga Yamuna basin	0.264	750.3 mm
4.	Varuna basin	0.318	596.7 mm
5.	Ganga Ramganga	0.232	1100.0 mm
6.	Daha inter basin	0.18	600.0 mm

Optimisation Method

This method involves the estimation of geo-hydrological parameters including transmissibility in X and Y directions (Txx, Tyy) Storage coefficient, (S), and recharge coefficient by minimising the square of the residue of the Boussinesq's equation with respect to these parameters within a stipulated domain.

The data required for this method is a record of historical water table and rainfall data.

This method has been used for Daha area and piedmont zone of Ganga-Yamuna doab.

The range of variation of various estimates for the two areas is given as below :

Table 2.8

Recharge Coefficient Variations In Ganga-Yamuna Doabs

Area	Txx m^2/day	Tyy —	S	Recharge coefficient	Time lag between rainfall and recharge
Piedmont Zone of Ganga-Yamuna Doab	1636 to 7520	1636 to 7520	0.087 to 0.2	0.15 to 0.28	0.3 to 2.4 days
Daha area	500.00 to 1000.00	1700 to 2500	0.10 to 0.15	0.14 to 0.18	2.1 to 4.1 days

c. Indian Meteorological Department

In this Department, the following work has been carried out in respect of determination of groundwater recharge parameters.

Estimation of water potential and groundwater recharge potential of rainfall in the river basins is generally done by the various Water Balance methods. Some of the techniques employed are the well known equation of mass conservation in the Hydrologic Cycle, the Khosla's formula for run-off and Thornthwait's techniques of water budgeting for moderate and large water sheds based on climatological parameters.

In these techniques rainfall is the input and evapotranspiration and run-off are the outputs. While data of rainfall and run-off are available as measured quantities, evapotranspiration is estimated by various empirical formula notably by Penman's formula. Water surplus and the resultant run-off and infiltration are obtained as derivatives of rainfall and evpotranspiration. Thus, groundwater recharge is estimated in an indirect way by the method of water balance.

In the estimation of groundwater recharge by the method of mass conservation, the formula used is :

$$P = (Et + RO) + F + GW$$

Where P = Precipitation
Et = Evapotranspiration
RO = Run off
F = Moisture required to saturate the soil to its Field Capacity (the present storage of moisture being known).
GW = Groundwater recharge.

Thornthwait's technique is widely used to estimate yields from the river basins wherein the rainfall in the area is budgeted against water losses as evapotranspiration. Actual water losses are worked out using rainfall data and soil characteristics which acts as a sort of reservoir for evapotranspiration losses during the periods of deficit rainfall.

In evaluating the water balance of a basin, precipitation (P) is compared with potential evapotranspiration (PE) on a monthly basis.

Water potential of the Upper Yamuna basin and potential evapotranspiration and groundwater recharge due to rainfall in Luni catchment in West Rajasthan have been estimated by the Mass Conservation Equation.

Water Balance of the lower Sutlej Catchment upto Bhakra Dam site, Mahanadi Catchment upto Hirakud Dam Site and the Chambal and the

Vedavati basins have been estimated by employing the Thornthwaite's technique. These studies only reveal the water surplus or deficit but give no relationship between Rainfall and Recharge.

d. Tata Institute of Fundamental Research, Bombay.

The tritium method of estimating the vertical recharge to groundwater reservoir was initiated in the country by this institute. Both the environmental tritium and artificial tritium tagging was employed, depending upon the situation in a region.

Measurements made of over a number of years indicate a recharge of about 5 per cent of rainfall in the semi-arid region of northern Gujrat. Similar measurements made in Western U. P. showed a much larger recharge from rainfall and applied irrigation. There were, of course, wide variations from one place to another. The details of the results (already published) are given as below :

Table 2.8

Results of Tritium Injection Studies

Sr. No.	Item	Western U. P.	Punjab	Haryana
1.	No. of sites	45	21	14
2.	Date of injection	June 71	June 72	June 73
3.	Date of sampling	Oct. 71	Nov. 72	Dec. 73
4.	Average Total recharge Re (in cm.)	21.5	8.2	8
5.	Average Total rainfall R (in cm)	99	46	47
6.	Average irrigation (in cm)	10	21	7
7.	% Recharge (Total)	22%	18%	17%
8.	% Recharge due to rainfall only	20%	12%	15%

e. National Geophysical Research Institute, Hyderabad.

The geohydrology group of this institute is engaged in measurement of recharge to groundwater arising from precipitation and also from canal and well irrigation. Both Environmental and Injected Tritium Techniques are used with greater emphasis on the latter method.

The Tritium method has been used for estimating recharge to groundwater in Lower Manner Basin of which data for 26 stations was used. The results obtained indicate a recharge of about 25 per cent of rainfall. In Vedavati river basin also, the Tritium injections have been done at 80 sites and results will be analysed shortly. Similar studies have been taken in SIDA Project Area. Studies are also proposed in Anantpur district of Andhra Pradesh.

To study the effect of canal and well irrigation on groundwater recharge, tritium injections have been made at about 15 sites in areas adjacent to Lower Bhavani canal and 15 corresponding sites in the non-ayacut area on the opposite bank of the canal in SIDA project area. Sites have also been selected for assessing the effect of well irrigation on recharge.

The Institute further proposes to undertake recharge investigation in the Deccan trap areas. These are proposed in the Sina-Man basin and the Betwa basin where the CGWB is already carrying out detailed investigations. Based on these studies, the Institute proposes to give a complete quantitative estimate of groundwater recharge for hard rock areas which cover nearly 70 per cent of the country.

CHAPTER III

STUDY OF CRITICAL AREAS

SELECTION OF AREA FOR SAMPLE STUDIES

In accordance with the IDA terms of reference the committee took up the work of detailed studies in a few selected over-exploited blocks of various states in India. As recommended by IDA, it was decided that the total number of areas be restricted to 29 to cover all the affected regions on a representative basis. The committee took into consideration the total numbei of critical areas as listed under ARDC II for different states and agreed for the following state-wise distribution of the study areas.

Table 3.1

Distribution of study areas in States

Sr. No.	State	No. of study areas
1.	Gujarat	3
2.	Maharashtra	3
3.	Haryana	5
4.	Karnataka	5
5.	Tamil Nadu	4
6.	Punjab	3
7.	Uttar Pradesh	3
8.	Rajasthan	3

The IDA had recommended that the study areas may not exceed 3 per state. However, considering the comparatively larger number of affected areas in Haryana and Karnataka which were 49 and 41 respectively, against the total number of 170 for all the states, the committee felt that in these 2 states the number of sample areas may be taken as 5 for each state and in Tamil Nadu, it may be taken as four in view of higher development there also.

The State Groundwater Organisation selected individual areas on the following basis.

(i) Areas where detailed groundwater assessment by SGO and/or CGWB has been carried out or is in progress since 1972.

(ii) Areas where water table seems to be declining and where the dug wells become dry for some days during the summer months.

(iii) Where according to the present assessment of groundwater resources the areas indicate over extraction.

(iv) The minimum population of wells in the selected study areas is more than 50.

Aerial Extent Of Study Areas And The Scale Of Mapping

IDA had suggested the aerial extent of 1,000 hectares for individual study areas. However, it was felt that some flexibility would be desirable in this matter and depending upon local conditions the extent of study areas may vary from 600 to 1,000 hectares or even more at the discretion of the concerned SGOs. It was also agreed that in hard rock areas, the areas selected should conform to the configuration of small water sheds and in flat alluvial areas approximately square blocks representing the typical conditions be demarcated by either streams, railway lines, canals, etc. IDA had advised a scale of 16″ to 1 Mile for the preparation of detailed maps. However, for the purpose of present study it was decided that a map on the scale of 2″ to 1 Mile be prepared for each study area though basic data may continue to be plotted on the cadestral maps of the states concerned.

Collection Of Relevant Hydrogeological And Other Data

It was tentatively agreed that the hydrogeological and other data would be compiled for one hydrological year.

METHODOLOGY OF STUDY

A. Technical Aspects

1. Well Inventory/Pumping Tests

IDA had suggested that complete inventory of wells as per proforma to be administered to about 30 owners of evenly distributed wells in the study areas may be prepared. The committee felt that it was too big a sample and it may be difficult to complete the work within a limited time. It was agreed that about 20% of the existing irrigation wells in operation or about 20 wells evenly spread over the areas be selected for data collection. As regards the pump tests to be carried out on the wells it was agreed that the same sample of 20% or 20 wells may be sufficient for this purpose. It was also decided to carry out tests on wells both in pre-monsoon and post-monsoon periods.

2. Inventory Of Key Observation Wells

The committee decided that key observation wells might be restricted to about 20% of the total number of wells existing in study areas. The key observation wells could be village water supply wells or large diameter irrigation wells of low average withdrawal. A minimum of about 10 observation wells may be selected and data of water table from these wells can be considered adequate for the prevailing hydrogeological conditions. It was also agreed that water level should be monitored continuously in these observation wells every fortnight.

B. Socio-Economic Aspects

In addition to the physical manifestations of groundwater over-development, there are socio-economic issues which are also of importance to World Bank and the GOI. The World Bank had suggested a proforma and had recommended that about 50% of farmers owning irrigation wells in each critical area be examined and an equal number of farmers be interviewed having no wells of their own. Further, in July 1978 the World Bank had specifically suggested to ARDC that in the terms of reference of the committee the establishment of financial loss suffered by the farmers in the critical areas due to increased extraction attributable to privately financed wells be also included.

In the final meeting of the committee the work relating to the above was reviewed and SGOs indicated that field work in connection with the above was hampered because of the farmers apathy to part with the required data. In view of this, the committee felt that whatever data might have been generated in the above surveys is not adequate to comment upon and hence it was decided to review the problem of financial losses suffered by the farmers in an indirect way. The committee also decided to avail of the data generated as a result of a sample survey carried out by ARDC in connection with Tamil Nadu Project Completion Report as well as the data provided by the Punjab SGO to the committee.

The committee felt that the socio-economic aspects of groundwater over-exploitation are indirectly related to the technical aspects. For two contrasting settings, i. e. Alluvial Terrain and Hard Rock Terrain, these are discussed below.

(a) Alluvial Terrain

The data provided by the SGO of Punjab was utilised to discuss the situation for the alluvial terrain. The SGO had worked out that due to groundwater over-exploitation the water table has gone down by 4 to 6 metres during the last 10 years in the Nakoder Area of Jullunder district. The pumpsets which were in operation, (located on the surface) had to be lowered by about 6 metres in the newly constructed pits. On the other hand, in the case of Malerkotla area of Sangrur district the SGO's data indicated that the water table which was 4 to 6 metres below ground level a decade back has gone down to 12 to 15 metres resulting in the deepening of existing pits which was shallow earlier. The additional financial burden on the cultivators due to added groundwater extraction has been worked out in the table below :

Table 3.2

Approximate cost of construction of new pits / deepening of existing pits

Study area	No. of tubewells affected	Approximate cost per unit Rs.	Total in lakhs Rs.	Remarks
(a) Nakoder area, Jullunder District	280	2,000	5.6	Construction of new pit of dimension 1.5 m by 1.5 m and depth 6 m
(b) Malerkotla area, Sangrur District	290	3,000	8.70	Deepening of the pits to a depth of 14 m

As regards the discharge of the tubewell in spite of escalating groundwater development it is reported that the original discharge have been maintained and the farmers have been able to maintain the same command as before. However with increasing head it is possible that the pumping system efficiency would have gone down resulting in higher power consumption and higher cost per unit volume of water.

(b) Hard Rock Area

In connection with the Tamil Nadu Project Completion Report, ARDC at the instance of World Bank had conducted a study with the main object of determining the effect of over exploitation on financial viability of investment

The study was restricted to the following Blocks in the various districts of Tamil Nadu.

	District	Taluk	Name of the Block
1.	North Arcot	Arni	Arni
2.	Salem	Athur	Athur
3.	Ramanathapuram	Srivilliputthur	Watrap
4.	Coimbatore	Coimbatore	Perur

As a result of the surveys carried out it has been established that the average thickness of the saturated zone of the water table aquifer pierced by dugwells during pre-monsoon period is varying from 1 metre in Perur Block of Coimbatore District to 5 metres in Arni Block of North Arcot District. The depth of wells inventoried range from 12 metres in Arni Block to 22 Metres in Perur Block of Coimbatore district. The data is tabulated below :

Table 3.3

Variation In Saturated Thickness In Different Blocks

Sr. No.	Name of the Block	Average saturated thickness	Maximum depth of the saturated zone
1.	Arni	5 m	12 m
2.	Athur	2 m	20 m
3.	Watrap	3 m	17 m
4.	Perur	1 m	20 m

In the above Blocks, data of the behaviour of the groundwater regimen indicates that only in Arni Block there has been a rising trend from 1971 to 1976 while in the case of other Blocks there has been a declining trend from 3.5 to 7.5 metres.

Financial Implications Of Groundwater Development In Highly Developed Areas

The data of well inventory in the different blocks of the districts indicate that there is a tendency among the farmers to augment the yield of wells which has been reduced due to progressive decline in water level from 1971 to 1976. In the case of Perur Block of Coimbatore district and Watrap block of Ramanathapuram District boring to a depth of 20 metres on an average has been attempted from the bottom of dugwell with a view to tap the deeper aquifer in contrast to Arni Block where groundwater development is still taking place by dugwell to a depth of 10 to 12 metres. In view of the rise in water table and satisfactory drawdown available, there is no such tendency to resort to groundwater development by boring. The data is tabulated as under :

Table 3.4

Well Inventory Data

Sr. No.	Name of the district	Name of the Block	No. of wells inventoried	No. of wells bored
1.	Salem	Athur	38	1
2.	Coimbatore	Perur	20	18
3.	Ramanathapuram	Watrap	22	9
4.	North Arcot	Arni	38	2

Thus, it can be seen that deepening by boring is common in the Perur Block and Watrap Block while it is not common in Athur Block of Salem District where the practice is only for deepening of the dugwell, by blasting.

The following are the prevalent unit cost for such deepening.

1.	Deepening of wells in Salem district	Rs.	3,000
2.	Deepening of wells in Coimbatore district (Blasting)	Rs.	4,500
3.	Deepening of wells by boring —(20m)	Rs.	2,000

In the case of Coimbatore District the deepening is generally from a greater depth say 15 metres to 18 metres while in the case of Salem District it is from 12 to 15 metres. The unit cost worked out hence are different.

Though exact number of wells deepened in the critical areas are not known, the committee felt that the progressive decline of water tables in the districts of Salem and Coimbatore definitely involves an additional financial burden by way of deepening. This is so because of the limited saturated zones available for development. Progressive declines in water table causes the desaturation of the aquifer resulting in lesser yields.

Summing up, it can be stated that the committee has been able to identify tentatively the following results of groundwater over-exploitation.

In the alluvial areas like Punjab etc. groundwater over-exploitation results in lowering of water level with consequent lowering of pumpsets but in view of large available drawdown the yields are not reported to have declined and irrigation as such does not suffer but only the cost of irrigation escalates marginally due to higher lifts involved. In contrast, in the hard rock areas like Tamil Nadu, due to limited saturated thickness available lowering of water level as a consequence of groundwater over-development results in desaturation of the water table aquifer progressively resulting in lesser yield and shrinkage of irrigated command per well.

The committee recommends that the SGOs pursue the above problem with a view to generate more data from critical areas so that the socio-economic aspects of groundwater over-exploitation are fully understood.

SUMMARY OF STATEWISE REPORTS

Gujarat

Introduction

The following areas were identified as critical under ARDC II and were taken up for detailed micro-level studies in Gujarat. The taluqs are (*i*) Mangrol taluq in Junagadh distiict (*ii*) Descroi taluq in Ahmedabad district and (*iii*) Deesa taluq in Banaskantha district. The name of taluq along with micro-level study areas and the geological setting is given below :

Table 3.5

Study Areas

Sr. No.	Name of taluq	Name of study area	Areal Extent (ha)	Rock type
1.	Mangrol, dist. Junagadh	Mankhotra	1000	Limestones
2.	Descroi, dist. Ahmedabad	Miroli	1000	Alluvial Deposit
3.	Deesa, dist. Banaskantha	Malgadh/Unpat	1062	—,,—

Hydrogeological Setting

(i) Mangrol Taluq, District Junagadh

The area is covered by marine limestone deposits known as Porbandar Limestone of pleistocene to recent age. These are underlain by miocene limestones known as Gaj beds. In some parts of the taluq, these are covered by recent alluvial deposits. Groundwater in the area occurs under water table and confined conditions. In the limestones it is under water table conditions, and in Gaj beds it is under confined conditions. Depth of wells in the study area varies from 10 to 36 metres below ground level (mbgl). In the western part, the wells are generally very deep compared to the eastern part. The pre-monsoon water levels vary from 11.0 to 26.5 mbgl. In western part of the area the decline of water table is largely due to over-pumping, pumps operating as much as 20 hours per day. In the eastern part, the pumps operate for about 5 to 6 hours per day. The discharge of wells vary from 8 to 18 cubic metres per hour.

(ii) Descroi Taluq, District Ahmedabad

The area under investigation comprises of recent alluvium consisting of sand, sandy silts, clay and kankar and occasionally gravels overlying the tertiary rocks or Deccan trap. The total thickness of alluvium in the area is not known but bore hole data from Oil and Natural Gas Commission records indicate that the thickness is over 600 metres. Groundwater in the study area occurs under water table and confined conditions. Depth to water table in the area varies from 2.05 to 15.10 metres below ground level. The water table is at shallow depth in the southern and south western parts. This may be due to the effect of surface irrigation system. The water levels are comparatively deeper in the northern and north eastern parts of the area.

(iii) Deesa Taluq, Banaskantha District

The taluq is underlain by recent alluvial deposits consisting of sand, clay and gravel uniformly overlying the granitic basement. The subsurface geological studies indicate that fine to medium grained sand zones predominate in the NE while towards SW alternate bands of clay are predominant. Groundwater occurs under both water table and confined conditions in the area. In the wells situated close to the river within one kilometer of the river, the water level ranges from 2.45 m to 8.85 m. and in wells which are away the water level ranges from 11.05 m to 24.25 m below ground level.

Macro-level Water Balance

The water balance has been estimated by the following methods :

Recharge

(1) Recharge due to rainfall has been calculated by Chaturvedi formula cross-checked by water level fluctuation method.

(2) Recharge from other sources like surface irrigation system has been taken as per norms.

(3) Gross draft from existing wells has been calculated based on existing number of wells and their average draft. The norms used for draft calculations are given below :

Draft

Open wells without pumpset	=	3.7 TCM/Yr
Well with pumpset	=	18.00 TCM/Yr (Alluvium)
		12.00 —do— (Hard rocks)
State deep tubewells	=	180 TCM/Yr.
GWRDC Tubewell	=	280 TCM/Yr.

A summarised statement of uptodate water balance is given below :

Table 3.6
Water-Balance for Study Areas

Sr. No.	Name of taluq	Rainfall recharge (mm^3)	Recharge Other Sources (mm^3)	Gross recharge (mm^3)	Net recoverable recharge (mm^3)	Draft (mm^3)	Balance potential available for development (mm^3)
1.	Mangrol	387	129	516	413	647	— 234
2.	Descroi	163	97	260	208	115	+ 93
3.	Deesa	185	75	260	208	182	+ 26

Response of Groundwater System To Development

The hydrographs of key observation wells being monitored in the vicinity of the study area were examined to determine the response of groundwater system to development. The following results were arrived at :

Table 3.7
Water-Balance In Relation To Water Level Trend

Sr. No.	Name of taluq	Net recoverable recharge (mm^3)	Draft (mm^3)	Balance Potential available (mm^3)	Trend of water levels
1.	Mangrol	413	647	— 234	Decreasing trend
2.	Descroi	208	115	+ 93	Average rise of 0.9 m/yr.
3.	Deesa	208	182	+ 26	A rise of 1.87 to 2.50 m from 1971 to 78.

Correlation Of Rainfall To Water Table Fluctuations ;

(a) **Mangrol Taluq :**

Hydrographs of observation wells and rainfall variation for the period 1970–78 were analysed. The rainfall variation shows that 1974 and 1976 were drought years but the rainfall increased from 1977. The water table shows a declining trend from 1971 and a rising trend from 1976. On the whole a fall of water table is noticed for 1971 to 1977.

(b) **Descroi Taluq :**

In case of Descroi taluq, the rainfall has been showing an increasing trend from 1975 till to date. 1974 was a year of low rainfall. The hydrographs of key observation wells also show in a general way a rising trend from 1974 commensurate with increasing rainfall.

(c) **Deesa Taluq :**

Variation of rainfall and water table fluctuation were analysed. The rainfall pattern shows that 1974 was a drought year and 1976 was also an year of lesser rainfall. The rainfall shows an increasing trend from 1976 onwards. The post-monsoon water table show a steady rise from 1970 to 1976. The effects of 1974 drought year were reflected in the well hydrographs.

Summing up, it can be stated that the two taluqs Descroi and Deesa are not overdeveloped as indicated by water balance as well as hydrograph study. In the case of Mangrol taluq, tendency for over development is well established by the decreasing trend of water levels as well as negative water balance.

Maharashtra

Introduction

In order to study the possible groundwater over-exploitated areas Sangli, Ahmedanagar and Nasik districts were selected. The following apparently over-developed watersheds were selected in accordance with the criterion that the minimum population of the wells in the study areas were not less than 50.

Table 3.8
Water-Shed Areas Selected

Sr. No.	District	Taluq	Watershed No.	Areal extent (ha)	Number of Existing wells
1.	Ahmednagar	Sangamner	GV–110	1800	235
2.	Sangli	Miraj	KR–50	1680	60
3.	Nasik	Malegaon	TE–130	1250	66

Hydrogeological Setting

(i) Watershed In Ahmednagar District

The watershed in Ahmednagar district comprises of Vesicular Zeolitic basalt having brecciated zones of 2 to 3 metres and having a total thickness of 12 to 15 metres. The area is also occupied by alluvium having an average thickness of 3.5 metres, and is confined to the axial portion of the watershed. The depth of wells range from 7 to 14m. below ground level. The post-monsoon water levels vary from 5.75 to 12 m. The yield of wells range from 30 to 152 m^3 per day during winter and 11 to 65 m^3 per day during summer.

(ii) Watershed In Sangli District

The area is occupied by grey columnar/fractured, hard massive trap. A local alluvial patch of 14 m thickness has also developed in this area. The depth of dug wells piercing basaltic formations vary from 9 to 13 metres below ground level. The water level vary from 4 to 6 metres in winter and 7 to 12 metres below ground level during summer. The yield of wells during winter vary from 30 to 35 m^3 and in summer 24 to 28 m^3 per day. The wells piercing local alluvium are 12 to 14 m in depth and depth to water table in them vary from 10 to 12 m. during winter and 12 to 13 m during summer. The yield varies from 150 m^3 per day to 210 m^3 per day during winter and from 80 to 130 m^3 per day during summer.

(iii) Watershed In Nasik District

The study area in Nasik district comprises of three basaltic lava flows along with erratic occurrence of local alluvium which is generally clayey but at places contain granular zones. The traverses and geological mapping of the area indicate three units of Deccan lava flows comprising of massive, amygdaloidal units. The depth of wells vary from 4 to 14 metres below ground level and the depth to water table varies from 2.50 to 8 m below ground level during post-monsoon period and 5 to 10 m. during summer months. The yield of wells ranges between 64 to 125 m^3 per day during winter and 32 to 109 m^3 per day during summer

Results Of Aquifer Performance Tests

In all the watersheds, 16 aquifer tests were conducted in addition to few tests conducted in the study area itself. It will be seen that in and around the study area of Ahmednagar district, the transmissivity of basaltic water table aquifer varies from 23 to 151 m^3 /m per day and sp. yield from 2.55 to 7.01 x 10^{-2}. In Sangli district the transmissivity of basaltic rocks vary from 40 to 100 m^3/m per day and sp. yield from 3 to 5 x 10^{-2}. In Nasik district the 'T' values range from 16 to 70 m^3/m per day while the sp. yield varies from 3 to 5 x 10^{-2}.

Macro Level Water Balance

Under the IDA agricultural credit project, the State Groundwater Organisation decided to work out the groundwater potentiality on watershed wise basis. The criteria for assessing groundwater recharge and discharge were based on ad hoc norms arrived at after detailed discussions with ARDC and GOI. Rainfall infiltration was arrived at by seasonal fluctuation/sp. yield method. A conservative estimate was adopted for evaluating contribution to groundwater recharge from recycled canal irrigation and groundwater. The draft was estimated on the basis of sample studies and an average draft of 10 to 12,000m^3/yr. was taken for energised wells and 5000m^3/yr. for wells worked with indigenous system. The draft was arrived at by taking the number of existing working wells in the area and multiplying it by the unit draft. The macro-level water balance uptodated is given below :

Table 3.9

Water Balance For Study Areas

Sr. No.	District and Water shed No.	Rainfall Recharge (mm^3)	Recharge from other sources (mm^3)	Gross recharge (mm^3)	Net recoverable recharge	Draft (mm^3)	Balance potential available (mm^3)
1.	Ahmednagar Dt. GV–110.	12.86	5.84	18.70	17.37	14.80	2.87
2.	Sangli Dt. KR–50	54.00	13.87	67.87	61.07	31.06	30.00
3.	Nasik Dt. TE–130	34.10	14.08	48.18	43.17	33.92	9.25

Response Of Groundwater System To Development

Data on observation wells fixed by SGO in Ahmednagar, Sangli and Nasik districts were examined to study the response of ground water system to development. There are in all 20 observation wells set up earlier in and around the watershed nos. GV 110, KR–50, TE–130 of Ahmednagar, Sangli and Nasik districts respectively. For the purpose of monitoring ground water regimen, data of observation wells in response to recharge and discharge was observed quarterly. The following quarters of the year were selected with a view to keep equal intervals of time between two successive readings.

(1) Observation for the First quarter 2nd and 3rd week of October.

(2) —do— Second —do— 3rd and 4th week of December

(3) —do— Third —do— 1st and 2nd week of March

(4) —do— Fourth —do— 3rd and 4th week of May

The hydrographs of these observation wells for the period 1975–77 were analysed and the following conclusions were arrived at.

Table 3.10

Water Balance In Relation To Water Level Trend

Sr. No.	Watershed	Net recove-rable recharge (mm^3)	Draft (mm^3)	Balance poten-tial (mm^3)	Trend of water levels (Post-monsoon) 1975–77
1.	Ahmednagar dist.	17.37	14.80	2.57	A rise of 2.5 m.
2.	Sangli dist.	61.06	31.60	30.00	Average rise of 1.00 to 2.00 m.
3.	Nasik dist.	43.17	33.92	9.25	Water table stationary

Correlation Of Rainfall Variation To Watertable Fluctuation

The key observation wells data was available only for the period 1975 to 1977 and its correlation was attempted with the rainfall data from 1975–77. In the two watersheds of Ahmednagar/Sangli the drought period occurred during 1976 while in Nasik dist. 1977 was a year of lesser rainfall compared to 1975 and 1976. The water level data for the post-monsoon period indicate that in the above watersheds the water table has either been rising from 1975 or has remained stationary.

Summing up, it can be stated that in Ahmednagar district though there is apparent high development the water table is showing a rising trend while in case of the other two watersheds the ground water development has not reached a critical stage as per water balance calculations and the observation wells are also showing a rising or stationery trend.

Haryana

Introduction

In Haryana, five areas have been selected by State Groundwater Organisation. They are from the list of critical areas identified by CGWB under ARDC II and are as under :

Table 3.11

Study Areas Selected

Sr. No.	Name of block	Name of micro area	Areal Extent (ha)	Geological setting
1.	Ladwa-Kurkshetra dist.	Radour	1000	Alluvial terrain
2.	Gurgaon-Gurgaon dist.	Jhaısa	1000	—,,—
3.	Rohtak-Rohtak dist.	Bhalout	1000	—,,—
4.	Thanesar-Kurkshetra dist	Bhor saidan	800	—,,—
5.	Jagadhari-Ambala dist.	Pansara	675	—,,—

The main criteria for selection was based on the groundwater balance of different blocks jointly worked out by ARDC/CGWB and SGO in 1975; which indicated likelihood of overdevelopment in these blocks.

Hydrogeological Setting

(i) Ladwa Block - Kurkshetra District

The area is underlain by alluvial deposits and groundwater occurs under both water table and confined condition. The depth to water varies from 3 to 9 metres below ground level during the pre-monsoon period. The area receives benefits of recharge from Western Jamuna Canal which runs for a distance of 3500 metres in the area.

(ii) Gurgaon Block - Gurgaon District

The salient observations of minor irrigation units are summarised in the table below :

Table 3.12

Well Inventory Data

Sr. No.	Particulars	No. of wells examined	Total depth (m)		DTW range (m)	
			From	To	From	To
1.	Wells	23	12.00	25.00	9	15
2.	Tubewells	136	14.00	40.00	8	16
3.	Dug-cum-bore wells	45	14.00	30.00	8	16
		10 m bore at the bottom of the well				

(iii) Rohtak Block - Rohtak District

The area falls under the Indogangetic alluvial plains and is traversed by channels of surface irrigation system. The depth to water table varies from 3 to 6 metres below ground level, during pre-monsoon and from 3 to 5 mbgl in post monsoon, with an average seasonal fluctuation of 1.0 to 1.5 m. In general there is a rise in water table in and around the study areas. The analysis of water samples collected during pre-monsoon indicate that quality of water is varying from marginal to saline with a very small patch of fresh water.

(iv) Thanesar Block - Kurkshetra District

The groundwater occurs under water table condition in the alluvial deposits and depth to water varies from 3 to 5 m bgl in pre-monsoon April and 3.2 to 7 m bgl in June 1978.

(v) Jagadhari Block - Ambala District

The groundwater regimen has been studied from a number of hydrographs of key observation wells maintained by Soil Conservation Dept and HMITC. The depth to water table varies from 3 to 6 metres below ground level as observed during June 1978 indicating shallow water table even during the pre-monsoon period.

Macro-level Water Balance

The water balance of blocks wherein areas have been selected for detailed studies, has been attempted on the agreed norms during the fourth meeting of the over-exploitation committee held at New Delhi. Earlier the balance used to be calculated based on seasonal fluctuation method with a conservative figure for recharge for recycled water. The uptodate water balance is tabulated below :

Table 3.13

Water Balance For Study Areas

Sr. No.	Blocks	Rainfall Recharge mm^3	Other souices Recharge mm^3	Gross Recharge mm^3	Recoverable recharge mm^3	Draft mm^3	Balance potential available mm^3
1.	Ladwa	23	227	255	179	410	— 231
2.	Gurgaon	45	53	99	69	107	— 38
3.	Rohtak	12	29	41	29	25	+ 4
*4.	Thanesar	38	197	235	165	347	— 182
*5.	Jagadhari	55	183	238	167	283	— 116

*Exclusively saline areas.

Response of Groundwater System To Development

The hydrographs of key observation wells being monitored in the areas under the study were examined to find out the response of groundwater system to development. The following results were obtained.

Table 3.14

Water Balance In Relation To Water Level Trend

Sr. No.	Block	Net recoverable recharge mm³	Draft mm³	Balance potential available mm³		Trend of waterlevels (75–77)
1.	Ladwa	179	410	—	231	A fall of 2.00 m from 1975–77
2.	Gurgaon	69	107	—	38	Marginal decline in 1975–77
3.	Rohtak	29	25	+	4	A rise of 2.00 m.
4.	Thanesar	165	347	—	182	A fall of 1.5 m.
5.	Jagdhari	167	283	—	116	Marginal rise of 0.5 m.... 1975–77

Correlation Of Rainfall With Water Table Fluctuation

Analysis of rainfall data for the blocks indicate that 1973–74 was a drought year and since 1974 rainfall has been increasing in all the blocks except Gurgaon where minimum rainfall was recorded in 1975. The water table fluctuation data available is only from 1975 i. e. in periods of higher rainfall and hence correlation could not be attempted.

Summing up, it can be concluded that out of the five blocks selected for study, over-extraction conditions do exist in Ladwa block by evidence of fall of water level even during 1975–77 years of higher rainfall. So is the case in Thanesar block where a fall of 1.5 m. was observed.

Karnataka

Introduction

The following areas identified as critical under ARDC II were taken up for micro-level studies in Karnataka. The taluqs are Challakere, Hoskote, Indi, Koppal and Sira. The groundwater survey unit of Karnataka identified five micro watersheds, one in each taluq as per the terms of reference of the groundwater over exploitation committee. Of these, the watershed in Indi taluq consists of traps. The water sheds in Sira, Koppal, and Challakere are of gneissic terrain whereas in Hoskote area, it is gneissic with laterite cappings.

Table 3.15

Study Areas Selected

Sr. No.	Name of taluq	Name of the micro watershed	Areal extent (ha)	Rock type	Existing wells
1.	Hoskote	Jinnegara	660	Gneiss & Laterite	39
2.	Challakere	Chikkamanra halli	650	Gneiss	21
3.	Sira	Hosahalli	1013	Granitic gneiss	75
4.	Koppal	Bisarhalli	1000	Gneiss	93
5.	Indi	Hanjagi	1700	Trap	42

Macro-level Water Balance

The water balance is estimated tentatively by the following method.

Recharge :

(a) The hydrographs of the observation wells based on the water level fluctuation data for the last 4 to 5 yrs. were correlated with rainfall for the corresponding period. With an assumed value of specific yield as 3% the groundwater recharge during kharif was calculated taking into consideration areal extent of the water table aquifer and net kharif draft. Apart from infiltration from rainfall, recharge by return irrigation was taken at 35% of water applied for irrigation in case of surface irrigation and 30% in case of groundwater irrigation.

Discharge

(b) The annual discharge from storage was estimated by the following methods

(i) conducting pump tests on wells representing different yield capacities by random sampling.

(ii) Running pump for four hours to either completely bail out all stored water or to create a possible maximum drawdown.

(iii) Recording recuperation in the pumped well at regular intervals for 4 hrs. for a period of 20 hrs. after cessation of pumping.

(iv) Annual discharge was calculated taking 150 days per year as irrigation days and multiplying it by the unit well discharge and number of wells.

(v) For wells with other modes of lift, the discharge was taken as 50% of the discharge for a well with pumpset.

The discharge estimated per well in the taluks are tabulated as below :

Table 3.16

Annual Drafts of Pumpage Works

Sr. No.	Name of taluq	Well with pumpsets Nos.	Well without pumpsets Nos.	Average annual discharge-in mm³/year — Energised wells	Non energised wells	Estimated annual draft mm³
1.	Hoskote	3095	4047	12335	6108	85.78
2.	Challakere	3182	1608	12335	6168	49.15
3.	Sira	3001	7113	3557	3757	37.42
4.	Koppal	1791	370	12335	6168	24.37
5.	Indi	3448	4961	14800	7400	87.74

The gross recharge was converted to net recoverable recharge by reducing it by a suitable percentage depending upon the nature of terrain. A summerised statement of uptodate water balance is given below.

Table 3.17

Sr. No.	Name of Taluq	Rainfall Recharge	Recharge from other sources (mm³)	Gross recharge (mm³)	Net recoverable recharge (mm³)	Draft (mm³)	Balance potential available (mm³)
1.	Hoskote	50.97	48.01	98.98	69.29	85.78	— 16.5
2.	Challakere	159.44	50.07	209.51	146.68	49.15	+ 97.5
3.	Sira	121.42	40.04	162.06	113.44	37.42	+ 76.02
4.	Koppal	120.60	26.81	147.41	103.19	24.37	+ 78.82
5.	Indi	184.83	38.64	223.47	201.12	87.74	+113.38

Response of Groundwater System To Development

The hydrographs of key observation wells monitored in the vicinity of study areas were studied to find out the response of groundwater system to development. The following results were obtained.

Table 3.18

Water Balance in Relation to Water Level Trend

Sr. No.	Taluq	Net recoverable recharge (mm^3)	Draft (mm^3)	Balance potential available (mm^3)	Trend of water levels
1.	Hoskote	69.28	85.78	− 15.5	Decline tendency in general
2.	Challakere	146.65	49.15	+ 97.5	Rising tendency
3.	Sira	113.44	37.42	+ 76.02	Water level maintained
4.	Indi	201.12	87.74	+113.28	Rising tendency
5.	Koppal	103.19	24.37	+ 78.82	Rising tendency

Correlation Of Rainfall To Water Table Fluctuation

Study of rainfall variation over the period 1973–77 indicate that in Hoskote taluq, the years 1974 and 1976 were of low rainfall while the year 1973, 75. 77 had higher rainfall. In the case of Challakere taluq, the years 1976–1977 were comparatively drought years while the other years were normal. The rainfall pattern in Sira taluq also indicated below normal rainfall in 1976 & 77 compared to 1973 to 75 which were years of normal rainfall. The Koppal taluq rain gauge stations did not show much variation in rainfall between 1973 to 77 while, in Indi taluq, the year 1976–77 were characterised by lower rainfall.

The above variations are well reflected in the behaviour of hydrographs of key observation wells. In Hoskote taluq during 1974–76, the post-monsoon water levels have shown a declining trend which was partly made up in 1977. The position in Challakere taluq also show a declining trend of post-monsoon water levels during 1975 to 1976 and rising in 1977. In Sira taluq, the post-monsoon water table show a declining trend for 1975 to 1976. The fairly uniform rainfall pattern in Koppal taluq is truly reflected in behaviour of the groundwater system. In Indi taluq drought years of 1976–77 have resulted in decline of post-monsoon water level.

Summing up

It can be stated that macrolevel water balance and its correlation with rainfall variation and hydrograph behaviour indicate that only Hoskote taluq is over exploited at present while the other taluqs have still substantial potential available for groundwater development as on 1–1–78. The inclusion of these taluqs in ARDC II list was due to highly conservative estimates of recharge parameters. The detailed water balance studies carried out since 1972 by CGWB/SGO have brought out new recharge parameter. Another reason for some of the areas being classified as critical is that some of these blocks are located in discharge areas of major river basins where computed vertical recharge is less due to lower seasonal water table fluctuations. In such cases, the average recharge for the basin as a whole should be considered rather than for the discharge or recharge area alone as it may result in under estimation or over estimation of groundwater potential.

Tamil Nadu

Introduction

The groundwater over exploitation committee provided the guide lines based on which Tamil Nadu State Groundwater Organisation selected the following four blocks from which areas were delineated for micro-level studies. The study areas are as under :

Table 3.19

Study Areas

Sr. No.	Name of the block	Name of the micro-area	Aquifer type	No. of existing wells
1.	Uppiliapuram (Trichy dist.)	Uppiliapuram	Granites	1115
2.	Usilampatti (Madurai dist.)	Usilampatti	Gneisses	516
3.	Pernampet (North Arcot dist.)	Pernampet	Weathered geneisses	960
4.	Arni (N. Arcot dist.)	Arni	—do—	232

Based on the rapid survey and first approximation studies (September 1977) it has been assessed that nearly 50 per cent of the blocks in the state are over developed. Out of this, the above four blocks have recorded a maximum groundwater development.

Hydrogeological Features :

The Uppiliapuram area is underlain by hard rocks consisting of granitic gneisses. The rocks are traversed by numerous minor faults with a central major fault along which the stream flows. The thickness of weathered zone is about 15 to 20 meters. The water level in the region is about 16 to 17 metres below ground level during pre-monsoon period. The seasonal fluctuation is very high and in the post-monsoon period the water table is about 3 metres below ground level. The depth of wells range from 18 to 23 metres and depth to water table from 16 to 17 metres below ground level during the pre-monsoon period.

The Usilampatti area mainly consists of gneisses, charnockites etc, traversed with a few veins of pegmatites and of quartz. The weathering thickness ranges from a few metres to 20 metres. The depth of wells in Usilampatti area range from 12 to 15 metres below ground level. The water level range from 6 to 8.35 metres below ground level during the summer and slowly rise to 3.50 metres below ground level during the post-monsoon period.

The Pernampet area is underlain by highly weathered granite gneisses and charnockite. The average weathered thickness is 15 metres. The total depth of wells range from 9.50 to 25 metres, while the water levels range from 8 to 20 metres below ground level in summer. The seasonal fluctuation of water table are quite high being of the order of 5 metres.

The Arni area in North Arcot district is constituted of weathered gneisses. The average weathered thickness is around 12 metres. The total depth of wells range from 9 to 17 metres. The water level range from 6 to 15 metres below ground level during summer and 4 to 10 metres during winter.

The total number of 45 pump tests on dugwells distributed in the above blocks were conducted and the data indicates that the transmissivity varies from 20 to 30 m^3/per day and permeability ranging from 2 to 15 m/day.

Macro Level Water Balance :

In Tamil Nadu for computing recharge, 10 per cent of average rainfall, 45 to 60 mm of return flow from irrigated fields and 45 mm from surface storage bodies was taken into account. From the figures obtained by the above method, 30 per cent was taken for uncontrollable losses due to evapotranspiration, effluent seepage etc. The discharge from wells was taken on the basis of actual sample studies in field and thus the average draft from energised and non-energised well was accounted for.

The recharge was also calculated by water table fluctuation and specific yield method taking 30 to 40 per cent as contribution from recycled irrigation water from surface/groundwater sources. In case of paddy irrigation a suitable higher figure was taken. From the gross recharge, thus calculated in undulating hard rock terrain, 25 to 40 per cent was deducted to account for uncontrollable losses while in flat areas of granite terrain, the effluent loss was taken as ten percent of gross recharge and net recoverable recharge was calculated. By adopting these liberal norms, the following groundwater potential was arrived at :

Table 3.20

Water Balance For Study Areas

Sr. No.	Block	Recharge		Gross Recharge	Net reco. Recharge	Draft
		Rain fall (mm^3)	Other source (mm^3)	(mm^3)	(mm^3)	(mm^3)
1.	Uppiliapuram	110	30	140	126	140
2.	Usalampatti	84	24	108	98	106
3.	Pernampet	130	72	202	189	184
4.	Arni	90	47	137	122	112

Response Of Groundwater System To Devolopment.

The hydrographs of key observation wells being monitored in the vicinity of study areas were examined and the following conclusions were arrived at :

Table 3.21

Water Balance In Relation To Water Level Trend

Sr. No.	Name of block	Net Recoverable recharge (mm^3)	Draft (mm^3) (mm^3)	Balance potential available	Trend of water Levels
1.	Uppiliapuram	125	140	—14	Lowering trend during drought period with a tendency to make up in 1977.
2.	Usilampatti	98	106	— 8	—do—
3.	Pernampet	189	184	— 4	Increasing trend since 1972-77 but lowering during 1972-74.
4.	Arni	123	112	+11	Either a stationery or a slightly rising trend

Correlation Of Rainfall Variation With Water Table Fluctuation

In and around Uppiliapuram block, 4 observation wells are being monitored since 1972. A perusal of hydrographs of these wells reveal that there is a lowering trend during the low rain fall years which was recovered to the original level during 1977 when the rainfall was normal.

In the Usilampatti area, four key observation wells are being monitored since 1972. The general, trend of the hydrographs indicate that there is a continuous lowering of water table during the periods of lower rainfall 1972–75 but it has regained to normal value during 1977 monsoon.

Four observation wells are being monitored in the Pernampet area for which water level data are available from 1972. The behaviour of hydrographs indicate that there is declining trend during the period 1972 to 1975 (drought years) while during years of normal rainfall the water table rises up to its normal level. There is an increasing trend of post-monsoon water levels from 1975 to 1977 except in the drought year of 1976.

In Arni area, three regular observation wells are available for which water levels were observed from November 1972 onwards. The critical study of the overall trend of hydrographs indicates that there is a steady increase since 1972.

It can be stated that the earlier water balance which showed a high rate of extraction were not commensurate with the response of the groundwater system to development. The water balance calculated as per revised norms also show little correlation between draft and water table behaviour which may be either due to underestimate of recharge or due to overestimate of draft. Further Research work is required in this direction. There should also be closely spaced net work of key observation wells in each block which can show response of water table to groundwater development.

Punjab

Introduction

In Punjab, three areas were jointly selected by CGWB, Water Resource Directorate, Punjab - and Groundwater Cell of the Agriculure Department of the State. The study areas are as under :

Table 3.22

Study Areas Selected

Sr. No.	Name of block	Name of micro-area	Areal extent (ha)	Geological setting	No. of existing wells
1.	Samrala (Dist. Ludhiana)	Khanna	1068	Alluvial Terrain	305 tubewell (25DW)
2.	Malerkotla / Ahmedgarh blocks (Dt. Sangrur)	Malerkotla Ahmedgarh	1200	—,,—	228
3.	Nakodar block (Dt. Jullunder)	Nakodar	1027	—,,—	150

The main criteria governing the selection of the areas was the drying up of wells in Malerkotla/Ahmedgarh blocks and necessity for progressive lowering of centrifugal pumps fitted in the shallow tubewells owned by the farmers in the three selected areas.

Physiography

The three areas lie within the vast Indogangetic alluvial plain. The area Nakodar lies in between east Bein, a natural drainage and river Sutlej. The study areas at Khanna and Malerkotla/Ahmedgarh are the uplands. The areas are fairly flat and are intensively cultivated.

The average annual rainfall in Malerkotla area is 542 mm, 806 for Khanna, area and for Nakodar 540 mm respectively for the last 9 to 10 years. The year 1974 has the lowest rainfall in all the 3 study areas. The average rainfall in 1974 was 212 mm, 400 mm, 295 mm at Malerkotla, Khanna and Nakodar areas respectively. The year 1977 has experienced maximum rainfall in Khanna (1294 mm) and Malerkotla (991 mm) while 1975 was the highest rainfall year in Nakodar areas (850 mm).

Hydrogeological Features

Hydrogeologically the three study areas form part of the vast Indo-Gangetic alluvial plain. The alluvium is chiefly composed of clays, silt, sand, gravels and kankar.

The Khanna area forms part of the old sandy tract south of Sutlej river. It is fed by the Bhakra canal system which came into operation in 1956. One side of the area is bounded by Khanna distributory. However, the area mainly depends upon groundwater for irrigation. The private tubewells are varying in depth from 75 to 150 m and are of filter type. Groundwater in the area occurs at a depth of 9 to 11 m. below the ground level during the pre-monsoon period.

The Malerkotla/Ahmedgarh area is located in the heart of old Sirhind canal tract but does not come under canal irrigation. The private shallow wells in the area range in depth from 100–150 m and are of filter type. The water levels in the area occur between depths of 11 to 14 m below ground level.

The Nakodar area is located in the South Western fringe of Bist Doab Tract between east Bein and River Sutlej. Two sides of the study area are bounded by the Sarih distributory and the Tut minor. The area therefore, depends upon groundwater as well as surface waters for irrigation. All the shallow tubewells in the study area are cavity type wells. The water level in the area stands at a depth of about 10 m. below ground level.

Macro-level Water Balance

The water balance of blocks wherein the study basins were selected was carried out in accordance with the norms suggested by the over-exploitation committee. In the absence of detailed analysis 18% of average rainfall was taken as contribution to groundwater reservoir. For determining recharge from artificial sources like canals, irrigated fields, suitable factors were adopted.

Groundwater Pumpage in the area is carried out by shallow tubewells/ deep tubewells and a few dugwells. The total annual draft of any well, depends upon its discharge and its number of working hours per year. For the present estimates the average discharge of a tubewell was taken as 0.3 cusecs in the districts under report. The districtwise weighted average working hours for diesel pump were taken from the economic statistical organisations which had carried out surveys in select district. For electrically operated tubewells, the working hours were taken from the Punjab State Electricity Board record for representative feeders. By multiplying the model draft with weighted average working hours of tubewells the gross draft per well was calculated. The gross draft so estimated was checked by taking random samples from the districts of Patiala/Ludhiana. The net draft after taking into consideration recycled water has been worked out to be 1.60 and 2.25 ham for Sangrur and Jullunder districts. The draft assumed for dugwells is 0.50 ham per annum. The net yearly draft for Direct Irrigation or Deep Tubewells is taken as 62 ham. Only a fraction of the total draft is by deep tubewells.

A summerised statement of uptodate water balance is given below:

Table 3.23

Water Balance For Study Areas

Sr. No.	Name of Block	Rain fall Recharge (mm^3)	Recharge from other sources (mm^3)	Gross recharge (mm^3)	Net recoverable recharge (mm^3)	Draft (mm^3)	Balance ground water (mm^3)
1.	Samrala	27	100	127	89	171	—72
2.	Malerkotla	44	92	135	95	128	—33
3.	Nakodar	49	90	139	97	147	—50
4.	Ahmedgarh	24	77	101	71	145	—74

Response Of Groundwater System To Development

The hydrographs of key observation wells being monitored in the vicinity of study areas have been examined to find out the response of groundwater system to development. The following observations were made.

Table 3.24

Water Balance In Relation To Water Level Trend

Sr. No.	Name of Block	Net recoverable recharge (mm^3)	Draft (mm^3)	Balance potential available (mm^3)	Trend of water levels
1.	Samrala block	89.00	171.00	— 72.00	1 m. fall
2.	Malerkotla/	95.00	128.00	— 33.00	1.5 m. fall
	Ahmedgarh/blocks	71.00	145.00	— 74.00	
3.	Nakodar block	97.00	147.00	— 50.00	Fall reported

The study of long term water table trends which is available for some of the blocks from 1895 are interesting. The key observation wells in Nakodar block show that from 1942 onwards the water table has been steadily rising reaching a peak in 1966–70. Thereafter it shows a declining trend till 1974 and then a rising trend. In the case of Ahmedgarh block the water table has remained fairly steady since 1920 and a lowering trend was observed in 1973–74 due to lower rainfall in the case of only Samrala block.

Correlation Of Rainfall To Water Table Fluctations

Study of the rainfall records for the rain gauge station at Saundhra Head work in the area show that the average rainfall had been declining from 1970 to 1974 and from 1974 onwards it has shown an increasing trend upto 1977. The water table behaviour in the two observation wells also show a sympathetic response viz. post-monsoon water table being deeper during 1974–75 and then increasing upto 1977.

Malerkotla - Ahmedgarh Areas

The distribution of rainfall from 1968–1977 for a raingauge station in this area show that here too the rainfall has been decreasing from 1969 to 1974 and then increasing to 1000 mm in 1977. The water table behaviour for the post-monsoon period also shows a similar trend with lowest water table being observed during 1974-75 and then tending to rise.

Nakodar Area

The rain guage station at Nakodar shows that rainfall has been decreasing from 1970 to 1974 and then rising to a peak in1975 and then decreasing in 1976 with a further tendency to rise in 1977. The post-monsoon hydrographs of key observation wells in this area show that the lowest water table was around 1974 and then a gradual increase was observed which is in conformity with the rainfall variation.

Summing up, the study so far carried out reveals that there is no steady decline of water table since 1970. The long term hydrographs data clearly indicate that the water table has either been rising or remained steady since 1942 but some decline of water table has been noted since 1972 over the last six years. This as well as negative water balance indicates over-exploitation in a few areas.

Uttar Pradesh

Introduction

The following areas were selected for detailed studies as per the guidelines given by the Groundwater Over-exploitation Committee.

(1) Area in Block Aurai, Tehsil Gyanpur, Dist. Varanasi.
(2) Area in Block Jagat, Tahsil and Dist. Badaun.
(3) Area in Block and Tehsil Fatehabad, Dist. Agra.

Hydrogeological Features Of The Area

All the three areas selected for intensive studies fall in the Gangetic Plain. The areas lying in Varanasi and Badaun districts are in Central Gangetic Plain whereas the Agra area is in the South-West border of this plain. Geologically the formations are unconsolidated fluviatile deposits of Quaternary to Recent age. These formations generally comprise of sands varying from fine to coarse grained, silt, clay and kankar with occasional beds of fine to medium gravel. These formations form bedded lense type structure interbedded at various places. The thickness of these formations vary from less than a metre to nearly 20 m. It has been observed that upto 50 m or so the beds are generally 5 to 10 metres thick. However, thicker beds of clay and sand are frequently encountered in deeper drillings.

The Agra area forms marginal alluvium where the thickness of alluvium is less than 200 metres. The sandstone basement, probably of Vindhyan group, has been encountered at a depth of 180 m. near the study area. The thickness of alluvial deposits in Agra dist. reduces towards west where hard rock basement is exposed. Observation of water levels in selected areas for pre-monsoon period of 1978 were made in 20 wells of Varanasi district, 13 in Badaun and 25 in Agra District. The depth to water table below ground level varies from 12 to 17 m in Varanasi district, 8 to 10 m. in Bedaun and 10 to 18 m. in Agra districts.

Macro-level Water Balance

The groundwater input components were calculated as follows : Recharge from rainfall was estimated by water table fluctuation/specific yield method and recharge on account of seepage from canals as per usual norms of 1.83 cusec/million sq. metres of wetted area of canals.

Return seepage from irrigation was calculated based on the norm of 35% of total water depth applied to the field for surface irrigation system. From the gross recharge so arrived at 30% was taken as loss due to evapotranspiration and effluent losses and the balance only was considered as net recoverable recharge.

The draft was calculated based on unit draft of different type of works as given below :

Persian wheels — 0.0092 mcm.

Private tubewells — 0.022 mcm.

For deep State tubewells the draft was taken on the basis of actual hours run and discharge of each well.

The uptodate water balance is given below :

Table 3.25

Water-Balance For Study Areas

Sr. No.	Name of block	Net Recoverable recharge (mcm)	Draft (mcm)	Balance available for development(mcm)
1.	Aurai (Varanasi district)	53.97	40.14	+13
2.	Jagat (Badaun district)	51.61	72.00	—20
3.	Fatehbad (Agra district)	46.75	63.90	—17

Response of Groundwater System To Development

The State Groundwater organisation has been maintaining hydrograph of wells in the vicinity of the area for the last 5 to 6 yrs. These were analysed and the results are summarised below :

Table 3.26

Water Balance In Relation To Water Level Trend

Sr. No.	Block	Net Recoverable recharge (mcm)	Draft (mcm)	Balance potential (mcm)	Trend of water level (1972–77)
1.	Aurai block (Varanasi district)	53.97	40.14	13.83	Either stationary or a rise of 1.5 m.
2.	Jagat block (Badaun district)	59.61	72.00	—20.39	Either stationary or decline of1.5 m
3.	Fatehbad block (Agra district)	46.75	63.97	—17.25	Declining trend of 3.5 to 4.00 m.

Correlation Of Rainfall Variation With Water Table Fluctuation :

In Aurai block of Varanasi district the post-monsoon water table shows a declining trend during the period 1972–76 and the rising trend in 1977. The rainfall data shows that 1972 was a drought year and hence lowering of water table was observed. Further, data for year 1973–74 is not available. In case of Jagat Block of Badaun district only the year 1974 can be considered as a drought year. The water table also shows deepest post-monsoon water levels during this period. In case of Fatehabad block of Agra district the water table shows declining trend for 1972 inspite of the fact that the rainfall was nearly average or exceeded it during the period 1971–73.

Summing up, it can be stated that the three blocks give different pictures. The Fatehbad and Jagat blocks has overdrafted conditions while Aurai block appears to be under-developed. To offset the lowering tendency in Agra/ Badaun districts, a check on the future exploitation need be exercised and feasibility of augmenting the recharge by a network of canal system examined by the State Groundwater Organisation.

Rajasthan

Introduction

The following areas identified as critical were taken up for micro level studies in Rajasthan. (1) Mathania area in Jodhpur district, (2) Beawar area in Ajmer district and (3) Jhotwara in Jaipur district. The State Groundwater Organisation initiated detailed field studies in the above three blocks as per terms of reference of the groundwater overexploitation committee. The areas selected along with their geological setting are tabulated below :

Table 3.27

Study Areas Selected

Sr. No.	Name of the block	Name of micro-level area	Areal extent (ha)	Geological setting
1.	Osia, Jodhpur dist.	Mathania	1500	Hard rocks
2.	Jawasa, Ajmer dist.	Beawar	1275	—do—
3.	Jhotwara, Jaipur dist.	Jhotwara	1000	Alluvial plains

Hydrogeological Features

(a) Manthania area, District Jodhpur

Groundwater occurs under water table conditions in the Bhander sandstones which are generally well bedded and weathered in their upper portions and are also jointed. The sandstones are underlain by Rhyolities which are soft due to weathering. The depth to water in the area varies between 12 to 32 m. with an average of 22 m as observed in the key observation wells during May 1978. The discharge of wells vary from 100 to 150 litres per day.

(b) Beawar area — District Ajmer

The hydrogeological units present in the area are garnet biotite schists intruded by pegmatites. The pegmatites are characterised by a set of joints which are at 120°to each other and act as easy channels for transmitting groundwater. The depth to water in this area was observed to vary from 5 to 16 metres below ground level during May 1978 with slope towards north. The yield of wells varied from 10,000 to 70,000 lit. per day with an average of 50,0000 litres per day during summer.

(c) Jhotwara area - District Jaipur

The principal water bearing formation of the area is Quaternary alluvium composed of unconsolidated to loosely consolidated deposits of sand, silt and clay associated with kankar and gravel at places. Groundwater generally occurs under water table conditions but semi-confined conditions also exist. Depth to water below ground level in the representative wells of the area was observed to vary from 12.30 to 24 m during May 1978. Further, the water table is shallow in the south eastern part of the area whereas the central and western part have deeper water table. The yield of irrigation wells inventoried in the area varied from 30,000 to 50,000 litres per hour and most of the dug-cum-bore wells sustain a good discharge for about 8 to 10 hours.

Macro-level Water Balance

The water balance was estimated for the blocks where studies have been taken by the following method which was agreed to during the fifth meeting of the over-exploitation committee.

The recharge was calculated by multiplying the average monsoon rise of water table corrected to normal rainfall multiplied by the estimated value of specific yield. In case of hard rock areas a value of 3% was taken for specific yield while in case of alluvial formations a value of 10% taken. The recharge from other sources during non-monsoon period is nil and the effective monsoon draft was added to the net recharge arrived at as above. This gross recharge was adjusted by a suitable percentage of 25–30% in case of hard rock areas with undulating terrain and 30% in case of alluvial formations to arrive at net recoverable recharge. The gross draft was converted into net draft by taking 30% as recycled groundwater. A summarised statement of uptodate water balance is given below :

Table 3.28

Water Balance For Study Areas

Sr. No.	Name of district where study area is situated	Recharge Rainfall (mm^3)	Other sources (mm^3)	Gross recharge (mm^3)	Net coverable recharge (mm^3)	Net Draft (mm^3)	Balance available for development (mm^3)
1.	Jodhpur dist.	48.00	—	48.00	39.00	15.00	+24.00
2.	Ajmer dist.	30.00	—	30.00	24.10	26.00	— 2.00
3.	Jaipur dist.	24.80	—	24.80	19.90	27.00	— 7.10

Summing up, both the areas in Ajmer and Jaipur districts are over developed while in case of Jodhpur district there is scope for more groundwater development.

CHAPTER IV

NEW NORMS FOR GROUNDWATER EVALUATION AND DEVELOPMENT

INTRODUCTION

In accordance with Section 3.08 of the ARDC II Project Report a sample study in a few over-exploited blocks was to be carried out under terms of reference indicated by IDA. The IDA had indicated that the approach to be adopted for such a detailed study would be "to refine the knowledge of groundwater situation and potential for minor irrigation investments." The Committee felt that this type of activity would require refining of the existing norms for groundwater assessment which were evolved in the year 1972 when detailed studies on groundwater assessment were in their early stages and only ad-hoc parameters were taken into consideration. Since then the Central Groundwater Board, different State Groundwater Organisations and Universities have carried out detailed water balance projects which have thrown much light on the various parameters for groundwater assessment and hence the committee felt that now a time has come to refine the existing groundwater assessment norms considering these aspects. After detailed study and discussions with the various State Groundwater Organisations the following new norms were finalised.

New Norms For Groundwater Evaluation

The Committee recommends the following norms for groundwater evaluation.

A. Recharge From Rainfall

(i) Alluvial Areas

In Sandy areas : 20 to 25% of Normal Rainfall
In areas which have
larger clay content : 15 to 20% of Normal Rainfall

(ii) Hard Rock areas : 10 to 15% of Normal Rainfall.

If on the basis of field studies the SGO finds that the percentage of rainfall infiltration is less than the above figures in either alluvial or hard rock areas then the actually observed value of percentage infiiltration should be adopted.

B. Recharge Due To Seepage From Canals

(i) **For canals in normal type of soils which have some clay content along with sand :**

15 to 20 ham/day/10^6 sq. metre of the wetted area, or
6 to 8 cusec/10^6 sq. ft. of the wetted area, or
1.8 to 2.5 cumec/10^6 sq. metre of the wetted area.

(ii) **For canals in sandy soils**

25 to 30 ham/day/10^6 sq. metre of the wetted area, or
10 to 12 cusec/10^6 sq. ft. of the wetted area, or
3 to 3.5 cumec/10^6 sq. metre of the wetted area.

C. Return Seepage From Irrigated Fields

a. Irrigation by Major Irrigation Sources (Gravity Canals)

(*i*) 35% of the water delivered at the outlet for application in the field.

This includes losses in field channels for which no separate estimate need be made.

(*ii*) 40% of the water delivered at the outlet for Paddy irrigation only.

This includes losses in field channels for which no separate estimate need be made.

b. Irrigation by All Minor Irrigation Sources (Tubewells, Lift Canals etc.)

30% of the water delivered at outlet.

This includes losses in field channels for which no separate estimate need be made.

In all the above cases the return seepage figures include losses in field channels and these should not be separately accounted for.

D. Seepagc From Thanks

44 to 60 cm. per year over the total water spread. The losses should be taken into account depending upon the agro-climatic conditions in the area.

E. It may be mentioned here that while estimating the gross recharge the amount of seepage from other sources like the influent seepage and seepage from ponds and lakes for which no norms have been prescribed in this report, should also be accounted for. In case of stage of development to be estimated at year 5, the additional recharge expected from the surface water projects to be commissioned during this period should also be added.

F. Net Recoverable Recharge

From the gross recharge calculated by sumning up all the inputs components, the net recoverable recharge may be taken as 70% of the gross recharge.

In case some of the State Groundwater Organisations feel that the percentage of net recoverable recharge may be different from the above, they should carry out detailed field studies to revise the above value in specific areas and submit the report to the Central Ground Water Board for examination with a view to consider any revision. If considered acceptable and justified, the Central Ground Water Board will recommend such revised percentage for specific block/blocks to ARDC for consideration and acceptance.

G. Water Level Fluctuation Approach

It was agreed that for areas where sufficient data is available and in all cases where the stage of groundwater development in a block/taluq is over 60% of the recoverable recharge the groundwater should be evaluated by the water table fluctuation and specific yield approach. The fluctuation of water table should be taken as the difference between the lowest pre-monsoon and the highest post-monsoon water levels in an observation well. Inconsistencies in observation can be smoothened out if contours of water level fluctuation in an area are drawn and judicious knowledge of the area is exercised to omit inexplainable and inconsistent observations. It is desirable that SGOs may draw groundwater contours of adjoining divisions under their administrative control and should put them on one map to check their continuity on a regional/basin / state level basis.

The specific yield values for different types of geological formations in the zones of fluctuations of water table may be adopted as below :

(*i*)	Sandy Alluvial areas	12	to	18 %.
(*ii*)	Silty Alluvial areas	6	to	12 %.
(*iii*)	Granites	3	to	4 %.
(*iv*)	Basalt	2	to	3 %.

The gross recharge evaluated by the water table fluctuation method corresponding to rainfall in the year of observation or average for the number of years of observations should be proportionately corrected to Normal Rainfall as given by the Indian Meterological Department in the area, on the basis of linear proportionality. From the gross recharge the net recharge can be estimated in accordance with the norms indicated above. If, after examination, ARDC finds that the recharge calculated on the basis of the water table fluctuation approach widely exceeds (more than 10%) the value estimated on the basis of the penetration norms, ARDC will review the matter if required, in consultation with the Central Ground Water Board.

While estimating groundwater availability by the water level fluctuation and specific yield approach the conceptual input and output components should not be lost sight of.

These are given below :

Conceptual Details In Water Balance Studies

Mean gross recharge	=	Mean recharge in the monsoon season + Mean recharge in the non-monsoon (rabi and summer) season.
Mean recharge during the monsoon season	=	Water table rise × specific yield × (normal monsoon rainfall ÷ actual monsoon rainfall) + net draft + effluent loss during the monsoon season (the last figure is proposed to be ignored).
Mean recharge during the rabi season	=	Non-monsoon rainfall contribution + seepage from canals + return flow from canal irrigation + seepage from lakes and ponds, etc.

The recharge due to recycled water from irrigation by groundwater has not been included here as only the net extraction has been accounted for on the yearly pumpage side.

Net recoverable recharge	=	70% of the mean gross recharge
Mean gross yearly extraction	=	Extraction during monsoon + Extraction during non-monsoon period
Net extraction	=	70% of gross extraction
Groundwater available	=	Net recharge — Net extraction
Stage of development expressed as a percentage	=	$\frac{\text{Net extraction}}{\text{Net recoverable recharge}} \times 100$

The rise in water table in an area as reflected in the difference in water levels between the pre-monsoon and post-monsoon period includes all components of recharge during the monsoon period including return seepage from the groundwater pumped during monsoon period and used for irrigational purposes during the period. However, the component of groundwater pumpage during monsoon period that does not go as return seepage to recharge the groundwater reservoir is not accounted for in the observed water level fluctuations even though it has come out from the goundwater reservoir This should, therefore, be separately added as a component of recharge during the monsoon period. This is taken as 70% of the gross draft during the monsoon/kharif period presuming that 30% goes as return seepage during this period.

It would be desirable to first evaluate the figure of mean gross yearly recharge rand mean gross yearly extraction before estimating the net water balance available for future development.

The concept of Net Water Balance has been introduced by the World Bank for clearance of minor irrigation works under ARDC III. This implies that :

(*i*) Future works should be cleared against Net Water Balance available for development.

(*ii*) The unit draft of each category of work should first be estimated as gross draft based upon field survey. Thereafter, the future number of works that can be cleared against the available net water balance should be based upon their net draft as 70% of the gross draft.

For example, if x is the net water balance in an area and Y is the gross draft of a particular type of pumpage work then the total number of works that can be cleared against X are $\frac{X}{0.7 \times Y}$

Stage of Groundwater Development

The stage of ground water development is taken as the ratio of the net draft to the net recoverable recharge :

OR

$$\text{Stage of Ground Water Development} = \frac{\text{Net Yearly Draft}}{\text{Net Yearly Recharge}} \times 100$$

In the present case when the net values are 70% of the gross, both on draft and recharge sides, the stage of groundwater development by implication equals the ratio of gross draft to gross recharge but conceptually the difference between the two should be recognised.

The stage of development as indicated above is for the year for which the discharge and recharge components have been estimated. Under ARDC III the stage of development has to be estimated at year 5. The method of making such an estimate is separately given as Appendix V of this report.

Observation Net Work

The assessment of groundwater resources in a block should be carried out by the water level fluctuation approach as far as possible. In case of Grey and Dark areas the assessment should necessarily be carried out by this approach. While estimating groundwater balance by the water level fluctuation approach the number of observation wells in an area should be kept in view. It has been observed that the intensity of observation wells maintained by the various SGOs in a block is generally not adequate. The intensity of observation wells depends upon many factors like the purpose, time and money required for the work. It has been recommended in the UNESCO Publication that there should be one observation well per 10 sq. km. of the area where the nature of the area is complex. It has also been recommended that for simple areas there can be lesser number of wells and a low figure of one to two wells per 1000 sq. km. has been recommended. However, under Indian conditions an intensity of a minimum of 1 well for every 100 sq. km. of area is considered adequate for estimation of average rise of water table in a block.

For confined aquifers the groundwater assessment should be made on a different approach based on "Rate Concept" rather than "Quantity Concept" In such cases the estimate of groundwater has to be made on the basis of transmissibility, hydraulic gradient and area of flow at the inflow and outflow sections.

The committee recommends for computation of groundwater recharge, the application of flow net analysis method especially for areas where the deep semi-confined and top unconfined aquifers, are interconnected should be applied In this case recharge can be estimated by studying the difference in quantity. of water crossing successive piezometric contours between limiting flow lines by the following equation.

$$R = \frac{Q_2 - Q_1 + \Delta h_1 A_1 S (2.18 \times 10^8)}{A_1}$$

where R = Rate of recharge in gpd/sq. mile

$Q_2 - Q_1$ = Difference in quantity of water crossing through successive contour lines between limiting flow lines in gpd.

Δh_1	=	Average rate of water level rise/fall in fpd.
A_1	=	Area between limiting flow lines and successive contours in sq. miles.
S	=	Specific yield

Statewise Groundwater Evaluation

In view of large Institutional Financing for Minor Irrigation Works under ARDC III, it was decided that all SGOs should work out groundwater availability in their states on a Block/Taluka/Watershed basis. This would indicate the stage of groundwater development as a percentage of resources available for development. The above studies may be completed as early as possible and the reports may be submitted to ARDC by December 1979. Each report may include the following maps:

(*i*) Map of the State as a whole showing the various districts and blocks/talukas to scale 1 inch = 16 miles or $1/10^6$.

(*ii*) Map of district/group of districts showing talukas/blocks where groundwater development is less than (1) 60% (2) 60% to 80% (3) over 80%. Scale : 1/500,000.

It was also agreed that in blocks/talukas where the ratio of groundwater development to utilisable recharge is 60% and above the groundwater assessment should be based on water level fluctuation approach.

Groundwater For Private Development

With a view to evaluate the extent to which groundwater resources are being developed through private investment it was agreed that the SGOs would work out the rate of groundwater development through private pumpage works over the last 5 to 10 years according to the availability of data and make projections of such development over the next 5 years. In some states where the rate of private development varies on a zonal basis the SGOs can make these studies on a zonal basis. The groundwater required for private development at the end of year 5 may be deducted from the total groundwater balance to arrive at a figure which can be developed by institutionally financed works. The details of methodology to work out the above are given in Appendix V.

Groundwater Control

It was felt that some control on groundwater development to ensure efficient working of adjoining wells without detrimental effects of mutual interference would be desirable. The spacing should also be such that the pumpage works are economically viable. The SGOs have to work out spacing for each type of work on a blockwise basis by actually carrying out the pump tests in each block or similar geohydrological areas. For this, pump tests for a minimum period of about 12 hours duration on tubewells in top unconfined aquifers to evaluate the values of T, S and R would be necessary. This period of pump test corresponds to the normal duration of continuous running of such wells during an year.

In case of dug wells without pump sets the value of the radius of influence (R) to determine spacing should be evaluated by carrying out short duration pump tests for a minimum period of 3 hours duration. These irrigation wells are generally pumped for longer periods but with a lesser discharge compared to what is likely to be pumped out by installing a pumping unit while carrying out these short duration pump sets. It can thus be taken that the value of radius of influence arrived at as a result of these tests would be fairly representative of the dug well unit for purposes of deciding their spacings.

Thus, the spacing of different type of works should be based upon the following studies.

1. The spacing should be 2 times the radius of influence estimated on the basis of pump tests as given above for the various categories of pumpage works

2. The spacing should be such that the pumpage works are economically viable. This implies that if a particular type of groundwater pumpage unit can irrigate a certain area, another unit should not be put in its irrigated command so as to avoid over capitalization on minor irrigation structures. Based upon the present irrigated area concept the economic viability of the various type of minor irrigation works require the following minimum spacings.

Table 4.1
Minimum Spacings Between Pumpage Works
(Economic Aspects Only)

Sr. No.	Type of Unit	Irrigated Area Hect.	Irrigated Area Acre	Spacing for Sq. Plot (m)	Spacing for Circular Plot	Recommended spacing (m)
I.	Alluvial Areas					
1.	Dug well	1	2.5	100	112	100
2.	Dug well with pumpset	2	5	140	160	150
3.	Shallow tubewell	3	7.5	170	200	180
4.	Deep tubewell	40	100	625	700	650
II.	Consolidated Rocks					
1.	Dug well with pumpset	2	5	140	160	150
2.	Medium Duty Tubewell	8	20	280	300	280

Different districts/talukas/blocks have different hydrogeological, climatic economic and social conditions and would require different spacings. From technical point of view the spacing can only be evaluated by actually carrying out pump tests in the field but the adopted spacing value in an area should be higher of the two as obtained by pump test results or as justified on economic considerations. It is therefore, suggested that the SGOs should carry out pump tests selecting similar geohydrological areas and then extend the programme to cover each block.

3. Till the SGOs are able to carry out pump tests in the field, the existing norms for spacing as applicable under ARDC II may continue under ARDC III lendings as well.

Further Studies

A. Groundwater Evaluation

With increased groundwater development it follows that institutional finance should be provided with greatest care. This requires rigorous groundwater assessment specially in areas where the stage of groundwater development is over 80% of the recoverable recharge.

(a) Groundwater Input Components

Estimation of recharge from rainfall, seepage losses from surface irrigation system and recycled groundwater can be fairly well estimated. Recharge due to leakage from deeper confined aquifers to the water table aquifer and influent seepage from streams has yet to be quantified by approporate analysis. It is suggested that further work in this direction may be taken up in the various SGDs.

(b) Groundwater Output Components

These require more attention in future than what they have got at present. Much of the groundwater extraction appear to be over-estimated resulting in giving an apparently higher stage of groundwater development. The groundwater extraction quantification has to be checked and counter-checked by different methods like fuel consumption data, crop water requirements and sample studies regarding average rate of groundwater withdrawal from different categories of Minor Irrigation Works. The other components of groundwater output is the effluent seepage and evapo-transpiration losses which have also to be quantified. The shallow water table areas have a tendency to reject groundwater recharge. In such areas the recoverable recharge has to be estimated on a more realistic basis so as to project correct possible development based on potential groundwater recharge. Further work in this direction is necessary.

Groundwater evaluation is being done at present on administrative units in view of the convenience for collecting statistical data regarding number of MI structures etc. However, if a particular administrative unit happens to fall in discharge areas of a major river basin especially in hard rock areas it is likely that the groundwater recharge computed by seasonal fluctuation approach would result in an under-estimation. Hence it is necessary that in the first instance, basin wise groundwater evaluation can be attempted wherein the recharge areas characterised by high seasonal fluctuation and discharge areas characterised by subdued fluctuation are separately delineated. Once this is done, the administrative units can be fitted and realistic potential recharge worked out.

B. Groundwater Monitoring

The real status of groundwater regimen in an area has to be reflected in the water table behaviour as judged from key observation wells in that area. For proper monitoring, a closely knit dense network of key observation wells have to be constructed if necessary by installation of piezometers in critical areas not covered by the usual well network. This is all the more important in Grey and Dark areas. This would also help in delineating on a macrolevel, the under-developed pockets in an otherwise overdeveloped block/taluka/ watershed.

The base flow measurement have also to be intensified in the highly developed areas which may also indicate the level of groundwater development and probable extent of recoverable losses.

C. Efficiency of Pumpsets

Field studies may be carried out to evaluate the efficiency of various types of pumping units and remedial steps suggested to improve the same.

Appendix I

OLD GUIDELINES FOR EVALUATION OF GROUNDWATER RESOURCES IN A REGION

(Based on reconnaissance survey and collection and compilation of the available geologic and hydrologic data and information).

I. INTRODUCTION

An exact evaluation of the groundwater resources in an area will require a comprehensive study of a highly complex nature, including appraisal of numerous geological and hydrological features. This will require large resources of trained men, material, equipment and money which can at best be afforded only in limited representative hydrologic units. In most of the groundwater worthy areas recourse has to be taken to selective studies which include preparing and maintaining inventory of the existing works and their withdrawal rates, monitoring the variations in the ground water levels/pressures and chemical quality of groundwater on a continuing basis and undertaking geological and hydrogeologic studies of a semi detailed type (limited in scope and extent) and filling up the gaps by collection of information from the on-going production programmes and by adopting techniques of correlation of the extent possible.

Efforts are currently under way to cover groundwater worthy areas of the country with special projects for comprehensive resources evaluation and to carry out semi detailed studies for remaining areas. Both these studies, are however, time consuming and have to be carried out over a number of years before they can effectively assist in throwing additional light on the geologic and hydrologic features and in refining the present results. Meanwhile, continuity of the production programme has also to be maintained. Fortunately to support this development, some geologic and hydrologic information is already available in most parts of the country. It becomes important in this context to adopt a flexible approach that will enable approximate assessment of groundwater potential in a region on the basis of available information and knowledge (whether meagre or intensive). An attempt has been made to outline the various steps that are involved in an appraisal of this type and the type of data that is required to be collected for such an appraisal.

II. Steps Involved In Approximate Appraisal

(1) MAKING AN EXHAUSTIVE INVENTORY OF THE EXISTING WELLS

As a first step it would be necessary to prepare an inventory of the existing groundwater utilisation works under five categories: (a) dug wells fitted with indigenous water lifts; (b) dugwells fitted with pump sets (electrical or diesel) (c) bore wells, (d) shallow tubewells; filter points and (e) deep/ medium tubewells. The inventory should indicate the location, depth, depth of boring/drilling, depth to water, construction features, type of equipment used, pumping record, water analysis, records of hours run and irrigation performance etc.

(2) COMPUTING EXISTING GROUNDWATER DRAFT

The existing draft can be estimated on the basis of an average withdrawal in terms of a metre for each type of work. This can be arrived at as a result of field observations and enquiries during the survey and/in consultation with the concerned technical officers in the area. The electric consumption per annum, if reliably obtained from the Electricity Boards, will help in exercising a second check on the withdrawal figures for works fitted with pumpsets.

If, in the absence of the above data the draft can be estimated on the basis of gross irrigated area from groundwater schemes in the area, for making this calculation a reasonable average depth of total application of irrigation per crop acre may be arrived at in consultation with the state Department of Agriculture.

(3) ESTIMATING RAINFALL RECHARGE TO GROUNDWATER

(*i*) Representative average rainfall in the project area can be determined by taking weighted average (By Thiesson or Isohytal Method) of the mean annual rainfall (average of about 30 years) of all the rain guage stations in the project area. More reliance should be placed on the figures of rain guage stations included in the IMD records.

(*ii*) Where no other reliable method or authentic data is available, the average annual contribution to groundwater from average rainfall can be calculated as below :

(a) In alluvial areas, by the following formula
(Known as the Chaturvedi formula)

$$Rp = 2.0\ (R-15)^{2/5}$$

Where R = annual rainfall in inches.

(The above relationship is applicable to the areas having annual rainfall in excess of 15″.)

and Rp = annual rainfall recharge to groundwater table in inches.

No adjustments may ordinarily be made for subsurface run-off losses in the alluvial areas unless there is a definite indication that such losses would exceed the possible recharge from the river sources or from other areas.

(b) **In hard rock areas,**

Due to wide variations in the local conditions, it will not be proper to adopt a generalised approach. After subtracting the subsurface run-off losses, which are likely to be substantial in the hard rock areas, the net contribution to groundwater recharge from the average rainfall may be taken upto 7.5%. depending upon the local topographical, geological and climatic factors. This is based on the assumption that the entire geographical area of the project is taken into account.

(*iii*) In project areas where some authentic data is available about the rise of the water table during the monsoon season, rainfall contribution to groundwater recharge may also be calculated as a second check by multiplying rise of the water table with estimated average value of the specific yield, and making adjustments for the withdrawal of groundwater if any, during the monsoon season and also for the seepage during the period from canals and other surface water sources which may exist in the area. While the figure worked out for the withdrawal would be added the figure computed for seepage would be substracted. The draw back in this approach is that the authentic data about the rise of the water table is usually available for a very limited number of years which may hardly be enough to give an average representative picture and also the estimation of average specific yield is difficult. The first handicap may be overcome to some extent by assessing the departure in the mean rainfall for the years for which water table data is available from the average rainfall (for 20 years or so) and then calculating the average representative value of the rise of the water table by proportionate adjustment. Average specific yield for unconfined aquifers may be calculated (it will be the same as the co-efficient of storage) if some pump test data is available. Alternatively, it may be inferred to some extent from the lithological logs available for the area. In applying this approach for a second check in the hard rock areas it will be necessary to reduce the resultant figure of recharge by 25 to 30% to allow for the sub-surface run-off losses.

(4) ESTIMATING GROUNDWATER RECHARGE FROM OTHER SOURCES

(*i*) Seepage from unlined canals may be calculated on the basis of 1.8 to 2.5 cumec per million sq. metres of the wetted area. Due adjustments should be made for the period the canal remains closed during the year.

After allowing for the evapotranspiration losses, about 75% of the seepage may be taken as groundwater recharge.

(*ii*) Recharge to groundwater from storage works, if any existing in the project area may be assumed at about 5% of the total storage.

(*iii*) Return flow to groundwater from irrigation may be calculated on the basis of 20% of the estimated average total irrigation application per crop-acres in the project area. Average total irrigation application per crop-acre may be taken as 20% except in prodominantly paddy areas where a higher figure may be assumed.

(5) CALCULATING BALANCE RECHARGE FOR FURTHER DEVELOPMENT

The difference between the total recharge i. e. the total of figures worked out in (3) and (4) above and the withdrawal from existing works as worked out in (2) above, will give the balance recharge available for further development

(6) CALCULATION FOR AVERAGE SPACING OF WORKS

(*i*) The average spacing between dugwells, borewells, and shallow tube- may be determined by the application of the following formula

$$Sm = 1000 \sqrt{\frac{R \times A \times C}{r \times 100}}$$

	Sm	=	distance between wells in metres
where	R	=	water requirement of crops in mm
	A	=	area of command of well in hectares
	C	=	cropping intensity
	r	=	Annual total groundwater recharge from all sources including rainfall, seepage from canals and tanks, recycled water from irrigation in the area.

(*ii*) In case of medium and deep tubewells the criterion for spacing may be specified on the basis of hydraulic-cone considerations to avoid mutual interference of wells.

(7) APPRAISAL OF OTHER FEATURES

Additional features to be appraised include :

(*i*) Topographical — spot levels/elevation contours, watershed and drainage lines, land forms etc.

(*ii*) Geological features — rock types exposed, characteristics and distribution and lithology of the ground water formations etc.

(*iii*) Density and distribution of existing groundwater utilisation works.

(*iv*) Depth to water table and water table behaviour.

(*v*) Quality of water in general and distribution of the saline and the fresh groundwater zones.

(*vi*) Results of pump tests/recuperation tests, if any, conducted in the area, including values, of the coefficient of storage and transmissibility.

(*vii*) Data on evapotranspiration, rainfall infiltration, seepage from canals, ponds, etc. that may be available in the region.

(*viii*) New surface water irrigation projects that are likely to provide irrigation in the project area in near future.

(*ix*) Present status and proposed soil conservation measures in the project area.

III. Approximate Assessment Of Groundwater Potential For Further Development

(1) The number of new works considered feasible in a project area should be based on the balance recharge available for further development. The additional withdrawal from the new works should not exceed the balance-recharge. The draft from the new works may be calculated on the same basis as draft from the existing work.

(2) The water balance estimated as per this guideline will represent a sort of average picture for the whole region covered. The actual water balance may be different for the various elementary watersheds in the project area. Hence, if the hydrologic data about rainfall and other parameters is available it will be desirable to work out the water balance separately for each elementary watershed in the project area.

(3) The groundwater recharge for further development may be considered effective and thus computed only for the cultivable areas in each elementary water-shed because the recharge in the non-cultivable areas such as forest, areas with exposed rocks etc. may not contribute to any usable groundwater resource.

(4) No additional works should be considered feasible in areas where the water table is progressively declining except in arid regions where deliberate mining of groundwater is attempted or the aquifers likely to be tapped are known to be saline for direct use for irrigation.

(5) A little calculated over-development may be permitted in areas which are likely to be served with fresh surface water irrigation projects in the near future, or where soil conservation measures currently in hand are expected to increase the groundwater re-charge in course of time.

(6) Formula/yardstick suggested for computing groundwater re-charge in this guideline are of generalised nature. If the available information about

the evapotranspiration rates, topographical features, soil permeability etc. suggest the need for modification in the approach or adjustments in result, the same can be carried out on the basis of available local experience.

(7) The calculation vide II (6) above give an average picture of the density and the spacing in respect of the new works considered feasible in the project area. It will be desirable that the density and spacing recommended may be varied in the light of available knowledge about variations of the topographical, hydrogeological and geological features in the project areas. In general, higher density can be provided in lower valley areas compared to the upland/head water region. The distribution of existing works may also throw some light on this aspect.

(8) The type of groundwater structures for new works in a project area should be based on the geological formations in the region. Generally, speaking, in the alluvial areas public tubewells should be recommended because the aquifers are deep seated and the farmers have small holdings. In areas where shallow aquifers are available, private tubewells (which are shallow) should be suggested. However, in some cases the small farmers may like to have dugwells instead of tubewells. Although these give lower yield, dugwells have an advantage in the financial position of the farmers. The farmer can have the dugwell bored in course of time and eventually may get it fitted with a pumpset. In semi-consolidated rocks, both tubewells as well as dugwells have to be considered. In consolidated hard rock areas, dug wells form the main item. Bore wells (which is the name given to tubewells in hard rock areas) may be recommended instead of dug wells in some areas wher elocal experience shows that bore wells give satisfactory yield.

IV. Data Required

The data required for conducting groundwater appraisal is outlined below:

(1) Maps to be compiled

(*i*) A suitable map showing the location of the project area and other features including : (a) topographical, water-shed and drainage lines and spot levels/elevation contours etc. (b) district and taluka boundaries; (c) roads, railways and transmission lines; (d) land use pattern and (e) water level maps.

(*ii*) A rough geological map of the area showing rock types exposed and other geomorphological features.

(*iii*) A large scale map (preferably in cadestral scale) showing the location of existing works and other geological and hydrological features, data/information about which is available.

(2) Brief account of the hydrogeological/hydrological studies already carried out in the area may be compiled including reference of the relevant technical publications.

(3) Hydrogeological data

This should include available data about the geological formations based on surface, geological field reconnaissance, geo-physical investigations and lithological logs of test and production wells.

(4) Hydrologic data

This should include :

(*i*) Water levels in the wells and their seasonal fluctuations.
(*ii*) Quality of surface and groundwaters in the area
(*iii*) Details of pump/recuperation tests in th areas and values of storage co-efficient, transmissibility, permeability and radius of influence of the various aquifers. This may be given in a tabular form.
(*iv*) rainfall data including statement of average annual and monthly rainfall with number of rainy days for as many years as possible.
(*v*) data of canals, tanks, ponds etc. including length of canals, their wetted perimeter, discharge and number of running days. Storage capacity of reservoirs/ponds should be given in a tabular form. If any research studies for estimating seepage from canals have been carried out in the area or nearby area of similar nature, the same may be given;
(*vi*) Evapotranspiration data

(5) Data regarding groundwater structures, their capacity, irrigation performance and withdrawal rates.

This should include :

(*i*) inventory of existing works as given below
   (a) dug wells fitted with indigeneous lifts
   (b) dugwells fitted with pumpsets
   (c) bore wells
   (d) shallow tubewells/filter points and
   (e) medium/deep tubewells
(*ii*) Design construction features and yield of works under each category.
(*iii*) type of soils, cropping pattern and land use data in the region.
(*iv*) An estimate about the irrigation requirements per crop acre to be irrigated by the well/tubewell, and
(*v*) expected irrigation performance and withdrawal rate of the typical works under each category.

The above information can be compiled in the following form.

Table 1.1

Format For Estimating Annual Extraction

Type of wells	Average discharge/ yield in m^3/day	Average gross irrigation (in crop/ Ha)	Average number of working hours per annum
Dug wells fitted with indigenous lifts			
Dug wells fitted with pumpsets			
Bore wells			
Shallow tubewells / filter points			
Medium / deep tubewells.			

Appendix II

SECOND AGRICULTURAL REFINANCE AND DEVELOPMENT CORPORATION CREDIT PROJECT

Statewise Groundwater utilisation

Districts containing Intensively Developed/or Potential Problem Areas

State	District	Tehsil/ Taluk	State	District	Tehsil/ Taluk
Gujarat	Ahmeda-bad	Dauesa	Haryana	Hissar	Barwala
		Viramgam			Hansi - I
					Sirsa
	Banaskantha	Deodar		Jind	Rajanand
		Deesa			
		Dhannera		Karnal	Assandh
					Madlauda
	Junagadh	Mangrol			Missang
		Veraval			Nilokheri
					Panipat
	Kutch	Anjar			Samalka
		Bachan			
		Lakhpet		Kuruksh-etra	Gulha
					Ladwa
		Mundra			Pundri
		Maliya			Sahabad
		Rapar			Thanesar
	Mehsana	Mehsana		Mohinder-garh	Atalinmgal
		Patan			Bawai
		Vijapur			Khanina
Haryana	Ambala	Barara			Khol
		Jagadhari			Narnaul
		Naraingarh			Chowdri
					Rowari
					Nangal

State	District	Tehsil/ Taluk
Haryana	Bhiwani	Bhadra
		Bhiwani
		Dadri I
		Dadri II
		Loharu
	Gurgoan	Ballabhgarh
		Gurgaon
		Hathin
		Nuh
		Pataudi
		Punhana
		Sohana
Karnataka	Bangalore	Bangalore south
		Devanahalli
		Doddaballapur
		Hoskote
	Belgaum	Attani
		Chikodi
		Gokak
		Hukkeri
		Raibagh
	Bellary	Harpanahalli
		Mallapur
	Bijapur	B. Bagewadi
		Bijapur
		Indi
		Jamkhandi
		Modhol
		Sindgi
	Chitra-durga	Challakere
		Chitradurga
		Hiriyur
		Jagalur
		Molakalmuri

State	District	Tehsil/ Taluk
Haryana	Rohtak	Bahadurgah
		Beri
		Jhajjar
		Kharkhoder
		Kalanaur
		Nhahar
		Rohtak
		Shalawas
	Sonepat	Ganaur
		Rai
		Sonepat
Mahara-shtra	Ahmed-nagar	Akola
		Rahuri
		Kopargaon
	Dhulia	Sangamener
		Dhulia
		Nandurbar
	Nasik	Chandur
		Kalwan
		Malegaon
		Satara
	Sangli	Khanapur
		Miraj
Orissa	Ganjam	Aska-Block
Punjab	Faridkot	Nilsinghwala
		Moga & southern parts of Jagraon
	Kapurth-ala West	Entire dist-rict except 5 km. wide belt along river Beas
	Ludhiana	Complete district except in the block along river Sutlej

State	District	Tehsil/ Taluk	State	District	Tehsil/ Taluk
Karnataka	Dharwar	Mundargi			
	Kolar	Bagepalli Bangarpet Chikkabballapur	Punjab	Patiala	Parts of Nabha and Sirhind
		Chintamani Gudibanda Kolar Malur Mulabagal Sidlaghatta		Sangrur	Complete district except in the part of Sangrur tehsil and western part of Barnala tehsil
			Rajasthan	Barmer	Entire district except Siwana block
	Mandya	Mandya Pandavapur Srirangapattanam		Ganganagar	Excepting the eastern parts and areas adjacent to canals
	Raichur	Koppal		Jaisalmer	Whole district excepting areas south of Jaisalmer
	Tumkur	Pavagada Koratagere		Jalore	Entire district
		Madhugiri Sira		Jodhpur	Jodhpur-Nathania area.
				Pali	Entire dist.
Tamil Nadu	Coimbatore	Avinashi Coimbatore Palladam	West Bengal	Birbhum	Bolapur Labpur Mayureshwar
	North Arcot	Arni Polur Wandiwash			Murarari Nalhati Rampurhat Upper Nanur
	Ramanadhapuram	Arupukottai Sattur		Burdwan	Kalna
		Srivalliputhur		Hooghly	Armabagh Balagarh

State	District	Tehsil/ Taluk
Tamil Nadu	Salem	Attur Salem
	Tirunel-veli	Koilpatti Nanguneri
Uttar Pradesh	Aligarh	Areas around Aligarh Iglas in Iglas Teh; and Sansi in Hathras Tehsil
	Badaun	Alapur in Daagani Tehsil and Kisrua in Badaun tehsil
	Bulande-shehar	Jewar and Rabupura in Khurja Tehsil
	Meerut	Baraut, Chhaprauli Kisanpur Baral and Daha in Baghpat Tehsil, Nidinagar and Pilkhua in Gaziabad Tehsil, Kharkhunda, Babugarh and Hapur in Hapur Tehsil, Bhawanipur and Jani-Khurd in Meerut Tehsil
West Bengal		Ganghat Pursurah
	Malda	Kharba Ratna
	Murshida-bad	Bharatpur Burwan Kandi Khargram
	Nadia	Krishnagar —1.

SECOND AGRICULTURAL REFINANCE AND DEVELOPMENT CREDIT PROJECT

CRITERIA FOR SPACING AND DENSITY OF WELLS

Participating banks and state agencies shall determine, each scheme submitted to ARDC involving groundwater development, permissible spacing and density of wells and anticipated water quality based upon local geologic and hydrologic conditions. Such determinations shall be reviewed by ARDC prior to sanction of any scheme. In the event any scheme proposes development exceeding the following guideline criteria, ARDC may sanction the scheme only after receipt and approval of additional details supporting data. ARDC shall maintain a record of all requests for relaxation of the following criteria, including the supporting data submitted and action taken for periodic field review by IDA.

A. WELL SPACING (MINIMUM SPACING IN METRES)

	Annual Rainfall n mm			
	Upto 500	500–1,000	1,000–1,500	over 1,500
Aquifer and well type				
Dug wells ∠a	180 m	150 m	110 m	100 m
with pumpset ∠b	250 m	200 m	150 m	100 m
Tubewells in Alluvium				
Shallow tubewells ∠c	275 m	225 m	175 m	150 m
Deep tubewells ∠d	1000 m	800 m	600 m	500 m
Tubewells in Sedimentary Rocks				
Medium Tubewells ∠e	700 m	700 m	700 m	700 m

∠a Typical annual withdrawal 5–6,000 m^3
∠b Typical annual withdrawal 10–12,000 m^3
∠c Typical annual withdrawal 15–25,000 m^3 at 25–40 m^3/hr.
∠d Typical annual withdrawal 300–400,000 m^3 at 150–200 m^3/hr.
∠e Typical annual withdrawal 75–125,000 m^3 at 75–100 m^3/hr.

Before reducing above spacing criteria, consideration must be given to such factors as : rainfall seasonal distribution, reliability and intensity; cropping pattern and water requirements, local geology, soils, and topography; existing development and historical water-level observation or aquifer tests; proposed withdrawal rates and volumes; and potential for added private developments.

B. WELL DENSITY

Permissible density of wells to be based upon a water-balance study of the appropriate elemental area considering all existing development and potential concurrent private development and using actual field data whenever possible instead of empirical assumptions.

Appendix IV

METHODOLOGY ADOPTED FOR GROUNDWATER EVALUATION IN SPECIAL PROJECTS OF CGWB

1. UNDP ASSISTED PROJECT IN ARID AND SEMI-ARID AREAS OF WESTERN RAJASTHAN AND GUJARAT (1971-73)

For quantitative assessment of groundwater the following two methods were used.

(*i*) Analysis of water level fluctuations.

(*ii*) Soil-moisture budget technique.

The equation used for working out the water balance was :

$$P = E + (Q_o - Qi) + (G_o - Gi) + S + G + L$$

Where P = Rainfall
E = Actual evaporation
Q_i = Inflow of river water
Q_o = Outflow of river water
G_i = Inflow of groundwater
G_o = Outflow of groundwater
S = Change in soil moisture + storage.
G = Change in groundwater storage i.e. water surplus or recharge
L = Change in lake storage

However, the equation was simplified separately for Rajasthan and Gujarat as given below :

For Rajasthan:

$P = E + S + G$ Since there was no surface flow.

For Gujarat :

$$P = E + S + G + (Q_o - Q_i)$$

The value of E was calculated by assuming E/PE as linear and taking E = O at wilting point and E = PE at field capacity. The water balance computation were made on daily basis. For each day the actual E was subtracted for the actual available soil moisture and on each day the rainfall was added to the soil moisture. At the beginning of wet season, the available soil moisture was taken as zero, and it was assumed that any excess water after soil saturation upto field capacity percolates downwards and becomes groundwater recharge or sub-surface runoff to river flow. The results obtained are given below :

Table 4.1

Recharge To The Various Aquifers In Rajasthan and Gujarat Area

RAJASTHAN

Sr. No.	Aquifer	Basin	Annual rainfall (mm)	Mean water level rise(cm)	Specific yield %	Recharge (mm)	Recharge as % of rainfall
1.	Quaternary aeolin sands	Sikar Basin	409	33	10	33	8 %
2.	Quaternary alluvium	Luni Basin	409	67	5	33	8 %
3.	Palana sand stone	Bikaner & Luni Basin	409	19	7	13	3 %
4.	Nagaur sand stone	Bikaner Basin	404	74	1	7	1.7 %
5.	Nagaur lime stone	—,,—	404	81	1	8	2 %
6.	Precambrain basement	—,,—	404	122	0.5	6	1.5 %

GUJARAT

Sr. No.	Place	Annual rainfall (mm)	Recharge (mm)	Recharge as % of rainfall
1.	Ahmedabad	708	124	17.5 %
2.	Palan	495	42	8.5 %
3.	Idar	807	115	14.2 %
4.	Deesa	529	116	21.9 %

Depending upon soil type the return flow from irrigation was taken as 20 to 35% of water applied.

2. CANADIAN ASSISTED GROUNDWATER PROJECT

This project covers groundwater balance studies in parts of hard rock areas of Andhra Pradesh and Karnataka.

Under this project long duration aquifer tests were carried out at 14 sites to determine the value of specific yield (Sy) which varied from 0.5% to 4%. The water table decline $\triangle$ h was also measured and dynamic groundwater recharge calculated as a product of Sy x $\triangle$ h. But these values were adjusted by comparing them with those estimated from Darcy's Law i. e., product of vertical fluid potential and vertical permeability of confining material.

Based upon the above technique the following results were arrived at. :

> The dynamic groundwater reserves are those which represent longterm average annual recharge due to precipitation under maximum groundwater use conditions. The richest dyanamic reserve in the project area approximate 0.15 metre/sq. km. (15 to 20 percent of average annual rainfall) in upland areas whereas the comparatively lesser dynamic reserve amount to about 0.01 m/sq. km. (approximates 1 to 5 per cent of average annual rainfall) in major valley bottoms of the Manjra and Musi river basins in the area. The average dyanamic reserve for the entire project area under maximum groundwater use condition approximate to 0.07 m/sq. km. or a total volume of 828 MCM or 8.3 per cent of the average annual rainfall.

The groundwater draft was estimated from water use data collected from local tehsil offices and the Department of the Bureau of Economics and Hydrogeological reconaissance under the project.

Having worked out the recharge and draft the following water balance was arrived at.

Hydrologic And Groundwater Balances

Where the long term change in surface and subsurface storage is negligible the hydrologic balance of a drainage basin may be represented by the following simplified hydrologic equation :

$$P = R + ET.$$

Where P = rainfall, R = run off and ET = evaporation and transpiration.

The simplified equation may be expanded to describe the movement of water through surface and groundwater cycles under natural groundwater flow conditions as given below.

$$P = (Rs + Rgw) + (ETs + ET\ gw).$$

Where Rs is runoff from surface and Rgw = runoff from groundwater or baseflow :

and ETs = evaporation and transpiration from the surface and ETgw = evaporation and transpiration from groundwater.

Alternatively, the expanded hydrologic equation may be written as :

P = Rs + ETs + Q. Anr.

Where Q. Anr. = Rgw + E Tgw.

q = specific volume recharge,

and Anr. = area of natural recharge.

Under the conditions of maximum groundwater use the entire area becomes a recharge area or

Amr = Anr + And,

Where Amr = area of maximum recharge and And = area of natural discharge.

Under those conditions

Rgw + Etgw = 0.

Q Amr = Σ Qp, where Σ Qp = the total discharge from all pumping wells, Q Amr is the Dynamic Groundwater Reserve, or the groundwater balance, under maximum groundwater use conditions. The dynamic groundwater reserve of the project area is estimated to be 8.2 per cent of average annual precipitation.

Under maximum groundwater use conditions the expanded hydrologic equation can be modified to =

P = Rs + ETs + Q. Amr, or

P = Rs + ETs + Σ Qp.

The factor P, Rs and Σ Qp are measurable to an acceptable accuracy and ETs, the most difficult component to measure, becomes the residual in the equation. ETS may be further sub divided as :

$Ets = Esw + ET_i + ETd$,

Where Esw = evaporation from open water.
ETi = evaporation and transpiration from irrigated areas.
and ETd = evaporation and transpiration from drylands.

Because Esw can be measured with reasonable accuracy and ET = Esw during high ET or irrigation periods the unknown in the equation "ETD" can be calculated as the residual.

In the CGWB—CAGP map area groundwater is not being fully utilised and therefore, Rgw = ETgw = O, and the applicable long term hydrologic equation is P = Rs + Rgw + ETs + Etg where Rs + Rg = R, and ETgw + ETs = ET. Parameters P and R are calculated to be 9958 mcm and 2266 mcm respectively over the Project area. The residual ET = P − R or 7692 mcm, which is 70 per cent of precipitation. The remaining 30 per cent of precipitation forms runoff, part of which is retained in surface reservoirs and the remainder flows out of the area during peak-flow periods. By nature of their equations runoff (R) and evapotranspiration (ET) are derived from both surface and groundwater sources under conditions of present groundwater use.

3. BETWA BASIN PROJECT

Betwa project is a water balance study project in collaboration with the United Kingdom. Its main aim is to assess groundwater recharge and thus the groundwater potential of the upper Betwa river basin and at the same time develop techniques which can be applied to similar areas elsewhere.

The water balance of the basin has been worked out by considering the seasonal cycle as a single period of water surplus during the monsoon and a single period of deficit during the remainder of the year. It becomes analogous to studying the response to a series of a single storms with uniform antecedent conditions.

During the monsoon period the monthly rainfall is greater than potential evapotranspiration for the four successive rainfall months whereas during the rest of the year the potential evapotranspiration exceeds rainfall. Thus a simple diagram may be drawn showing the period of surplus or excees rainfall over evaporation and the subsequent period of deficit. The soil moisture recharge may be superimposed on this diagram which then shows, to use the terminology of Thornwaite (1948), a period of soil moisture recharge followed by a period of water surplus and then at the end of monsoon a period of soil of moisture utilisation followed by period of water deficit. As th: surplus includes groundwater recharge as well as surface runoff, the soil moisture recharge clearly must equal the soil moisture utilisation in the Betwa basin because the soil moisture recharge is always full at the end of the monsoon and always reaches wilting point during the dry season. The soil moisture recharge or 'root constant' should be reasonably constant from year to year in absence of land use change and may be considered as a first charge on the net rainfall.

Further more, brief periods of drought during the monsoon and most periods of rain during the rest of the year do not affect this cycle. The soil moisture deficit during dry periods in the monsoon will not approach wilting point and the occasional rainfall surplus during November or December will not be sufficient to eliminate the soil moisture deficit. Thus, the net rainfall or gross seasonal surplus can be deduced by subtracting monthly potential transpiration from the monthly catchment rainfall and adding these monthly figures to give the net rainfall for the year.

This calculation will be affected by the use of calendar months and catchment rainfall. Because the beginning and end of the monsoon do not coincide with calendar months, some storms during a generally dry months will be neglected. In months when rainfall exceed evaporation at some stations but not at all the use of catchment rainfall may reduce the apparent surplus but the widespread nature of rainfall will make this rare. These effects might be overcome by using 10 day rainfall but it may be noted that they will introduce a scatter of data and perhaps reduce the apparent net rainfall values for some years.

If one accepts the deduction that soil moisture recharge is a fixed charge on the net rainfall and then makes the reasonable assumption that the surplus is divided proportionately between runoff and groundwater recharge, it is possible to make deductions about both processes by comparing seasonal net rainfall with annual runoff. The soil moisture recharge is the intercept on the horizontal axis or the net rainfall required before any runoff occurs; the groundwater recharge is the divergence between the 45° line and the net rainfall/runoff points.

However, this approach is most easily applied directly to the basin whose land use is reasonably homogenous because the rooting depth and thus the soil moisture recharge and actual evaporation will vary with land use. In this case it is necessary to take into account the portion of the basin with forest cover. The transpiration from the forest is likely to be greater than from grass lands during the monsoon period and the trees appear to continue to transpire at the potential rate until the leaves wilt prior to shedding duration (March or April) and the source of this extra moisture must be a deeper root system and thus a higher root constant and increased soil moisture recharge. Until detailed water balance studies of a forested tributatary can be carried out, it is necessary to treat the forest contribution to the runoff as falling between two extremes. At one extreme one could assume that the forested area is similar to the rest of the basin and at the other extreme one could assume that runoff from the forested area is negligible since potential transpiration exceeds rainfall over the year as a whole. These two assumptions are equivalent to treating the forest root constant as equal to gross or as infinite. The correct figure lies between these two extremes.

For the first assumption, it shows the seasonal net rainfall, neglecting as irrelevant the occasional heavy rainfall in November and December compared with the runoff expressed as mm from the whole basin. The regression of runoff (Q) and on net rainfall (R′) gives the equation $Q = 0.708 R' - 88.3$

(R′ = 0.812), when the outliners for 1930 and 1971 are omitted. However the tendency of a regression equation to under estimate the slope and thus the intercept, when the correlation is affected by scatter, makes it preferable to fit a line by eye. This shows that soil moisture recharge over the basin is about 175 mm and the average groundwater recharge is about 75 mm.

For the second assumption, the estimated tree cover of 0.125 means that the effective catchment should be reduced by this fraction so that the runoff may be recalculated for 0.875 of the whole basin. It is evident that the alternative assumption for behaviour of the forest does not affect the estimated soil moisture recharge which is the average for the non-forested part of the basin but does affect the estimated groundwater recharge which is reduced to about 25 mm and is well within the scatter of the data.

The analysis shows that the estimate of groundwater recharge is sensitive not only to scatter in the data but also to uncertainties in behaviour of the forest. The estimated average groundwater recharge varies from about 25 to 75 mm but the soil moisture recharge is estimated at about 175 mm.

It should be noted that the portion of groundwater recharge which returns to the river as sub-surface runoff during the dry season is not revealed by an analysis of the annual runoff but can be deduced from a study of monthly flows. This 'shallow' groundwater storage at the end of monsoon may be equated with the subsequent base flow component of riverflow. Flow records suggest that this base flow component or runoff after the last month of surplus rainfall is of the order of 30–50mm for the whole basin.

This analysis may be extended to cover other areas. It will be seen that the groundwater recharge is either discharged into the river during the dry season or if the water table is sufficiently deep it is entirely lost to gauging records. In other words recharge to surface layers or to deeper aquifers can be deduced from an analysis of flow recession curve or from water balance studies, respectively. The soil moisture recharge and storage, on the other hand may be estimated simply by comparing net rainfall and runoff.

The analysis described above has shown that the seasonal rainfall pattern is simlar over the whole basin that the variability of annual rainfall is proportional to the mean and that the rainfall in a single month can be expressed as a catchment average. The potential evaporation during the monsoon months can also be estimated with sufficient precision to give a reasonable estimate of the seasonal surplus or net rainfall. Gross and net rainfall when compared with the annual runoff for a 50 year period give the following summary of the water balance.

	Mean (mm)	Standard deviation	Coefficient of variability
Gross rainfall	1138	211	.185
Net rainfall	583	170	.292
Runoff	339	151	.447

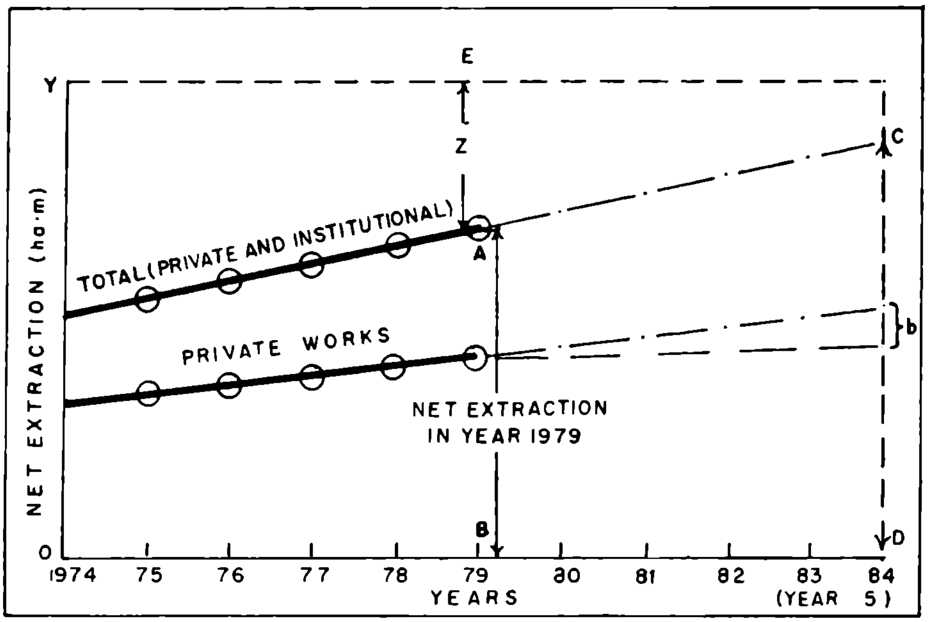
Comparison of annual values of the seasonal surplus and runoff shows that the seasonal soil moisture recharge is about 175 mm. This figure has a number of practical implications. It is the amount of storage available for flood attenuation and because its recharge is the first call on the rainfall this storage is available for crop growth after the monsoon each year supplemented by limited rainfall during the growing season.

Although an estimate of the groundwater recharge over the basin can in principle be deduced from the water balance, the scatter of the data does not in this case permit a precise estimate. Physical studies will be required to measure more precisely the groundwater recharge which takes place either locally to maintain dry weather flows or which goes to deeper water bodies.

ESTIMATION OF STAGE OF GROUNDWATER DEVELOPMENT

The projected draft of groundwater at year 5 can be estimated on the basis of the method given below.

The total net annual extraction of groundwater may be plotted against the year for the period for which the data is available. Then the plot should be projected as shown below :



Gross Recharge = X

Net Recoverable Recharge = 70% of X=Y

Bal. groundwater available in 1979 = Y — Net extraction = Z = AE

AB = Net Extraction (1979) = 70% of Gross Extraction

CD = Net Extraction at year 5 (1984)

b = Additional groundwater required by private works at year 5 (1984)

$$\text{Stage of Development} = \frac{\text{Total Net Extraction at year 5 (CD)}}{\text{Net Recoverable Recharge}}$$

Balance groundwater available for development by Institutional Sources = (z—b)

The projections at year 5 should be based on 5 years data for white areas where the stage of development at year 5 is upto 60%. These projections should be based on 10 years data in Grey areas where the stage of development is between 60% — 80% and on 15 years data in case of Dark areas where the stage of groundwater development is over 80%.