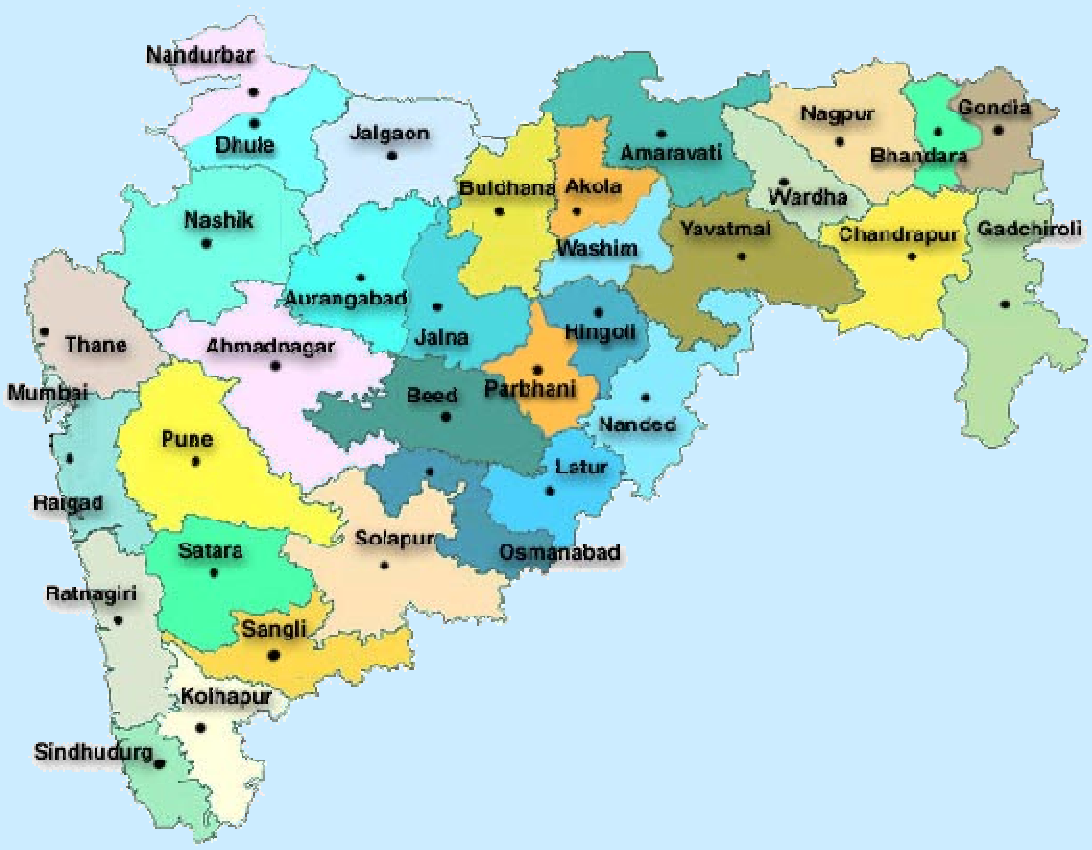
REPORT ON

DYNAMIC GROUNDWATER RESOURCES OF MAHARASHTRA

AS ON MARCH, 2004



Groundwater Surveys And Development Agency,
Water Supply and Sanitation Department,

Government of Maharashtra

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REPORT ON

DYNAMIC GROUNDWATER RESOURCES OF MAHARASHTRA

AS ON MARCH, 2004

Prepared by -

Groundwater Surveys and Development Agency, GoM

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Central Ground Water Board, Central Region, Nagpur

FINAL REPORT

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FOREWORD

Maharashtra is one of the most well endowed states in the country in respect of rainfall, but it may soon become a state where large parts of it face perennial water shortage, if urgent institutional, policy and technological initiatives are not taken to address both the quantity and the quality issues of groundwater. There are 40,785 villages and 45,528 hamlets in the state with the total population of 96.7 million of which 41.13 million is urban and 55.57 million is rural. Almost 82% of the total rural population is relying on agriculture. Out of the total area under irrigation in Maharashtra, 28.75 lakh hectares (71%) are irrigated by groundwater and 11.83 lakh hectares (29%) are served by flow / canal irrigation. Out of the total ground water consumed, 85% is for irrigation, 10% is for industries and only 5% is for domestic consumption. Drinking water needs of 90% of the total rural population are entirely met from groundwater.

Groundwater is a natural resource with both ecological and economic value and is of vital importance for sustaining life, health and integrity of ecosystems. This resource is however, increasingly threatened by over-abstraction which has insidious long-term effects. Scarcity and misuse of groundwater pose a serious and growing threat to sustainable development and livelihood.

The availability of groundwater is extremely uneven, both spatially and temporally and so will be the case in future. The uneven distribution of groundwater can be mainly attributed to highly heterogeneous lithology and due to uneven distribution of rainfall.

While first major but adhoc attempt of estimating groundwater resource estimation was made during 1973 but the first scientific groundwater resource assessment of Maharashtra was made during 1979 on the basis of Overexploitation Committee Report. Since then various committees constituted by Government of India and Government of Maharashtra have made attempts from time to time to estimate the groundwater resources. After due consideration of the limitations in the earlier methodologies, the Groundwater Estimation Committee (GoI), during 1997, proposed the revised methodology known as GEC 97.

Based on these GEC 97 guidelines, GSDA has completed the exercise of Groundwater Resource Estimation of Maharashtra as on March, 2004. As per this, the total rechargeable groundwater resource in the State is computed as 32,96,109 Hectare Meter (Ham) or (32.96 BCM) and the Net ground water availability is 31,21,404 Hectare Meter (Ham) or (31.21 BCM). Out of these, 1,50,883 Ham or 1.51 BCM is earmarked for domestic and industrial requirement and the remaining is available for future irrigation. Between 1988 and 2004, the groundwater use has increased by 4.03Ham (i.e. from 11.05 to 15.09 BCM).

A note of caution is required to be put on record, here, regarding the happy position that may emerge from the statement in the preceding paragraph i.e. while after subtracting the present groundwater draft of 15.09 BCM it looks that there is still a balance of 15.13 BCM. The present irrigation draft is to the tune of 14.24 BCM, leaving behind a fairly good groundwater balance. Unfortunately major part of these balances exists in the areas where development is not required for either irrigation or for drinking and/or is in areas, which are not favorable for development. It is observed that even the draft figure is not accurate (much less than actual) because except for Latur and Osmanabad, the draft from irrigation borewells/tubewells has not been accounted for. It is a well-known fact that large number of irrigation borewells/tubewells are the main source of irrigation in all the parts of the State and large number of them are not even on record for electricity connections. If draft from those borewells/tubewells had been accounted for then the balance position would have certainly emerged as alarming and it is a ground reality.

Groundwater resource estimation is mainly dependent on the quality of the basic data. Many a times because of the lack of accurate data the resource assessment misleads the Planners, Administrators and Technocrats in formulating various development activities. If the agricultural borewell/ tubewell data was made available to GSDA the groundwater utilization status of Maharashtra would have changed drastically, some of the semicritical units would have been converted to critical or even over-exploited. The non-availability of the data is the main constraint in resource assessment.

On the basis of the present resource assessment, out of the total 1505 watershed, 76 watersheds are categorised as overexploited i.e. the groundwater development is more than 100% of the recharge and the water table during either Post or Pre monsoon interval or both shows declining trend. 20 watersheds are categorised as critical where groundwater development is more than 90% of the recharge and where water table, either Post or Pre monsoon interval or both, shows significant declining trend and 163 watersheds are categorised as semi-critical where groundwater development is between 70 and 90% of the recharge and where water table, either Pre or Post monsoon interval, shows declining trend.

Out of the total tashils 7 tashils are categorized as Over Exploited, one tashil is categorized as Critical and 23 tashils are categorized as Semi-Critical. Out of 23 tashils, in 11 tashils the exploitation is more than 95% i.e. they are in the verge of transformation into the Over Exploited category. It may be mentioned here that the areas which have emerged as overexploited, critical or semi-critical are the areas in which we have the lowest rainfall, highest percentage of water guzzling commercial crops and showing alarming as well as progressive deterioration of the ground water and soil quality.

Groundwater is one amongst the State's most important natural resources. It provides drinking water to urban and rural community, supports irrigation and industry, sustains the flow of streams and rivers and maintains wetland ecosystem. There is a significant freshwater deficit in many areas of the State. Human health, welfare, food security are at risk unless the groundwater resources are managed more effectively and efficiently. It is necessary to note that over abstraction of ground water over years without any compensatory replenishment is affecting large tracts of land adversely. The non-replenishment of the shallow aquifers and depletion of the deeper aquifers on account of unregulated sinking of deep borewells/tubewells, almost amounting to "water-mining" unmindful of the adverse ecological effects is one of the contributory causes for recurring droughts. Concerted action, therefore, is needed to reverse the present trend of periodic occurrence of droughts.

Effective management of groundwater depends on a holistic approach, it also links the land and water use across the catchment area of groundwater aquifer. The development and management should be based on a participatory approach, involving users, planners and policy makers at all levels. It is necessary to formulate and adopt a long-term policy to protect groundwater by preventing pollution and overuse. This policy should be comprehensive and implemented at all appropriate levels. It should be consistent with other water management policies and be duly taken into account in other sectoral policies.

It will be instructive to understand the international experience especially of California, Brazil, Texas, South Africa and Israel if we have to ensure availability of water for sustained development. We may have to forge basin/ sub-basin water partnerships at least to avoid the unpleasant break out of conflicts between upstream and the down stream dwellers. Concepts like Village Water Accounting/ Balance, District Water Accounting, Basin/ Sub-basin Water accounting, Region and State Water Accounting will have to be popularized and made a basis for equitable distribution of water.

An appropriate policy is required to be adopted for preferential allocation of groundwater (actually, water in general), giving appropriate weight to competing users and balancing short-term demands with long-term objectives. Legal provisions specific to peculiarities of groundwater management will have to be formulated and promulgated. Legislation may contain provisions for its effective implementation including the mandate, competence and power of the relevant authorities in accordance with the principles of State Water Policy. It is high time that Government's right to control groundwater abstraction and use as well as all activities with potential impact, both on the quantity and quality of groundwater resources may be established by legislation.

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PREFACE

Ground Water is a replensihable resource and is readily available resource for the mitigation of distress caused by the various natural disasters like droughts, floods, earthquakes, tsunami, cyclone, etc. In the State of Maharashtra, ground water is an important source of irrigation and caters 71% of the total irrigation. Even though, ground water is a replenishable resource, but not replenishing evenly, because of the heterogeneous composition of the rock formation and its availability is not uniform throughout the State. Hence, it is very much essential to quantify the ground water resources precisely for its proper management and judicious use.

Even though, the assessment of ground water resources was attempted in the year 1949, the first effort to estimate the ground water resources on scientific basis was made in 1979 through a committee known as the "Ground Water Over Exploitation Committee" constituted by the Government of India under Ministry of Agriculture. Based on the recommendations of the above committee the Central Ground Water Board was assigned the job of estimating the ground water resources of the country under the precise context of National Water Policy, which recommends subsequent estimation of ground water resources.

Subsequently, the Ministry of Water Resources, Government of India had constituted another committee under the Chairmanship of Chairman, Central Ground Water Board which is known as "GROUND WATER ESTIMATION COMMITTEE -1984 (GEC 84)" and this methodology till recently formed the basis of ground water assessment in the country. Based on this methodology, the total replenishable ground water resources in the State of Maharashtra was estimated as 3.33998 m.ham/year, the gross ground water draft estimated on prorates basis during 1988 was 0.94257 m.ham/year and the balance ground water resource was 1.58674 m.ham/year and the Stage of ground water development was 29.37 %.

While using the machinery of GEC 1984 methodology, several improvements were felt. In order to improve the GEC-84 methodology, several workshops and seminars were conducted. Apart from the above, a Steering Committee was formed and the Committee has recommended revision of Ground Water Estimation Methodology and the "GROUND WATER ESTIMATION COMMITTEE – 1997 (GEC-97)" was constituted and recommended re-estimation of ground water resources using the Revised GEC-1997 Methodology.

Now the GEC-97 brought out the policy framework, which forms the basis for the methodology to be followed by all the States and Union Territories in India for ground water resource estimation. The State Government which was having good network of monitoring and the ground water development in their States have been assigned to determine the ground water recharge, draft etc. As per the advise of Government of India, a committee was formed in the State of Maharashtra, where the Chairman will be the Principal Secretary to Government of Maharashtra and the Member Secretary will be the Regional Director, Central Ground Water Board, Nagpur. The Committee in its meeting assigned the quantification work to the State Ground Water Department and the CGWB was assigned to determine the specific yield etc.

Based on GEC-97, the Groundwater Surveys and Development Agency, Government of Maharashtra in collaboration with the Central Ground Water Board has completed its first exercise and prepared a report on "Estimation of Ground Water Estimation in Maharashtra". This report was *reviewed by the State High-Level Technical Committee under the Chairmanship of the Principal Secretary, Water Supply and Sanitation Department, Government of Maharashtra and was accepted after critical discussion.*

On a later stage, the Ministry of Water Resources, Government of India has constituted 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 assessment based on GEC-97 methodology. The R&D Advisory Committee was headed by the Chairman, Central Ground Water Board and members from various State Departments constitutes the Committee. The resources estimated by each State has to submit their report to the Advisory Committee for its approval. The report of Maharashtra State was submitted to the Advisory Committee and the committee has approved the report. The total annual dynamic groundwater resources of Maharashtra as on March 2004 is 3.296 m.ham and the net ground water availability is 3.121 m.ham. The total annual gross ground water draft is 1.508 m. ham, the net annual ground water availability for future irrigation development is 1.509 m.ham and the Stage of ground water development is 48.33 %. In the earlier assessment (GEC-84) the number of dark, grey and white watersheds were 34, 80 and 1389 respectively. On the basis of present assessment (GEC-97), out of total 1505 watersheds in Maharashtra, 76 watersheds are categorized as over-exploited, 20 as Critical, 163 as Semi Critical and remaining 1242 as Safe watersheds.

The present report on "Dynamic Ground Water Resources of Maharashtra as on March 2004" is the culmination of efforts made by the CGWB and GSDA. The GSDA, which has been doing a pioneering work in assessing the ground water resources of Maharashtra on watershed basis, has contributed significantly in the preparation of this report. This report reflects the various suggestions and modifications made by the expert group of R&D Advisory.

(K. KEERTHISEELAN)

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Central Ground Water Board

Ministry of Water Resources, Govt. of India

Central Region, Nagpur

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GROUNDWATER RESOURCE ESTIMATION

IN THE STATE OF MAHARASHTRA

Chapter 1 Introduction

Groundwater resource assessment is the determination of the source, extent, dependability and quality of groundwater resources, on which the evaluation of the possibilities of the utilisation and control depends. Estimation of groundwater is also important for the construction and the maintenance of the States water supply infrastructure, especially those that are dependent on groundwater. This report provides an overview of the groundwater resources of Maharashtra for a vast range of activities like agricultural, domestic and industrial water supply. It will form the basis for understanding the existing and planning the future use of groundwater and to decide the management options on a holistic basis. This data also provides inputs that would be used to understand the dynamics of the various sector wise demands and ensure sustainability for different water sector activities.

The accurate groundwater resource assessment will help the policy makers in determining the extent, contours and nature of:

- Co-ordinating and integrating mechanisms, now, required in the field of water sector.
- New legislation and regulations, and
- Strategies and policies that deal with the priority of uses and conflict resolution mechanism (through mutually beneficial bargaining- basin/sub-basin water partnerships).

In short, groundwater resources assessment is a prerequisite for sustainable development of States natural resources.

The present availability and requirement of water is extremely uneven, both spatially and temporally and so will be case in the future. Rapid population growth and intensive anthropogenic activities have put both surface and groundwater under heavy stress, and significantly fresh water is becoming scarce and dearer in many areas. It is believed that in the coming decades most of the Earth's population will face a critical situation with regards to availability of water. The water deficiency will become a factor affecting the living standards of populations adversely. Surprisingly, it is observed that the potential water availability for the Earth's population is decreasing from 12.9 tcm to 7.6 tcm/year/person. To understand more about the water resource deficit that will face us in the future it is very important to analyse the present situation and understand rate of change in specific water resource availability in relation to socio-economic, geohydrologic and physiographic conditions.

In the State of Maharashtra, groundwater is an essential component for many water strategies and systems. It is therefore essential that the groundwater resource estimation is accurate so as to prepare strategies for the long-term management of this precious resource and for ensuring the long-term safety and well being of all the sections of the society.

Groundwater resource estimation is mainly dependent on the quality of the data. Many a times because of the lack of good quality data the resource assessment misleads the planners, administrators and technocrats in formulating various developmental activities. Even today, the situation is no better. Systematic information on groundwater withdrawal by various sectors through different groundwater structures is unavailable. Even with sincere efforts made by the GSDA, it was not possible to obtain the required data, especially the well census data. The State of Maharashtra is covered mostly by highly heterogeneous and structurally complicated rock formations, wherein it is very difficult to generalise any methodology or guidelines on hydrogeological aspects. In Deccan Trap there is no well-defined, uniformly distributed, homogeneous aquifer system. Even during the process of recharge the surface water in the given area does not uniformly replenish the subsurface. For assessing the groundwater resources on a regular basis it is necessary to determine certain hydrogeological factors, which define the groundwater regime. This includes precipitation, storativity of the bedrock, aquifer characteristics, water quality and the overall environment.

1.1 Background

Groundwater has emerged as an important source to meet the water requirements of various sectors. Demands for groundwater resources are ever increasing and competition amongst users has intensified. The sustainable development of groundwater requires precise quantitative assessment based on reasonably valid scientific principles. The occurrence, movement and storativity of groundwater are quite complex, being governed by several factors like geology, geomorphology, hydrogeology, meteorology and above all the human activities. All these factors make the precise assessment of groundwater very difficult and there is no direct technique available for precise assessment. Hence the methods applied for groundwater resource estimation are all indirect. There are several techniques and methodologies *in vogue* for estimation of groundwater resources. Quantification of groundwater resources is often critical and no single comprehensive technique is yet identified which is capable of estimating accurate groundwater assessment. Since groundwater is a replenihsable resource, its proper and economic development on a sustainable basis requires its realistic assessment. The estimation must be seen as an interactive procedure. Initial estimation are revised and refined by comparing these results with the results obtained by adopting alternative methods and third party studies.

1.2 Review of Groundwater Resources Assessment Methodologies

There are numerous methodologies for estimation of groundwater resources both by empirical method and by field studies. They are generally based on hydrological budget technique. The hydrologic budget equations based on the law of “conservation of matters”, as applies to the hydrologic cycle, defines the total water balance.

Attempts have been made from time to time by various working groups/ committees constituted by GoI and GoM to estimate the groundwater resources of the State based on the status of available data and in response to developmental needs. But due to the paucity of scientific data and incomplete understanding of the various parameters involved in recharge and discharge process all the earlier estimations were tentative and best approximations. The basic concept considered for hydrologic budget is the hydrological cycle.

The first approximate evaluation of groundwater in Maharashtra was done during 1973 on the basis of guidelines circulated by the Ministry of Agriculture, Government of India (GoI). The said guidelines recommended the norms for groundwater recharge from rainfall and from other sources. These norms were ad *hoc* basis and without any scientific base. During this exercise, for the sake of accurate estimation of groundwater resources the State was divided into 1505 elementary watersheds. Subsequently during 1979, the first attempt to estimate the groundwater resource on the basis of scientific database was made. A high-level groundwater over-exploitation committee was constituted by the A.R.D.C (Agricultural Refinancing Development Corporation). The committee was headed by the Chairman, C.G.W.B (Central Ground Water Board) and included member representatives from the State Groundwater Organizations and financial institutions. This committee was formed to define norms for groundwater resource computations.

In the year 1982, GoI constituted groundwater estimation committee (GEC) with its members drawn both from State groundwater organizations and from various other organizations engaged in hydrogeological studies and groundwater development. This committee after reviewing the data collected by various organizations recommended the methods for the estimation of groundwater resources known as GEC 1984.

1.3 Recommendations of GEC 1984

The committee recommended two approaches for groundwater resource assessment namely

- Water level fluctuations and specific yield methods
- Rainfall infiltration methods

The total replenishable groundwater resources are estimated by computing annual replenishable groundwater recharge plus potential recharge in shallow water level areas. The annual groundwater recharge includes the following components:

Annual groundwater recharge = Recharge during monsoon + non monsoon RF recharge + seepage from canals + return flow from irrigation + inflow from influent rivers, etc. + recharge from submerged lands

The annual recharge during monsoon is calculated based on water table fluctuation and specific yield method. Change in groundwater storage volume during pre and post monsoon period, which is in turn the product of specific yield, water level fluctuation and the geographical area, is the groundwater draft during monsoon. The other factors considered during the computation of recharge during the monsoon are:

- Recharge during canal seepage during monsoon
- Recharge from recycled water from groundwater irrigation
- Recharge from recycled water from monsoon
- Surface water irrigation during monsoon
- Rainfall normalization factor.

The total groundwater resources thus computed would be available for utilization for irrigation, domestic and industrial uses. Out of total groundwater resources 15% was kept for domestic and industrial use and the remaining 85% was kept for irrigation. On the discharge side only groundwater draft for irrigation purpose has been considered. Thus the total quantity withdrawn was termed as gross draft.

For working out the water balance, 70% of the gross extraction was taken as net draft. The rest 30% was presumed to go as return flow to the groundwater regime. The categories of watersheds were made on the basis of stage of development at years 5. The various categories were:

White	< 65%
Grey	> 65% to < 85%
Dark	> 85% to < 100%
Overexploited	> 100 %

Using this approach, during 1998 the renewable groundwater annual recharge in the state was 31,54,461 Ham, with the annual draft of 8,83,707 Ham, leaving the balance of 22,70,754 Ham. In the State 1392 watersheds were declared as white, 87 watersheds as grey and 26 watersheds were declared as dark. About 14,53,654 wells existed during this assessment.

1.4 Merits and Limitations of GEC 1984 Methodology

The basic merits of the GEC 1984 methodology are: (a) simplicity (b) suitability of the method with regard to the data normally available from the ground water level monitoring programs 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. The two approaches recommended by the GEC-1984 can therefore still form the basis for ground water assessment.

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

1.4.1 Units for ground water recharge assessment

The GEC-1984 does not explicitly specify the unit to be used for ground water assessment, but it is implied 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.

1.4.2 Delineation of areas within a unit

The GEC-1984 methodology does not take into account the spatial variability of ground water availability within a unit. There is a necessity for delineation of different sub-areas within a unit for ground water assessment viz. command, non-command and poor ground water quality areas.

1.4.3 Season-wise assessment of ground water resource

There is a clear need expressed for season-wise assessment of the ground water resource for Kharif, Rabbi 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.

1.4.4 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, and (c) possibility of duplication of resource estimation as the flow which enters the confined aquifer is already estimated under unconfined 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.

1.4.5 Estimation of specific yield

The ground water level fluctuation method requires the use of specific yield value as a key input for assessment of groundwater recharge. The GEC-1984 suggests that for semi-critical and critical areas, pump tests (APT- Aquifer Performance Test) may be used for the estimation of specific yield. Regarding regional ground water assessment in hard rock areas, determination of specific yield through pump tests has several limitations

1.4.6 Ground water draft estimation

Groundwater draft refers to the quantity of ground water that is being withdrawn from the aquifer. Groundwater draft is a key input in ground water resource estimation. Hence, accurate estimation of groundwater draft is highly essential to calculate the actual groundwater balance available.

1.4.7 Groundwater flow

The groundwater 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 groundwater availability in the unit, subject to the natural loss or gain of water in the monsoon season due to base flow and inflow/outflow.

1.4.8 Return flow from ground water draft

The GEC-1984 recommends that 30% of gross groundwater 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 groundwater 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%.

1.5 Improvements by GEC 1997 Methodology

In 1995, GoI constituted a new committee headed by the Chairman, C.G.W.B to review the Groundwater Estimation Committee Methodology (1984) and to look into the related issues. GEC (1997) upheld the basic approach of GEC 1984 i.e. computation of groundwater recharge using the water level fluctuation method and rainfall infiltration factor. However, several improvements were suggested over the previous methodology as listed below:

a) It is proposed that watershed may be used as the unit for ground water resource assessment in hard rock areas, which occupy about $2/3^{rd}$ of the state. For alluvial areas, the resources assessment based on block-wise may be adopted.
b) It is proposed that the total geographical area of the unit for resource assessment be divided into sub areas such as hilly regions, saline ground water areas, canal command areas and non-command areas, and separate resource assessment may be made for these sub areas.
c) Groundwater recharge assessment should be made separately for monsoon season and the non-monsoon season.
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) An alternate methodology is provided for the estimation of specific yield based on the application of ground water balance and water level fluctuation in the dry season. The methodology may be applied to non-command areas in hard rock regions.

f) With regard to norms for specific yield and recharge factor for rainfall, though a range is provided, a single value is recommended for normal application in each type of hydrogeological unit, unless use of other values can be justified.

g) 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.

h) 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.

i) Explicit focus is introduced on: (a) recharge due to water conservation structures and (b) additiona1 recharge from rainfall due to adoption of watershed development techniques with associated soil conservation measures.

j) Greater clarity is introduced in the water level fluctuation method for recharge assessment with regard to net ground water inflow and base flow terms.

k) Norms for return flow from irrigation are based on the source of irrigation (ground water or surface water), type of crop (paddy or non-paddy), and depth to water table below ground level.

l) Normalisation of rainfall was based on regression analysis.

m) About 5 to 10 percent of the total annual ground water potential may be assigned to account for natural discharges in the non-monsoon season. Allocation for domestic and industrial water supply is to be based on population density and relative load on ground water for these purposes.

n) Categorisation of areas for groundwater development is to be made based on the stage of ground water development and the long-term trend of pre-monsoon and post-monsoon groundwater levels. Accordingly, a four-fold categorisation is suggested as a) safe areas, b) semi-critical areas, c) critical areas and d) over-exploited areas.

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

1.6 Constitution of Committee for Maharashtra for present assessment

The groundwater estimates for the State of Maharashtra have been computed by the Ground Water Survey and Development Agency in collaboration with the Central Ground Water Board on the guidelines given by the Groundwater Estimation Committee (GEC-1997) constituted by Ministry of Water Resources, GoI, New Delhi *vide* Resolution No. 3/9/93-GW (II) 2332, dated 13.11.1995. The Groundwater Survey and Development Agency has finalized this groundwater estimation report in consultation with the officers of Central Ground Water Board. The Report gives groundwater potential of different districts of the State on watershed basis and also information about the Semi-critical, Critical and Over-Exploited watersheds. A Technical Committee has been constituted, as advised by Government of India, vide their letter No. 18-36/83-GW dated 10th May 1985. The Committee comprises of the following members:

- Secretary, Water Supply & Sanitation Department, GoM - Chairman
- Chief Engineer and Jt. Secretary, Irrigation Department GoM. - Member
- Director, Social Forestry, Pune - Member
- Director, Groundwater Surveys Development .Agency, Pune - Member
- Director, Soil Conservation & Watershed Management, Pune - Member
- Regional Director, C.G.W. B, Nagpur - Member and Convenor
- Managing Director, Maharashtra State Co-operative Agricultural and Rural Development Bank, Mumbai - Member
- Representative of NABARD - Member
- Chief Engineer, Minor Irrigation- Local Sector, Pune - Member
- Deputy Director, G.S.D.A.(R&D) Pune, - Member
- Representative of Mahatma Phule Agricultural University, Rahuri - Member

The Committee was required to consider the report submitted by Groundwater Survey and Development Agency and submit observations to the Government about various recommendations made in the report and for giving comments wherever necessary for onward submission to Government of India.

The 1st meeting of the State high level Technical Committee as held on 2nd April 2002 under the Chairmanship of The Secretary, Water Supply and Sanitation Department, Government of Maharashtra. The Committee discussed various aspects such as Methodology of GEC 1997, Draft Report, validity of database, constraints, etc. However, due to some abnormalities in the assessments, a Technical Sub-Committee to review, update and finalise Draft Report was constituted. The following was the constitution of the Technical Sub-Committee:-

Deputy Director, (R&D), GSDA - Convener

Mr. S. K. Bansal, CGWB - Member

Mr. D. Venkateshwaran, CGWB - Member

Rep. of Chief Engineer, Minor Irrigation (Local Sector), Pune - Member

Dr. A. R. Tamhankar, NABARD - Member

Mr. A. Chandra, Joint Director, Social Forestry - Member

The Technical Sub-Committee was entrusted with the following responsibilities:

- Look into availability of data and to update draft report.
- To verify the draft data, especially pertaining to Irrigation Department
- Look into variations of Recharge component of GEC 1984 vis-a-vis GEC 1997
- To prepare the final Draft Report

1.7 Static Resources

The discussion in the preceding paragraphs was with respect to dynamic annually replenihsable resource. As per the National Water Policy, the extraction of groundwater should be limited to the amount which is being recharged annually i.e. Dynamic or Replenishable resource. Below the Dynamic Resource, which is the potential in the zone of water level fluctuation lies 'Static' or 'In-Storage' Resource. The 'Static' implies reserve stock of ground water, which should be utilised only in case of extreme eventualities like drought conditions. Presently, there is no fine demarcation to distinguish the dynamic resources from the static resources. Water table hydrograph could be an indicator to distinguish the dynamic sources and at times it is difficult to distinguish between dynamic and static resources when water tables are deep.

The computation of Static Resource is being done as follows:

Static Groundwater = Thickness of the aquifer below x areal extent x specific yield

Chapter 2 About Maharashtra

Maharashtra State has a geographical area of 30.77 million hectares. The State has 35 districts and 353 talukas. The State has 2 urban districts i.e. Mumbai and Mumbai Sub-Urban where as the remaining 33 districts are rural. There are 336 cities and towns in the State, out of which 40 have population more than 100,000. There are 40,785 villages and 45,528 hamlets (w*adi, vasti* or *pada*). Map of Maharashtra showing District Administrative boundaries considered for Groundwater Resource Assessment is shown figure. The population of the State is 96.7 million (2001) of which 41.13 million is urban and 55.57 million is rural. Maharashtra is mainly an agriculture State with 82% of rural population relying on agriculture. Recently though, there is migration of 2% population, annually, from rural to urban areas. Out of total area of 30.77 million ha, 21.04 million ha (68 %) is cultivable and 6.20 million ha (20 %) is under forest. Agriculture productivity of the cultivable land is Rs. 16000/- per hectare. The salient features of Maharashtra are given below:

2.1 Salient Features of Maharashtra

2.1.1 Location:

Longitude 72º 30’ 00” to 80º 30’ 00”
Latitude 15º 40’ 00” to 22º 00’ 00”

2.1.2. *Area* : 30.77 million hectares

2.1.3. *Coastline*: 720 km.

2.1.4. *Physiography:* The Physiography of Maharashtra is depicted.

HDP area: 6.15 million hectares

MDP area: 15.39 million hectares

UDP area : 9.23 million hectares

2.1.5. *Rainfall zones*:

High Rainfall: 2000 to 3500 mm

DPAP Area : 400 to 700 mm

Assured Rainfall: 800 to 1250 mm

2.1.6. *Soils*:

Plains and Central Highlands: Brown to black calcareous loams and clay.

Western Ghats and Peninsular Plateau: Shallow lithbrown to dark brown gravel, loams on high slopes, red to reddish brown laterites and lateritic soils on high level

Costal Plains: Laterites and lateritic soils red to reddish brown loam of non-lateritic origin.

2.1.7. *Geology*:

Formation	Area (in 000 sq km)	%
Quaternary Alluvium	14498	4.71
Deccan Trap lava flows	250026	81.25
Gondwana Rock	4808	1.56
Proterozoics	6190	2.01
Precambrian	32191	10.46

2.1.8. *Cultivable Area*: 210390 sq. kms.

2.1.9. *Forest Area*: 61935 sq. kms.

2.1.10. *Irrigation potential created (by all sources)*: 36.93 lakhs hectare.

2.1.11. *Cropping Pattern*:

Konkan: Paddy, horticulture and vegetables.

Western Maharashtra: Jowar, wheat, sugarcane, groundnut, onion, horticulture, sunflower, etc.

Central Maharashtra: Jowar, wheat, cotton, sugarcane, grams, vegetables, sunflower, safola.

Vidarbha: Paddy, Jowar, wheat, cotton, orange, grams, chilli.

Khandesh: Jowar, maize, grams, banana, wheat and chilli

2.1.12. *River basins*:

There are 15 river basins in Maharashtra.

Basin	**No. of watersheds**	**Area (sq. km)**
Narmada	08	1595
Tapi East	184	32770
Godavari	190	43283
Krishna	97	20237
Westerly Flowing	97	31933
Bhima	161	35922
Wainganga	161	27558
Wardha	117	21397
Godavari Purna	101	16362
Penganga	108	22972
Purna Tapi	98	16732
Manjara	78	15835
Sina	58	12234

Indravati	31	5488
Pranhita	16	3395

2.2 Rainfall:

The distribution of rainfall across the State is variable and is strongly influenced by physiography. The Western Ghats, popularly known as the 'Sahyadri' rises up from the coastal plains- 'Konkan' upto a maximum height of 1654 m. It forms a fairly continuos hill range in the north-south direction and forms a major water divide along the western parts of the State. The Konkan coast experiences high rainfall upto 3000 mm. The Sahyadris also act as a barrier to the advancing southwest monsoon and also receive copious rainfall. However, they form a rain shadow zone on the eastern side where the rainfall is generally between 400- 700 mm but at times less than 400 mm. This region constitutes the Drought Prone Area of the State. Thus, the central part of the State almost always reels under scarcity and droughts. Ninety-nine talukas in the State are chronically drought affected. The region towards east of Marathwada and Vidarbha receives up to 1250 mm rainfall and falls within the assured rainfall zone. Variability of rainfall over the State is generally high ranging from 20 to 35 %, except in coastal areas where it is less than 20%.

2.3 Geology:

The geology of Maharashtra is famous for the Deccan Traps, which occur in all the districts of the State, except Bhandara, Gondia and Gadchiroli. The other geological formations, older and younger than Deccan Traps, occur in the northeast and as isolated patches in the Sindhudurg and Ratnagiri districts. The stratigraphic succession of the geologic formations in the State is given in Table 1. The variation in hydrological properties is due to inherent physical characteristic.

2.3.1 Precambrian rocks:

The Precambrian rocks of Maharashtra are as varied and diverse as is found in Peninsular India. They are mostly confined to the northeastern parts and fringe areas of the State. Most of these rocks are older than 3.5 billion years and are invariably metamorphosed. Major lithotype is that of rocks belonging to the Peninsular Basement Complex. These are mostly gneisses with enclaves of schists and amphibolites. Gneisses occur in Nagpur, Bhandara, Chandrapur, Gadchiroli and Sindhudurg districts. Besides this, the metasediments belonging to Sausar Series are also exposed in the Nagpur and Bhandara districts and include a variety of rock types such as calcgranulites, calciphyres, quartzites, geisses, schists and manganese bearing 'gondites'. Structurally, these rocks are intensely folded and faulted as these were subjected to a number of tectonic events. Another group of rocks popularly referred to as the Sakoli Series is exposed in the Gadchiroli, Chandrapur, Nagpur and Bhandara districts. These consist of pelitic, psamopelitic and metabasic sediments and include phyllites, schists, amphibolites, quartzites and associated basic instrusives. The Iron Ore Series constitutes an important iron ore bearing formation in the Gadchiroli and Sindhudurg districts. The rocks consist of quartzites and Banded Hematite Quartzites with sizeable quantities of exploitable iron ore.

2.3.2 Proterozic Rocks:

The Basement Gneissic Complex are overlain by the Proterozoic sediments. The limestone rocks equivalent to the Cuddapah Super Group exposed in Andhra Pradesh, are exposed in small areas in the southern part of Gadchiroli district. Another equivalent rock formations referred to as Kaladgi Group rest directly on the Precambrian rocks in Sindhudurg and Kolhapur districts. The Kaladgi rocks consist of sandstones and shales and have give rise to important deposits of silica sands. Rocks belonging to this formation occur below the Deccan Trap flows in Kolhapur district. Vast areas in the districts of Nanded, Yavatmal, Chandrapur and Gadchiroli, are occupied by the rocks of the Vindhyan Super Group. They consist of limestones, dolomitic limestones, purple shales and feldspathic sandstone.

2.3.3 Gondwana System:

The coal bearing Gondwana sediments were deposited in basins formed by the rifting of the Gondwana protocontinent. The sedimentary rocks belonging to the Gondwana system can be

Table 1. Stratigraphy of rock types occurring in Maharashtra

Age	**Geology**	**Geographical distribution in the State**
Recent- Quaternary	Alluvium, Laterite, Beachrock	Alluvium in parts of Dhule, Jalgaon, Buldana, Akola and Amravati districts. Laterites in Kolhapur, Satara, Sangli, Ratnagiri, Raigad and Thane districts. Beachrock along the beaches, Konkan coast
Lower Eocene Upper Cretaceous	Deccan Trap Volcanic Lava flows with inter-trappean beds. Lametas and Bagh Beds.	All the districts of the State except Bhandara, Gondia, Gadchiroli Parts of Nandurbar and Nagpur.
Jurassic (Up.	Chikiala and Kota	Sironcha taluka of Gadchiroli district.

Gondwana)	Stages: Limestone.	
Triassic	Paachmari and Maleri Stages: Clays, Sandstones.	Sironcha taluka of Gadchiroli district and Achalpur taluka of Amravati district.
Permian (Lw. Gondwana)	Mangli Beds, Sandstones.	Warora taluka of Chandrapur district.
	Kamathi series Sandstones, Shales, Coal	Nagpur, Chandrapur and Yavatmal districts.
	Barakar series Sandstone, Shales and Coal	Nagpur, Chandrapur and Yavatmal districts.
Upper Carboniferous	Talchir series	Nagpur, Chandrapur and Yavatmal districts.
Proterozoic	Vindhyan Super Group (Limestones, Shales, Sandstones).	Yavatmal, Nanded and Chandrapur districts
	Cuddapah equivalent Limestones and Shales.	Sironcha Taluka of Gadchiroli district.
	Kaladgi Super Group Sandstones, Shales Conglomerates	Ratnagiri, Sindhudurg and Kolhapur districts.
Precambrian.	Sakoli Series, Iron Ore Series	Gadchiroli, Chandrapur, Nagpur and Bhandara districts.
	Sausar Series	Nagpur and Bhandara districts.
	Peninsular Basement Complex	Gadchiroli, Chandrapur, Nagpur, Bhandara and Sindhudurg districts.

divided into two groups namely the Lower and the Upper. The Lower Gondwana sediments include the Talchir series, the oldest group of rocks followed by Barakar series, Kamthi series and Mangli beds. The Talchir series include serrated boulders and green shales, sandstone, clays and mudstones that were deposited during the glacial period.The Barakar series consists of a thick succession of alternate layers of sandstones and shales with interbedded coal seams. The youngest group of rocks belonging to the lower Gondwana sequence is known as the Mangli beds and consists of conglomerates, grits and sandstones and is exposed in Warora taluka of Chandrapur district. The upper Gondwana sediments include Pachmari, Maleri, Kota and Chikli group and are mainly exposed in Sironcha taluka of Gadchiroli district. Around Bairamghat in Amravati district, the Pachmari group sediments are exposed. They essentially consist of sandstones, shales and clays and include number of plant fossils.

2.3.4 Lameta and Bagh Beds:

The rocks formations referred to the Bagh Beds are exposed along the southern bank of Narmada River in Akkalkuwa taluka, Nandurbar district and comprise of siliceous limestones and sandstones. The Lametas comprise essentially of calcareous sandstone, cherty limestones and clays. The Lameta and Bagh Beds are referred to as infra-trappean beds i.e. occurring below the Deccan Traps. The are located at various places and along the fringes of the Deccan Traps near Nagpur and in Amravati district.

2.3.5 Deccan Volcanic Province (Deccan Traps):

The Cretaceous-Eocene Deccan Volcanic Province occupies more than 500,000 sq. km area in parts of western and central India and is an important geological formation in the Indian sub-continent. In Maharashtra, it occupies an area of about 2,46,784 sq. km, which is about 82% of the State. The Traps are composed of a thick pile of lava flows seldom separated by flow top breccia or 'red bole'. The individual lava flow varies greatly in thickness from a few metres to as much as 30-35 meters. In the fringe areas i.e. around Mumbai, Nagpur, etc. intertrappean sediments, which consists of sandstones, shales, marls etc. is exposed between flows. The basaltic flows that constitute the shallow- and deeper aquifers present inconsistent and complex hydrogeological pattern. Although climatic, physiographic and rainfall vary widely across the State, the inherent differences in the lava type, their geometry and the superimposing fabric of post-volcanic tectonics are more important locally in contributing to anisotropic nature of the aquifer. The Deccan Trap aquifers can be broadly divided into the following major physical units:

- Dense, compact and massive basalt,
- Vesicular/amygdaloidal basalt,
- Jointed or fractured basalt.

The intrusive dyke swarms occur along two tectonic belts i.e. the West Coast and the Narmada-Tapi River. Most of the dykes are hypabassal. The dykes cut across number of flows and form an important physiographic feature- sometimes occurring as ridges (positive feature) and at other places forming linear depressions (negative features). The dykes control groundwater movement and as such are known to be 'carriers' or 'barriers'.

2.3.6 Alluvial Deposits:

The alluvial deposits generally occur along the lower reaches of major river valleys. Two well known alluvial deposits namely, Tapi Valley (districts of Dhule and Jalgaon) and the Purna Valley (districts of Buldhana, Akola and Amravati) are recognised. These alluvial deposits belong to slightly older period (Quaternary) in geological history then most of the alluvial deposits in the coastal areas of the country. The alluvial deposits in the Tapi and Purna valleys occur in separate, rather, long narrow basins and occupy a total area of 10,500 sq. km. of which Tapi covers an area of 4100 sq. km and Purna covers 6400 sq. km. On the basis of exploratory drilling, it is known that, these alluvial deposits attain considerable thickness, maximum being about 425 m.b.g. l. Minor alluvial deposits are also known to occur in other parts of the State such as along Bhima, Godavari, Wardha, Wainganga, Penganga rivers and along some of their tributaries.

2.4 Groundwater Province of Maharashtra

On the basis of geological formations, the State can be divided into the following groundwater provinces: -

i. Precambrian metamorphic groundwater province

ii. Proterozoic sedimentary groundwater province

iii. Gondwana groundwater province

iv. Deccan Trap volcanic groundwater province

v. Alluvial groundwater province

2.4.1. *Precambrian metamorphic groundwater province*

The basement complex rock types such as schists, gneisses, granite, amphibolites and basic intrusives constitute this province. The rocks are very hard and compact and possess practically no primary porosity. However, these are highly weathered and are fractured, sheared and jointed due to numerous tectonic episodes. The secondary porosity is therefore

of prime importance in this province. The yield from the wells in this province generally varies from 45 to 80 m^3/day and the water level fluctuation varies from 2 to 8 metres b.g.1. However, the wells located on major lineaments or shear zones have higher yields (100 to 150 m^3/day).

2.4.2 *Proterozoic sedimentary groundwater province:*

The compact sediments mainly comprise of Vindhyan and Kaladgi formations. The total area occupied by these sediments is 6,217 sq. km. The Vindhyans comprise of limestones, sandstones and shales. Groundwater occurs in these rocks under phreatic as well as semi-confined conditions. The dug wells piercing the Vindhyan rock types range in depth between 5 and 12 m and static water levels range between 2 and 7 m. b.g.l. The diameters of the wells range between 3 and 5 m. The limestones at places are massive but are generally bedded and exhibit vertical joints. In some places, particularly in Yavatmal and Chandrapur districts they develop 'karst' topography. Geomorphological features such as sink holes, galleries and caverns associated with this topography impart secondary porosity and permeability to this formation. The wells in this area generally sustain a discharge of 50 to 100 m^3/day.

2.4.3 *Gondwana sedimentary groundwater province:*

The Gondwana sedimentary rock formations are confined chiefly to the districts of Nagpur, Chandrapur, Yavatmal and Amravati. These sediments occupy a total area of about 4,801 sq. km and comprise of sandstones, shales and clays of varying thickness and degree of compaction. These rocks posses primary porosity. However, due to block faulting and intra-formational faulting and fracturing, secondary porosity is generated within these formations. Occasionally, lenses of pebbles and gravels are also encountered. There are possibilities of encountering confined aquifers in these type of rocks. Few exploratory tube wells drilled by Groundwater Surveys and Development Agency and Central Ground Water Board have indicated a discharge of 100 to 300 m^3/day. The dug wells in these types of rocks vary in depth from 10 to 20 m. The water levels vary from few metres to 8 m.b.g.l. The yield ranges between 50 and 300 m^3/day. Groundwater Surveys and Development Agency has drilled large number of tube wells in this formation, especially for drinking water purposes.

2.4.4 *Deccan Trap volcanic groundwater province*:

The Deccan Traps, which occupy about 82% of the total area of the State, is a major groundwater province for consideration and evaluation of groundwater potential in the State. The basalt lava flows are formed as wide spread flows forming extensive plateaus. The entire pile of near horizontal lava flows show variation in their physical character, thereby influencing the aquifer parameters. While considering the occurrence of groundwater in the basaltic hard rocks, which possess very poor primary porosity it is interesting to note that the basaltic lava flows develop vesicular character, especially, in the flow crust. Further, secondary features like weathering, jointing, and shearing develop storage space, which make the basaltic rocks capable of holding and transmitting groundwater. The vesicles, the joint system and inter-flow zones contribute considerably to the yield of the basaltic flow. The yield is considerably affected by other two factors namely, degree of weathering and topographic setting. Weathering increases porosity and permeability and topographic setting affects the movement and discharge of groundwater. Thus a highly weathered vesicular lava flow has good porosity and permeability and proves to be a good aquifer. However, the inter flow horizons such as red boles tend to become clayey and sometimes reduce the aquifer properties. Groundwater in the basaltic aquifers occurs under phreatic and semi-confined conditions. The massive lava flows and thick red-bole layers tend to inhibit vertical movement of groundwater and thus act as confining aquicludes. The productive aquifers when favourably situated receive recharge and groundwater moves down the slopes till it is withdrawn by abstraction structures such as dugwells or natural discharge (spring). The water level and yields of wells are a function of the permeability and thickness of the aquifer encountered. The entire succession of lava flows act as multi-aquifer system. The average depth of wells varies from 9 to 15 m and diameter varies from 4 to 8 m. The range of water level varies from 3 to 7 m and the yield ranges from 75 to 100 m^3/day in winter. Wells located in favourable sites have very good yields ranging from 150 to 200 m^3/day. In the Deccan traps the low availability of groundwater is attributed to its peculiar geomorphological and geological set up. The lava flows are individually different in their ability to receive, hold as well as to transmit water. The availability and productivity of groundwater in Deccan Trap is entirely dependent in its inherent physical property such as the size and distribution of vesicles, number and spacing of interconnected joints and fractures and degree of weathering.

2.4.5 *Alluvial groundwater province:*

The alluvial deposits in Tapi and Purna valleys are unique in that, they have been deposited in faulted basins. The northern - boundaries of the two basins are faulted and the floors of the basins have sunk to relatively greater depths. The basements have a slope towards north in both the cases. The weathering and erosion of the Satpuras have contributed considerable volume of material in filling up of the two basins. The foothills of the Satpuras have a thick accumulation of pediment deposits commonly referred to as the ‘bazada zone’. The thickness of the zone varies considerably but holds tremendous potential as far as artificial recharge to the depleting groundwater is concerned. The alluvial deposits in the basins have attained a maximum thickness of about 400 m at Akot in Akola district of Purna valley and about 300 m at Yawal in Jalgaon district in the Tapi valley. The alluvial sediments in the two basins generally consist of clays, silt, sand, pebbles and boulders. The sand, gravel, boulders etc. occur in one or more beds of 2 to 13 m in thickness, generally within a depth of about 100 m and sometimes even down to the depth of 250 m below surface. Boulders and gravels sometimes mixed with clays are predominant in the northern part of alluvial area in the Purna basin.

The alluvial deposits in the two areas consist of different type of water bearing horizons. The most important amongst them are the beds of sand, gravel and boulders, as these beds receive recharge, and store and transmit large quantities of groundwater. The alluvial material generally contain one shallow aquifer within a depth of about 20 m and one deep confined aquifer below 30 m. Central Ground Water Board has carried out extensive exploratory drilling in Tapi (57 tube wells) and Purna (78 tube wells) alluvial areas. The depth of these tube wells range from 17 to 322 m. b.g.l. and their yield range is from 5 to 45 lps. The exploratory study has shown that the alluvium is deposited in faulted basin which have prominent northerly tilting basement of the Deccan Trap. The 300 to 350 m thick alluvial deposits can be divided into younger alluvium up to 80 m depth and older alluvium below it. The younger alluvium contains 2 to 4 granular aquifer zones, which have excellent hydrologic parameters. The water levels in open wells vary in depth from 15 to 30 m. In areas bordering Satpura in the north water levels are deeper and the wells are 30 m or more in depth. Most of the existing dug wells yield 100 to 300 m^3/day, though in few case higher yields are observed. Groundwater Surveys and Development Agency has drilled large number of' tube wells in these formations especially for drinking water purposes. The chemical quality of groundwater in the aquifer of alluvial deposits is generally good in northern part. However, in Purna alluvial areas the groundwater in shallow aquifers, especially in the southern part of the basin is saline.

2.5 Water Quality

The chemical quality of groundwaters from the shallow basaltic aquifers is good (electrical conductivity ~501-1000 $\mu s\ cm^{-1}$). In most samples the pH values range from 7.5 to 8.5 indicationg the alkaline nature of the groundwaters. In Maharashtra, the saline groundwaters (electrical conductivity ~2001-3000 $\mu s\ cm^{-1}$) are present in three geographically distinct areas viz. the coastal areas of Konkan, the Purna alluvial basin and the upland DPAP areas. The chemical quality of groundwaters for deeper aquifers however represents a different picture. Saline groundwater patches (electrical conductivity > 2001µs cm^{-1}) are reported from the Konkan coast (Thane, Raigad, Ratnagiri), Purna (Buldana, Akola, Amravati) and the DPAP areas (Pune, Sangli,). The Hardness of groundwaters range between 100 to 500 mg/lit which is suitable for drinking purposes. The fluoride concentration in groundwaters from the Precambrian basement rocks and Proterozoic sediments are above prescribed limits. Such occurrences have been reported from districts such as Chandrapur, Nagpur, Gadchiroli, Yavatmal, Bhandara and Sindhudurg where drinking water is not suitable for consumption. However, it is to mention that these are treated as point sources and not applicable to the entire watershed.

Chapter 3. Ground Water Resource Estimation Methodology, 1997

The previous ground water resource assessment of the state was done based on the recommendations of Ground Water Estimation Committee - 1984 (GEC'84). The GEC'84 methodology was subsequently modified in the light of enhanced database and new findings of experimental studies in the field of hydrogeology. The present methodology used for resources assessment is known as Ground Water Resources methodology - n1997 (GEC'97). In GEC'97, two approaches are recommended-water level fluctuation method and norms of rainfall infiltration method. The water level fluctuation method is based on the concept of storage change due to difference between various input and output components. Input refers to recharge from rainfall and other sources and subsurface inflow into the unit of assessment. Output refers to ground water draft, ground water evapotranspiration, base flow to streams and subsurface outflow from the unit. Since the data on subsurface inflow / outflow are not readily available, 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 a s negligible.

Thus the ground water resources assessment unit is in general watershed particularly in hard rock areas. In case of alluvium areas, administrative block can also be the assessment unit. In each assessment unit, hilly areas having slope more than 20% re deleted from the total area to get the area suitable for recharge. Further areas where the quality of groundwater is beyond the usable limits should be identified and handled separately. The remaining area after deleting the hilly area and separating the area with poor quality groundwater quality is to be delineated into command and non-command areas are done separately for monsoon an non-monsoon seasons

3.1 Ground water recharge

Monsoon Season

The resources a ssessemnt during monsoon season I sestimateed as the sum total of the change in storgae and gross draft. The change in storgae is computed by multiplying water level fluctuation between pre and post monsoon periods with the area of assessment and specific yield. Monsoon recharge can be expressed as:-

$$R = h \times S_y \times A + D_G$$

where,

h = rise in water level in the monsoon season, S_y = specific yield

A = area for computation of recharge, D_G = gross ground water draft

The monsoon ground water recharge has two components- rainfall recharge and recharge from other sources. Mathematically it can be represented as-

$R(Normal) = R_{rf}(normal)+R_c + R_{sw} + R_t + R_{gw} + R_{wc}$

where,

R_{rf} is the normal monsoon rainfall recharge. The other sources of groundwater recharge during monsoon season include R_c, R_{sw}, R_t, R_{gw}, R_{wc} which are recharge from rainfall, seepage from canals, surface water irrigation, tanks and ponds, ground water irrigation, and water conservation structures respectively.

The rainfall recharge during monsoon season computed by Water Level Fluctuation (WLF) method is compared with recharge figures from Rainfall Infiltration Factor (RIF) method. In case the difference between the two sets of data are more than 20%, then RIF figure is considered, other wise monsoon recharge from WLF is adopted. While adopting the rainfall recharge figures, weightage is to be given to the WLF method over adhoc norms method of RIF. Hence, wherever the difference between RIF and WLF is more than 20%, data have to be scrutinised and corrected accordingly.

Non- Monsoon season

During the non-monsoon season, rainfall recharge is computed by using Rainfall Infiltration Factor (RIF) method. Recharge from other sources is then added to get total non-monsoon recharge. In case of areas receiving less than 10% of the annual rainfall during non-monsoon season, the rainfall recharge is ignored.

Total annual ground water recharge

The total annual groundwater recharge of the area is the sum-total of monsoon and non-monsoon recharge. AN allowance I kept for natural discharge in the non-monsoon season by deducting 5% of total annual ground water recharge, if WLF method is employed to compute rainfall recharge during monsoon season and 10% of total annual ground water recharge if RIF method is employed. The balance ground water available accounts for existing ground water withdrawal for various uses and potential for future development. This quantity is termed as Net Groundwater Availability.

Net Groundwater Availability = Annual Ground Water Recharge - Natural discharge during non monsoon season

Norms for estimation of recharge

GEC97 methodology has recommend norms for various parameters being used in ground water recharge estimation. These norms vary depending up on water bearing formations and agroclimatic conditions. While norms for specific yield and recharge from rainfall values are to be adopted within the guidelines of GEC'97, in case of other parameters like seepage from canals, return flow from irrigation, recharge from tanks and ponds, water conservation structures, result of specific case studies may replace the ad-hoc norms.

3.2 Ground water draft

The gross yearly ground water draft is to be calculated for irrigation, domestic and industrial uses. The gross ground water draft would include the ground water extraction from all existing ground water structures during monsoon as well as during non-monsoon period. While the number of ground water structures should preferably be based on the latest well census, the average unit draft from different types of structures should be based on specific studies or ad -hoc norms in GEC'97 report.

3.3 Stage of groundwater development and categorisation of units

The stage of ground water Development is defined by:

$$\text{Stage of groundwater Development (\%)} = \frac{\text{Existing Gross Ground water draft for all uses}}{\text{Net annual Groundwater Availability}} \times 100$$

Categorisation of areas for groundwater development

The units of assessment are categorised for groundwater development based on two criteria - a. stage of groundwater development, and b. long term trend of pre and post monsoon water levels. Four categories are- **Safe** areas which have groundwater potential for development; **Semi-Critical** areas where cautious groundwater development is recommended; **Critical** areas; and **Over-exploited** areas where there should be intensive monitoring and evaluation and future ground water development be linked with water conservation measures. The criteria for categorisation of assessment units are as follows:

Sr. No.	**Stage Of GW Development**	**Significant Long Term Decline**		**Category**
		Pre-Monsoon	**Post- Monsoon**	
1	**≤ 70 %**	No	No	SAFE
		Yes/No	No/Yes	**To be re-assessed**
		Yes	Yes	**To be re-assessed**
2	**> 70 to ≤ 90 %**	No	No	**SAFE**
		Yes/No	No/Yes	**SEMI CRITICAL**
		Yes	Yes	To be re-assessed
3	**> 90 to ≤ 100 %**	No	No	*To be re-assessed*
		Yes/No	No/Yes	***SEMI CRITICAL***
		Yes	Yes	***CRITICAL***
4	**> 100 %**	No	No	*To be re-assessed*
		Yes/No	No/Yes	***OVER EXPLOITED***
		Yes	Yes	***OVER EXPLOITED***

Note: 'To be re-assessed' means that data is to be checked and reviewed. If the groundwater resource assessment and the trend of long-term water levels contradict each other, this anomalous situation requires a review of the ground water resource computation, as well as the reliability of water level data.

The long-term ground water level data should preferably be for the period of 10 years. The significant rate of water level decline may be taken between 10 and 20 cm per year depending upon the local hydrogeological conditions.

3.4 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, 2002, requirement for domestic water supply is to be accorded priority. The requirement for domestic and industrial water supply is to be kept based on the population as projected to the year 2025. The water available for irrigation use is obtained by deducting the allocation for domestic and industrial use, from the net annual ground water availability.

3.5 Poor quality ground water

Computation of ground water recharge in poor quality ground water is o be done on the same line as described above. However, in saline areas, there may be practical difficulty due to non-availability of data, as there will usually be no observation wells in such areas. Recharge assessment in such cases may be done based on Rainfall Infiltration Factor method.

3.6 Apportioning of ground water assessment from watershed to development unit

Where the assessment unit is a watershed, the ground water assessment is converted in terms of an administrative unit such as Block/Taluka/Mandal. This is done by converting the volumetric resource in to depth unit and then multiplying this depth with the corresponding area of the Block.

3.7 Additional Potential Recharge

In shallow water table areas, particularly in discharge areas rejected recharge would be considerable ad water level fluctuation area subdued resulting in underestimation of recharge component. In the area where the ground water level is less than 5 m below ground level or in water logged areas, ground water resources have to be estimated up to 5m bgl only based on the following equations:

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

where,

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

A = area of shallow water table zone

Chapter 4 Computation of groundwater resources estimation in the State

4.1 Norms adopted for Groundwater Estimation, March 2004

4.1.1 *Resources assessment unit*

Basically both recharge and draft was computed considering watershed as unit and within that command, non-command and poor quality a subunit. The final assessment of the potential is apportioned and presented as taluka wise.

4.1.2 *Assessment area*

Out of the total geographical area, the hilly area (slope > 20%) was identified and deleted and only groundwater worthy area is considered.

4.1.3 *Method of Resource assessment*

Out of the total 2316 sub units, for 2166 subunits (i.e. 93%) the water table fluctuation method is adopted. Resources worked out respectively for monsoon and non-monsoon.

4.1.4 *Specific yield*

For non-command area as per GEC-97 guidelines the dry season specific yield is considered. The dry season specific yield for Deccan Traps varies from 0.95% to 2.5% as against the allotted value of 1 to 3% with an average of 2%.

4.1.5 *Rainfall infiltration factor*

6-12% is considered in basaltic area because in Konkan strip, most of the area is capped by very hard and compact massive unit. Hence 6-12 % is considered. (as per GEC-97: 6-14%).

4.1.6 *Recharge due to canal seepage*

15 Ham per day/million sq. m wetted area for unlined canals and 20% of it for lined canals.

4.1.7 *Recharge from Tanks and Ponds*

Average water spread area * No. of days * 0.00144 meters per day per Ha.

4.1.8 Recharge from water conservation structure

50% of the total storage.

4.1.9 *Return flow from irrigation*

	SWL < 10	SWL 10-25
GW - P/NP	45/25	35/15
SW - P/NP	50/30	40/20

4.1.10 *Categorisation*

As per guideline Assessment unit wise (clubbing both command and non-command)

4.1.11 *Stage of development*

As per guidelines.

4.1.12 *Unit Draft*

The average unit draft of dug wells works out to be 0.964 ham with the range from 0.6 to 1.5 ham. For bore wells, the unit draft ranges from 1.5 ham to 2.5 ham.

4.2. Present Evaluation

For the purpose of groundwater estimation and evaluation the Maharashtra state is divided 1505 elementary watersheds. The recharge is estimated for the groundwater worthy area of all the watersheds. The non-worthy area comprising of steep slops (Slope more than 20 %), Hill Tops and Rock Waste have been deleted. The worthy area of the watershed is also known as groundwater assessment area. Each watershed is further delineated into groundwater poor quality area, where the quality of the groundwater is beyond the usable limits, command area and non-command area, likewise each watershed is divided in to three assessment subunits. But all the subunits may not be present in the single watershed. Hence, the assessment was carried out on a watershed basis, although initially the assessment was carried out for the command and non-command areas. The groundwater estimation is carried out for 29 districts of Maharashtra i.e. combined estimate for Parbhani- Hingoli, Dhule-Nandurbar, Bhandra-Gondia and Akola-Washim. Groundwater estimation is not carried out for Greater Bombay district also.

The current estimation of groundwater recharge as brought out in the report is based on GEC 1997 methodology. As per this, the total rechargeable fresh groundwater resources in the State are computed as 32.96 BCM and the net ground water availability is to the tune of 31.21 BCM. The present gross draft for all purpose is 15.09 BCM out of which 14.24 is the present irrigation draft.

The inflow component of groundwater resources has been divided based on the contribution from natural recharge due to rainfall and augmentation from canal irrigation system. Though the rainfall has been principal source for groundwater recharge the canal seepage and return flow of irrigation has also been significant in certain districts of the State. The groundwater resources assessment for the State as a whole indicates that there is still a large balance of groundwater potential. Despite this, certain watersheds in the State have already attained the stage of over-exploitation/critical stage where the further groundwater development should be restricted. The Elementary watershed map of Maharashtra showing stages of groundwater development is shown on back page of this volume. There are 76 overexploited, 20 critical and 163 semi critical watersheds. The district-wise details of the assessment area (command and non-command), categorisation of watersheds, details of resource assessment, existing dugwells, borewells and draft is given in the Annexure 1-5. Annexure no. 6 shows the comparison between the Groundwater resource assessment carried out in Maharashtra based on GEC 84 (1988) and GEC-97 guidelines (2004).

4.3 Some Constraints

- It may be noted that water balance exercises are not carried out under GEC 1997 methodology as inflow - out flow components. Outflow components are considered as negligible with watershed as a boundary.

- The long term water level trend and stage of development are considered for declaring an area as safe or critical or semi-critical or overexploited. In cases, where Percentage Departure (PD) is large, monsoon rainfall recharge is computed using rainfall infiltration factor (*ad hoc* norms), which implicitly suggest that water level data is not representative. However, long-term water level data of the same wells are used for categorisation, which is contradictory.

- The long-term trend computed from linear regression analysis depends on the first data considered for the analysis. If the data pertains to the drought year, the trend becomes a rising trend and if the first data pertains to the above normal rainfall year, the trend gets reversed. A simple regression analysis may not reflect the actual field situation.

- For determination of domestic and industrial requirement an empirical relationship is suggested in the absence of adequate data. However, the industrial requirement should also be made mandatory.

- In spite of the cumbersome computations, the final categorization is not always realistic confirming the ground truth.

- A part of the watershed may have well showing declining trend while the rest may have wells showing rising trend. In such cases, the categorisation becomes subjective and in reality we may have multiple categorisation for each assessment sub-unit.

4.4 Future Strategies

Since there is no direct method of quantifying the groundwater resource potential the methodology adopted for estimation of this resource and figures estimated using these methodologies have always been subject to debate and controversies. For the same reason there is a constant urge for improving on the techniques and refining of database. However, any such changes should be preceded with the proper evaluation of the existing norms and techniques. In some cases difficulties have been noticed in computing the resources using GEC 1997 guidelines. The reasons include paucity of data, usage of certain norms or conditions suggested in GEC 1997 that leads to over or under estimation of recharge component. In such cases, it may be mentioned here, a flexible approach within the broad guidelines of GEC 1997 was adopted which yielded results more or less confirming the ground realities.

Several refinements to the recommended methodology along with the alternative approaches has been suggested in the report of GEC 1997 itself. These include:

- Geographic unit for assessment: watershed in hard rock, block in alluvial areas
- Employing remote sensing technique
- Computerisation of GEC methodology of resource estimation
- Refinement of database and norms for estimation of recharge based on R&D studies
- Distributed parameter modelling, and
- Soil moisture balance method as an alternative approach

Out of the above, State of Maharashtra has already been using watershed concept for resource assessment since 1973 for demarcation of groundwater non-worthy and worthy areas and Remote Sensing tools are also being used. In addition to this, computerisation of GEC 1997 methodology and refinement of data has also been attempted. As per the suggestion made by GEC 1997 the watershed wise exercise has been made to divide the groundwater recharge into two components – natural recharge and augmented recharge. The natural recharge includes recharge from rainfall, seepage from ponds, tanks, and ground inflow. The augmented recharge includes return flow from surface irrigation, groundwater irrigation along with other artificial recharge component.

Large-scale groundwater development significantly changes the recharge-discharge regime as a function of time. Thus, hydrologic budget computed under steady state condition may be considerably modified with time on account of groundwater development in the area.

It is therefore recommended that assessment of hydrologic budget of the area may be carried out periodically giving the due considerations to the prevailing groundwater development scenario and constituent modification in the recharge-discharge regime.

Justification for reduction in recharge

It is observed that the recharge during 1998 (as per GEC 84) was 37. 87 BCM and as per GEC 1997 (as on 2004) the total annual fresh replenishable recharge is 32.96 BCM. There is a reduction in recharge by 4.91 BCM to the tune of 14%. The reduction in recharge is mainly attributed to the following reasons.

1. During 1988 as per GEC 1984 methodology the entire area of the watershed in terms of the entire area of State (30.77 million hectare or 307713 km^2) was considered for resource assessment. As per GEC 1997 methodology the assessment area is reduced to 26.03 million-hectare from 30.77 million hectare. i.e. overall reduction is by 17%. In some districts like Thane, Raigad, Ratnagiri the reduction is even up to 50%.
2. During 1988, only 370 watersheds (only 24%) the resource assessment was done by WTF method. In the remaining 74% of the area RIF method was adapted by using total area x 12% infiltration factor. During 2004 out of 2316 subunits 2166 i.e. 93% is assessed by WTF method.
3. In Konkan district i.e. Thane, Raigad, Ratnagiri and Sindhudurg districts as per GEC-84, the Groundwater resource assessment was made only by RIF method considering the high rainfall. As per GEC-97 (2004) in 94% of the watersheds the resource assessment was done by WTF method, hence the recharge has been reduced considerably compared to GEC-84 methodology.
4. In RIF infiltration method the overall 12% recharge was considered. In high rainfall zone where the rainfall > 1200 mm the rainfall cut off range limited to 1200 mm was considered i.e. to say that even in Konkan without considering the groundwater worthy condition total area x RF (1200 mm) x 12% was considered resulting in exorbitant recharge.
5. In some watersheds from districts Solapur, Jalna, Beed, Nanded, Amravati, Buldhana and Chandrapur even during 1998 the resource assessment was done by WTF method. However, the average specific yield of the entire watershed was considered The specific yield value were varying between 2-4.5% where as during 2004 the dry season specific yield is considered the average value varies between 1 to 2.5%.
6. Under WTF method, during 1988 the cumulative WT fluctuation of all the observation wells from 1973-88 in the watershed was considered.
7. Explanation for lowering of category – In BM-7 of Pune district, during 1988 Groundwater Assessment canal irrigation and surface irrigation was not considered, subsequently the canal system was started. During 2004 Groundwater Resource Assessment an additional input of 609 hm recharge id added.

   In GV-15 of Nashik district, the surface irrigation component of 348 hm and recharge due to tanks and ponds to the tune of 155 hm total in to 503 hm is added dui\ring 2004 Groundwater Assessment.

   Hence in both the watersheds groundwater exploitation reduced below 85% of stage of development.

As per the irrigation draft figure is concern it is increased from 11.06 BCM to 14 .27 BCM. All the districts the irrigation draft is increased compared to 1988. District wise supporting statement A & B is enclosed at the end.