REPRINT

REPORT OF THE GROUND WATER RESOURCE ESTIMATION COMMITTEE

GROUND WATER RESOURCE ESTIMATION METHODOLOGY

Ministry of Water Resources
Government of India

NEW DELHI
2009

FOREWORD

Ground water has emerged as an important source to meet the water requirements of various sectors including the major consumers of water like irrigation, domestic and industries. The sustainable development of ground water resource requires precise quantitative assessment based on reasonably valid scientific principles. The Ground Water Estimation Committee- 1984 till now formed the basis of ground water assessment in the country. The ground water development programme implemented in the country was also guided by ground water resource availability worked out from this methodology. The experience gained in last more than one decade of employing this methodology supplemented by number of research and pilot project studies has brought to focus the need to update this methodology of ground water resource assessment. The National Water Policy also enunciates periodic assessment of ground water potential on scientific basis. The Ministry of Water Resources, Govt. of India, therefore, constituted a committee consisting of experts in the field of ground water to recommend a revised methodology. This report is the final outcome of the recommendations of the committee.

The revised methodology as recommended has incorporated number of changes compared to the recommendations of Ground Water Estimation Committee - 1984. In this methodology, watershed has been adopted as the assessment unit in hard rock areas. Ground water assessment has to be made separately for non command and command areas and areas of poor quality of ground water have to be treated separately. Ground water recharge has to be assessed separately for monsoon and non monsoon seasons. An alternative methodology has been provided for estimation of specific yield based on application of ground water balance in dry season which would be applicable in the non command part of hard rock areas. Norms for return flow from irrigation are now based on the source of irrigation i.e. ground water or surface water, type of crops, and depth to water table below ground level. An explicit provision is now introduced on recharge due to water conservation structures. Ground water levels has been made an integral part of ground water assessment and categorisation of areas for ground water development is now based on stage of ground water development and long term trend of these levels. Allocation for domestic and industrial water supply is now recommended based on population density and relative load on ground water for this purpose.

The report also recommends constitution of a Standing Committee - "Research and Development Advisory Committee on Ground Water Estimation" to provide required research and development support in the field of ground water resource assessment.

This report is the ultimate culmination of the efforts of the members of the committee and other experts in the field of ground water who have made significant contribution in revising this methodology. The group to draft the report of this committee has done a laudable job in not only preparing the draft report for discussions of the committee members but has also finalised the same after modifications as desired by them. I would like to express my appreciation to Shri Santosh Kumar Sharma, Member Secretary and Regional Director, Central Ground Water Board who with his untiring efforts and significant contributions has ably assisted the committee in preparing this report. It is hoped that the recommendations of the committee would be followed by different states for reassessing the ground water resources on realistic basis.

(ARUN KUMAR)
Chairman & Addl.Secretary
Central Ground Water Board
Ministry of Water Resources
Government of India

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Quantification of the ground water recharge is a basic pre-requisite for efficient ground water resource development and this is particularly vital for India with widely prevalent semi arid and arid climate. The soil and water resources are limited often being in a delicate balance. For rapidly expanding urban, industrial and agricultural water requirement of the country, ground water utilization is of fundamental importance. Reliable estimation of ground water resource, is therefore, a prime necessity.

Quantification of ground water resources is often critical and no single comprehensive technique is yet identified which is capable of estimating accurate ground water assessment. The complexities of the processes governing occurrence and movement of ground water make the problem of ground water assessment somewhat difficult, mainly because not only enormous data is to be procured, but a multidisciplinary scientific approach is to be adopted for space and time location of ground water, in quantity as well as quality. Ground water being a replenishable resource, its proper and economic development on a sustainable basis requires its realistic assessment.

Ground water resource estimation must be seen as an interactive procedure. Initial estimates are revised and refined by comparing these to results of other methods and ultimately with its field manifestation. The methodologies adopted for computing ground water resources have undergone a continuous change and adohocism adopted earlier have given way to definite field tested norms. The computation methods, like the ground water resources itself, have been dynamic in nature and gradual refinement has taken place with the generation of more and more data input and with better understanding of science of ground water.

At present, the methodology recommended by “Ground Water Estimation Committee” in 1984 (GEC 1984) is being adopted to compute the ground water resources of the country in volumetric terms. After 1984, the Central Ground Water Board, State Ground Water Organizations, Universities and other Organizations have undertaken a number of studies on ground water assessment. The data generated from these studies indicate the necessity to modify the prevalent methodology. The National

Water Policy too enunciates periodic reassessment of ground water resources on a scientific basis.

1.2 COMPOSITION OF THE COMMITTEE

With the above background in view, the Ministry of Water resources, Government of India constituted a committee to review and revise the Ground Water Resource Estimation Methodology and to look into related issues (Annexure 1). The committee consisted of the following Members :

1.	Chairman, Central Ground Water Board	Chairman
2.	The Commissioner (CAD&MI), Government of India, Ministry of Water Resources, Krishi Bhawan, New Delhi - 110 001.	Member
3.	Member (Survey, Assessment and Monitoring), Central Ground Water Board, NH IV, Faridabad - 121 001 (Haryana)	Member
4.	The General Manager, National Bank for Agriculture & Rural Development (NABARD) Sterling Centre, Shivsagar Estate, Dr. Annie Besant Road, Post Box No. 6552, Mumbai - 400 018	Member
5.	Smt. Krishna Bhatnagar, Principal Secretary to Govt./ Shri D.C. Sharma, Chief Hydrogeologist, Government of Rajasthan, Ground Water Department, Jodhpur (Rajasthan).	Member
6.	The Director, State Water Investigation Dte, Govt. of West Bengal, Calcutta (WB)	Member
7.	The Chief Engineer (SG&SWRGC) Govt. of Tamil Nadu, Water Resources Organisation,	Member

Public Works Department,
Chennai - 600 009 (Tamil Nadu).

8. Dr. M.K. Khanna, — Member
Superintending Geohydrologist,
Government of Madhya Pradesh,
Ground Water Survey Circle,
Bhopal (MP).

9. Shri S.C. Sharma, — Member
Director,
Govt. of Gujarat,
Ground Water Resource Dev. Corpn.,
Near Bij Nigam, Sector-10A,
Gandhinagar (Gujarat).

10. Dr. S.N. Shukla, — Member
Principal Secretary (Irrigation)
Govt. of Uttar Pradesh,
Secretariat, Lucknow (UP).

11. Dr. P. Babu Rao, — Member
Director,
Ground Water Department,
B.R.K.R. Govt. Office Complex,
7th & 8th Floor, B-Block Tank Bund Road,
Hyderabad - 500 029.

12. The Director, — Member
Govt. of Maharashtra,
Ground Water Survey and Dev. Agency,
PMT Building, Shankar Seth Road,
Swar Gate, Pune - 411 037 (MAHA).

13. Dr. Prem Shankar, — Member
Director,
Govt. of Bihar,
GW & MI Development,

Mithapur Agriculture Farm,
Patna (Bihar).

14. Shri J.K. Batish, Research Officer in Ground Water Cell, Agricultural Department, Govt. of Haryana SCO-3, Sector-17 E, Chandigarh. — Member

15. Dr. Gurcharan Singh, Jt. Director Agriculture (Hydrogeology), Agriculture Department, Govt. of Punjab, Chandigarh. — Member

16. Dr. G.C. Mishra, Scientist "F" Incharge Ground Water, National Institute of Hydrology, Jal Vigyan Bhawan, Roorkee - 247 667. — Member

17. Dr. D. Kashyap, Professor, Department of Hydrology, University of Roorkee, Roorkee - 247 667. (UP). — Member

18. Dr. S.P. Rajagopalan, Head of Computer Application Div., Centre for Water Resources Dev. and Management, (P.B. No. 2), Kunnamangalam, (MBR), Kozhikode - 673 571 (Kerala). — Member

19. Dr. K. Sridharan, Prof. of Civil Engineering, Indian Institute of Science, Bangalore - 560 012. (Karnataka) — Member

20. Shri Nabi Hassan, — Member

Director,
Ground Water Dept. Uttar Pradesh,
9th Floor, Indira Bhawan,
Ashok Market, Lucknow (U.P.).

21. Dr. P.R. Reddy, Head. Geology Division, National Remote Sensing Agency, Balanagar, Hyderabad - 500 037, (Andhra Pradesh). — Member (Vide MOWR letter dated 3.7.1996)

22. Shri Santosh K. Sharma, Director, Central Ground Water Board, Jamnagar House, Mansingh Road, New Delhi - 110011. — Member Secretary

1.3 TERMS OF REFERENCE

The terms of reference of this Committee are as follows :

1. To make an assessment of the scientific work done in the field with a view to replacing, firming up or updating the various parameters and their values currently used in the assessment of ground water resources.
2. To look into the details of the methodology recommended by Ground Water Estimation Committee (1984) and to suggest aspects which call for a revision. The Committee may, if considered necessary, update the existing or recommend a new methodology for the assessment of ground water resources in different hydrogeological situations and climatic zones.

3. To recommend norms for various parameters applicable to different geological formations and climatic and agricultural belts, etc. which should be precisely adopted for better assessment of the resources.
4. To recommend the smallest hydrogeological and/or administrative unit required to be adopted for assessment of ground water resources.
5. Any other aspects relevant to the terms referred to above.

The Committee was to submit its report within a period of 6 months from the date of issue of resolution. Subsequently, the period of the committee was extended up to 31/10/1996.

1.4 PROCEEDINGS OF THE COMMITTEE

After the constitution of the Committee, letters were addressed to Members of the Board of CGWB, State Ground Water Organizations, senior officers of CGWB, scientific and research organizations dealing with ground water, universities, NABARD and other experts to elicit their views on ground water estimation. The response from them was overwhelming and detailed comments and views were received suggesting various changes in the methodology. Based on these views an Approach Paper on "Revision of Ground Water Estimation Methodology" was prepared for consideration of the Committee. The list of the major contributors is given in Annexure 2.

The first meeting of the Committee was held on 14.02.1996 under the Chairmanship of Dr. R.K. Prasad, Chairman, CGWB. The Committee, after reviewing the Approach Paper, decided to constitute the following four sub groups.

(i) Sub-Group for recommending norms of parameters to be used in ground water resource assessment

1. Dr. K. Sridharan - Convener
2. Director, GSDA, Pune - Member
3. Dr. Gurcharan Singh - Member
4. Dr. D.C. Sharma - Member
5. Director, SWID, Calcutta - Member
6. Engineer-in-Chief (Mech.) Irrigation Deptt., U.P - Member

(ii) Sub-Group for methodology for computation of ground water resource assessment

1. Shri N.R. Tankhiwale - Convener
2. Dr. S.P. Rajagopalan - Member
3. Shri S.C. Sharma - Member
4. Dr. D. Kashyap - Member
5. Shri Santosh K. Sharma - Member

(iii) Sub-Group on alternative methods for ground water resource assessment

1. Dr. G.C. Mishra - Convener
2. Dr. S.P. Rajagopalan - Member
3. Dr. D. Kashyap - Member
4. Shri N. Kittu - Member

(iv) Sub-Group on ground water withdrawal and suggestion for development strategies

1. Dr. P. Babu Rao - Convener
2. Chief Engineer (SG&SWRGC), Chennai - Member
3. Dr. Prem Shankar - Member
4. Shri J.K. Batish - Member
5. Dr. M.K. Khanna - Member

The second Meeting of the Committee was convened on 19.07.96 under the Chairmanship of Shri Arun Kumar, Additional Secretary (WR) and Chairman, CGWB. The reports of the Sub Groups were presented during this meeting and were discussed. It was decided during the meeting to constitute a Group for Drafting the Report of the Committee consisting of the following members :

1. Dr. K. Sridharan - Convener
2. Sri. N.R. Tankhiwale - Member
3. Dr. S.P. Rajagopalan - Member
4. Dr. Gurcharan Singh - Member
5. Sri. Santosh Kumar Sharma - Member Secretary

The group finalised its report after two meetings and the draft report was circulated to all the members of the Committee for their views. The third meeting of the Committee was held on 25th October, 1996. The draft report of “Ground water Resource Estimation Committee - 1997” was discussed in detail during the fourth meeting held on 14th May 1997. The views expressed by the members for revised methodology were considered and necessary modifications wherever needed were made and report of the Committee finalised.

CHAPTER 2

NATIONAL SCENARIO OF GROUND WATER

2.1 HYDROGEOLOGICAL SETUP

India is a vast country with varied hydrogeological situations resulting from diversified geological, climatological and topographic setups. The rock formations, ranging in age from Archaean to Recent, which control occurrence and movement of ground water, widely vary in composition and structure. Physiography varies from rugged mountainous terrains of Himalayas, Eastern and Western Ghats and Deccan plateau to the flat alluvial plains of the river valleys and coastal tracts, and the aeolian deserts in western part. Similarly rainfall pattern also shows region-wise variations.

The following categories have been evolved to describe the ground water characteristics of various rock types occurring in the country :

1. **Porous rock formations**
   (a) Unconsolidated formations.
   (b) Semi - consolidated formations.
2. **Hard rock/consolidated formations**

2.2 POROUS ROCK FORMATIONS

2.2.1 Unconsolidated formations

The sediments comprising newer alluvium, older alluvium and coastal alluvium are by and large the important repositories of ground water. These are essentially composed of clay, sand, gravel and boulders, ferruginous nodules, kankar (calcareous concretions), etc. The beds of sand and gravel and their admixtures form potential aquifers. The aquifer materials vary in particle size, rounding and in their degree of assortion. Consequently, their water yielding capabilities vary considerably. The coastal aquifers show wide variation in the water quality both laterally and vertically.

The piedmont zone of the Himalayas is skirted at some places by artesian aquifers under free flowing conditions extending from Jammu and Kashmir in the west to Tripura in the east. The hydrogeological conditions and ground water regime in Indo-Ganga-Brahmaputra basin indicate the existence of large quantities of fresh ground water at least down to 600 m or more below land surface, for large scale development through heavy duty tubewells. Bestowed with high rainfall and good recharge conditions, the ground water gets replenished every year in these zones. The alluvial aquifers to the explored depth of 600 m have transmissivity values from 250 to 4000 m^2/day and hydraulic conductivity from 10 to 800 m/day. The well yields range upto 100 litres per second (lps) and more, but yields of 40-100 lps are common.

2.2.2 Semi-consolidated formations

The semi-consolidated formations are chiefly composed of shales, sandstones and limestones. The sedimentary deposits belonging to Gondwana and tertiary formations are also included under this category. The sandstones form highly potential aquifers locally, particularly in Peninsular India. Elsewhere they have only moderate potential and in places they yield meagre supplies. These sediments normally occur in narrow valleys or structurally faulted basins. Though these formations have been identified to possess moderate potential, the physiography of the terrain, normally restricts exploitation. Under favourable situations, these sedimentaries give rise to artesian conditions as in parts of Godavari valley, Cambay basin and parts of west coast, Pondichery and Neyveli in Tamil Nadu. Potential semi-consolidated aquifers particularly those belonging to Gondwanas and Tertiaries have transmissivity values from 100 to 2300 m^2/day and the hydraulic conductivity from 0.5 to 70 m/day. Generally the well yields in productive areas range from 10 to 50 lps. Lathi sandstone and Nagaur sandstone in Rajasthan and Tipam sandstone in Tripura State also form productive aquifers.

2.3. HARD ROCK FORMATIONS

2.3.1 Consolidated formations

The consolidated formations occupy almost two thirds of the country. From the hydrogeological point of view, the consolidated rocks are broadly classified into the following three types :

a) Igneous and metamorphic rocks excluding volcanic and carbonate rocks
b) Volcanic rocks
c) Carbonate rocks

The nature, occurrence and movement of ground water in these formations are described below.

2.3.2 Igneous and metamorphic rocks excluding volcanic and carbonate rocks

The most common rock types are granites, gneisses, charnockites, khondalites, quartzites, schist and associated phyllite, slate etc. These rocks possess negligible primary porosity but are rendered porous and permeable due to secondary porosity by fracturing and weathering.

Ground water yield also depends on rock types. Granite and gneiss are better sources than charnockite. The ground water studies carried out in the crystalline hard rocks reveal the existence, along certain lineaments, of deeply weathered and fractured zones, locally forming potential aquifers. These lineament zones are found to be highly productive for construction of borewells.

In areas underlain by hard crystalline and metasedimentaries viz. granite, gneiss, schist, phyllite, quartzite, charnockite etc., occurrence of ground water in the fracture system has been identified down to a depth of 100m and even upto 200m locally. In most of the granite/gneiss area, the weathered residium serves as an effective ground water repository. It has been noted that the fracture systems are generally hydraulically connected with the overlying weathered saturated residium. The yield potential of the crystalline and metasedimentary rocks shows wide variations. Bore wells tapping the fracture systems generally yield from less than 1 lps to 10 lps. The transmissivity value of the fractured rock aquifers vary from 10 to 500 m^2/day and the hydraulic conductivity varies from 0.1 to 10m/day.

2.3.3 Volcanic rocks

The basaltic lava flows are mostly horizontal to gently dipping. Ground water occurrence in them is controlled by the contrasting water bearing properties of different lava flows. The topography, nature and extent of weathering, jointing and fracture pattern, thickness and depth of occurrence of vesicular basalts are the important factors which play a major role in the occurrence and movement of ground water in these rocks. Basalts or Deccan Traps usually have medium to low permeabilities depending on the presence of primary and secondary porosity. Pumping tests have shown that under favourable conditions, bore wells yield about 3 to 6 lps at moderate drawdowns. Transmissivity values of these aquifers is generally in the range of 25 to 100m^2 /day and the hydraulic conductivity varies from 0.05 to 15m/day.

2.3.4 Carbonate rocks

Carbonate rocks include limestone, marble and dolomite. Among the carbonate rocks, limestones occur extensively. In the carbonate rocks, solution cavities lead to widely contrasting permeability within short distances. Potential limestone aquifers are found to occur in Rajasthan and Peninsular India in which the yields range from 5 to 25 lps. Large springs exist in the Himalayan region in the limestone formations.

2.4 GROUND WATER QUALITY

The ground water in most of the areas in the country is fresh. Brackish ground water occurs in the arid zones of Rajasthan, close to coastal tracts in Saurashtra and Kutch, and in some zones in the east coast and certain parts in Punjab, Haryana, Western UP etc., which are under extensive surface water irrigation. The fluoride levels in the ground water are considerably higher than the permissible limit in vast areas of Andhra Pradesh, Haryana and Rajasthan and in some places in Punjab, Uttar Pradesh, Karnataka and Tamil Nadu. In the north-eastern regions, ground water with iron content above the desirable limit occurs widely. Pollution due to human and animal wastes and fertilizer application have resulted in high levels of nitrate and potassium in ground water in some parts of the country. Ground water contamination in pockets of industrial zones is observed in localised areas. The over-exploitation of the coastal aquifers in the Saurashtra and Kutch regions of Gujarat has resulted in salinisation of coastal aquifers. The excessive ground water withdrawal near the city of Chennai has led to sea water intrusion into coastal aquifers.

2.5 GROUND WATER RESOURCE POTENTIAL

The total annual replenishable ground water resource is about 43 million hectare metres (Mham). After making a provision of 7 Mham for domestic, industrial and other uses, the available ground water resource for irrigation is 36 Mham, of which the utilisable quantity is 32.5 Mham. The utilisable irrigation potential has been estimated as 64 million hectares (Mha) based on crop water requirement and availability of cultivable land. Out of this, the potential from natural rainfall recharge is 50.8 Mha and augmentation from irrigation canal systems is 13.2 Mha. The irrigation potential created from ground water in the country till 1993 is estimated as 35.4 Mha.

Inspite of the national scenario on the availability of ground water being favourable, there are pockets in certain areas in the country that face scarcity of water. This is because the ground water development over different parts of the country is not uniform, being quite intensive in some areas resulting in over-exploitation leading to fall in water levels and even salinity ingress in coastal areas. The declining water levels have resulted in failure of wells or deepening of extraction structures leading to additional burden on the farmers.

Out of 4272 blocks in the country (except Andhra Pradesh, Gujarat and Maharashtra where ground water resource assessment has been carried out on the basis of mandals, talukas and watersheds respectively), 231 blocks have been categorised as “Over-exploited” where the stage of ground water development exceeds the annual replenishable limit and 107 blocks are “Dark” where the stage of ground water development is more than 85%. Besides, 6 mandals have been categorised as “Over-exploited” and 24 as ‘Dark’ out of 1104 mandals in Andhra Pradesh. Similarly out of 184 talukas in Gujarat, 12 are “Over-exploited” and 14 are ‘Dark’ and out of 1503 watersheds in Maharashtra, 34 are ‘Dark’.

2.6 GROUND WATER DEVELOPMENT SCENARIO

During the past four decades, there has been a phenomenal increase in the growth of ground water abstraction structures due to implementation of technically viable schemes for development of the resource, backed by liberal funding from institutional finance agencies, improvement in availability of electric power and diesel, good quality seeds, fertilisers, government subsidies, etc. During the period 1951-92, the number of dugwells increased from 3.86 million to 10.12 million, that of shallow tubewells from 3000 to 5.38 million and public bore/tubewells from negligible to 68000. The number of electric pumpsets has increased from negligible to 9.34 million and the diesel pump sets from 66,000 to about 4.59 million. There has been a steady increase in the area irrigated from ground water from 6.5 Mha in 1951 to 35.38 Mha in 1993. During VIII plan, it is anticipated that 1.71 million dugwells, 1.67 million shallow tubewells and 11,400 deep tubewells would be added. Similarly number of electric pumpsets and diesel pumpsets is expected to rise by 2.02 million and 0.42 million respectively. Such a magnitude of ground water development requires realistic assessment of ground water resources to avoid any deleterious effects on ground water regime and to provide sustainability to the ground water development process.

2.7 NATIONAL WATER POLICY ON GROUND WATER DEVELOPMENT

The ‘National Water Policy’ adopted by the Government of India in 1987 regards water as one of the most crucial elements in developmental planning. It emphasizes that the efforts to develop, conserve, utilise and manage this resource have to be guided by national perspective. Water is a scarce and precious national resource to be planned, developed and conserved as such and on an integrated and environmentally sound basis.

The National Water Policy enunciates the following guidelines for ground water.

- There should be a periodic reassessment on scientific basis of the ground water potential, taking into consideration the quality of the water available and economic viability.
- Exploitation of ground water resources should be so regulated as not to exceed the recharge possibilities, as also to ensure social equity. Ground water recharge projects should be developed and implemented for augmenting the available supplies.
- Integrated and coordinated development of surface water and ground water and their conjunctive use should be envisaged right from the project planning stage and should form an essential part of the project.
- Over-exploitation of ground water should be avoided near the coast to prevent ingress of sea water into fresh water aquifers.

The present action of revising the ground water estimation methodology is a sequel to the tenets of the National Water Policy for periodic reassessment of ground water potential on scientific basis.

CHAPTER 3

RECOMMENDATIONS OF THE GROUND WATER ESTIMATION COMMITTEE (1984)

3.1 REVIEW OF GROUND WATER RESOURCE ASSESSMENT METHODOLOGIES

Attempts have been made from time to time by various Working Groups/Committees/Task Force, constituted by Government of India to estimate the ground water resources of the country based on status of available data and in response to developmental needs. But, due to paucity of scientific data and incomplete understanding of the parameters involved in recharge and discharge processes, all these early estimations were tentative and at best approximation.

In 1972, guidelines for an approximate evaluation of ground water potential was circulated by the Ministry of Agriculture, Government of India to all the State Governments and financial institutions. The guidelines recommended norms for ground water recharge from rainfall and from other sources.

The first attempt to estimate the ground water resources on a scientific basis was made in 1979. A High Level Committee, known as Ground Water Over Exploitation Committee was constituted by the then Agriculture Refinance and Development Corporation (ARDC). The committee was headed by the Chairman, CGWB and included as its members representatives from the state ground water organizations and financial institutions. This Committee recommended definite norms for ground water resources computations.

In the year 1982, Government of India constituted “Ground Water Estimation Committee” (GEC) with the members drawn from various organizations engaged in hydrogeological studies and ground water development. In 1984 this Committee, after reviewing the data collected by central and state agencies, research organisations, universities, etc. recommended the methods for ground water recharge estimation. The recommendations of this Committee are summarised in this chapter.

3.2 RECOMMENDATIONS OF GEC (1984)

GEC(1984) recommended two approaches for ground water resource assessment, namely (1) ground water level fluctuation and specific yield method and (2) rainfall infiltration method.

3.2.1 Ground water level fluctuation and specific yield method

The water table fluctuation and specific yield approach has been recommended for recharge estimation.

Generally, a well hydrograph follows a definite trend like stream hydrograph with a peak followed by a recession limb. The recession limb in a post-recharge period is characterised by two distinct slopes-one a steep one (from August to October/November) and other a gentler one (from October/November to June). The steeper limb signifies the quick dissipation of a major part of recharge during the later part of recharge period itself. This recession of water table is sluggish in alluvial areas compared to hard rock areas wherein a substantial recession occurs within one or one and half month after the peak water level is achieved.

Due to less demand and adequate soil moisture in later half of recharge period and under prevailing agricultural practice in India, the fast receding limb of hydrograph is not considered for computation of utilisable recharge. The utilisable recharge is estimated based on pre-monsoon (April-May) to post-monsoon (November) water level fluctuation for the areas receiving South-west monsoon. Similarly for the areas receiving North-east monsoon water level fluctuations of pre-monsoon (November) and post-monsoon (March) have been taken into consideration.

The monitoring of water level network stations needs to be adequate in space and time and analysis of data carried out keeping in view the hydrogeological situation. The inconsistencies in observations which may arise due to varied hydrogeological factors should be smoothened out.

The specific yield values of the geological formations in the zone of water table fluctuation as computed from pumping tests are to be utilized in the recharge estimation. As a guide following values computed in different studies are recommended :

(I)	Sandy alluvial area	12 to 18 percent
(ii)	Valley fills	10 to 14 percent
(iii)	Silty/Clayey alluvial area	5 to 12 percent
(iv)	Granites	2 to 4 percent
(v)	Basalts	1 to 3 percent
(vi)	Laterite	2 to 4 percent

(vii)	Weathered Phyllites, Shales, Schist and associated rocks.	1 to 3 percent
(viii)	Sandstone	1 to 8 percent
(ix)	Limestone	3 percent
(x)	Highly Karstified Limestone	7 percent

3.2.2 Normalisation of rainfall recharge

The water table fluctuation in an aquifer corresponds to the rainfall of the year of observation. The rainfall recharge estimated should be corrected to the long term normal rainfall for the area as given by India Meteorological Department.

For calculating the annual recharge during monsoon the formula indicated below may be adopted.

$$\text{Monsoon Recharge} = (S + DW - Rs - Rigw - Ris) \times \frac{\text{Normal Monsoon Rf}}{\text{Annual Monsoon Rf}} + Rs + Ris$$

where,

S = change in ground water storage volume during pre and post monsoon period (April/May to November), (million cubic metre or mcm) obtained as below:-

Area (sq.km.) x Water level fluctuation (m) x Specific yield

The areas not suitable for recharge like high hilly and saline area should be excluded.

DW = gross ground water draft during monsoon (mcm)

Rs = recharge from canal seepage during monsoon (mcm).

Rigw = recharge from recycled water from ground water irrigation during monsoon (mcm).

Ris = recharge from recycled water from surface water irrigation during monsoon (mcm)

RF = rainfall (metre).

To eliminate the effects of drought or surplus rainfall years, the recharge during monsoon is estimated as above for a period of 3 to 5 years and an average figure is taken for long term recharge. Recharge from winter rainfall may also be estimated on the same lines.

3.2.3 Rainfall infiltration method

In areas where ground water level monitoring is not adequate in space and time, rainfall infiltration may be adopted. The norms for rainfall infiltration contributing to ground water recharge are evolved, based on the studies undertaken in various water balance projects in India. The norms for recharge from rainfall under various hydrogeological situations are recommended in the following table.

Table : Rainfall infiltration factor in different hydrogeological situations

S.No	Hydrogeological situation	Rainfall infiltration factor
1	Alluvial areas	
	a. Sandy Areas	20 to 25 percent of normal rainfall
	b. Areas with higher clay content	10 to 20 percent of normal rainfall
2	Semi-Consolidated Sandstones (Friable and highly porous)	10 to 15 percent of normal rainfall
3	Hard rock area	
	a. Granitic Terrain	
	(i) Weathered and Fractured	10 to 15 percent of normal rainfall
	(ii) Un-Weathered	5 to 10 percent of normal rainfall
	b. Basaltic Terrain	
	(I) Vesicular and Jointed Basalt	10 to 15 percent of normal rainfall
	(ii) Weathered Basalt	4 to 10 percent of normal rainfall
	c. Phyllites, Limestones, Sandstones, Quartzites, Shales, etc.	3 to 10 percent of normal rainfall

The normal rainfall figures are taken from India Meteorological Department which is main agency for collection and presentation of rainfall data. The ranges of rainfall infiltration factor are recommended as a guideline and need to be adopted based on their applicability to prevalent hydrogeological situation. Besides natural ground water recharge estimation, recharge due to seepage from canals, return seepage from irrigated fields, seepage from tanks and lakes, potential recharge in water logged and flood prone areas are computed based on following recommended norms.

3.2.4 Recharge from other sources

Recharge due to seepage from canals

The following norms may be adopted in most of the areas except where realistic values have been arrived at, from project studies.

(i) For unlined canals in normal type of soil with some clay content along with sand :-

15 to 20 ham/day/10^6 sq.m of wetted area of canal

(ii) For unlined canals in sandy soils :-

25 to 30 ham/day/10^6 sq.m of wetted area

(iii) For lined canals, the seepage losses may be taken as 20 percent of the above values.

Return seepage from irrigation fields

(i) Irrigation by surface water sources

(a) 35% of water delivered at the outlet for application in the field. The variation in percentage of seepage may be guided by studies undertaken in the area or in a similar area.

(b) 40% of water delivered at outlets for paddy irrigation only.

(ii) Irrigation by ground water sources

(a) 30% of the water delivered at outlet. For paddy irrigation 35% as return seepage of the water delivered may be taken.

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

Seepage from tanks

The seepage from the tanks may be taken as 44 to 60cm per year over the total water spread. The seepage from percolation tanks is higher and may be taken as 50% of its gross storage. In case of seepage from ponds and lakes, the norms as applied to tanks may be taken.

3.2.5 Annual ground water recharge

The annual replenishable ground water recharge includes the following components :

Total annual recharge = Recharge during monsoon + Non-monsoon rainfall recharge + Seepage from canals + Return flow from irrigation + Inflow from influent rivers etc. + Recharge from submerged lands, lakes etc.

3.2.6 Potential recharge in specific situations

Besides the estimation of normal recharge, the methodology recommends computation of potential recharge in shallow water table areas/waterlogged areas and in flood prone areas.

Potential resource in water logged area and shallow water table zones

Potential ground water resource = (5 - B) X A X Specific Yield

where

B = depth to water table below ground surface in pre-monsoon period in shallow aquifers (m)

A = area of shallow water table zone (m^2)

The planning of minor irrigation works in the areas indicated above should be done in such a way that there are no long term adverse effects on water table. The behaviour of water table in the adjoining area which is not waterlogged should be taken as a guide for development purposes.

The potential recharge from flood plains may be estimated on the same norms as for ponds and lakes, i.e., 44 to 60cm per year over the water spread area for period equal to the retention period.

3.2.7 Total ground water resources

The total ground water resources for water table aquifers is taken as annual ground water recharge plus potential recharge in shallow water table zone.

The total ground water resource, thus computed would be available for utilization for irrigation, domestic and industrial uses. The base flow in rivers is a regenerated ground water resource and is some times committed for lift irrigation schemes and other surface irrigation works. It is, therefore, recommended that 15% of total ground water resources be kept for drinking and industrial purposes, for committed base flow and to account for the irrecoverable losses. The remaining 85% can be utilized for irrigation purposes. But wherever the committed base flows, domestic and industrial uses are more than 15%, the utilisable resources for irrigation may be considered accordingly.

3.2.8 Ground water draft

The ground water draft is the quantity of ground water withdrawn from the ground water reservoirs. The total quantity withdrawn is termed as gross draft. The annual ground water draft of a structure is computed by multiplying its average discharge and annual working hours. The number of working hours can be calculated by the hourly consumption of electrical or diesel energy. The ground water draft is also calculated by the irrigation requirement of crops in the command area of the structure. For working out ground water balance, 70% of gross extraction is taken which is known as Net Ground Water Draft. The 30% is presumed to go as return seepage to ground water regime.

3.2.9 Categorization of areas based on level of ground water development

The level of ground water development in an area is to be taken as the ratio of net yearly draft to total utilisable ground water resources for irrigation. It can be expressed as,

$$Level\ of\ ground\ water\ development\ =\ \frac{Net\ yearly\ draft}{Utilizable\ resource\ for\ irrigation} \times 100$$

For the purpose of clearance of schemes by financial institutions, categorization of areas based on level of ground water development at year 5 has been recommended as follows :

Category of areas	Stage of ground water development (%) at Year 5
(a) White	$<$ 65%
(b) Grey	$>$ 65% but $<$ 85%
(c) Dark	$>$ 85% but $<$ 100%

In dark areas, micro-level surveys are required to evaluate the ground water resources more precisely for taking up further ground water development.

3.2.10 Norms of development for various types of structures

The norms/yardsticks of area irrigated from various types of ground water minor irrigation units in different states as indicated by them are given below.

S.No.	**Type of Minor Irrigation work**	**Area Irrigated (ha.)**
1.	Andhra Pradesh	
	Dugwell with mhot	0.5
	Dugwell with pump set	2.0
	Private tubewell	4.0
2.	Bihar	
	Dugwell without pump	
	(i) Upto 3m dia	0.6
	(ii) From 3 to 6m dia	1.0
	Dug cum borewell	
	Tubewell	

	(i) 10cm dia	4.0
	(ii) 5cm dia	2.0
	Diesel pumpset on dugwell/	
	Surface water sources	
	(i) 5 HP pump set	2.0
	(ii) Pump above 5 HP	4.0
3.	Haryana	
	Dugwell	1.2
	Shallow Tubewell	4.3
4.	Punjab	
	Dugwell	1.0
	Shallow Tubewell	5.0
5.	Madhya Pradesh	
	Dugwell	1.0
	Shallow Tubewell	6.8
6.	Maharashtra	
	Dugwell with pump set	2.0
	Dugwell with mhot	0.5

S.No.	**Type of Minor Irrigation work**	**Area Irrigated (ha.)**
7.	Tamil Nadu	
	Private Tubewell	8.0
	Filter point	4.0
	Boring in well	0.8
	Deepening of well	0.8
8.	Uttar Pradesh	
	Masonry well	1.0
	Persian wheel (addl.)	0.5
	Boring (small/marginal farmers) addl.	0.5

	Pump set on boring	5.0
	Tubewell	5.0
9.	Tripura	
	Shallow tubewell	4.0
	Artesian well	0.5
10.	West Bengal	
	Dugwell	0.4
	Shallow Tubewell	3.0
11.	Rajasthan	
	Dugwell	2.0
	Low duty tubewell	2.0
	Dug cum borewell	4.0

These areas are to be multiplied by applicable water depth to get the draft of ground water.

The above data indicate that the norms vary from state to state depending upon the existing agriculture practices, local hydrogeological conditions, availability of power etc. and as such it is recommended that regional norms may be developed by the states and Central Ground Water Board based on sample surveys. In case of Public Tubewells, data for discharge and running hours is already available and that should be used for computation of draft.

3.2.11 Computation of ground water resources in confined aquifer

For the confined aquifers which are hydrogeologically separate from shallow water table aquifers, the ground water assessment may be done by rate concept. The ground water available in a confined aquifer equals the rate of flow of ground water through this aquifer. The rate of ground water flow available for development in a confined aquifer in the area can be estimated by using Darcy's law as follows :

$$Q = TIL$$

where,

Q = Rate of flow through a cross-section of aquifers in m^3 /day.

T = Transmissivity in m^2/day

I = Hydraulic Gradient in m/km

L = Average width of cross-section in km.

The transmissivity may be computed from pumping test data of tubewells. Leakage from overlying or underlying aquifer may also be accounted for in the calculation of ground water available for development in a confined aquifer.

The tubewell draft tapping a deeper confined aquifer may be treated separately and may be accounted for at the time of quantitative assessment of deeper confined aquifer. The total draft of these tubewells may be taken as gross draft of which 30 percent may be taken recycled and may be added as recharge to water table aquifers. The utilisable recharge may be taken as 85 percent of the total ground water flow available for development.

The computation of lateral flow in the confined aquifer may be done by flow net analysis method by computing all the parameters reflected in Darcy's formula. However, for working out the optimum development of the confined aquifers, it is recommended that the recharge area of the confined aquifers may be demarcated, the average annual recharge to the confined aquifer in this recharge area estimated, and the extent of development of this aquifer is limited to this amount of recharge indicated above.

3.2.12 Static ground water resources

The quantum of water available for development is usually restricted to long term average recharge or in other words to "Dynamic Resource". However, recent data indicate that even in states with high degree of ground water development, water levels have not shown a declining trend. It is, therefore, considered that temporary depletion of water table taking place in drought years is made up in years of high rainfall or in other words the utilisation of static reserves and consequent depletion in water levels in drought years is made up during years of high rainfall. This may be studied by comparing the long term rainfall and the water table hydrograph to establish the periodical recharge. In such areas it would be desirable that the ground water reservoir be drawn to the optimum limit to provide adequate scope for its recharge during the following monsoon period. An estimate of static ground water reserve is desirable for planning the optimum utilisation for future development of the ground water resources of an area.

The static ground water resource in an area may be computed as below:

Static Ground Water = Thickness of the aquifer below the zone of water level fluctuation (m) down to exploitable limit. x Areal extent of the x Specific yield of the

Reserve (m^3)

aquifer (m²)	aquifer

The development of static resource has to be done carefully and cautiously. It is recommended that the static ground water resource, basin wise/district wise in each state may be evaluated. However, no development schemes based on this resource be taken up at this stage.

CHAPTER 4

REVIEW OF GROUND WATER ESTIMATION METHODOLOGY (1984) AND RECENT CASE STUDIES

4.1 INTRODUCTION

Two approaches for ground water assessment are recommended by the GEC - 1984, namely: (a) ground water level fluctuation method, (b) norms of rainfall infiltration. Improvement in the existing methodology requires a relook on the concepts and details of the methodology, as well as an evaluation and utilisation of the case studies of ground water assessment in the recent years in different parts of the country. While going through such a review process, one may also keep in view the status of data on ground water resource evaluation, as available in the country presently. The methodology as recommended by the GEC - 1984 is reviewed here, both on its merits and limitations. The chapter also provides a review of recent case studies on ground water assessment in various parts of the country, and the type of data that is available, both from routine observations and from special studies.

4.2 MERITS OF EXISTING METHODOLOGY

The existing methodology outlined in Chapter 3 has some basic merits. As per this methodology, ground water recharge is to be estimated based on ground water level fluctuation method, as applied for the monsoon season. If adequate data of water level observations are not available, rainfall infiltration factor norms is to be used. The basic merits of these methods are: (a) simplicity (b) suitability of the method with regard to the data normally available from the ground water level monitoring program of the state and central government agencies (c) reliability and robustness of the ground water level fluctuation method, as it is based on the well established principle of ground water balance, and (d) provision of an alternate approach based on the rainfall infiltration factor, in the absence of adequate data of ground water levels. It may be noted that though the rainfall infiltration factor method is empirical, the approach provides scope for continuous improvement, as the norms can be periodically revised and refined for different agro-climatic and hydrogeological regions, based on case studies of ground water assessment in different regions of the country.

While alternate methodologies for ground water recharge assessment are possible, the ground water level fluctuation method, based on the concept of ground water balance, is the most suitable and reliable at this point of time, considering the type and extent of data available. As the ground water assessment has to be done all over the country at each block/taluka/mandal level, there is also a need to retain the alternate empirical approach based on specified norms, for application in areas without adequate water level data. The two approaches recommended by the GEC - 1984 can therefore still form the basis for ground water assessment.

4.3 LIMITATIONS OF EXISTING METHODOLOGY

Several issues have been raised with regard to the methodology recommended in the GEC - 1984 Report. The limitations of the existing methodology are summarised as follows.

4.3.1 Unit for ground water recharge assessment

The GEC - 1984 does not explicitely specify the unit to be used for ground water assessment, but it is implied in the discussions that the assessment is to be made for an administrative unit, namely a block. While an administrative unit is convenient from development angle, it is not a natural hydrological unit. Watershed has been proposed as a more desirable option, and in fact, some states are presently using watershed as the unit for ground water assessment. However, it is to be recognised that in alluvial areas, there may be ground water flow across watershed boundary also, as surface and subsurface water divides may not coincide. It has also been suggested that the unit for ground water assessment should be based on geomorphological and hydrogeological characteristics.

4.3.2 Delineation of areas within a unit

The existing methodology does not take into account the spatial variability of ground water availability within a unit. The estimation of ground water recharge as per the GEC - 1984 has basically three components: (a) recharge from rainfall (b) recharge from return flow from irrigation and other sources (c) potential recharge in waterlogged and shallow water table areas. Among these, the recharge from rainfall is the only component which is available in a distributed way over the entire block or taluka. Recharge from return flow from surface water irrigation, is mainly relevant only to canal command areas. In alluvial areas, some component of return flow from canal irrigation may be available downstream of the command area, but even here, the availability is spatially restricted. The potential recharge from waterlogged and shallow water table areas can also distort the estimate of available ground water, since this recharge can be realised only under special circumstances, and even then this water may be available only locally. Separate assessment may also be required for areas where ground water is saline. Hence, there is a necessity for delineation of different sub-areas within a unit for ground water assessment.

4.3.3 Season-wise assessment of ground water resource

There is a clear need expressed for season-wise assessment of the ground water resource, for Kharif, Rabi and summer seasons or for monsoon and non-monsoon seasons. It is felt that this approach may explain the paradox of water not being available in summer even for drinking purposes in hard rock areas, while the stage of ground water development as evaluated based on the GEC - 1984 recommendations indicate good availability for development.

4.3.4 Ground water resource estimate in confined aquifer

The GEC - 1984 has made a brief mention regarding ground water resource estimation in confined aquifers, based on Darcy's law. Questions have been raised on this aspect on three grounds: (a) practical utility of this estimate (b) reliability of the estimate, in view of the difficulty of delineating the confined and unconfined parts, or the recharge and discharge parts (c) possibility of duplication of resource estimation as the flow which enters the confined aquifer is already estimated under unconfied aquifer part due to their inter-relationship. However, there may be situations in alluvial areas where ground water estimate in confined aquifer may be an important aspect.

4.3.5 Estimation of specific yield

The ground water level fluctuation method requires the use of specific yield value as a key input for assessment of ground water recharge. The GEC - 1984 suggests that for semicritical and critical areas, pumping tests may be used for the estimation of specific yield. Regarding regional ground water assessment in hard rock areas, determination of specific yield through pumping tests has several limitations. First, there is an inherent bias in the location of test wells in terms of potential yield of the well for future utilisation. Thus the local value may not be an average representation of the region. Secondly, pumping tests are more useful for estimating transmissivity value than specific yield value. Small duration pumping tests on dug wells are not suitable for the estimation of specific yield. Third, a proper estimation of parameters (including specific yield) from long duration pumping tests in hard rock areas, requires the use of fairly sophisticated modelling techniques, and simplistic estimates based on Theis curve (or some other simple models) may result in wrong assessment of specific yield. In alluvial areas, pumping tests may yield more representative values of specific yield , but here also, the tests should be of sufficiently long duration.

4.3.6 Ground water draft estimation

Ground water draft refers to the quantity of ground water that is being withdrawn from the aquifer. Ground water draft is a key input in ground water resource estimation. Hence, accurate estimation of ground water draft is highly essential to calculate the actual ground water balance available. The following three methods are normally used in the country for ground water draft estimation.

(a) Based on well census data : In this method, the ground water draft is estimated by multiplying the number of wells of different types available in the area with the unit draft fixed for each type of well in that area. This method is being widely practiced in the country.

(b) Based on electrical power consumed : In this method, the ground water draft estimation is done by multiplying the number of units of power consumed for agricultural pumpsets with that of the quantity of water pumped for unit power.

(c) Based on the ground water irrigated area statistics : In this method, the ground water draft is estimated by multiplying the acreage of different irrigated crops (cultivated using ground water) with that of the crop water requirement for each crop.

In the recent years, studies conducted by NRSA have shown that remote sensing data collected from earth orbiting satellites provide information on ground water irrigated crops and their acreage. This can form an additional or alternate method for draft estimation in non-command area.

4.3.7 Ground water flow

The ground water level fluctuation method as per the GEC - 1984 does not account for ground water inflow/outflow from the region and also base flow from the region, as part of the water balance. This means that the recharge estimate obtained provides an assessment of net ground water availability in the unit, subject to the natural loss or gain of water in the monsoon season due to base flow and inflow/outflow.

4.3.8 Return flow from ground water draft

The GEC - 1984 recommends that 30% of gross ground water draft used for non-paddy areas may be taken as return flow recharge, and this is raised to 35% for paddy areas. It is generally felt that with respect to ground water irrigation, these estimates of recharge from return flow are high, particularly for non-paddy areas. It is even felt that when the water table is relatively deep and the intensity of ground water application is relatively low, return flow recharge may be practically negligible. On the other hand, some data available from Punjab, Haryana and Western UP suggests, that the return flow from paddy areas may be higher than 35%.

4.4 IMPROVEMENTS IN EXISTING METHODOLOGY

After due consideration of the limitations discussed above, several improvements are proposed in the existing methodology based on ground water level fluctuation approach. These are as follows.

a) It is proposed that watershed may be used as the unit for ground water resource assessment in hard rock areas, which occupy about 2/3rd of the country. The assessment made for watershed as unit may be transferred to administrative unit such as block, for planning developmental programmes. For alluvial areas, the present practice of assessment based on block-wise basis is retained. The possibility of adopting doab as the unit of assessment in alluvial areas needs further detailed studies.

b) It is proposed that the total geographical area of the unit for resource assessment be divided into subareas such as hilly regions, saline ground water areas, canal command areas and non-command areas, and separate resource assessment may be made for these subareas. Variations in geomorphological and hydrogeological characteristics may be considered within the unit.

c) A qualitative approach for assessing season-wise availability is suggested. Directions are provided for data acquisition programme in future, for further improvement of estimate in this regard.

d) The focus of ground water recharge assessment may be for unconfined aquifers. In specific alluvial areas where resource from deep confined aquifer is important, such resource may have to be estimated by specific detailed investigation, taking care to avoid duplication of resource estimation from the upper unconfined aquifers.

e) It is proposed that for hard rock areas, the specific yield value may be estimated by applying the water level fluctuation method for the dry season data, and then using this specific yield value in the water level fluctuation method for the monsoon season to get recharge. For alluvial areas, specific yield values may be estimated from analysis of pumping tests. However, norms for specific yield values in different hydrogeological regions may still be necessary for use in situations where the above methods are not feasible due to inadequacy of data.

f) The problem of accounting for ground water inflow/outflow and base flow from a region is difficult to solve. If watershed is used as a unit for resource assessment in hard rock areas, the ground water inflow/outflow may become negligible. The base flow can be estimated if one stream gauging station is located at the exit of the watershed.

g) Norms for return flow from ground water and surface water irrigation are to be revised taking into account the source of water(ground water/surface water), type of crop (paddy/non-paddy) and depth of ground water level.

h) The needs for drinking water and industrial water use are to be decided based on the population density of the area.

4.5 REVISION OF NORMS FOR GROUND WATER ASSESSMENT

As stated in Section 4.2, there is a need to retain the recommendation of norms for recharge assessment for use in situations where adequate data of ground water level is not available. However, these norms are to be periodically revised, based on the results and observations of recent ground water assessment studies in various parts of the country. In a large country like India, such studies are undertaken by a number of central and state government agencies, research institutions, universities, non-government organisations etc. These studies may be of varied quality and rigour. Procurement and analysis of these data require considerable time. In the limited time available for the Committee, only some of these data could be studied.

While it is reasonable to adopt a specific standardised methodology of ground water assessment for 5 years, it is necessary to update the norms on an annual basis, based on the results of case studies of several ground water assessment across the country. For this, it is recommended that a Standing Committee may be formed, which may be authorised to revise the norms periodically and circulate it to the different states. To facilitate the work of this Standing Committee, an initial effort is first required to prepare a data bank, comprising the results of ground water assessments made by different central and state government agencies, research institutions, universities, non government organizations etc. Once the initial data bank is available, updating it to include subsequent investigations will require less effort. The Standing Committee may evolve a format for collection of information of the data bank. In evolving the format, the approach proposed under the Hydrology Project may be kept in view. With the formation of a Standing Committee, it may be possible to provide norms on a state-wise basis for different agro-climatical and hydrogeological regions, once the initial data bank is created. However, the present Committee has made a limited review of case studies of ground water assessment in the last 10 to 15 years, in order to revise the norms for ground water assessment.

4.5.1 Case studies of ground water assessment

The studies on ground water assessment in recent years can be broadly catagorised as follows:

(a) Blockwise ground water assessment by state ground water agencies and Central Ground Water Board, based on the recommendations of the GEC - 1984. (b) Detailed pilot studies undertaken in specific areas by the Central Ground Water Board. (c) Ground water assessment through computer modelling as part of the pilot studies referred above or otherwise. (d) Recharge assessment in a number of watersheds/basins, using the injected Tritium method, made by the National Geophysical Research Institute. (e) Studies by National Remote Sensing Agency and other agencies of Indian Space Research Organisation.

Normally, the results of blockwise assessment based on the ground water level fluctuation method should have formed the basis for the revision of the norms. However, there is a problem in using these results for the present purpose, as the estimate of recharge is based on adhoc assumption for the value of specific yield. Revising adhoc norms for recharge based on estimates, which themselves are based on adhoc norms for specific yield, hardly looks appropriate. For example, for granitic terrains in Karnataka, the recharge based on the water level fluctuation approach is estimated as 13% of rainfall, using a specific yield value of 3%. The detailed modelling studies for the Vedavati River basin in Karnataka has indicated an average specific yield value of 2% for similar terrains. If the latter value of specific yield is adopted and the recharge values are revised, the recharge reduces to 8.7% instead of 13%. In view of these difficulties, greater importance is given in the present review to ground water assessment based on detailed pilot studies, where rigorous methods have been applied for the estimation of both specific yield and recharge factor. The recharge estimate in different regions, based on injected Tritium method, is also considered in revising the norms.

Annexure 3 presents a summary of results from a number of case studies, which were reviewed. For the sake of brevity and simplicity, a standard format is used in the presentation, providing summary information on project, source of information, period of study, location, area, soil/rock type, methodology of assessment, estimated results for specific yield and recharge factor. It is to be noted that such a simple presentation may hide important data and limitations relevant to the assessment. However, in an overview as attempted here, consideration of finer details of individual projects is hardly feasible and is beyond the scope of this Committee.

The case studies presented in Annexure 3 contain recharge estimates based on the water level fluctuation approach recommended by the GEC - 1984, detailed pilot studies where a rigourous water balance is made both for the rainy and non-rainy seasons, studies based on computer modelling using finite difference or finite element method, recharge estimates based on Tritium injection technique, studies based on soil moisture measurement technique, and other miscellaneous estimates. The results presented in Annexure 3 form the principal basis for the revised norms recommended in this report. Besides, the comments provided by a number of agencies in response to the request of the Central Ground Water Board form another important input.

4.6 GROUND WATER DEVELOPMENT

There are two faces to ground water assessment, the estimation of ground water recharge from rainfall and other sources and the assessment of development potential. These require an estimate of present ground water draft. Ground water draft has to be necessarily estimated by indirect methods such as well census, electricity consumption and area irrigated from ground water. There can be considerable uncertainties in these estimates, unless a careful review is made for consistency from different approaches. In planning further development based on the potential, it is necessary to review the average ground water draft and associated irrigation command for different types of ground water structures.

CHAPTER 5

RECOMMENDATIONS ON

GROUND WATER RESOURCE ESTIMATION METHODOLOGY

5.1 INTRODUCTION

The revised ground water resource estimation methodology as proposed by the committee is presented in this chapter. The methodology as recommended here, may be adopted in future for ground water resource estimation. The two approaches recommended by the GEC - 1984, namely ground water level fluctuation method and rainfall infiltration factor method, can still form the basis for ground water assessment. However, several improvements are made in the basic approaches based on the discussions presented in Sections 4.3 to 4.5. In the proposed methodology, distinctions such as hard rock areas and alluvial areas, canal command areas and non-command areas and recharge in monsoon season and non-monsoon season, are kept in view. It is recommended that recharge due to rainfall in the monsoon season is to be estimated by ground water level fluctuation method, unless adequate data is not available, for which case rainfall infiltration factor method may be used. The ground water recharge assessment is essentially for unconfined aquifers. The problem of confined aquifers is separately discussed in Section 5.17. The usable ground water resource is essentially the dynamic resource which is recharged annually by rainfall and other sources. The concept of static ground water resource is discussed in Section 5.16.

5.2 GROUND WATER BALANCE EQUATION

The water level fluctuation method is based on the application of ground water balance equation, which is stated in general terms as follows for any specified period,

Input -Output = Storage increase (1)

In the above equation, the terms input and output are used in the general sense, referring to all components of ground water balance, which are either input to the unit, or output from the unit of ground water system taken up for resource assessment (ex : watershed, block etc.). Hence input refers to recharge from rainfall and other sources and subsurface inflow into the unit. Output refers to ground water draft, ground water evapotranspiration, base flow to streams and subsurface outflow from the unit.

Eqn.1 holds good for any period and hence it can be applied to the year as a whole or to different seasons in the year separately. From ground water assessment point of view, it is desirable to apply the equation separately for different seasons, such as monsoon and non-monsoon seasons or kharif, rabi and summer seasons.

The right side term in eqn. 1, namely storage increase (positive for storage increase, negative for storage decrease), is given as a function of the ground water level change and specific yield. Hence ground water level measurements at the beginning and end of the season form necessary input for the estimation of storage change.

The input and output terms in eqn. 1 include subsurface inflow and outflow components across the boundary of the unit, which depend on the transmissivity and hydraulic gradient. It is advantageous to adopt the unit for ground water assessment as basin/subbasin/watershed, as the inflow/outflow across these boundaries may be taken as negligible.

5.3 UNIT FOR GROUND WATER RECHARGE ASSESSMENT

Watershed with well defined hydrogeological boundaries is an appropriate hydrological unit for ground water resource estimation. In hard rock areas, the hydrogeological and hydrological units normally coincide, which may not be the case in alluvial areas where the aquifers traverse the basin boundaries. In hard rock areas which occupy about 2/3rd area of the country, assessing the ground water on watershed as a unit is more desirable. In many states where the development unit is either a block or a taluka or a mandal, based on the ground water resource worked out on watershed as a unit, the final assessment of ground water potential may be apportioned and presented on block/taluka/mandal-wise basis, which would facilitate planning of development programmes. In case of alluvial areas where it is difficult to identify watershed considering the trans-boundary aquifer system, the present methodology of assessing the ground water potential on block/taluka/mandal-wise basis may continue. For purposes of classification into alluvial or hard rock areas, the predominant hydrogeology of the unit is to be considered. Hence, localised alluvial patches occurring in predominantly hard rock area should be considered as part of the watershed unit in hard rock area. In the states where switch over to watershed is not possible immediately, the present practice of assessing the ground water potential for block/taluka/mandal may continue for sometime even for hard rock areas. However, the state ground water departments shall endeavour to demarcate and switch over to watershed as a unit for assessment, within a period not exceeding 5 years.

In each unit, ground water assessment may be made once in three years. However, the ground water draft figures can be updated every year.

5.4 DELINEATION OF SUBAREAS IN THE UNIT

GEC - 1984 provides for assessment of ground water resources in an administrative unit, namely block, without any subdivision. Treating the entire block area as a single unit has resulted in certain distortions, wherein a block as a whole may be categorised as a region with good potential for ground water development, but in practice, it is possible that in a large part of the block, in the summer season, water may be scarce even for domestic supply. This anomaly can be removed, if the ground water assessment in a block is done, keeping in view the spatial and seasonal variability of ground water resource. With this in view, the following recommendations are made with regard to delineation of subareas within the unit, which may be a watershed (hard rock areas) or a block/taluka/mandal (alluvial areas).

First, out of the total geographical area of the unit, hilly areas (slope greater than 20%) are to be identified and deleted as these are not likely to contribute to ground water recharge. However, the local topographical and geomorphological situations such as valley, terrace, plateau occurring within (>) 20% slope zone may be considered for recharge computations. Out of the remaining area after deleting the hilly area, areas where the quality of ground water is beyond the usable limits as presently decided and practiced in the state, should be identified and handled separately. It may not be correct to recommend a uniform quality standard for all the areas in different states, due to variations in quality norms criteria prevalent in the use of ground water. The ground water resource beyond the permissible quality limits has to be computed separately. The area with brackish/saline ground water be delineated and the ground water resource of these areas be computed separately. The remaining area after deleting the hilly area and separating the area with poor ground water quality, is to be delineated as follows :

(a) Non-command areas which do not come under major/medium surface water irrigation schemes.

(b) Command areas under major/medium surface water irrigation schemes.

If felt necessary, within these two types of areas, further subdivision based on geomorphological and hydrogeological characteristics may be made.

5.5 SEASON-WISE ASSESSMENT OF GROUND WATER RESOURCES

Ground water recharge assessment is to be made separately for the non-command and command areas in the unit as delineated in Section 5.4. For each of these subareas, recharge in the monsoon season and non-monsoon season is to be estimated separately. For most parts of the country receiving the main rainfall from South west monsoon, the monsoon season would pertain to kharif period of cultivation. In areas of the country, such as Tamil Nadu, where the primary monsoon season is the North east monsoon, the period of monsoon season should be suitably modified. For purposes of recharge assessment using water level fluctuation method, the monsoon season may be taken as May/June to October/November for all areas, except those where the predominant rainfall is in the North east monsoon season. This recommendation means that an additional period of one month after cessation of monsoon is taken to account for the base flow which occurs immediately following the monsoon period, but may not be utilised for ground water development, based on present practices. Generally, a well hydrograph follows a definite trend like stream flow hydrograph with a peak followed by a recession limb. The recession limb in the post monsoon period, particularly in hard rock areas, is categorised by two slopes: a steep limb from September-October to October-November and other gentle limb from October-November to May-June. The steeper limb indicates that whatever rise has taken place during the monsoon period, of the total, a significant part is lost soon after the end of rainfall. The rate of recession of the water level is relatively rapid in the beginning, for a period of $1\text{-}1^{1}/_{2}$ months immediately after the water level rises to maximum. Due to less demand for ground water in view of adequate moisture in soils, the resource available during this period are not fully utilised. It is therefore, recommended that the ground water recharge may be estimated on pre-monsoon (May-June) to post monsoon (October-November) water level fluctuations for the areas receiving rainfall from South west monsoon. In areas where the predominant rainfall is due to North east monsoon, the period for recharge assessment may be based on pre-monsoon (October) to post monsoon (February) water level fluctuations. Hence, in these areas also an additional month is taken in the monsoon season, to account for the steep part of the recession limb.

5.6 GROUND WATER ASSESSMENT IN NON-COMMAND AREA

5.6.1 Methodology

It is recommended that ground water recharge be estimated on ground water level fluctuation and specific yield approach since this method takes into account the response of ground water levels to ground water input and output components, and as such appears more scientific, realistic and directly measurable, unlike other approaches where assumptions need to be made for most of the components. This, however, requires adequately spaced setting up of observation wells and water level records for a sufficiently long period. It is proposed that there should be atleast three spatially well distributed observation wells in the unit, or one observation well per 100 sq km, whichever is more. If the unit comprises of both command and non-command areas, then atleast five observation wells must be available in the unit, such that atleast two observation wells are available in each type of subarea. Also, water level observations must be available for a minimum period of 5 years, along with corresponding rainfall data in the unit. Regarding frequency of water level data, pre and post monsoon observations preferably in successive years, are the minimum requirement. It would be ideal to have monthly water level measurements to record the peak rise and maximum fall in the ground water levels. Efforts should be made to install continuous water level recorders in key representative locations of the unit of recharge estimation. In units or subareas where adequate data on ground water level fluctuations are not available as specified above, ground water recharge may be estimated using rainfall infiltration factor method. Section 5.6.2 describes recharge assessment based on water level fluctuation method and Section 5.6.3 deals with the recharge assessment based on rainfall infiltration factor method.

5.6.2 Ground water level fluctuation method

The ground water level fluctuation method is to be used for recharge assessment in the monsoon season. For non-command areas, recharge in the non-monsoon season is a small component and may be estimated empirically, as described subsequently. In applying the ground water level fluctuation method, two alternate approaches are possible: 1. Case a: Estimate specific yield from long duration pumping tests or based on norms for the particular hydrogeological area, and use this value of specific yield in the ground water balance equation for the monsoon season to estimate recharge. This approach is more suitable for alluvial areas or in hard rock areas when data/information about base flow in the dry season is not available. 2. Case b : Ground water balance equation applied separately for the dry season to estimate specific yield, and then use this value of specific yield in the ground water balance equation for the monsoon season to estimate recharge. This approach will provide a more reliable assessment of recharge in hard rock areas where adequate data/information about base flow in the dry season is available, or the base flow in the dry season is practically negligible.

Case a:

In this approach, specific yield value is obtained from long duration pumping tests or from norms for different hydrogeological areas. In using pumping tests to obtain specific yield value, it may be noted that unless the tests are of sufficiently long duration (minimum pumping duration of 16 hrs), proper assessment of specific yield value is difficult. In situations where specific yield value cannot be estimated by other means, the norms given in Section 5.9.1 may be used.

Computation of recharge for the monsoon season :

The water level fluctuation method is applied for the monsoon season to estimate the recharge. The ground water balance equation for the monsoon season in non-command areas is given by,

$$R_G - D_G - B + I_S + I = S \quad (2)$$

where

R_G = gross recharge due to rainfall and other sources including recycled water

D_G = gross ground water draft

B = base flow into streams from the area

I_S = recharge from streams into ground water body

I = net ground water inflow into the area across the boundary(inflow - outflow)

S = ground water storage increase

All quantities in eqn. 2 refer to the **monsoon season** only, as defined in Section 5.5.

In eqn. 2, if the area under consideration is a watershed, the net ground water inflow term, I may be taken as zero. If there is inflow and outflow across the boundary, in theory, the net inflow may be calculated using Darcy law, by delineating the inflow and outflow sections of the boundary. Besides such delineation, the calculation also requires estimate of transmissivity and hydraulic gradient across the inflow and outflow sections. These calculations are most conveniently done in a computer model (Section 6.1.7), and for the present ground water assessment as prescribed in these recommendations, the net inflow term, I may be dropped.

There are similar difficulties in estimating the base flow and recharge from streams in eqn. 2. If the unit of assessment is a watershed in hard rock area, a single stream gauge monitoring station at the exit of the watershed can provide the required data for the calculation of base flow. As such data is not available in most of the cases, it is recommended that the base flow term and recharge from stream in eqn.2 may also be dropped.

After deleting net inflow and base flow terms in eqn. 2, the resultant recharge term now refers to the possible recharge under the present status of ground water development in the area. This possible recharge is the gross recharge minus the natural discharges in the area during the monsoon season. To signify this, the R_G term in eqn.2 is rewritten as R. Eqn.2 is now rewritten as,

$$R = S + D_G \qquad (3)$$

where

R= possible recharge, which is gross recharge minus the natural discharges in the area in the monsoon season (R_G - B + I +I_S)

Substituting the expression for storage increase S in terms of water level fluctuation and specific yield, eqn.3, becomes,

$$R = h \times Sy \times A + D_G \qquad (4)$$

where

h = rise in water level in the monsoon season

A = area for computation of recharge (Section 5.4)

S_y = specific yield

The recharge calculated from eqn. 4 gives the available recharge from rainfall and other sources for the particular monsoon season. For non-command areas, the recharge from other sources may be recharge from recycled water from ground water irrigation, recharge from tanks and ponds and recharge from water conservation structures, if any (ex : check dams, percolation tanks, nala bunds etc.). The recharge from rainfall is given by,

$$R_{rf} = R - R_{gw} - R_{wc} - R_t$$
$$= hxS_y \times A + D_G - R_{gw} - R_{wc} - R_t \qquad (5)$$

where

R_{rf} = recharge from rainfall

R_{gw} = recharge from ground water irrigation in the area

R_{wc} = recharge from water conservation structures

R_t = Recharge from tanks and ponds

The estimation of recharge from ground water irrigation (R_{gw}), recharge from water conservation structures (R_{wc}) and recharge from tanks and ponds (R_t) may be made based on the norms presented in Section 5.9.4 to 5.9.7. The recharge from rainfall estimated as per eqn.5 is for the particular monsoon season. The procedure for normalisation of this recharge for estimating recharge corresponding to the normal monsoon rainfall, is given in Section 5.6.2.1.

Case b :

In this approach, the specific yield is estimated from ground water balance in the dry season, and based on this specific yield value, recharge is estimated from ground water balance in the monsoon season. The approach is suitable in hard rock areas where data regarding base flow in the dry season is available or base flow in the dry season is practically zero.

The period January to May (5 months) is suitable for dry season balance, except in areas where predominant rainfall is in the North east monsoon where the period March to May (3 months) may be used. Ignoring the net inflow term due to subsurface flow and assuming that the recharge from rainfall during the dry season is practically nil, the ground water balance in the dry season is given by,

$$h \times S_y \times A = D_G - R_{gw} + B \qquad (6)$$

where

h = decrease in ground water level

D_G = gross ground water draft

R_{gw} = recharge recycled from ground water irrigation

B = base flow from the area

All quantities in eqn. 6 refer to the **dry season** only, as defined in this section. The estimation of recharge from ground water irrigation (R_{gw}) may be made based on the norms presented in Section 5.9.4. In eqn. 6, the recharge term from water conservation structures and from tanks and ponds are not included, because it is expected that these recharge effects would have become negligible by the time the dry season commences. The specific yield value can now be calculated from eqn. 6 as follows.

$$S_y = \frac{D_G - R_{gw} + B}{h \times A} \qquad (7)$$

Once specific yield value is determined from the water level fluctuation data in the dry season, the recharge in the monsoon season can be calculated from eqn. 4, applying the water level fluctuation method for the monsoon season. The corresponding recharge from rainfall is obtained from eqn. 5, where the terms R_{gw}, R_{wc} (recharge from ground water irrigation and water conservation structures in the monsoon season) and R_t (Recharge from tanks and ponds) are obtained from the norms presented in Section 5.9.4 to 5.9.7. The procedure for normalisation of recharge from rainfall in the monsoon season, with regard to normal monsoon rainfall, is given in Section 5.6.2.1.

5.6.2.1. Estimation of normal recharge during monsoon season

The rainfall recharge obtained by using eqn. 5 provides the recharge in any particular monsoon season for the associated monsoon season rainfall. This estimate is to be normalised for the normal monsoon season rainfall which in turn is obtained as the average of the monsoon season rainfall for the recent 30 to 50 years. The normalisation procedure requires that, a set of pairs of data on recharge and associated rainfall are first obtained. To eliminate the effects of drought or surplus years, it is recommended that the rainfall recharge during monsoon season is estimated using eqn. 5 not only for the current year for which assessment is being made, but also for atleast four more preceding years. This will result in atleast 5 pairs of data being obtained. If the current assessment year and the four years preceding it are uniformly dry years or wet years, it is desirable to consider more than five years for normalisation.

Let R_i be the rainfall recharge and r_i be the associated rainfall. The subscript i takes values 1 to N where N is usually atleast 5. The rainfall recharge, R_i is obtained as per equation given below :

$$R_i = h \times S_y \times A + D_G - R_{gw} - R_{wc} - R_t \quad (8)$$

where,

R_i = rainfall recharge estimated for the i^{th} particular year

h = rise in ground water level in the monsoon season for the i^{th} particular year

S_y = specific yield

A = area for computation of recharge

D_G = gross ground water draft in monsoon season for the i^{th} particular year

R_{gw} = recharge from groundwater irrigation in the monsoon season for the i^{th} particular year

R_{wc} = recharge from water conservation structures in the monsoon season for the i^{th} particular year

R_t = recharge from tanks and ponds in the monsoon season for the i^{th} particular year

Those pairs of R_i and r_i as obtained above which have R_i as negative or nearly zero should be omitted, and only those pairs of data in which R_i is greater than zero should be considered for further computations in the normalisation procedure. It is also likely that all the R_i values as obtained above are consistently negative or nearly zero. In such a case, the water table fluctuation method should be dispensed with, and the normal rainfall recharge during the monsoon season should be estimated by the rainfall infiltration factor method based on rainfall infiltration factors as given in section 5.9.2.

After the pairs of data on R_i and r_i have been obtained as described above, a normalisation procedure is to be carried out for obtaining the rainfall recharge corresponding to the normal monsoon season rainfall. Let r(normal) be the normal monsoon season rainfall obtained on the basis of recent 30 to 50 years of monsoon season rainfall data. Two methods are possible for the normalisation procedure.

The first method is based on a linear relationship between recharge and rainfall of the form,

$$R = a\, r \tag{8a}$$

where,

R = rainfall recharge during monsoon season

r = monsoon season rainfall

a = a constant

The computational procedure to be followed in the first method is as given below:

a) Each pair of R_i and r_i are used to obtain $[R_{rf}\text{ (normal)}]_i$ as,

$$\left[R_{rf}(\text{normal})\right]_i = R_i \times \frac{r(\text{normal})}{r_i} \tag{8b}$$

b) The normal monsoon season rainfall recharge, R_{rf} (normal) is then computed as,

$$R_{rf}(\text{normal}) = \frac{\sum_{i=1}^{N}\left[R_{rf}(\text{normal})\right]_i}{N} \tag{8c}$$

The second method is also based on a linear relation between recharge and rainfall . However, this linear relationship is of the form,

$$R = ar + b \tag{8d}$$

where,

R = rainfall recharge

r = rainfall

a and b = constants.

The two constants 'a' and 'b' in eqn. 8d are obtained through a linear regression analysis.

The computational procedure to be followed in the second method is as given below :

a) The following four terms are computed.

$$S_1 = \sum_{i=1}^{N} r_i \qquad (8e_1)$$

$$S_2 = \sum_{i=1}^{N} R_i \qquad (8e_2)$$

$$S_3 = \sum_{i=1}^{N} r_i^2 \qquad (8e_3)$$

$$S_4 = \sum_{i=1}^{N} r_i R_i \qquad (8e_4)$$

b) The regression constants 'a' and 'b' are computed as,

$$a = \frac{NS_4 - S_1 S_2}{NS_3 - S_1^2} \qquad (8f_1)$$

$$b = \frac{S_2 - aS_1}{N} \qquad (8f_2)$$

c) The rainfall recharge during monsoon season for normal monsoon season rainfall condition is computed as,

R_{rf} (normal) = a x r(normal) + b (8g)

After the rainfall recharge for normal monsoon season rainfall using the water table fluctuation method has been estimated as described above, it is to be compared with the rainfall recharge estimated by rainfall infiltration factor method based on rainfall infiltration factors as given in section 5.9.2. A term, PD which is the difference between the two expressed as a percentage of the latter is computed as,

$$PD = \frac{R_{rf}(normal, wtfm) - R_{rf}(normal, rifm)}{R_{rf}(normal, rifm)} \times 100 \quad (8h)$$

where,

R_{rf} (normal, wtfm) = rainfall recharge for normal monsoon season rainfall estimated by the water table fluctuation method

R_{rf} (normal, rifm) = rainfall recharge for normal monsoon season rainfall estimated by the rainfall infiltration factor method

The rainfall recharge for normal monsoon season rainfall is finally adopted as per criteria given below :

a) If PD is greater than or equal to -20%, and less than or equal to +20%, R_{rf} (normal) is taken as the value estimated by the water table fluctuation method.

b) If PD is less than -20%, R_{rf} (normal) is taken as equal to 0.8 times the value estimated by the rainfall infiltration factor method.

c) If PD is greater than +20% , R_{rf} (normal) is taken as equal to 1.2 times the value estimated by the rainfall infiltration factor method.

The total recharge during the monsoon season for normal monsoon season rainfall condition is finally obtained as,

$$R(normal) = R_{rf}(normal) + R_{gw} + R_{wc} + R_t \quad (9)$$

where,

R(normal) = total recharge during monsoon season

R_{rf} (normal) = rainfall recharge during monsoon season for normal monsoon season rainfall

R_{gw} = recharge from ground water irrigation in the monsoon season for the year of assessment

R_{wc} = recharge from water conservation structures in the monsoon season for the year of assessment

R_t = recharge from tanks and ponds in the monsoon season for the year of assessment

5.6.2.2 Estimation of normal recharge during non-monsoon season

Recharge from rainfall

The recharge from rainfall during the non-monsoon season may be estimated based on the rainfall infiltration factors given in Section 5.9.2, provided the normal rainfall in the non-monsoon season is greater than 10% of the normal annual rainfall. If the rainfall is less than this threshold value, the recharge due to rainfall in the non-monsoon season may be taken as zero.

Recharge from other sources

Recharge during the non-monsoon season from other sources, namely from ground water irrigation (R_{gw}), tanks(R_t) and from water conservation structures (R_{wc}) are to be estimated from the norms given in Section 5.9.4 to 5.9.7.

Total recharge in non-monsoon season

The total recharge in the non-monsoon season is obtained as the sum of recharge from rainfall in the non-monsoon season and recharge from other sources in the non-monsoon season.

5.6.3 Recharge assessment based on rainfall infiltration factor

If adequate data of ground water levels are not available, the ground water level fluctuation method described in Section 5.6.2 can not be used. In such a situation, recharge may be estimated based on the rainfall infiltration factor method. The norms to be used for recharge from rainfall and from other sources are presented in Section 5.9. Recharge from rainfall in monsoon season is given by

$$R_{rf} = f \times A \times \text{Normal rainfall in monsoon season} \qquad (10)$$

where

f = rainfall infiltration factor given in Section 5.9.2

A = area of computation for recharge

The same recharge factor may be used for both monsoon and non-monsoon rainfall, with the condition that the recharge due to non-monsoon rainfall may be taken as zero, if the normal rainfall during the non-monsoon season is less than 10% of normal annual rainfall. In using the method based on the specified norms, recharge due to both monsoon and non-monsoon rainfall may be estimated for normal rainfall, based on recent 30 to 50 years of data. It is necessary to have adequately spaced rain gauge stations within and outside the unit taken up for recharge computation. While adopting this method due weightage should be given to the nearby raingauge stations.

For non-command areas, recharge from other sources correspond to recharge from ground water irrigation and recharge from water conservation structures. These are to be estimated separately for monsoon and non-monsoon seasons based on the norms presented in Section 5.9. The total recharge is given by Eq. 9.

5.6.4 Total annual recharge

The total annual recharge is obtained as the sum of recharge in the monsoon season and recharge in the non-monsoon season, where in each season, the recharge comprises of recharge from rainfall and recharge from other sources.

5.7 GROUND WATER ASSESSMENT IN COMMAND AREA

5.7.1 Methodology

Recharge assessment in command areas may be done on the same lines as in non-command areas, except that two important additional components of recharge are to be considered, namely recharge due to seepage from canals and recharge due to return flow from surface water irrigation. In command areas, these two components may be significantly more than the recharge due to rainfall. Recharge from these sources may be significant both in monsoon and non-monsoon seasons and hence, the estimation of specific yield based on the application of ground water balance equation in the dry season, as described in case (b) in Section 5.6.2 is difficult to apply. Hence in applying water level fluctuation method in command areas, the method as described in Case (a) in Section 5.6.2 may be used. If adequate data of water level fluctuations is not available as defined in Section 5.6.1, the method based on rainfall infiltration factor may be used.

5.7.2 Ground water level fluctuation method

As in the case of non-command area, the ground water level fluctuation method may be applied for estimating the recharge in the monsoon season for the command area also. The monsoon season corresponds to the predominant rainfall season, as defined in Section 5.5 for different areas.

Eqn. 4 gives the available ground water recharge in the **monsoon season**, after allowing for net inflow and base flow terms. The recharge term calculated in eqn. 4 gives the recharge from rainfall and other sources for the particular monsoon season. For command areas, recharge from other sources include recharge due to seepage from canals, recharge due to return flow from surface water irrigation and ground water irrigation, recharge from storage tanks and ponds, and recharge from water conservation structures. The recharge from rainfall is given by,

$$R_{rf} = h \times S_y \times A + D_G - R_c - R_{sw} - R_t - R_{gw} - R_{wc} \qquad (11)$$

where,

R_{rf} = recharge from rainfall

R_c = recharge due to seepage from canals

R_{sw} = recharge from surface water irrigation

R_t = recharge from storage tanks and ponds

R_{gw} = recharge from ground water irrigation

R_{wc} = recharge from water conservation structures

D_G = gross draft in the command area

h = rise in ground water level in the command area

A = area of the command area for recharge assessment

S_y = specific yield

In eqn. 11, all quantities refer to the monsoon season only. For particular command areas, one or more of the recharge quantities from other sources may be zero (not being relevant for the area). It may be noted that the net ground water inflow across the boundaries (I in eqn. 2) has been ignored. This may not be true especially, in the case of alluvial areas where the choice of assessment unit (block/taluka) is based on administrative considerations. Hence, in such cases a freedom is given for including the component of net ground water flow across the boundaries. This can be estimated as the product of gradient of ground water flow, transmissivity of the aquifer and the length across which flow takes place. The transmissivity value in these computations should be on the basis of long duration aquifer performance tests.

The rainfall recharge obtained by eqn. 11 provides the recharge in any particular monsoon season for the associated monsoon season rainfall. This estimate is to be normalised for the normal monsoon season rainfall which in turn is obtained as the average of the monsoon season rainfall for the recent 30 to 50 years. The normalisation procedure to be followed in this case is identical to what has been described earlier in Section 5.6.2.1, and involves the following :

a) Computation of a set of pairs of data on rainfall recharge, R_i and associated rainfall, r_i for i = 1 to N in which N is atleast 5.
b) Considering only those pairs of R_i and r_i in which R_i is greater than zero for further computations in the normalisation procedure.
c) Dispensing with the water table fluctuation method if all R_i values are consistently negative or nearly zero, and adopting instead the rainfall infiltration factor method for computing the rainfall recharge in the monsoon season based on rainfall infiltration factors as given in Section 5.9.2.
d) Using the pairs of data on R_i and r_i , and estimating the rainfall recharge for normal monsoon season rainfall condition by either of the two methods of normalisation.
e) Comparing the rainfall recharge under normal monsoon season rainfall condition as obtained by the water table fluctuation method with that obtained by the rainfall infiltration factor method, and finally assigning the rainfall recharge value on the basis of a set of criteria so that, unreasonably high or low estimates of rainfall recharge by the water table fluctuation method are avoided.

The computational procedure in this case is also similar to what has been described in Section 5.6.2.1., except that, in place of eqn. 8, the expression to be used for the rainfall recharge term R_i is,

$$R_i = h \times S_y \times A + D_G - R_c - R_{sw} - R_t - R_{gw} - R_{wc} \qquad (12)$$

where,

R_i = rainfall recharge estimated for the i^{th} particular year

h = rise in water level in the monsoon season for the i^{th} particular year

S_y = specific yield

A = area for computation of recharge
D_G = gross ground water draft in the monsoon season for the i^{th} particular year
R_c = recharge due to seepage from canals for the i^{th} particular year
R_{sw} = recharge from surface water irrigation for the i^{th} particular year
R_t = recharge from tanks and ponds for the i^{th} particular year
R_{gw} = recharge from ground water irrigation for the i^{th} particular year
R_{wc} = recharge from water conservation structures for the i^{th} particular year

The total recharge during the monsoon season for normal monsoon season rainfall condition is finally obtained as,

$$R(normal) = R_{rf}\,(normal) + R_c + R_{sw} + R_t + R_{gw} + R_{wc} \quad (13)$$

where,

R(normal) = total recharge during monsoon season
R_{rf} (normal) = rainfall recharge during monsoon season for normal monsoon season rainfall
R_c = recharge due to seepage from canals in the monsoon season for the year of assessment
R_{sw} = recharge from surface water irrigation in the monsoon season for the year of assessment
R_t = recharge from tanks and ponds in the monsoon season for the year of assessment
R_{gw} = recharge from ground water irrigation in the monsoon season for the year of assessment
R_{wc} = recharge from water conservation structures in the monsoon season for the year of assessment

5.7.2.1 Estimation of normal recharge during non-monsoon season

Recharge from rainfall

The recharge from rainfall during the non-monsoon season may be estimated based on the rainfall infiltration factors given in Section 5.9.2, provided the normal rainfall in the non-monsoon season is greater than 10% of the normal annual rainfall. If the rainfall is less than this threshold value, the recharge due to rainfall in the non-monsoon season may be taken as zero.

Recharge from other sources

Recharge during non-monsoon season from other sources, namely from canal seepage (R_c), surface water irrigation (R_{sw}), tanks (R_t), ground water irrigation (R_{gw}), and water conservation structures (R_{wc}) are to be obtained using the norms presented in Section 5.9.

Total recharge in non-monsoon season

The total recharge in the non-monsoon season is obtained as the sum of the recharge from rainfall in the non-monsoon season and recharge from other sources in the non-monsoon season.

5.7.3 Recharge assessment based on rainfall infiltration factor

If adequate data of ground water levels are not available, the ground water level fluctuation method described in Section 5.7.2 can not be used. In such a situation, recharge may be estimated based on the rainfall infiltration factor method. The norms to be used for recharge from rainfall and from other sources are presented in Section 5.9. The same recharge factor may be used for both monsoon and non-monsoon rainfall, with the condition that the recharge due to non-monsoon rainfall may be taken as zero, if the normal rainfall during non-monsoon season is less than 10% of normal annual rainfall. In using the method based on the specified norms, recharge due to both monsoon and non-monsoon rainfall may be estimated for normal rainfall, based on recent 30 to 50 years of data. It is necessary to have adequately spaced rain gauge stations within and outside the unit taken up for recharge computation. While adopting this method due weightage should be given to the nearby raingauge stations.

For command areas, recharge from other sources correspond to recharge due to seepage from canals, recharge from surface water irrigation, recharge from storage tanks and ponds, recharge from ground water irrigation and recharge from water conservation structures. These are to be estimated separately for monsoon and non-monsoon seasons based on the norms presented in Section 5.9.

5.7.4 Total annual recharge

The total annual recharge is obtained as the sum of recharge in the monsoon season and recharge in the non-monsoon season, where in each season, the recharge comprises of recharge from rainfall and recharge from other sources.

5.8 GROUND WATER ASSESSMENT IN SALINE AREAS AND WATER LEVEL DEPLETION ZONES

5.8.1 Saline areas

It is stated in Section 5.4 that in each unit, area with brackish/saline ground water be delineated and the ground water resource of these areas be computed separately. However, in saline areas, there will be the practical difficulty due to non availability of data, as there will be usually no observation wells in such areas. In view of this limitation, recharge assessment may be based on rainfall infiltration factor method, using the norms provided in Section 5.9.

5.8.2 Water level depletion zones

There may be areas where ground water level shows a decline even in the monsoon season. The reasons for this may be any one of the following : (a) There is a genuine depletion in the ground water regime, with ground water draft and natural ground water discharge in the monsoon season(outflow from the region and base flow) exceeding the recharge. (b) There may be an error in water level data due to inadequacy of observation wells.

If it is concluded that the water level data is in error, recharge assessment may be made based on rainfall infiltration factor method. If, on the other hand, water level data is assessed as reliable, the ground water level fluctuation method as described in Section 5.6.2 may be applied for recharge estimation. As h in eqn. 4 is negative, the estimated recharge will be less than the gross ground water draft in the monsoon season. It must be noted that this recharge is the gross recharge minus the natural discharges in the monsoon season. The immediate conclusion from such an assessment in water depletion zones will be that the area falls under the over-exploited category, with need for micro level study (vide Sections 5.11 and 5.14)

5.9 NORMS FOR ESTIMATION OF RECHARGE

5.9.1 Norms for specific yield

S.No	Formation	Recommended Value (%)	Minimum Value (%)	Maximum Value (%)
(a)	Alluvial areas			
	Sandy alluvium	**16.0**	12.0	20.0
	Silty alluvium	**10.0**	8.0	12.0
	Clayey alluvium	**6.0**	4.0	8.0
(b)	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	**3.0**	2.0	4.0
	Weathered granite, gneiss and schist with significant clay content	**1.5**	1.0	2.0
	Weathered or vesicular, jointed basalt	**2.0**	1.0	3.0
	Laterite	**2.5**	2.0	3.0
	Sandstone	**3.0**	1.0	5.0
	Quartzite	**1.5**	1.0	2.0
	Limestone	**2.0**	1.0	3.0
	Karstified limestone	**8.0**	5.0	15.0
	Phyllites, Shales	**1.5**	1.0	2.0
	Massive poorly fractured rock	**0.3**	0.2	0.5

Note : Usually the recommended values should be used for assessment, unless sufficient data based on field study is available to justify the minimum, maximum or other intermediate values.

5.9.2 Recharge from rainfall

S.No	Formation	Recommended Value (%)	Minimum Value (%)	Maximum Value (%)
(a)	Alluvial areas			
	Indo-Gangetic and inland areas	**22**	20	25
	East coast	**16**	14	18
	West coast	**10**	8	12
(b)	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	**11**	10	12
	Weathered granite, gneiss and schist with significant clay content	**8**	5	9
	Granulite facies like charnockite etc.	**5**	4	6
	Vesicular and jointed basalt	**13**	12	14
	Weathered basalt	**7**	6	8
	Laterite	**7**	6	8
	Semi-consolidated sandstone	**12**	10	14
	Consolidated sandstone, quartzite ,limestone (except cavernous limestone)	**6**	5	7
	Phyllites shales	**4**	3	5
	Massive poorly fractured rock	**1**	1	3

Note:1. Usually, the recommended values should be used for assessment, unless sufficient information is available to justify the use of minimum, maximum or other intermediate values.

2. An additional 2% of rainfall recharge factor may be used in such areas or part of the areas where watershed development with associated soil conservation measures are implemented. This additional factor is subjective and is separate from the contribution due to the water conservation structures such as check dams, nalla bunds, percolation tanks etc. The norms for the estimation of recharge due to these structures are provided separately. This additional factor of 2% is at this stage, only provisional, and will need revision based on pilot studies.

5.9.3 Recharge due to seepage from canals

(a) Unlined canals in normal soils with some clay content along with sand :	1.8 to 2.5 cumecs per million sq m of wetted area (or) 15 to 20 ham/day/million sq m of wetted area
(b) Unlined canals in sandy soil with some silt content :	3.0 to 3.5 cumecs per million sq m of wetted area (or) 25 to 30 ham/day/million sq m of wetted area
(c) Lined canals and canals in hard rock area :	20% of above values for unlined canals

Notes :

1. The above values are valid if the water table is relatively deep. In shallow water table and waterlogged areas, the recharge from canal seepage may be suitably reduced.
2. Where specific results are available from case studies in some states, the adhoc norms are to be replaced by norms evolved from these results.

5.9.4 Return flow from irrigation

The recharge due to return flow from irrigation may be estimated, based on the source of irrigation (ground water or surface water), the type of crop (paddy, non-paddy) and the depth of water table below ground level, using the norms provided below.

Recharge as percentage of application

Source of irrigation	Type of crop	Water table below ground level		
		<10m	10-25 m	>25m
Ground water	Non-paddy	25	15	5
Surface water	Non-paddy	30	20	10
Ground water	Paddy	45	35	20
Surface water	Paddy	50	40	25

Notes:

1. For surface water, the recharge is to be estimated based on water released at the outlet. For ground water, the recharge is to be estimated based on gross draft.
2. Where continuous supply is used instead of rotational supply, an additional recharge of 5% of application may be used.
3. Where specific results are available from case studies is some states, the adhoc norms are to be replaced by norms evolved from these results.

5.9.5 Recharge from storage tanks and ponds

1.4 mm/day for the period in which the tank has water, based on the average area of water spread. If data on the average area of water spread is not available, 60% of the maximum water spread area may be used instead of average area of the water spread.

5.9.6 Recharge from percolation tanks

50% of gross storage, considering the number of fillings, with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season.

5.9.7 Recharge due to check dams and nala bunds

50% of gross storage (assuming annual desilting maintenance exists) with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season.

5.10 GROUND WATER POTENTIAL

5.10.1 Net annual ground water availability

The total annual ground water potential obtained for the unit, refers to the available annual recharge after allowing for natural discharge in the monsoon season in terms of base flow and subsurface inflow/outflow. This annual ground water potential includes the existing ground water withdrawal, natural discharge due to base flow and subsurface inflow/outflow in the non-monsoon season, and availability for future development. As the ground water development progresses, the natural discharge gets suitably modified. However, while deciding on the ground water available for future development, some provision needs to be kept for natural discharge in the non-monsoon season.

By deleting hilly areas from the unit for ground water assessment, it is quite likely that dense forest areas are excluded. In view of this, ground water loss due to transpiration by deep rooted trees may be quite small in the area of assessment. In the water level fluctuation method, a significant part of base flow is already accounted by taking the post monsoon water level one month after the end of rainfall. The base flow in the remaining non-monsoon period is likely to be small, especially in hard rock areas. However, detailed data for quantitative assessment of the natural discharge is not generally available. Considering these factors, it is recommended that 5 to 10% of the total annual ground water potential may be assigned to account for natural discharges in the non-monsoon season. The balance will account for existing ground water withdrawal for various uses and potential for future development. This quantity is termed as the net annual ground water availability. The net annual ground water availability should be calculated separately for non-command areas and command areas.

5.10.2 Allocation of ground water resource for utilisation

The net annual ground water availability is to be apportioned between domestic, industrial and irrigation uses. Among these, as per the National Water Policy, requirement for domestic water supply is to be accorded priority. This requirement has to be based on population as projected to the year 2025, per capita requirement of water for domestic use, and relative load on ground water for urban and rural water supply. The estimate of allocation for domestic and industrial water requirement may vary for the units in different states. In situations where adequate data is not available to make this estimate, the following empirical relation is recommended.

Allocation for domestic and industrial water requirement =

$$22 \text{ X } N \text{ X } L_g \text{ mm per year} \qquad (14)$$

where

N = population density in the unit in thousands per sq. km.

L_g = fractional load on ground water for domestic and industrial water supply (≤ 1.0)

In deriving eqn. 14, it is assumed that the requirement of water for domestic and industrial use is 60 lpd per head.

The water available for irrigation use is obtained by deducting the allocation for domestic and industrial use, from the net annual ground water availability. This is termed as net annual ground water availability for irrigation. To determine the potential for future irrigation development from ground water, the existing ground water draft for irrigation has to be deducted, from the net annual ground water availability for irrigation. The resulting ground water potential is termed as the net annual ground water availability for future irrigation development. The Net annual ground water availability for future irrigation development should be calculated separately for non-command areas and command areas.

5.11 CATEGORISATION OF AREAS FOR GROUND WATER DEVELOPMENT

5.11.1 Stage of ground water development

The stage of ground water development is defined by,

Stage of ground water development (%) =

$$\frac{\text{Existing gross ground water draft for all uses}}{\text{Net annual ground water availability}} \times 100 \qquad (15)$$

The net annual ground water availability is defined in Section 5.10.1. The existing gross ground water draft for all uses refers to the total of existing gross ground water draft for irrigation and all other purposes. The stage of ground water development should be obtained separately for non command areas and command areas.

5.11.2 Long term ground water trend

The stage of ground water development is one index of the balance between ground water available and utilisation. As the stage of development approaches 100%, it indicates that potential for future development is meagre. However, the assessment based on the stage of ground water development has inherent uncertainties. The estimation of ground water draft is likely to be associated with considerable uncertainties, as it is based on indirect assessment only using factors such as electricity consumption, well census, and area irrigated from ground water. The denominator in eqn. 15, namely net annual ground water availability also has uncertainties due to limitations in the assessment methodology, as well as uncertainties in the data. In view of this, it is desirable to provide an alternate index of the present status of ground water regime, based on long term trend of ground water levels.

It is recommended that in addition to obtaining an assessment of Net annual ground water availability and stage of ground water development, as part of the ground water assessment, the long term trend of ground water levels in the unit should be presented. A figure is to be prepared giving the variation of pre and post monsoon ground water levels with years, for a minimum period of 10 years. Both pre and post monsoon water level trends may be shown on the same figure. For ensuring conciseness in presentation and clarity in interpretation, average water level trend as obtained from the different observation wells in the area may be plotted. This figure should be treated as an integral component of ground water assessment. Separate figure may be prepared for command and non-command areas in the unit, if both types of areas are present.

In interpreting the long term trend of ground water levels, the following points may be kept in view. If the pre and post monsoon water levels show a fairly stable trend, it does not necessarily mean that there is no scope for further ground water development. Such a trend indicates that there is a balance between recharge, draft and natural discharge in the unit. However, further ground water development may be possible, which may result in a new stable trend at a lower ground water level with associated reduced natural discharge.

If the ground water resource assessment and the trend of long term water levels contradict each other, this anamolous situation requires a review of the ground water resource computation, as well as the reliability of water level data.

5.11.3 Categorisation of areas for ground water development

The units of assessment can be categorised for ground water development based on the stage of ground water development(eqn.15) and the long term trend of pre and post monsoon ground water levels. The following categorisation is proposed based on these two factors.

Safe areas with potential for development

(a) Areas where ground water resource assessment shows stage of ground water development (eqn.15) at 70% or lower, and there is no significant long term decline of pre or post monsoon ground water levels.

(b) Areas where ground water resource assessment shows stage of ground water development (eqn.15) more than 70%, but less than 90%, and both pre monsoon and post monsoon ground water levels do not show a significant long term decline. However, in these areas, caution may be exercised in planning future development, with regard to quantum of additional ground water withdrawal.

Semi critical areas for cautious ground water development

Areas where ground water resource assessment shows stage of ground water development (eqn.15) more than 70%, but less than 90%, and either pre monsoon or post monsoon ground water level shows a significant long term decline.

Critical areas

(a) Areas where ground water resource assessment shows stage of ground water development (eqn. 15) more than 90%, but less than 100%, and either pre monsoon or post monsoon ground water level shows a significant long term decline.

(b) Areas where ground water resource assessment shows stage of ground water development (eqn. 15) less than 100%, but both pre monsoon and post monsoon ground water levels show a significant long term decline.

(c) Areas where ground water resource assessment shows stage of ground water development (eqn. 15) more than 100%, but either pre monsoon or post monsoon ground water level does not show a significant long term decline.

Over - exploited areas

Areas where ground water resource assessment shows stage of ground water development (eqn.15) more than 100% and both pre and post monsoon ground water levels show a significant long term decline.

In over-exploited areas, there should be intensive monitoring and evaluation and future ground water development be linked with water conservation measures. In fact, more widespread adoption of water conservation measures based on watershed management techniques will be beneficial even in semi critical and criitical areas.

5.12 DEVELOPMENT OF GROUND WATER POTENTIAL

5.12.1 Estimation of ground water draft

The gross yearly ground water extraction for irrigation should be considered instead of net ground water draft. The gross ground water draft would include the ground water extraction from all the existing ground water structures during monsoon as well as during non-monsoon period. This should preferably be based on the latest well census conducted by the state and updating the same based on the growth rate and/or ground water programme cleared and implemented by various agencies. For computing the ground water draft, it is necessary to study and decide the average unit draft from different types of ground water structures. This unit draft should be considered based on the well yield capacity, its command area and techno-economic viability of a ground water structure.

Some of the dug wells and tubewells become non-operative either due to water table receding much below the depth of the well or due to silting, or due to water quality problems, or due to failure of the well or the useful life of the well has expired. In such cases since these wells are not likely to be revived, the ground water draft from these wells need not be considered. Estimation of the number of these disused wells may be reflected by a depreciation factor. This depreciation factor should be considered while estimating the ground water draft. This factor shall be decided by the respective State Ground Water Department.

Ground water draft can also be estimated by alternate methods other than well census method. These alternate methods may be estimation based on: (a) electric power consumption for agricultural pumpsets, (b) statistics of area irrigated by ground water and the associated crop water requirements, and (c) use of remote sensing data to obtain seasonal data on area of different irrigated crops in non-command areas, where only ground water irrigation is used.

In view of the uncertainties in the estimation of ground water draft by any of these methods, it is clearly desirable to use more than one method for draft estimation, to enable a cross check.

5.12.2 Development of ground water

The development of potential evaluated as net annual ground water availability for future irrigation development (Section 5.10.2) is to be achieved in a phased manner through construction of different types of ground water structures, feasible as per the hydrogeological situation. To plan such a development, the following table provides the guidelines for annual draft for different types of ground water structures in the states, based on the prevalent practices. In canal command areas, the present utilisation of wells is suboptimal and hence these practices cannot provide the true potential of the wells. In view of this, the norms for ground water draft given in the table are based on the data for non-command areas, except in situation where wells in the command areas are optimally utilised.

Average Annual Gross Draft for Ground Water Structures in Different States

S. No.	State	Type of ground water structure	Average gross unit draft (ham)
1.	Andhra Pradesh	Dugwell with Mhot	0.35
		Dugwell with Pumpset	0.65
		Borewell with Pumpset	1.3
		Shallow Tubewell	2.05

		Medium Tubewell	4.1
		Deep Tubewell	5.85
2.	Assam	Shallow Tubewell with Pumpset	3.0
3.	Bihar	Dugwell	0.6
		Private tube well with Pumpset	1.0
		Bamboo boring with Pumpset	0.75
		Deep tube well	30.0
4.	Gujarat	Dugwell with Pumpset	0.8
		Borewell with Pumpset	1.2
		Private shallow Tubewell	1.85
		Medium Deep Tubewell	6.0
		Deep Tubewell	30.0
5.	Haryana	Dugwell with Pumpset	1.5
		Private shallow Tubewell with Pumpset	1.81
		Deep Tubewell	15.0
6.	Himachal Pradesh	Medium Deep Tubewell with Pumpset	2.5
7.	Karnataka	Dugwell with Pumpset	0.9
		Borewell with Pumpset	1.7
		Dug cum Borewell with Pumpset	1.98
8.	Kerala	Dugwell with Pumpset	0.5
		Borewell with Pumpset	0.7
9.	Madhya Pradesh	Dugwell with Mhot	0.8
		Dugwell with Pumpset	1.5
		Borewell with Pumpset	1.5
		Private shallow tubewell with Pumpset	3.0

S. No.	State	Type of ground water structure	Average gross unit draft (ham)
10.	Maharashtra	Dugwell with Mhot	0.45
		Dugwell with Pumpset	1.57
11.	Orissa	Dugwell with Mhot	0.21
		Dugwell with Pumpset	1.0
		Filter Point with Pumpset	2.1
		Private Tubewell with Pumpset	7.0

		Deep Tubewell with Pumpset	17.5
12.	Punjab	Shallow Tubewell with Pumpset	1.3 - 3.4
		Deep Tubewell with Pumpset	18.0
13.	Rajasthan	Dugwell with Pumpset	0.52
		Private Tubewell with Pumpset	1.4
		Dug cum borewell with Pumpset	1.23
		Deep Tubewell	2.28
14.	Tamil Nadu	Dugwell with Pumpset	0.4 -1.0
		Private Tubewell with Pumpset	1.0 - 2.0
		Borewell with Pumpset	1.0
15.	Tripura	Shallow Tubewell with Pumpset	3.0
		Artesian Well	0.37
16.	Uttar Pradesh	Dugwell with Mhot	0.37
		Dugwell with Pumpset	0.75
		Private Tubewell with Pumpset	3.7
		Deep Tubewell	22.0
17.	West Bengal	Dugwell with Pumpset	0.3
		Private Tubewell with Pumpset	1.52
		Deep Tubewell with Pumpset	18.5

The irrigation potential of each type of structure will depend on the cropping pattern, crop water requirements, and the extent of irrigation support (full or supplementary).

Under some situations, additional potential recharge may be available in water logged and shallow water table areas, which can be realised by depressing the water level by pumping to receive the additional recharge. A development plan for this additional resource has to be prepared separately (Section 5.15).

5.13 APPORTIONING OF GROUND WATER ASSESSMENT FROM WATERSHED TO DEVELOPMENT UNIT

Where the assessment unit is a watershed, there is a need to convert the ground water assessment in terms of an administrative unit such as block/taluka/mandal. This may be done as follows.

A block may comprise of one or more watersheds, in part or full. First, the ground water assessment in the subareas, non-command and command areas of the watershed (Section 5.4) may be converted into depth unit (mm), by dividing the annual recharge by the respective area. The contribution of this subarea of the watershed to the block, is now calculated by multiplying this depth with the area in the block occupied by this sub-area. This procedure must be followed to calculate the contribution from all the sub-areas of watersheds occurring in the block, to work out the total ground water resource of the block.

The total ground water resource of the block should be presented separately for each type of sub-area, namely for non-command areas, command areas and saline/brackish water areas, as in the case of the individual watersheds.

5.14 MICRO LEVEL STUDY FOR CRITICAL AREAS AND OVER-EXPLOITED AREAS

In all areas which are catagorised as semi-critical or worse it is necessary to increase the density of observation wells. In critical and over-exploited areas as defined based on classification given in Section 5.11.3, it is necessary to carry out micro-level studies to reassess the ground water recharge and draft. Following approach may be adopted :

1. The micro-level studies in the critical and over-exploited areas in hard rock terrain should be based on only watershed as a unit and not administrative unit.
2. The area may be sub-divided into different hydrogeological sub-areas and into recharge area, discharge area and transition zone and also on quality terms.
3. The number of observation wells should be increased to represent each such sub-areas with atleast one observation well with continuous monitoring of water levels.
4. Hydrological and hydrogeological parameters particularly the specific yield should be collected for different formations in each sub-area.
5. Details regarding other parameters like seepage from canals and other surface water projects should be collected after field studies, instead of adopting recommended norms. Base flow should be estimated based on stream gauge measurement.
6. The data of number of existing structures and unit draft should be reassessed after fresh surveys and should match with the actual irrigation pattern in the sub-area.
7. All data available with CGWB, SGDs and other agencies including research institutions and universities etc. should be collected for the watershed/sub-areas and utilised for reassessment.
8. Ground water assessment for each sub-areas may be computed adopting the recommended methodology and freshly collected values of different parameters. The

assessment may be made separately for monsoon and non-monsoon period as well as for command and non-command areas.

9. The ground water potential so worked out may be cross-checked with behaviour of ground water levels in the observation wells and both should match. If it does not, the factor that causes such an anamoly should be identified and the revised assessment should be re-examined.

10. Based on the micro-level studies, the sub-areas within the unit and the unit as a whole may be classified adopting norms for categorization as recommended in Section 5.11.3.

5.15 ADDITIONAL POTENTIAL RECHARGE UNDER SPECIFIC CONDITIONS

5.15.1 Waterlogged and shallow water table areas

The quantum of water available for development is usually restricted to long term average recharge or in other words “Dynamic Resources”. But the resource calculated by water level fluctuation approach is likely to lead to under-estimation of recharge in areas with shallow water table, particularly in discharge areas of sub-basin/watershed/block/taluka and waterlogged areas. In such cases rejected recharge may be substantial and water level fluctuations are subdued resulting in under-estimation of recharge component. It is therefore, desirable that the ground water reservoir should be drawn to optimum limit before the onset of monsoon, to provide adequate scope for its recharge during the following monsoon period.

In the area where the ground water level is less than 5m below ground level or in waterlogged areas, the resources in such waterlogged and shallow water table zones, upto 5m below ground level are potential and would be available for development in addition to the annual recharge in the area. It is therefore recommended that in such areas, ground water resources may be estimated upto 5m bgl only assuming that where water level is less than 5m bgl, the same could be depressed by pumping to create space to receive recharge from natural resources. It is further evident that these potential recharge would be available mostly in the shallow water table areas which would have to be demarcated in each sub-basin/watershed/block/taluka.

The computation of potential resource to ground water reservoir can be done by adopting following equation:

Potential ground water resource = (5-D) x A x Specific yield (16)

where

D = depth to water table below ground surface in pre-monsoon period in shallow aquifers.

A = area of shallow water table zone.

The planning of future minor irrigation works in the waterlogged and shallow water table areas as indicated above should be done in such a way that there should be no long term adverse effects of lowering of water table upto 5m and the water level does not decline much below 5m in such areas. The behaviour of water table in the adjoining area which is not water logged should be taken as a bench mark for development purposes.

This potential recharge to ground water is available only after depression of water level upto 5m bgl. This is not an annual resource and should be recommended for development on a very cautious approach so that it does not adversely affect the ground water potentials in the overall area.

5.15.2 Flood prone areas

Ground water recharge from a flood plain is mainly the function of the following parameters:

(i) Areal extent of flood plain

(ii) Retention period of flood

(iii) Type of sub-soil strata and silt charge in the river water which gets deposited and controls seepage.

Since collection of data on all these factors is time taking and difficult, in the mean time, the potential recharge from flood plain may be estimated on the same norms as for ponds, tanks and lakes (Section 5.9.5). This has to be calculated over the water spread area and only for the retention period.

5.16 STATIC GROUND WATER RESOURCE

The quantum of ground water available for development is usually restricted to long term average recharge or dynamic resources. Presently there is no fine demarcation to distinguish the dynamic resources from the static resources. While water table hydrograph could be an indicator to distinguish dynamic resources, at times it is difficult when water tables are deep. For a sustainable ground water development, it is necessary to restrict it to the dynamic resources. Static ground water resources could be considered only during the eventuality of extreme drought conditions, that also for drinking water purposes. It is also recommended that no irrigation development schemes based on static ground water resources be taken up at this stage. The computation of static ground water resources may be done after delineating the aquifer thickness and specific yield of the aquifer material. The computations can be done as follows:-

$$\text{Static ground water reserve} = \text{Thickness of the aquifer below the zone of water level fluctuation down to exploitable limit} \times \text{Areal extent of the aquifer} \times \text{Specific yield of the aquifer.} \qquad (17)$$

5.17 CONFINED AQUIFER

There are two types of situations of occurrence of confined aquifers. In hard rock areas, the upper water table aquifer in the weathered zone is connected to the deeper fracture zone, which is semi-confined. In such situations, the assessment procedure already given for unconfined aquifer accounts for the full recharge, and hence no separate assessment is to be made for the confined aquifer.

In specific alluvial areas, resource from a deep confined aquifer may be important. If the confined aquifer is hydraulically connected to the overlying shallow water table aquifer, it is a semiconfined aquifer, and not strictly a confined aquifer. If there is no hydraulic connection to the overlying water table aquifer, the resource may have to be estimated by specific detailed investigations, taking care to avoid duplication of resource assessment from the upper unconfined aquifers.

5.18 SUMMARY REPORT OF GROUND WATER ASSESSMENT

A summary for each unit adopted for ground water assessment is to be presented in the format given in the following table. This table should also be accompanied by two graphical plots, one for the command area and the other for the non command area showing the trend of water table fluctuations during pre monsoon and post monsoon seasons as described in Section 5.11.2.

SUMMARY REPORT IN RESPECT OF EACH GROUND WATER ASSESSMENT UNIT

Ground Water Assessment Year :

Name of State/Union Territory :

Name of Ground Water Assessment Unit :

Type of Ground Water Assessment Unit :
(Watershed/Block/Taluka/Mandal)

Type of Rock Formation :

Areal extent in hectares of

a) Ground Water Assessment Unit :
b) Command Area :
c) Non-command Area :
d) Poor Ground Water Quality Area :

A) Zone suitable for ground water recharge and also of good ground water quality

Sl. No	Description of Item	Non-Command area		Command area	
		hectare metres	mm	hectare metres	mm
1	Recharge from rainfall during monsoon season				
2	Recharge from other sources during monsoon season				
3	Recharge from rainfall during non-monsoon season				
4	Recharge from other sources during non-monsoon season				
5	Total annual ground water recharge (1+2+3+4)				
6	Natural discharge during non-monsoon season				
7	Net annual ground water availability (5-6)				
8	Existing gross ground water draft for irrigation				

9	Existing gross ground water draft for domestic and industrial water supply
10	Existing gross ground water draft for all uses (8 + 9)
11	Allocation for domestic and industrial water supply upto next 25 years
12	Net ground water availability for future irrigation development (7-8-11)
13	Method adopted for computing rainfall recharge during monsoon season (Water table fluctuation method / Rainfall infiltration factor method)
14	If response to Sl. No. 13 is water table fluctuation method, how was specific yield value adopted (Norms/Pumping test / Dry season water balance method)
15	Existing stage of ground water development as a percentage ([10/7] x 100)
16	Is there a significant decline of pre-monsoon water table levels (Yes/No)
17	Is there a significant decline of post-monsoon water table levels (Yes/No)
18	Categorisation for future ground water development (safe / semi- critical / critical / over-exploited)

B) Zone suitable for ground water recharge but of poor ground water quality

Sl. No	Description of Item	hectare metres	mm
1	Recharge from rainfall and other sources, if any, during monsoon period		
2	Recharge from rainfall and other sources, if any, during non-monsoon period		
3	Total annual ground water recharge (1+2)		
4	Natural discharge during non-monsoon period		
5	Net annual ground water availability (3-4)		
6	Existing gross ground water draft, if any		
7	Net ground water availability for future use (5-6)		

C) Additional annual potential recharge in hectare metres in the ground water assessment unit

1. Waterlogged and shallow water table area :
2. Flood prone area :
3. Total :
   (1+2)

CHAPTER 6

FUTURE STRATEGIES

6.1 REFINEMENTS TO THE RECOMMENDED METHODOLOGY

6.1.1 Introduction

The methodology for ground water resource estimation as described in Chapter 5 is based on relatively sound scientific basis. It also meets adequately well the practical requirements for formulating rational ground water development strategies. It is also commensurate with available human resources, their level of technical skill and available infrastructure facilities with the state level ground water organisations which have to actually apply the methodology. However, it is to be also recognised that the methodology has considerable scope for refinements and improvements which can be planned to be achieved in a time bound and phased manner for future assessment. Some of these refinements which are necessary are briefly described below.

6.1.2 Geographic unit for assessment

Most states have been adopting the administrative unit of a development block/taluka/mandal as the geographic unit for estimating and presenting ground water potential. The methodology presented in Chapter 5, while accepting the continuation of this procedure for the present, also makes a specific recommendation that within a time period of 5 years, all states which are predominantly characterised by hard rock terrain should change over to watershed as the unit for assessment. Similar adoption of a watershed in the case of states characterised predominantly by alluvial terrain has not been recommended for the following two major reasons:

a) The relatively flat topography imposes difficulties in delineating proper watershed boundaries.

b) Unlike in hard rock areas, there can be substantial ground water flow across the boundaries of a watershed in the case of alluvial areas, thereby negating the advantage of a watershed over an administrative block for computing ground water balance.

It is however, recognised that, in the case of states which are predominantly characterised by alluvial terrain, the adoption of a geographic unit on the basis of hydrologic/hydrogeologic considerations may be necessary in due course of time. One such unit offering considerable scope for adoption is a “Doab” which is a land area enclosed within two major stream courses. Such a geographic unit has both the advantages of easy delineation of the boundary and no ground water transfer across the boundaries. The only limitation is that a “Doab” will be relatively much larger in areal extent covering probably two, three or even more development blocks. Under these circumstances the following approach is recommended :

a) A few representative doabs in the alluvial plains may be first identified. The number can be about 8 to 10 distributed in the major states like Punjab, Uttar Pradesh and Bihar.

b) The ground water estimation following the methodology described in Chapter 5 can be applied to these representative doabs and results evaluated.

c) The practicality of switching over to doabs on a uniform basis for the entire state in the alluvial plains can then be evaluated and if found feasible, a switch over to doabs as the geographic unit can be effected.

6.1.3 Employing remote sensing techniques

Remote sensing techniques can be profitably employed for quantifying various components of the methodology described in Chapter 5. For instance, one area which has considerable scope is the estimation of the draft in situations where only one mode of irrigation (ground water) is predominantly employed. Another area is the delineation of good and poor ground water quality zones. All such areas in which remote sensing techniques can be successfully employed need to be identified and conscious steps initated to apply the technique on a wide scale.

6.1.4 Computerisation of the ground water resource estimation methodology

The application of the methodology for ground water estimation as described in Chapter 5 in the case of most of the states will be predominantly through a manual procedure. Even where automated systems employing computers are used, such applications will be only for different components in isolation from others. A need therefore, arises for a concerted effort to computerise the whole process of the application of the ground water resource estimation methodology as given in Chapter 5. The advantages of such a computerisation are,

a) Uniformity in the presentation of ground water resource estimation by different states

b) A possibility to rapidly cross-check the computations

c) Easy extraction of set of desired information

d) Easy revision of the computations for alternative paramater values.

6.1.5 Data monitoring

The availability of adequate data will be the key to the successful application of the methodology of ground water resource estimation as given in Chapter 5. This will particularly become more relevant when a switch over is made to a watershed as the basic geographic unit for ground water estimation. Attention therefore, needs to be focussed in respect of each watershed on the following:

a) Establishment of appropriate grid of observation wells for monitoring water table fluctuations

b) Atleast one rain gauge station for monitoring daily rainfall

c) Atleast one pan evaporimeter for evaporation measurements

d) One stream gauge at the exit of the watershed with emphasis on base flow measurements

e) Adequate number of field level experiments for measurement of aquifer parameters, seepage loses, infiltration rates, soil moisture etc.

6.1.6 Norms for estimation of recharge

Norms for specific yield and norms for estimation of recharge from rainfall and other sources are provided in Section 5.9 for use in situations where adequate data are not available. An attempt has been made in Chapter 5 to specify these norms in as realistic manner as possible. It is however, necessary that, a proper mechanism be evolved through which these norms can be periodically evaluated and refined based on field level studies carried out by the Central Ground Water Board and State Ground Water Organisations, and research contributions emanating from academic institutions of higher learning, national and state level R&D institutes in the water sector etc.

6.1.7 Distributed parameter modelling

The methodology described in Chapter 5 is essentially a lumped parameter system approach although the physical ground water unit has been categorised into a few distinct and relevant sub-units. Consequently, spatial variations are not adequately taken care of. A need therefore arises to consciously employ computer based distributed parameter system approach using techniques like finite difference, finite element and boundary integral equation methods. Such application for atleast a few selected hydrogeologic units should be undertaken in a phased and time bound manner.

6.2 ALTERNATIVE METHODOLOGY

6.2.1 introduction

The methodology described in Chapter 5 for ground water resource estimation is essentially a water balance approach in which :

a) The physical system for which the water balance is carried out is a lumped system representing the ground water regime (below the water table). It has a number of input and output components.

b) Only one of the input component namely, recharge from rainfall is considered to be unknown. All other components are considered to be such that they can be either directly estimated individually, or ignored due to some reasonably valid factor, or accounted for in some indirect manner.

c) The algebraic sum of all input and output components is equated to the change in storage within the ground water regime as reflected by the water table fluctuation. This in turn results in estimating the single unknown namely, recharge from rainfall.

The last mentioned characteristic imposes considerable importance on the water table fluctuation and the associated specific yield of the ground water regime. In situations where the change in ground water storage cannot be determined due to lack of adequate data on water table fluctuation and specific yield, the methodology as described in Chapter 5 allows the estimation of recharge due to rainfall in a direct manner as a percentage of the rainfall.

There is a genuine need for an alternative methodology for computing the recharge from rainfall which does not make use of the water table fluctuation. This need has also been emphasised in the approach paper on the Hydrology Project. One direct advantage of the application of such an alternative methodology is that the recharge from rainfall thus estimated can be used to corraborate the estimate obtained by using the water table fluctuation method and thereby gain confidence in the validity of the estimate. In case there is a discrepancy in the two estimates, it is also advantageous in the sense that it can motivate practicing hydrogeologists to look more closely into the discrepancies and seek scientific explanations. This, in turn, can considerably enhance their understanding of all issues related to ground water resource estimation.

6.2.2 Soil water balance method

One such alternative methodology is the soil-water-balance method, which has been widely applied in a very profitable manner to many watersheds in North America, Europe and Israel. The main characteristics of the soil-water-balance method are briefly mentioned below:

a) It is essentially a water balance approach similar to the methodology presented in Chapter 5. However, it significantly differs in the sense that the physical system for which the water balance is applied comprises of the zone above the water table. This system is again divided into two sub-units, one an upper zone representing the vegetative surfaces, leaf litter and ground surface, and the other a lower zone representing the vertical soil profile above the water table.

b) The sub-system representing the upper zone has a number of input and output components. The algebraic sum of these components is equated to the change in soil moisture. Given a rainfall input, P in mm/day, and potential evpotranspiration, E_p in mm/day, the output component of excess rainfall, PM in mm/day is obtained. PM contributes to surface runoff, Q in mm/day, and to replenishment to the lower zone, PEM in mm/day. Determination of Q requires the use of a suitable method such as SCS method.

c) The lower zone also has a number of input and output components. The algebraic sum of these components is equated to the change in soil moisture within the lower zone. Given the value of PEM in mm/day, and the evaporation, E_a in mm/day, the output component of natural replenishment to the ground water system below, GW in mm/day is finally obtained. GW represents the recharge from rainfall to the ground water regime.

d) The application of the method yields reliable results only if the water balance is carried out over a number of very small discrete time periods. The recommended time duration is one day. On the other hand, the methodology presented in Chapter 5 allows much larger durations of time period in which the water balance is carried out. For instance, one year has been divided into only two descrete time durations.

e) The method also requires that the water budget model is calibrated with actual field data before it is applied.

f) The characteristics mentioned in items (d) and (e) above result in the requirement of innumerable repetitive calculations to be performed which cannot be realistically done in a manual procedure. The use of a computer software is essential. The algorithm for this software is not complex and efficient software are also available.

The alternative methodology described above has its significant advantages. However, given the limitations of lack of data on meteorological, hydrologic and soil characteristics on a watershed basis obtained through a comprehensive system of field level instrumentation, it is probably not practical to immediately apply the method on a very wide scale. The state level ground water organisations may also not have the required infrastructure facilities. Under these circumstances, the following approach is recommended:

a) A few representative watersheds meeting the data requirements are to be first identified. The number can be about 8 to 10 and located in different hydrogeologic settings.

b) The alternative methodology of soil-water-balance method is to be applied for these watersheds.

c) The results obtained are to be correlated with those obtained through the application of the methodology given in Chapter 5.

d) The scope to extend the application of the method on a much wider scale is to be evaluated and if found feasible, it should be extended in a phased manner.

6.3 RECOMMENDATIONS

6.3.1 Introduction

A set of future programmes on ground water estimation have been identified and briefly explained in the previous two sections under the following major sub-headings:

a) Refinements in the application of the recommended methodology as given in Chapter 5.

b) Adoption of alternative methodologies.

The realisation of these future programmes into reality will to a large extent depend on extensive R & D support. This in turn requires that,

a) A number of R & D projects are clearly identified and their objectives well defined.

b) Each identified R & D project is assigned to competent groups of people with adequate financial support and with clear terms and conditions for responsibility to the required R & D output from these projects.

c) Periodic evaluation and monitoring of the implementation of these R & D projects is ensured.

d) An appropriate mechanism is evolved for adoption of the results from the R & D projects by the national and state level ground water organisations.

e) The infrastructure facilities with national and state level ground water organisations are strengthened based on actual needs.

f) The technical skill of the human resources in national and state level ground water organisations is periodically upgraded through well designed training modules.

6.3.2 Formation of Standing Committee

In order to ensure that the above requirements listed in the previous section are successfully fulfilled, it is recommended that, a Standing Committee with a suitable name, composition, duration and terms of reference be constituted by the Ministry of Water Resources, Government of India. Suggestions in this regard are given below:

a) Name of the Standing Committee:

" R & D Advisory Committee on Ground Water Estimation"

b) Composition

i)	Chairman, CGWB	: Chairman
ii)	A senior level Officer of CGWB	: Vice Chairman
iii)	A senior level Officer of CGWB	: Member-Secretary
iv)	A senior level Officer of NABARD	: Member
v)	Three suitable representatives with R&D inclination from Ground water Departments of States/Union Territories	: Members
vi)	Four ground water experts from academic institutions of higher learning in science/engineering/ technology and from national and state level R&D institutions in the water sector. These experts should be provided with appropriate TA/DA grants. They should also be suitably compensated through an	: Members

honorarium for the time and effort put by them. The latter will also ensure i) a more serious level of commitment from them, ii) make them answerable for their contributions and iii) a high quality of work output from them.

c) Duration

The Standing Committee can initially have a duration of five years.

d) Terms of Reference

i) Identify a few selected major thrust areas of research with reference to ground water estimation and identify a number of R&D projects in each thrust area, and formulate clear objectives to be achieved in each R&D project.

ii) Identify component groups of people to whom each R&D project can be assigned, approve a well defined and time bound technical programme for implementing each R&D project, and recommend necessary financial support to be released for implementing each R&D Project.

iii) Periodically evaluate and monitor the progress of each R&D project in relation to the approved objectives and technical programme.

iv) Evolve an appropriate mechanism through which it is ensured that the results from all R&D projects find profitable application by national and state level ground water organisations.

v) Identify and recommend specific strengthening of infrastructural facilities with national and state level ground water organisations.

vi) Formulate appropriate training modules for upgrading technical skill of the human resources available with national and state level organisations, recommend competent groups of people/institutions to whom the responsibility of undertaking the training modules can be assigned, and recommend necessary financial support to be released for undertaking these training modules.

vii) Identify a series of workshops/seminars/conferences on ground water estimation which can be organised, formulate clear objectives to be achieved in each such event, decide a convenient time schedule for them, recommend organisations/institutions to whom the responsibility of conducting these can be assigned, and recommend the financial support to be released for organising the same.

For efficient working of the "R&D Advisory Committee on Ground Water Estimation", it is also recommended that from among the members of this Committee, the following five working groups can be formed,

a) Working Group on periodic revision of norms to be adopted for ground water assessment

b) Working group on data monitoring, data storage and retrieval systems, management information systems, geographic information systems and decision support system

c) Working group on distributed parameter modelling using finite difference, finite element and boundary integral equation methods

d) Working group on alternative methodologies for ground water resource estimation

e) Working group on strengthening infrastructure facilities with national and state level ground water organisations and on upgrading the technical skill of the human resources in these organisations.

The formation of the "R & D" Advisory Committee on Ground Water Estimation" as recommended above, and its functioning on a regular basis will take some time to materialise because a number of necessary formalities may have to be first gone through both by the Central Ground Water Board and the Ministry of Water Resources, Government of India. However, there are some items of work which come under the scope of the proposed Committee and also have a bearing on the immediate application of the ground water estimation methodology as given in Chapter 5. These items are :

a) Preparing a comprehensive data bank on information pertaining to norms to be made use of in ground water resource estimation obtained from all ground water assessment studies made by government agencies, research institutions, universities, non-governmental organisations etc., after first deciding a proper format in which the information have to be collected, stored and retrieved. It may be mentioned here that the present Committee could review only a few limited case studies due to shortage of time. Once the initial data bank is available, updating it to include the results from subsequent investigations will require much less effort. The data bank will then form the source of information on proper norms to be adopted for ground water estimation by ground water organisations in different states.

b) Providing detailed guidelines for the step by step computational procedure to be followed while actually applying the ground water estimation methodology as given in Chapter 5, evolving the appropriate format in which all the results of ground water estimation are to be presented in a tabular and/or graphical form, and preparing a comprehensive software for the recommended ground water estimation methodology.

The above items of work need to be taken up immediately. In this connection, it is recommended that, the first Working Group on standardisation of norms alone be immediately constituted and the tasks mentioned above be assigned to this Working Group. The financial implication will be minimum and limited to TA/DA of expert members from universities/R & D organisations. The duration of this Working Group can be initially for one year period, by the end of which all the formalities for constituting the full "R & D Advisory Committee on Ground Water Estimation" may have been completed. The Working Group constituted now can be integrated with the full committee at that time. The composition of the Working Group to be immediately constituted can be as given below.

i) One senior level Officer of CGWB : Member (Convener)

ii) One senior level Officer from NABARD : Member

iii) Two nominees from State Ground Water Organisations : Member

iv) Two ground water experts from R & D Organisations/Universities :Member

ANNEXURE 1

MOWR Resolution No. 3/9/93-GW (II)/2332 , dated 13.11.95

GOVERNMENT OF INDIA

MINISTRY OF WATER RESOURCES

SHRAM SHAKTI BHAVAN, NEW DELHI

No: 3/9/83-GW(ll) dated: 13.11.95

RESOLUTION

In November, 1982, the Government had constituted a Committee for going into all the aspects of Ground Water Estimation and for recommending methodologies for Ground Water Estimation which could be adopted. The Committee submitted its report in March 1984. Since then the Central Ground Water Board and State's Ground Water Organisations have undertaken a number of studies in different situations which have led to revision of parameters for ground water resources. Therefore, with a view to reviewing the Ground Water Resources Estimation Methodology and to look into all the related issues, it has been decided to constitute a Commitee on Ground Water Estimation. The Committee will consist of the following:

(i) Chairman, CGWB	Chairman
(ii) Commissioner (CAD & MI)	Member
(iii) Chief Hydrogeologist & Member, CGWB	Member
(iv) Chief General Manager, NABARD, Bombay	Member
(v) One representative each from the State Govts. of Andhra Pradesh,Maharashtra, West Bengal, Bihar, U.P., Gujarat, Madhya Pradesh, Tamil Nadu, Haryana, Punjab and Rajasthan.	Member
(vi) Scientist 'F', Incharge, Ground Water NIH, Roorkee	Member
(vii) Prof. D. Kashyap, Department of Hydrology, University of Roorkee, Roorkee.	Member
(viii) Dr. S.P. Rajagopalan, Scientist 'F', Head, Computer Division, Centre of Water Resources Development & Management, Kozhikode, Calicut district, Kerala.	Member
(ix) Prof. K. Sridharan	Member

Department of Civil Engineering,
Indian Institute of Science,
Bangalore

Shri Santosh Kumar Sharma, Secretary
Scientist 'D', CGWB

Chairman can opt more Members on the Committee or invite special representatives representing different interests/organisations upto a limit of five. The terms of reference for the Committee will be as follows.

1. To make an assessment of the scientific work done in the field with a view to replacing, firming up or updating the various parameters and their values currently used in the assessment of ground water resources.
2. To look into the details of the methodology recommended by Ground Water Estimation Committee (1984) and to suggest aspects which call for a revision. The Committee may, if considered necessary update the existing or recommend a new methodology for the assessment of ground water resources in different hydrogeological situations and climatic zones.
3. To recommend norms for various parameters applicable to different geological formations and climatic and agricultural belts, etc, which should be precisely adopted for better assessment of the resources.
4. To recommend the smallest hydrogeological and / or administrative unit required to be adopted for assessment of ground water resources.
5. Any other aspects relevant to the terms referred to above.

The Committee will submit its report within 6 months from the issue of the Resolution.

Sd/-
(I.B. Karn)
Deputy Secretary to the Govt. of India

ANNEXURE 2

LIST OF PRINCIPAL CONTRIBUTORS FOR REVISION OF GROUND WATER ESTIMATION METHODOLOGY

1. Dr. A. Achuta Rao, Director (Retd), CGWB
2. Shri. R. C. Agarwal, Superintending Engineer, IP & DP Circle Lucknow
3. Shri. R. P. Agarwal, Director, MER, Bihar
4. Shri. R. M. Agashe, Director (Retd), CGWB
5. Shri. A.V.S.S. Anand, Assistant Hydrogeologist, CGWB
6. Shri. Arun Kumar, Additional Secretary (WR) and Chairman, CGWB
7. Dr. R. N. Athavale, Scientist “G”, NGRI, Hyderabad
8. Shri. R. G. Ayade, NABARD
9. Dr. P. Babu Rao, Director, Andhra Pradesh Ground Water Department
10. Shri. S. J. Bagde, Director, GSDA, Pune
11. Shri. J. K. Batish, Agricultural Department, Haryana
12. Bhabha Atomic Research Centre, Mumbai
13. Chief Engineer, SG & SWRGC, WRO, PWD, Tamil Nadu
14. Department of Mines and Geology, Karnataka
15. Shri. J. P. Dias, DGM (Retd), NABARD
16. Directorate of Ground water, Kerala
17. Dr. Gurucharan Singh, Jt. Director, Punjab State Department of Agriculture
18. Dr. C. P. Gupta, Scinetist “G”, NGRI, Hyderabad
19. Dr. K. S. Hari Prasad, Indian Institute of Science, Bangalore
20. Shri. M. A. Haseeb, Director, CGWB, Raipur
21. Institute of Water Studies, Chennai
22. Shri. V. Jagannathan, Scientist “D”, CGWB, Bangalore
23. Shri. M. C. Jindal, Scinetist “D”, CGWB, Chandigarh

24. Dr. John Kurien, NABARD
25. Shri. L. K. Joshi, Jt. Secretary (A), MOWR
26. Shri. K. R. Karanth, Director (Retd), CGWB
27. Prof. D. Kashyap, University of Roorkee, Roorkee
28. Dr. M. K. Khanna, Superintending Geohydrologist, Madhya Pradesh
29. Shri. N. Kittu, Member (SAM), CGWB
30. Shri. V. V. S. Mani, Director (Retd), CGWB
31. Shri. V. D. Mathur, NABARD
32. Shri. M. Mehta, Director, CGWB, Nagpur
33. Dr. G. C. Mishra, National Institute of Hydrology, Roorkee
34. Prof. M. S. Mohan Kumar, Indian Institute of Science, Bangalore
35. Shri. B. Moulick, Director, State Water Investigation Directorate, Calcutta
36. Shri. D.S.S. Murthy, Scientist “D”, CGWB
37. Shri. Nabi Hasan, Ground Water Directorate, Uttar Pradesh
38. Shri. R. K. Nagpal, NABARD
39. Dr. N. B. Narasimha Prasad, CWRDM, Kozhikode
40. Orissa Lift Irrigation Corporation Ltd.
41. Dr.Y.J.Pardhasaradhi, Regional Director, CGWB(SWR), Bangalore
42. Dr. B. D. Pathak, Chairman (Retd), CGWB
43. Shri. Paul Prabhakar, Scientist “C”, CGWB
44. Shri. V. S. Prakash, Scientist “D”, CGWB
45. Dr. R. K. Prasad, Ex-Chairman, CGWB
46. Dr. Prem Shankar, Ground Water Department, Bihar
47. Dr. S. P. Rajagopalan, Centre for Water Resources Development and Management, Kerala
48. Shri. K. C. B. Raju, Director (Retd), CGWB
49. Prof. Rama Prasad, Indian Institute of Science, Bangalore
50. Dr. V. Ramesam, DST
51. Dr. S. S. Rao, NABARD

52. Dr. P. R. Reddy, NRSA, Hyderabad
53. Regional Director, CGWB (SR), Hyderabad
54. Regional Director, CGWB, Kerala
55. Regional Director, CGWB (CR), Nagpur
56. Regional Director, CGWB (SECR), Chennai
57. Dr. Saleem Romani, Regional Director, CGWB, Bhopal
58. Shri. Santosh Kumar Sharma, Regional Director and Member Secretary
59. Shri. M. M. Sarbhukan, Director (Retd), GSDA, Maharashtra
60. Dr. M. Sekhar, Indian Institute of Science, Bangalore
61. Shri. D. C. Sharma, Chief Hydrogeologist, Ground Water Department, Rajasthan
62. Shri. S. C. Sharma, Director, GWRDC, Gujarat
63. Shri. V. M. Sikka, Scientist “D”, CGWB
64. Dr.K. Satyamurthy, DC(S), CGWB
65. Shri. Sondhi, PAU, Ludhiana
66. Prof. K. Sridharan, Indian Institute of Science, Bangalore
67. Dr. A. Srisailanath, Regional Director, CGWB
68. Shri. Suraj Kumar Sharma, Member(SAM), CGWB
69. Dr.S.P. Sinha Ray, Member(SML), CGWB
70. Shri. N. R. Tankhiwale, NABARD
71. Tubewell Organisation of Irrigation Department, Uttar Pradesh
72. Shri. Varadarajan, Scientist “D”, CGWB, Chennai

ANNEXURE 3

CASE STUDIES OF GROUND WATER ASSESSMENT

1. SIDA assisted ground water project, Coimbatore

Source of information : Central Ground Water Board
Report date : 1980
Location : Entire drainage basins of Noyil river, Vattamelai river, upper reaches of Ponnani river in the districts of Coimbatore & Trichy in Tamil Nadu and Palghat & Trichur in Kerala.
Area : 8150 sq km
Soil/ rock type : hornblende-biotite gneiss; garnet-sillimanite gneiss; charno-ckite; granite
Methodology : Water balance approach
Results :

(a)Specific yield : not indicated
(b)Rainfall recharge factor value : 5.7% in Kerala part of Ponnani basin
23.2% in eastern parts of Noyil basin
(c)7% of canal input in Lower Bhavani scheme observed as return flow in Noyil river.

2. Canadian assisted ground water project, Hyderabad

Source of information : Central Ground Water Board
Location : Parts of Medak, Hyderabad & Mehboob Nagar districts in AP and small parts of Bidar & Gulburga districts in Karnataka
Area : 11,620 sq km
Soil/ rock type : red soil, black cotton soil, red lateritic soil, sedantry black cotton soil, granite,basalt
Methodology : Specific yield from long duration pumping tests at 8 sites. Recharge from water balance using specific yield values from pumping tests
Results :

(a) Specific yield values

Vuggy laterite	: 0.02
Lateritic clays	: 0.01
Weathered basalt	: 0.01
Bhima series-limestone	: 0.005
Weathered granite	: 0.04
Weathered granite & alluvium	: 0.01-0.025

(b) Rainfall recharge factor value : 8.3% (under max. developement)

3. Sina-Man ground water project

Source of information : Central Ground Water Board

Report date : 1982

Location : South Maharashtra

Area :

Sina Basin	: 11,970 sq km
Man Basin	: 4,710 sq km
Soil/rock type	: Basaltic rocks

Methodology : Specific yield estimates based on pumping tests; recharge estimates based on water level fluctuations.

Results :

(a) Specific yield estimates

Sina Basin	: 0.026
Man Basin	: 0.022
High grounds	: 0.013
Valley slopes	: 0.024
Flood plains	: 0.039

(b) Rainfall recharge factor

Sina Basin	: 23.7%
Man Basin	: 18.5%

(c) Recharge from percolation tanks : 50% of the storage

(d) Rechage from irrigation tanks : 9-21% of live capacity

(e) Return flow from well irrigation : Nil

(f) Return flow from canal irrigation : 15% of application

(g) Canal seepage : 8-31% of the discharge released at the head

4. Indo-British ground water project for Upper Betwa River basin

Source of information : Central Ground Water Board

Report date : 1984

Location : Upper catchment of Betwa River basin, in MP & UP (major part in MP)

Area : 20,600 sq km

Soil/ rock type : Hard rock-Deccan Traps, Vindhyans, Bundelkhand granites

Methodology : Specific yield estimates based on a) pumping test b) soil moisture measurement c) water balance in dry season; recharge estimates by water balance using above specific yield values.

Results :

(a) Specific yield estimates

Pumping tests : 0.005

Soil moisture measurements : 0.011

Water balance method : 0.01

(b) Rainfall recharge factor

Neon sub-basin : 4-9.5%

Bina sub-basin : 3.9%

Bah sub-basin : 3.7-5.3%

Entire project area : 3.7-5.6%

5. UNDP project on ground water studies in the Ghaggar River Basin in Punjab, Haryana, Rajasthan

Source of information : Central Ground Water Board

Report date : 1985

Location : Parts of Haryana, Punjab, Rajasthan, Himachal Pradesh, and Chandigarh

Area : 42,200 sq km

Soil/rock type : Thick sand layers, with a mixture of loam in the soil

Methodology : Specific yield estimates based on pump tests; recharge estimates based on water level fluctuation method, analysis of hydrometeorological data, and soil moisture budget technique; seepage from canals based on inflow-outflow method, radiotracer method, and empirical formula.

Results :

(a) Specific yield estimates

South eastern parts : 0.05

Most of Kandi area : 0.20

(b) Rainfall recharge factor (water level fluctuation method)

Area in Haryana : 6.2-19.2% (Ave. 13.7%)

Area in Punjab : 1.1-35.5% (Ave. 18.2%)

Area in Rajasthan : 5.3%

(c) Seepage from canals (Inflow-outflow method)

Major canals : 3.4-6.4 cumecs per million sq m of wetted area

Minor canals : 1.2-3.2 cumecs per million sq m of wetted area

6. SIDA assisted coastal Kerala ground water project

Source of information : Central Ground Water Board

Report date : 1992

Location : Quilon, Alleppey, Ernakulam, Kottayam, Pathanamthitta, and parts of Mallapuram, Palghat, Trichur, Idukki, Trivandrum districts

Area : 23,300 sq km

Soil/ rock type : lateritic soil coastal alluvium, reverine alluvium, forest loam crystalline rocks-charnockites,biotite gneiss, granite

Methodology : specific yield estimated from water balance in non-rainy period for 3 years for small water sheds; recharge estimated from water balance in monsoon period ,using specific yield values estimated for the water sheds; alternate methods also used for recharge for verification

Results :

Name of basin	Average rainfall recharge(%)
Vamanapuram	5.4
Ithikkara	4.6
Kallada	3.9
Pamba	3.8
Meenachil	4.5
Periyar	2.2
Chalakudi	6.3
Kole lands	7.3
Ponnani	7.7

There is no effective recharge from the non-monsoon rainfall.

Results of detailed studies in Pamba river basin

Area = 4337 sq km

(a) $R_c = m (x-x_0)$

where R_c = recharge in mm, x = rainfall in mm, x_0 = threshold rainfall in mm, m= constant.

Except for a small area, x_0 varies from 235 to 467 mm & m varies from 0.32 to 0.82.

Average rainfall recharge factor = 5%

(b) Surface water irrigated area:

Area = 20,000 ha

Recharge from rainfall = 115 mm

Recharge from surface water irrigation = 669 mm (40% of total water let out)

Results of detailed studies in Kole Lands basin

Area = 1690 sq km

(a) Average rainfall recharge factor = 7%

(b) Seepage from canals & return flow from paddy fields = 48% of water let out

7. Vedavati River Basin Project

Source of information : Indian Institute of Science and Central Ground Water Board

Report date : 1980

Location : Karnataka and Andhra Pradesh

Area : 24, 200 sq km

Soil/rock type : Granite;gneiss;schist

Methodology : Computer model (finite difference), with simultaneous estimation of specific yield and recharge factor by model calibration.

Results :

(a) Specific yield value : 0.01-0.04

(b) Rainfall recharge factor value : 3-15%(average 6.3%)

8. Narmadasagar and Omkareshwar Composite Command

Source of information : Indian Institute of Science and Narmada Planning Agency, MP

Report date : 1985

Location : Khargone, Khandwa and Dhar Districts, MP

Area : 385,000 ha

Soil/rock type : Deccan trap basalts and Vindhyans

Methodology : Computer model (finite difference), with simultaneous estimation of specific yield and recharge factor by model calibration

Results :

(a) Specific yield value : 0.007-0.06 (average 0.018)

(b) Rainfall recharge factor value : 3-34% (average 9.4%)

9. Tank Command

Source of information : Indian Institute of Science and Narmada Planning Agency, MP

Report date : 1985

Location : Satak Tank in Khargone District, MP

Area : 5049 ha

Soil/rock type : Basalt and alluvium

Methodology : a) integral water balance b) computer model (finite difference) with simultaneous estimation of specific yield and recharge factor by model calibration

Results :

(a) Specific yield value : 0.022

(b) Rainfall recharge factor value : 15%

(c) Recharge factor for surface water application : 33% of water released at head

10. Tank command

Source of information : Indian Institute of Science and Narmada Planning Agency, MP

Report date : 1985

Location : Kunda Tank in Dhar District, MP

Area : 2510 ha

Soil/rock type : Basalt and alluvium

Methodlogy : a) integral water balance b) computer model (finite difference) with simultaneous estimation of specific yield and recharge factor by model calibration

Results :

(a) Specific yield value : 0.034

(b) Rainfall recharge factor value : 16%

(c) Recharge factor for surface water application : 35% of water released at head

11. Command of Bargi Diversion Project in Narmada Valley

Source of information : Indian Institute of Science and Narmada Valley Development Authority, MP

Report date : 1991

Location : Jabalpur District, MP

Area : 93,750ha

Soil/rock type : Deccan trap rock

Methodology : Computer model (finite difference), with simultaneous estimation of specific yield and recharge factor by model calibration

Results :

(a) Specific yield value : 0.008-0.035 (average 0.024)

(b) Rainfall recharge factor value : 1.7-7.5% (average 6.1%)

12. Command of Bargi Diversion Project in Sone Valley

Source of information : Indian Institute of Science and Narmada Valley Development Authority, MP

Report date : 1991

Location : Jabalpur, Satna and Rewa Districts, MP

Area : 273,900 ha

Soil/rock type : Vindhyan system comprising of stratified formations of sandstones, shales and limestones

Methodology : Computer model (finite difference), with simultaneous estimation of specific yield and recharge factor by model calibration

Results :

(a) Specific yield value : 0.009-0.038 (average 0.021)

(b) Rainfall recharge factor value : 2.2-7.0% (average 5.3%)

13. Chitradurga District

Source of information : Indian Institute of Science and National Drinking Water Mission

Report date : 1992

Location : Chitradurga District, Karnataka

Area : 11, 000 sq km

Soil/rock type : Granite; gneiss

Methodology : Computer model (finite difference), with simultaneous estimation of specific yield and recharge factor by model calibration

Results :

(a) Specific yield value : 0.005-0.035 (average 0.011)

(b) Rainfall recharge factor value : 1.5-20% (average 4.3%)

14. Field Irrigation Plot

Source of information : Indian Institute of Science
Report date : 1993
Location : Near Bangalore
Area : 0.3 ha
Soil type : red loam
Methodology : a) soil moisture measurements b) unsaturated flow modelling (finite element)
Results :

Combined recharge factor for rainfall and ground water irrigation : 12-16%

15. Recharge Measurements using Tritium Injection Technique

Source of information : National Geophysical Research Institute

Results

Studies have been made by National Geophysical Research Institute at a number of sites all over the country in different agroclimatic and hydrogeological regions and a summary of these results are presented below.

Sl No.	Basin/ watershed (area in sq. kms)	Mainrock Types	Rainfall (mm)	Mean (mm)	Recharge (%)
1	Punjab (50,360)	Alluvium	460	56	12.2
2	Haryana (44,210)	Alluvium	470	70	14.9
3	Western U.P. (3,970)	Alluvium	990	198	20.0
4	Sabarmati (8,200)	Alluvium	995	127	12.8
5	Jam (400)	Basalt	1050	131	12.5
6a	Shahdol Dt. (225)	Sandstone	929	103	11.1
6b	Shahdol Dt. (100)	Granite Gneiss	805	98	12.2

Sl No.	Basin/ watershed (area in sq. kms)	Mainrock Types	Rainfall (mm)	Mean (mm)	Recharge (%)
6c	Shahdol Dt. (100)	Basalt	965	71	7.3
7	Kukadi (1150)	Basalt	612	46	7.5
8	Godavari-Purna (1090)	Basalt	652	56	8.6
9	Aurepalle (64)	Granite	750	109	14.5
10	Lower Manner (1600)	S.St,Shale	1250	117	9.3
11	Mannila (40)	Granite Gneiss	390	24	6.1
12	Vedavati (Lower) Hagari(3680)	Granite Gneiss	565	6	1.1
13	Marvanka (2400)	Granite Gneiss Schist	550	42	7.6
14	Chitravati (6,100)	Granite Gneiss Schist	615	25	4.1
15	Kunderu (8,650)	St.St.Shale L.St,Quartzite	615	29	4.7
16	Vedavati (W.Suvarnamukhi) (1960)	Granites Gneiss Schist	565	39	6.9
17	Neyveli (790)	Sandstone	1398	191	13.6
18	Neyveli (500)	Alluvium	1004	161	16.0

19	Noyil (3420)	Granites Gneiss Schist	715	69	9.6
20	Ponnani (3,970)	Granites Gneiss Schist	1320	61	4.6
21	Vattamalaikarai (510)	Granites Gneiss Schist	460	61	13.2
22a	Upper Hatni Watershed(45)	Granites Phyllites	935	97	10.3
22b	Upper Hatni Watershed(37)	Sandstone	935	113	12.1
22c	Upper Hatni Watershed(13)	Basalt	935	55	5.9

16.Observations on Return Seepage Losses

(a) Return seepage losses for puddled rice fields on sandy loam soil

Source of Information : Punjab Agricultural University

Location : PAU Farm

Type of Irrigation	Study Period	Average Return Seepage (% of total water applied)
1. Continuous Submersible	1974-77	78.2
2. 1 day drainage	1974-77	72.8
3. 2 day drainage	1975-77	72.2
4. 3 day drainage	1975-77	66.6
5. 5 day drainage	1975-77	62.0

Above seepage losses are at one metre below soil surface. Depth to water level is 8 m below ground level. No accurate estimate is available as to the percentage of above infiltration which reaches ground water reservoir.

(b)Studies by U.P. Irrigation Research Institute, Roorkee

Method applied - Tritium Tagging Method

Area - Eastern Yamuna Canal Command Area (Saharanpur, Muzzafarnagar Meerut and Ghaziabad, Western U.P.)

Hydrogeological - Unconsolidated alluvial formation

(i) Recharge due to Rainfall by Tritium Tagging method

Area	% of rainfall recharge
1. Gandak Command	21.4
2. Ganga Sarda Area	24.1
3. Agra Mathura Area	22.5
4. Roorkee Area	18.5
5. Deoband Branch Command Area	18.2
6. Eastern Yamuna Canal Command Area	21.0
7. Sarda Sahayak Command Area	20.8
8. Saryu Canal Command Area	21.2

(ii) Recharge due to applied Irrigation

Sl No	Name of Test Area	Crop	Recharge due to applied irrigation (%)
1	Dhanauri State Agricultural farm	Paddy	51.7
	Dist. Hardwar	Wheat	23 to 25
2	Bawari State Agricultural farm	Paddy	56.6
	Dist. Muzaffarnagar	Wheat	23 to 24
3	Meerut Regional and	Paddy	59.7
	Demonstration Agricultural	Wheat	27.8 to 34
	Centre Meerut		
4	Devla private farm Dist.	Paddy	62.0
	Saharanpur	Wheat	27 to 34
		Sugarcane	36.0
5	Biradsi private farm Dist.	Paddy	61.0
	Muzaffarnagar	Wheat	26 to 33
6	Imdikhera private farm Dist.	Sugarcane	34 to 40

	Hardwar		
7	Deoband Canal Command Area	Paddy	51 to 59
		Wheat	24 to 34
8	Eastern Yamuna Canal	Paddy	52 to 60
	Command Area	Wheat	25 to 33
9	Sarda Sahayak Command Area	Paddy	50 to 60
		Wheat	23 to 34
		Sugarcane	34 to 38
		Pasture land	22 to 26
10	Saryu Canal Command Area	Paddy	52 to 58
		Wheat	25 to 32

Average values of recharge

Wheat Crop	23 to 34% of applied irrigation
Paddy Crop	52 to 64% of applied irrigation
Sugarcane	34 to 38% of applied irrigation
Pasture Land	22 to 26% of applied irrigation

(c) Irrigation and Power Research Institute, Amritsar

Area - Upper Basin Doab Command Tract Punjab

Method used - Double ring cylindrical infiltrometer

Basal Infiltration - 0.65cm/hr to 3.51cm/hr
(sandy loam soil)

(d) School of Hydrology, Roorkee University

Method - Finite difference model for ponded condition and compute ponded depth

Results - Return flow from applied irrigation

Crop	% of return flow
Rice (loamy sand)	60
Wheat	40

17. Summary of Information provided by the Ground Water Department, Rajasthan

The following table gives the recharge as percentage of rainfall for different districts. In the water balance approach, specific yield values are assumed based on the terrain.

District	Block	Rock type	Specific Yield (%)	Recharge due to monsoon rainfall (%)
Alwar	Bansur	Older alluvium	15	13
Dholpur	Bari	Older alluvium	12	21
Dholpur	Bari	Sandstone	3	12
Jhalawar	Pirawa	Basalt	2	9.5
Jhalawar	Kanpur	Sandstone	2.5	13
Bundi	K. Patan	Shale	1.25	7.5
Ajmer	Kekri	Gneiss	1.5	9

Bhilwara	Kotri	Gneiss	1.5	11
Udaipur	Jhadol	Phyllite/ Schist	2	10
Jodhpur	Bhopalgarh	Sandstone	4	11
Jodhpur	Bilara	Limestone	7	12
Churu	Sardar Shahar	Younger alluvium	8	8
Churu	Sri Dungar garh	Tertiary sandstone	6	8
Jaisalmer	Sam	Parewar sand stone	2.5	1.5
Jaisalmer	Sam	Younger alluvium	8	3

18.Information Provided by the Directorate of Ground water Surveys and Development Agency, Maharashtra

Percolation Tank

Case study at Village : Adgaon, Taluka : Aurangabad,
District : Aurangabad

	1989-90	1990-91
	tcm	tcm
Gross storage	50	50
Evaporation losses	15 (30%)	15.77 (31.5%)
Recharge to ground water	35 (70%)	34.23 (68.5%)

Case study at Village : Pendgaon, Taluka : Beed,
District : Beed

	1984	1986
	mcft	mcft
Gross storage	6.57	6.57
Evaporation losses	0.914 (14.6%)	0.75 (11.4%)
Recharge to ground water	4.200 (63.9%)	5.54 (84.3%)
Seepage losses	1.456 (21.6%)	0.28 (4.3%)

Nala Bunds

Nala bunds are constructed across nalas, at proper sites. Normally the capacity of each nala bund is 0.36 mcft. These structures are useful for recharge to ground water locally.

Present Norms:

Presently recharge to ground water from Nala Bund is not taken into account. However, these structures are being practised in large number under 'Jalsandharan Programme, as such these structures are recommended for recharge factors.

Case Study at Village : Adgaon, Taluka : Aurangabad,
District : Aurangabad

	1989-90 tcm	1990-91 tcm
Gross storage	360 (19 bunds)	52.8 (15 bunds)
Evaporation losses	120 (33%)	22.2 (42%)
Recharge to ground water	240 (67%)	30.6 (58%)

Case Study at Ralegaon Sindhi, Taluka : Parner,
District : Ahmednagar

	1989-90 tcm	1990-91 tcm
Gross storage	313.40 (32 bunds)	307.86 (32 bunds)
Evaporation losses	38.70 (12.4%)	28.33 (9.2%)
Recharge to ground water	274.40 (87.6%)	279.60 (90.8%)

19. Ground water assessment in Karnataka

Source of information : Central Ground Water Board

Methodology : Water level fluctuation method, based on assumed specific yield value

Summary of results

Terrain	Assumed value of specific	Rainfall recharge factor

	yield	%
Granite	0.03	13
Gneiss	0.03	16
Basalt	0.02-0.03	12
Schist	0.03	13
Limestone	0.02-0.03	11
Laterite	0.03	16

20. Recharge estimate from surface water irrigation system

Source of information : Central Ground Water Board

Canal System : Command areas of Kukas bunds and Morel bunds

Methodology : Based on monitoring of observation wells at regular intervals prior to release of water into the canal, during the canal irrigation, and after the closure of the canal.

Results

Recharge factor based on total input in the canal (conveyance and on-field recharge)

Kukas command area : 35%

Morel command area : 33%

21. Review study by National Institute of Hydrology

Summary of observations regarding rainfall recharge factor

(a) Alluvial area of Indo-Gangetic plain, based on Tritium tracer study : 17-22%

(b) Alluvial area of Gujarat State, based on Tritium tracer study : 3.3-13% (Average 7.1%)

(c) Hard rock area (Deccan trap) in Betwa basin, based on soil moisture balance study : 4.4%

(d) Granite region based on Tritium tracer study (2 sites) : 8.3 & 6.1%

(e) Gondwana sandstone region, based on Tritium tracer study (2 sites) : 15.5 & 5.4%

(f) Hard rock area in Maner basin in Andhra Pradesh,
based on Tritium tracer study : 7.6%

(g) UNDP study in Rajasthan

Quaternary aeolian sand	: 8.0%
Palana	: 3.0%
Nagaur sandstone	: 1.7%
Nagaur limestone	: 2.0%
Basement crystalline	: 1.5%

Summary of observations regarding seepage loss from canals

(a) Ganga canal near Roorkee, with silty clay bank and waterlogged condition in the vicinity, using radio isotopes : 0.35 cumecs per million sq m of wetted area.

(b) Salawa distributary of upper Ganga canal in Meerut districts, using ponding method : 1.69 cumecs per million sq m in head reach
0.97 cumecs per million sq m in head reach

(c) Sarda Sahayak Feeder canal, using analytical method : 5.66 cumecs per million sq m of wetted area

(d) Lower Bhavani canal (estimate) :16-20% of canal discharge

(e) Canals in Vedavati basin (estimate) : 9-10% of canal discharge

Recharge from percolation tanks

Study of 12 percolation tanks in Ahmednagar :36.0-76.7% of storage in the tanks (Average 50.9%)

Return flow from irrigation

(a) Experimental and analytic study reported in literature : 32%

(b) Paddy field in Parkal experimental basis in Andhra Pradesh : 16-82%

22. INFORMATION PROVIDED BY CENTRAL GROUND WATER BOARD, CENTRAL REGION, NAGPUR ON PERCOLATION TANKS

Sr. No	Village / Name of PT	Storage Capacity (TCM)	Actual Storage (TCM)	Evaporation Losses (TCM)	Visible Seepage (TCM)	Recharge to G.W. (TCM)	Efficiency of PT		Area Benefitted (ha)	Geology
							% of 3	% of 4		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
DISTRICT & TALUKA : AHMAD NAGAR, JEUR SUB-BASIN, YEAR 1990-91										
1	Dhangar	85	168	18	66	84	99	50	60	Fractured Massive Basalt
2	Khandoba	110	153	26	34	93	85	62	29	Vesicular Basalt
3	Kharkhel	80	114	5	67	42	53	37	47	-do-
4	Mahadev	110	183	12	88	83	75	46	33	-do-
5	Talpati	90	149	25	56	68	76	46	50	-do-
6	Mangdhara	37	68	9	29	30	81	45	50	-do-
7	Todmalvasti	16	32	2	18	12	75	38	16	-do-
8	Jeur Village tank	9	29	3	18	8	89	28	8	-do-
9	Sond	70	91	9	39	43	61	47	38	-do-
10	Hagzari	160	210	33	56	121	63	57	34	-do-
11	Deodhara	12	26	4	10	12	100	51	10	Fractured Basalt
12	Waghvasti	50	77	10	30	37	74	47	10	-do-

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
DISTRICT : JALAGAON, TALUKA - YAWAL, WATERSHED : TE 17, YEAR - 1994-95										
1	Nagjhira	350	179	6	Nil	173	50	97	150	P.T. are over size
2	Baghjhira	45	20	1	Nil	19	42	96	20	-do-
DISTRICT: AMRAVATI, TALUKA: WARUD, WATERSHED : WR-2, YEAR 1994-95										
1	Pimpalkhuta	221	482	92	93	297	134	62	150	Fractured Basalt
2	Mangona	173	574	79	148	347	201	60	150	Weathered Basalt
CEMENT PLUGS :										
1	Tembhurkheda, Gawhankund Road	0.295	0.816	0.249	-	0.567	192	69	5	Weathered Basalt
2	Tembhurkheda, Bhimdi Road	0.165	0.504	0.166	-	0.338	205	67	5	-do-