STUDY OF GROUNDWATER SUSTAINABILITY IN GURGAON DISTRICT, HARYANA

A Thesis Submitted to University of Delhi
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in

CIVIL ENGINEERING

By

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Under the Guidance of

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CERTIFICATE

This is to certify that the thesis entitled **"Study of Groundwater Sustainability in Gurgaon District, Haryana"** submitted by Mr. Vijender Kumar Malik for the award of degree of Doctor of Philosophy in Civil Engineering is based on the bonafide research work carried out by him during the period 2009 to 2012 under my supervision. Mr. Vijender Kumar Malik fulfills the requirement of the regulations laid down for the Ph.D. program of University of Delhi, Delhi.

To the best of my knowledge, the work presented in this thesis is an original contribution and has not been submitted, either in partial or full, to any other University or Institute for the award of any degree or other similar title or recognition. He is allowed to submit the work for the award of Ph.D. in Civil Engineering in University of Delhi, Delhi.

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CANDIDATE’S DECLARATION

I hereby declare that the work presented in this thesis titled **“Study of Groundwater Sustainability in Gurgaon District, Haryana”** submitted for the award of degree of Doctor of Philosophy in Civil Engineering, is an authentic record of my own research work carried out under the guidance and supervision of Prof. S.K. Singh, Professor and Head, Department of Civil & Environmental Engineering, Delhi Technological University, Delhi (Formerly Delhi College of Engineering, Delhi).

The work presented in this thesis is an original contribution and has not been submitted either in partial or full, to any other university or Institute for the award of any degree or other similar title or recognition.

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Euripides (484 BC – 406 BC) once told that, "The best and safest thing to keep a balance in your life, acknowledge the great powers around us and in us. If you can do that, and live that way, you are really a wise man." So it is essential that I acknowledge the great powers, which paved the way on which I have walked so far. As a prelude to my thanksgiving, at first I wish to thank the almighty for giving me powers to complete my entire course … after all He is the "greatest".

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(Vijender Kumar Malik)

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LIST OF ABBREVIATIONS AND PRINCIPLE SYMBOLS

Symbol	Abbreviation
a_{psy}	coefficient of psychrometer [°C^{-1}]
a_s	fraction of extraterrestrial radiation reaching the earth on an overcast day [-]
a_s+b_s	fraction of extraterrestrial radiation reaching the earth on a clear day [-]
CGWB	Central Ground Water Board
c_p	specific heat [MJ kg^{-1} °C^{-1}]
c_s	soil heat capacity [MJ m^{-3} °C^{-1}]
D_e	cumulative depth of evaporation (depletion) from the soil surface layer [mm]
D_r	cumulative depth of evapotranspiration (depletion) from the root zone [mm]
d	zero plane displacement height [m]
d_r	inverse relative distance Earth-Sun [-]
DP	deep percolation [mm]
DP_e	deep percolation from the evaporation layer [mm]
E	evaporation [mm day^{-1}]
e°(T)	saturation vapour pressure at air temperature T [kPa]
e_s	saturation vapour pressure for a given time period [kPa]
e_a	actual vapour pressure [kPa]
$e_s - e_a$	saturation vapour pressure deficit
ET	evapotranspiration [mm day^{-1}]
ET_o	reference crop evapotranspiration [mm day^{-1}]
ET_c	crop evapotranspiration under standard conditions [mm day^{-1}]
exp[x]	2.7183 (base of natural logarithm) raised to the power x
G	soil heat flux [MJ m^{-2} day^{-1}]
G_{sc}	solar constant [0.0820 MJ m^{-2} min^{-1}]
H	sensible heat [MJ m^{-2} day^{-1}]
h	crop height [m]
I	irrigation depth [mm]
I_w	irrigation depth for that part of the surface wetted [mm]
J	number of day in the year [-]
K_c	crop coefficient [-]
$K_{c\ ini}$	crop coefficient during the initial growth stage [-]

$K_{c\ mid}$	crop coefficient during the mid-season growth stage [-]
$K_{c\ end}$	crop coefficient at end of the late season growth stage [-]
$K_{c\ max}$	maximum value of crop coefficient (following rain or irrigation) [-]
L_{ini}	length of initial growth stage [day]
L_{dev}	length of crop development growth stage [day]
L_{mid}	length of mid-season growth stage [day]
L_{late}	length of late season growth stage [day]
LAI	leaf area index [m^2 (leaf area) m^{-2} (soil surface)]
m.ha	Million hector
m^3/time	meter cube per unit time like hour, day
N	maximum possible sunshine duration in a day, daylight hours [hour]
n	actual duration of sunshine in a day [hour]
n/N	relative sunshine duration [-]
P	rainfall [mm], atmospheric pressure [kPa]
p	evapotranspiration depletion factor [-]
R	specific gas constant [0.287 kJ kg^{-1} K^{-1}]
R_a	extraterrestrial radiation [MJ m^{-2} day^{-1}]
R_l	longwave radiation [MJ m^{-2} day^{-1}]
R_n	net radiation [MJ m^{-2} day^{-1}]
R_{nl}	net longwave radiation [MJ m^{-2} day^{-1}]
R_{ns}	net solar or shortwave radiation [MJ m^{-2} day^{-1}]
R_s	solar or shortwave radiation [MJ m^{-2} day^{-1}]
R_{so}	clear-sky solar or clear-sky shortwave radiation [MJ m^{-2} day^{-1}]
r_a	aerodynamic resistance [s m^{-1}]
r_l	bulk stomatal resistance of well-illuminated leaf [s m^{-1}]
r_s	(bulk) surface or canopy resistance [s m^{-1}]
R_s/R_{so}	relative solar or relative shortwave radiation [-]
T	air temperature [°C]
T_{max}	daily maximum air temperature [°C] T_{mean} daily mean air temperature [°C]
T_{min}	daily minimum air temperature [°C]
TAW	total available soil water of the root zone [mm]
TEW	total evaporable water (i.e., maximum depth of water that can be evaporated from the soil surface layer)[mm]

u_2	wind speed at 2 m above ground surface [m s^{-1}]
α	albedo [-]
γ	psychrometric constant [kPa °C^{-1}]
Δ	slope of saturation vapour pressure curve [kPa °C^{-1}]
δ	solar declination [rad]
ε	ratio molecular weight of water vapour/dry air (= 0.622)
η	mean angle of the sun above the horizon
θ	soil water content [m^3(water) m^{-3}(soil)]
λ	latent heat of vaporization [MJ kg^{-1}]
λET	latent heat flux [MJ m^{-2} day^{-1}]
ρ_a	mean air density [kg m^{-3}]
ρ_w	density of water [kg m^{-3}]
σ	Stefan-Boltzmann constant [4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}]
ϕ	latitude [rad]
ω	solar time angle at midpoint of hourly or shorter period [rad]
ω_1	solar time angle at beginning of hourly or shorter period [rad]
ω_2	solar time angle at end of hourly or shorter period [rad]
ω_s	sunset hour angle [rad]

ABSTRACT

Groundwater is an important source of water for domestic, agricultural, and industrial requirements. Gurgaon district, which is economic capital of Haryana state, stands at very critical juncture due to its alarming decrease in ground water levels. As surface water potential is not promising in the district, there is increased dependence on ground water for meeting almost all types of water requirements. Gurgaon district is located between $76^0$40" E to $77^0$15" E longitude and $28^0$10" N to $28^0$32" N latitude and have geographical area of 1254.62 Sq. Km with an average elevation of 220 meters for its four blocks viz. Gurgaon, Sohna, Farukhnagar and Pataudi. The share of rural population is 64.42% of the total population and agriculture is the predominant occupation of the majority of the people in Gurgaon district. The main source of the irrigation is tube-well, which irrigates about 96.8% of the total irrigated area. Indiscriminate use of underground water for agricultural and other uses has depleted the ground water to the level of over exploited category.

The agriculture in Gurgaon district started transforming in sixties and seventies due to advent of electrification and green revolution. Due to high use of natural and artificial resources, the production and productivity of the district noticed a marked increase. Though, the development of tubewell irrigation has contributed significantly to the increase in food production and reduction in poverty, sustainable development and management of this resource has posed many challenges in recent years. Strategically located Gurgaon district and especially Gurgaon city and block, at a distance of thirty-two kilometers from Delhi, it is an important town of N.C.R. and forms a part of Delhi Metropolitan Area. It is challenged by a very fast growth rate with increasing construction activities for residential and commercial activities which has added fuel to fire. Major problems associated with the ground water development and management are over exploitation of ground water, water logging and salinity, ground water pollution and ultimately precise evaluation of ground water potential. Continual debate on falling water table and deteriorating soil health has prompted general public, farmers, scientists and policy makers to rethink. Presented research is major attempt in this direction to suggest sustainable solutions to offer mentioned problems.

Thirty five years period ranging from 1974 to 2008 has been used for the analysis of all data. Total period under consideration was divided into five year average scenarios. For each scenario of average of five years, water balance was carried out for water budget year viz. June of current period to June of next period. In this time period, two stress

periods were considered viz. June to September (120 days Monsoon Period) and October to next June (245 days Non-Monsoon Period). Monsoon stress period was simulated at four time steps (end of each month) and non-monsoon period was simulated at eight time steps (end of each month) when used with MODFLOW model. Thus 1974 to 2008 period was divided into seven five year average time periods, and each period was divided into two stress periods giving total 14 stress periods (7×2) and 84 time steps (7×12). Block was considered as basic unit for all calculations as per the guidelines of central ground water board. Future prediction for year 2025 and 2050 has also been carried out for planning purpose.

Intense competition among user's viz. agriculture, industry, and domestic is main force driving natural resources in unsustainable manner. Therefore major objective of research was to prepare integrated ground water resource roadmap indicating gradual development of ground water resources, its present and prospects in terms of quantity, depth and locations considering above users. Thorough analysis of rainfall data, geomorphologic features, topography, landform characteristics, soil characteristics and natural land cover of Gurgaon district was carried out as first step. Groundwater is an integral part of the environment, and hence cannot be looked upon in isolation. Therefore blockwise water balance of Gurgaon district was carried out using all components of input and output. Input parameters considered in groundwater system were rainfall, recharge due to rainfall and recharge due to irrigation. Output parameters also called as pumping or withdrawal parameters considered were domestic water use, agricultural water use, industrial water use, domestic and other animal's water use and institutional water use. Standard professional methods like central ground water board methods for recharge estimation, Priestley-Taylor method for crop water requirement estimation were used for calculation of input and output calculations.

Proper assessments of groundwater recharge and pumping at past, present and future is of paramount importance in the management of groundwater resources in optimal manner. For this and to represent data spatially we used Modflow model (Version 5.3.1 © Chiang, W. H. and Kinzellbach, W., 1991-2001). MODFLOW, a modular three-dimensional finite difference groundwater flow model developed by the U. S. Geological Survey simulates saturated flow in three dimensions. MODFLOW is probably the most widely used, tested and verified model today because of its versatility and an open structure.

Total Gurgaon district area of 1254.62 km^2 was modeled using 102 column and 66 rows making total grid cell number of 6732, in which 3861 cells were coming within the boundary of Gurgaon district. Each grid cell had 570.03 m length by 570.03 m width making 324934.20 m^2 area. Ground water observation well data for about 75 wells evenly spread all over the geographic area of Gurgaon district was utilized for the analysis. Then input of model parameters viz. storage coefficient (0.011) and effective porosity (0.16) were given and transmissivity was specified as the model calculated value. Then results were obtained for aquifer parameters viz. storage coefficient, and transmissivity using pump tests and average value of Theis' Method, Cooper-Jacob Method, Chow's Method solutions and recovery test. MODFLOW model was calibrated to match the observed drawdown with model calculated drawdown using different values of aquifer parameters. Using this calibrated model and water balance inputs of 35 years averaged over five year period, recharge, pumping, balanced water as well as horizontal exchange at various time developmental stages and potential were estimated.

Calibrated model was also utilized for future prediction for 2025 and 2050 for monsoon and non-monsoon periods as well as for various management decisions like situation under normal rainfall conditions, effect of water conservation assisted recharge and roof top harvested water recharge on drawdown of groundwater resources of Gurgaon district. For identification of potential ground water recharge sites, first of all water extraction pattern and water deficit area were identified. To obtain these contours of water drawdown at the end of each five year average period was carried out. These contours were then superimposed on the three dimensional mesh wire diagram of water table head of corresponding water withdrawal. For preparation of 3-D diagram help of Surfer was taken. Human activities, such as ground water withdrawal, irrigation etc. change the natural flow pattern, and these changes must be accounted for sustainable solutions. Therefore studying the water withdrawal contour diagrams, flow pattern was identified. In addition to this, studying water withdrawal contours and flow pattern, potential sites of water recharge for water conservation schemes on large scale were identified.

Study of ground water sustainability of Gurgaon district, Haryana thus gives quantitative and spatial information on different components of ground water resources, their net and potential availability, block wise plans of water balance and various measures for sustainability of groundwater resources. Substantial study over sufficient long duration will result in significant saving of time and cost. This information is very useful in narrowing down the target areas for identifying recharge sites and understanding flow patterns. The spatial information generated on past, present and future prospects, depth & quantity at single site will help the planners and decision makers for devising sound and feasible ground water development plans.

Chapter 1

Introduction

Chapter-1
INTRODUCTION

1.1 Background

Groundwater, the nature's precious gift, once believed to be inexhaustible source of water, is now becoming more scarce and scarce in urban as well as in rural areas. Groundwater is an important source of water for domestic, agricultural, and industrial requirements. Due to invasion by sewage drains and gutters, most of the surface water sources are unable to serve clean and safe water. In today's context of water supply, groundwater is believed to be the most reliable source of water and large number of users competes for this limited source of water.

Water scarcity is becoming an increasing problem across the world, with 35% of the global land surface being semi-arid (Stanger, 1995). In 1997, it was reported that approximately 80% of countries suffer from serious water shortages, which encompasses 40% of the world's population (Nigam *et al*., 1997).

1.2 Groundwater Resources of India and Future Challenges

India's irrigation potential has increased from 22.6 m-ha in 1952 to 92.7 m-ha in 1996-97 in which share of ground water is about 50 per cent (CWC, 2000). Importance of ground water resources in India can be realized by the fact that about 60 per cent of irrigated food production depends on irrigation from ground water wells (Shah *et al*., 2000). There had been studies which suggest that productivity of ground water is 1.5 to 3 times more than the surface water (Chambers, 1988; Dhawan, 1989) due to the fact that it is available at the point of use, requires minimum conveyances infrastructure, is available on demand and maximizes the water application efficiency. Other advantages of ground water use are lesser cost of storage, short gestation period and relatively more dependable source of water supply.

Though, the development of tube well irrigation has contributed significantly to the increase in food production and reduction in poverty, sustainable development and management of this resource has posed many challenges in recent years. Major problems associated with the ground water development and management are over exploitation of ground water in several parts of the country, water logging and salinity due to rising water table in major irrigation commands, correct assessment of ground water potential and ground water pollution. The number of ground water structures in our country has increased rapidly from 4 million in 1950-51 to 18 million in 1996-97. It has been reported that decline in water level could reduce India's harvest by 25 per cent or more in coming years (Seckler *et al*., 1989).

1.3 Groundwater situation in NCT Delhi and Gurgaon District in particular

Situation in India's capital is not much different. National Capital Territory (NCT) of Delhi is in serious grip of water crisis, more so during dry season when the situation gets worse. As the demand and supply gap widens, more groundwater is being pumped. The need to have independent and reliable water supply has led to excessive, and at times, indiscriminate groundwater withdrawal in different parts of the territory. In NCT Delhi, sufficient amount of surface water is available during monsoon season. This is due to large scale paving, which produces high volumes of runoff. Part of this can be stored in to aquifer for future use by the well-known technique of groundwater recharge, which otherwise passes through drains and gets polluted and drained off in Yamuna River.

The town of Gurgaon, one of the 22 "Satellite" towns in the National Capital Region (N.C.R.), is symbolic of the modern trends of urbanization and planned development being witnessed in the past decades. Gurgaon has evolved from a mere piece of agricultural land to the suburb of Delhi catering to the ever-growing requirement of the region, be those industrial, commercial, or even residential. The NCR Regional Plan has envisaged Gurgaon as a metro centre in Central NCR and shall have a high level of physical, social and economic infrastructure, better than the capital.

Nearness to Delhi is one of the main factors contributing to its rapid urbanization. It not only shreds the urban load of Delhi but also endorses and serves home to the latest development in technology and urbanization. Intense competition among user's viz. agriculture, industry, and domestic is main force driving natural resources in unsustainable manner.

The district has been declared a ‘dark zone’ for its gradually decreasing level of ground water. Since the surface water potential is not promising in the district, there is increased dependence on ground water for meeting the agricultural domestic and industrial requirements resulting in depletion off ground water resources in the district. The district has seen a sharp decline in ground water table by four to six feet per year (2006-2008).Located between the East longitudes of 74°27’00’’ and 77 ° 35’00’’ and North latitudes of 21° 39’00’’and 30°55’00’’,the district is having a geographical area of 1254 Sq.Km. The share of rural population is 64.42% of the total population and agriculture is the predominant occupation of the majority of the people in Gurgaon district. 92.4% of the net sown area is irrigated in the district. The main source of irrigation is tube-well, which irrigates about 96.8% of the total irrigated area. Indiscriminate use of underground water has depleted the ground water to the level of over exploited category.

1.4 Groundwater Sustainability

The sustainable use of groundwater should begin by tapping primarily deep percolation, and secondarily shallow percolation. The latter should be exploited only if its effects on the baseflow of neighboring streams and water bodies are shown to be minimal (Ponce, V. M., 2010). Detailed hydrological, environmental and geological studies are required to determine the exact amount of recharge under different conditions. Pre-development and various stages of development dependent hydrological studies are necessary to assess and monitor the effect on groundwater use to suggest sustainable solutions. To guarantee sustainability, these studies should also accompany planned groundwater development.

Estimation of groundwater recharge requires proper understanding of the recharge and discharge processes and their interrelationship with geological, geo-morphological, soil, land use, and climatic factors (Thornthwaite and Mather, 1957). Recharge greatly depends on the occurrence and distribution of rainfall and to some extent on other climatic parameters like temperature and atmospheric pressure. Due this fact, the understanding of interrelationship between rainfall and recharge is of paramount importance in groundwater recharge studies. Also, transpiration from the tree species, loss of water due to capillary rise and vapor transport due to temperature gradient has significant role in withdrawal of recharged water. Therefore, before planning any recharge scheme it is imperative to have through knowledge of these processes.

Organizations engaged in the groundwater recharging have been suggesting recharging all the volume of water that is available in the form of surplus runoff and designing the recharge structures accordingly. Adopting this strategy, many areas may witness prolonged standing water condition, if aquifer does not have enough capacity to store the recharged water. This is another important aspect to be taken into consideration. Recharge potential of the aquifer determines the volume of the water that can be put into the aquifer, and plays a key role in the selection of the recharge structure. Therefore, assessment of suitability and capability of the aquifer to store and yield the recharged water will be an added advantage in the planning process.

Large numbers of mathematical models based on physical, tracer or numerical modeling techniques are available in the literature for the estimation of recharge potential of an aquifer. (Scalton *et al*., 2001).A variety of groundwater recharge structures have been developed for artificial recharge of aquifers, choice of which is governed by the aquifer characteristics, local topography, geology and soil conditions and quantity of water to be recharged.

Presented research provides all necessary requirements in which detailed analysis of last 35 years, taking 5 year average scenarios, both in monsoon and non-monsoon seasons has been carried out. Instead of suggesting one rigid plan of action, various possible alternatives, concerns and problems have been given. Facts and figures of in depth analysis of groundwater system of Gurgaon district have been given in results and discussion chapter. To help decision makers, baseline conditions (normal rainfall and no pumping), effect of roof top water harvesting and water conservation structures as well as future predictions for year 2025 and 2050 (monsoon and non-monsoon classified) have been given. To identify problems and suggest solutions, spatial analysis using Surfer software has also been given. It is expected that utilizing these all information, various stake holders, decision makers and planners may arrive at sustainable solutions for groundwater utilization in Gurgaon district.

1.5 Need of Study

Large-scale urbanization and industrialization has immensely changed the patterns of land use through encroachment on various types of land and forests areas leading to environmental degradation with serious consequences especially for water resources.

The unsustainable use of groundwater resources in Gurgaon district has led to various levels of impact on different hydrological, ecological and other natural resources like freshwater bodies, biodiversity, ecosystems etc. If such practices remain continued then there will be serious consequences like decrease of baseflow, loss of wetlands and streams, degradation of rivers and permanent damages to wildlife habitat. Other impacts might be drying up of wells, salt-water intrusion and land subsidence.

A pragmatic approach to the problem demands sustainable development so as to meet the needs of the present generation without endangering the quality of environment for future generations. The urban residential, commercial and Industrial systems in order to meet the global standards have adopted methods to meet their demands which are not environmental friendly. Therefore present situations demand the breakthrough solutions for sustainable development which can maintain balance between development and environment.

1.6 Objectives of Research

Following are the objectives of the proposed research work:

i. To study various components of groundwater balance with major focus on the sustainability for Gurgaon District of Haryana State, India.
ii. The computation of net ground water resource availability and potential.
iii. To make block wise plan for the sustainable usage of groundwater resources for future using MODFLOW by simulation, modeling and flux computations.
iv. To recommend remedial measures for future policy for sustainable use of groundwater resources in Gurgaon District of Haryana State, India.

Chapter 2

Review of Literature

Chapter-2
REVIEW OF LITERATURE

2.0 Introduction

Groundwater recharge is the downward flow of surface water joining the water table and thereby adding an additional amount of water to groundwater reservoir. Groundwater recharge may be natural or artificial. Natural recharge takes place naturally without any intervention and human effort. Artificial recharge systems are the engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to aquifers to augment groundwater resources (Bouwer, 2002).

According to UNEP artificial recharge of groundwater is the planned human activity of augmenting the amount of groundwater available through the works designed to increase the natural replenishment or percolation of surface waters into the groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction (UNEP, 2000). Central Groundwater Board of India defines artificial recharge as the process by which the groundwater reservoir is augmented at a rate exceeding that under natural conditions of replenishment (CGWB, 1994).

The main source of groundwater recharge is the rainfall. The other sources of groundwater recharge are

i. Recharge due to seepage from the canals
ii. Return seepage from the irrigation fields
iii. Seepage from the tanks

At a given locality, recharge is largely governed by number of processes. Infiltration is the first and foremost process that regulates the flow of water to underlying formations. Infiltration is largely dependent on the surface soil conditions and vegetative cover. The infiltrated water may or may not reach the groundwater table because of limitations posed by the processes occurring in the unsaturated zone. There may be considerable reduction in the recharge, even under favorable infiltration rate, due to presence of low conductivity horizons and low transmissivity of the aquifer. In such cases infiltrated water may disappear as interflow to nearby location where it runs off or evaporates instead of joining water table. It may also happen that surface soil may possess limited infiltration rate, but the aquifer material bears good transmissivity and high percolation rate. If this situation prevails in areas of good rainfall it gives rise to production of high runoff volumes.

Natural recharge is how natural (meteoric) groundwater is formed as the difference between the water inputs into the soil (precipitation and infiltration from the streams, lakes, or other natural bodies) and outputs (evapotranspiration and runoff) (Bouwer, 2002). Natural recharge is typically about 30-50% of precipitation in temperate humid climates, 10-20% of precipitation in dry climates (Bouwer, 1989, 2000c; Tyler *et al*., 1996).

Based on several field studies, CGWB of India has also estimated the natural groundwater recharge for various zones of India. For alluvial plains covering Indo-Gangetic and inland areas, east coast and west coast recharge varies between 8-22% of precipitation. In hard rock areas of Indian peninsula, recharge was estimated as 5-14% of the precipitation.

Estimation of groundwater recharge and its availability around the year is very important activity for efficient and sustainable groundwater resource management in a given area. Several field methods and groundwater models are available for the estimation of groundwater recharge.

In this chapter a thorough review on groundwater recharge processes, factors affecting groundwater recharge, various methods for the estimation of groundwater recharge and assessment of rechargeable runoff have been presented.

2.1 Recharge Process

Number of processes occurring at the soil surface, in the vadose zone and in the aquifer itself affects the rate of recharge directly or indirectly.

Lerner (1997) put forth three processes by which recharge occurs. These are,

i. Diffuse percolation, as unsaturated flux or a saturated front (Piston-type flow),
ii. Macro-pore flow through root channels, desiccation cracks and fissures, and
iii. Preferential flow caused by unsaturated wetting fronts and different soil physical characteristics within the soil.

Rainfall supplies the land surface with water, soil allows the water to infiltrate to the water table, and a deeper geologic framework provides the permeability necessary for the deeper flow.

The other processes that govern the recharge are summarized below.

2.1.1 Infiltration Rate

Infiltration is the first and the foremost process that has its great influence on quantity and rate of recharge, particularly in the situations when surface methods of groundwater recharge are followed. Infiltration is associated largely with the land surface. A natural depression with good infiltrating soils underlain by transmissive aquifers constitutes good sites for the percolation ponds.

2.1.2 Vegetation Evapotranspiration

Due to the high evapotranspiration rates, vegetation bears good powers of controlling the groundwater recharge; this fact makes vegetation as an important parameter in assessing the recharge potential at a site. Recharge is generally much greater in the non-vegetated than vegetated regions (Gee *et al*., 1994) and greater in the areas of annual crops and grasses than in areas of trees and shrubs (Prych, 1998). Enhanced recharge consists mainly of vegetation management to replace the deep-rooted vegetation by shallow rooted vegetation or bare soil, or by changing to plants that intercepts less precipitation with their foliage, thus increasing the amount of water that reaches the soil. In wooded areas, this is achieved, for example, by replacing the conifers with deciduous trees (Querner, 2000). Studies conducted by Gee *et al*., (1994) at Hanford have shown that when desert plants are present on sandy or gravelly surface soils, deep drainage was reduced but not eliminated.

2.1.3 Clogging Ability of Aquifer Material

Water sources for in- and off-channel recharge systems should be of adequate quality to prevent clogging of infiltrating surface by the undue accumulation of suspended solids, by formation of bio-films and biomass on and in the soil; by precipitation of calcium carbonate or other salts on and in the soil; or by formation of gases that remain entrapped in the soil, where they block the pores and reduce hydraulic conductivity. Clogging of the infiltrating surface and reduction in the infiltration rate are the bane of all artificial recharge schemes (Baveye *et al*., 1998; Bouwer *et al*., 2001; Bouwer and Rice 2001). Pretreatment of water to reduce suspended solids and regular drying of the system to enable drying and cracking of clogging layer might be necessary to minimize the clogging effect.

2.1.4 Capillary Rise

Water that has passed the root zone can be assumed to have escaped the evapotranspiration and could recharge the groundwater reservoir. However, mechanisms exist that can cause soil water to ascend from considerable depths, notably under arid and semi arid conditions. Coudrain-Ribstein *et al*., (1998), for example, report on isotope studies that suggest fluxes of about 1mm/year by capillary rise from the water table at a depth of about 20m.

2.1.5 Vapour Transport

This is another mechanism that produces considerable flux in situations with a temperature gradient. De Vries *et al*., (2000) measured an average temperature difference of 4^{o}C in the Botswana Kalahari sand beds between the root zone causing upward vapour transport during the winter and downward vapour transport during summer of about 0.2-0.3 mm per season.

2.1.6 Preferential Flow

Percolation of rainwater through cracks, fissures and worm and root channels in the soil (preferential flow paths) is receiving increasing attention from scientists all over the world. De Vries, (2000) reported that preferential flow contributes on average -50% of the estimated recharge, though values as high as 70-90% are known.

De Vries and Simmers (2002) have presented comprehensive studies on various processes, which govern the recharge. They reported that interaction of climate, geology, morphology, soil condition and vegetation determines the recharge process. In addition to infiltration, permeability, rainfall and aquifer parameters, transpiration by vegetation, vapor transport, fluxes of capillary rise and hydraulic gradient from paleoclimatic conditions remains as an important processes that regulates recharge. Vegetation transpires considerable amounts of water from water table and it's significant effect was found in the range of 20 to 30 m below ground level. Loss of water by vapor transport and capillary rise was reported as 0.2 to 0.3 mm/season and 1 mm/year respectively.

2.2 Factors affecting groundwater recharge

The mechanism by which water reaches to the saturated zone greatly depends on various aquifer and unsaturated zone properties. Various recharge parameters that have influence on the quantity and rate at which water is recharged are discussed here.

2.2.1 Specific yield

Specific yield is the volume of water that can be drained from the unit volume of aquifer formation under the influence of gravity. Specific yield of aquifer becomes a vital parameter when water table fluctuation method is employed for the estimation of groundwater recharge and also in the estimation of static and dynamic groundwater resource of the area.

Singh, (2002) distinguished between static and dynamic groundwater component. The dynamic groundwater resource is amount of groundwater available in zone of water level fluctuation. Whereas static groundwater component is groundwater contained within the permanently saturated zone of the groundwater reservoir, and represents total groundwater reserve minus the dynamic component.

Static component of groundwater is estimated as :

$$Q_s = b^* A^* S_y \qquad \text{............ (2.1)}$$

Where: Q_s = static groundwater reserve (m^3)

b = thickness of aquifer below the zone of groundwater level fluctuation down to exploitable limit (m)

A = areal extent of the aquifer (m^2)

S_y = specific yield of the aquifer (dimensionless)

Specific yield concept gives clear idea of how much water the aquifer can store and it is a good indicator of storage potential of the aquifer. But how good it is as a reservoir is dependent on how quickly you can get the water out of it. Specific yield increases as sediment size decreases down to medium sands, but then begins to decrease, as sediments get smaller than medium sand. This is largely due to surface tension of water, which causes more and more of the water to adhere to individual particles, as they get smaller. Small particles have much larger surface area per unit volume and it is this surface area that water spreads over. The water released in the rock to surface tension is called pendular water (Fetter, 2001).Norms for the specific yields provided in the report of Groundwater Resource Estimation committee of CGWB (1997) are presented in Table2.1

2.2.2 Hydraulic conductivity

Hydraulic conductivity is the rate at which volume of water is moving through a given area of aquifer when subject to a hydraulic gradient. Hydraulic conductivity is measured in volume per unit time per unit area i.e. m^3/m^2 day or simply as m/day. Some typical values of hydraulic conductivity of aquifer material are presented in Table 2.2.

Permeability is the ability of a rock or a rock or earth material to transmit water, while hydraulic conductivity is a measure of this ability determined by the size and shape of the pore spaces in the medium and their degree of inter connection and also by the viscosity of the fluid.

Table 2.1 Norms for selection of Specific yield (%) value for different types of aquifer

Aquifer / Area Type	Recommended	Minimum	Maximum
A) Alluvial areas			
Sandy alluvium	16	12	20
Silty alluvium	10	8	12
Clayey alluvium	6	4	8
B) Hard rock areas			
Weathered granite, gneiss and schist, with low clay content	3	2	4
Weathered granite, gneiss and schist with significant clay	1.5	1	2
Weathered or vesicular jointed basalt	2	1	3
Laterite	2.5	2	3
Sand stone	3	1	5
Quartzite	1.5	1	2
Limestone	2	1	3
Karstified limestone	8	5	15
Phyllites, shales	1.5	1	2
Massive poorly fractured rock	0.3	0.2	0.5

(Source: CGWB, 1997)

Hydraulic conductivity of aquifer formation is a function of under listed parameters of aquifer material:

i. *Median grain size*. Hydraulic conductivity and grain size has direct relationship. As grain size increases, pore spaces are larger and permeability increases because surface tension effects are reduced.

ii. *Sorting*. In case of poorly sorted material there are more chances of the large pores to get filled by the smaller sized particles because of their movement with the flowing water. This situation gives rise to reduced hydraulic conductivity. However, if the percentage of clay particles is comparatively less they stick to the other larger size particles by the adhesive force and hydraulic conductivity may be of considerable magnitude.

Table 2.2 Typical hydraulic conductivity values of various soils.

Type of formation	cm / hr
Unconsolidated deposits	
Gravel	5764.84
Clean sand	571.347
Silty sand	57.705
Silt, loess	0.57083
Glacial till	0.05707
Un-weathered marine clay	0.00005
Rocks	
Shales	0.000057
Un-fractured metamorphic and igneous rocks	0.0000057
Sandstone	0.057083
Limestone and dolomite	0.0571347
Fractured metamorphic and igneous rocks	5.7083
Permeable basalt	570.83
Karst limestone	570.83

(Source: Freeze and Cherry, 1979)

iii. *Weathering,* which creates secondary pores
iv. *Degree of fracturing:* a highly fractured zone creates more pathways for the movement of water and the consequence is increased permeability.
v. *Characteristics of fluid (viscosity, density)*
vi. *Anisotropy* gives information about the velocity at which water move in different directions.

In general, unconsolidated sands have high porosity and permeability, which is an indication of better aquifer. A basalt aquifer may also have high hydraulic conductivity if it contains sufficient amount of fractures, and can act as a good aquifer with good water yields.

Another important consideration is layering of the aquifer. Layering determines the method to be adopted for the recharge of the aquifer. If a relatively impervious layer at shallow depth overlies aquifer, the surface spreading methods of recharge will be of no use, as water will start encroaching root zone, and the consequence will be the problem of water logging. Therefore, for having the insight of layering of aquifer strata, it is important to evaluate hydraulic conductivities at different depths.

2.2.3 Physiography

An understanding of physiography provinces is useful in developing conceptual model of recharge in a system (Scanlon *et al*, 2002). This will help in identifying the recharge sources, flow mechanisms and spatial variability in the recharge.

2.2.4 Soil texture

Fine textured soils, like clay series, though they are having higher porosities, they are less permeable owing to small size of pores, which imparts high resistance to flow. In contrast, coarse textured soils, like sandy soils, bears good permeability values and has greater recharge rates in general. Cook *et al*., (1992) have found out an apparent negative correlation between clay content in the upper 2m depths and recharge rate. Therefore, knowledge of the soil texture and their permeability values is highly important in the recharge schemes where surface spreading techniques are used for the artificial recharge of aquifers.

2.2.5 Effective porosity

Effective porosity is the interconnected pore volume or void space in aquifer material that contributes to fluid flow in a reservoir. Effective porosity does not include isolated pores and pore volume occupied by water adsorbed on clay minerals or other grains. Total porosity is the total void space in the rock whether or not it contributes to fluid flow. Effective porosity is typically less than total porosity. Porosity determines the maximum volume of water that can be held in the pores of formation. Porosity of the formation depends on the type of packing of particles (cubical, rhombic or rhombohedral) constituting an aquifer and it practically independent of the diameter of the particles forming an aquifer. Other factors that affect the porosity are,

- Sorting
- Grain shape
- The size and abundance of fractures
- The extent of cementing between particles

Table 2.3 Porosity of some geologic materials

Sl. No.	Geologic materials	Percentage (%)
1.	Un compacted mud	40 – 70 %
2.	Unconsolidated sand	25 – 50 %
3.	Sandstone	5 – 30 %
4.	Shale	< 10 %
5.	Unfractured igneous rock	< 5 %
6.	Unfractured marble	< 3 %

(Catherine, 2004)

Taneja and Khepar (1996), carried out investigations on effect of artificial recharge on the various parameters of the aquifer using a sand tank model simulating the confined aquifer. A cavity well was constructed, and analytical solution of the well hydraulics was developed. By discharging and recharging the well, data on the rise and fall of the water table were collected Aquifer parameters were estimated by substituting these data in the analytical solution. It was observed that during the recharge through the well, the hydraulic conductivity and the specific storage coefficient of the aquifer decreased by 15% and 13% respectively in relation to those of discharge. Also, the aquifer parameters found to be least affected with the change in the rate of recharge or discharge.

2.3 Methods for estimation of groundwater recharge

Number of methods is available in the literature for the estimation of natural and artificial recharge to the aquifer, selection of which depends on available data, local geographic and topographic conditions, spatial and temporal scale required and reliability of results obtained by different methods. According to Scanlon *et al*. (2002) techniques based on the surface water and unsaturated-zone data provide estimates of potential recharge, whereas those based on groundwater data provides estimate of actual recharge. Owing to uncertainties involved in each approach, he suggested to use multiple techniques to increase the reliability of the results.

2.3.1 Water table fluctuation (WTF) method

In the application of WTF method the basic assumption is that, the rise in the groundwater level in unconfined aquifer is only due to recharge water arriving at the water table. Recharge is calculated as

$$R = S_y\, dh/dt = S_y\, \Delta h/\Delta t \qquad \text{…………… (2.2)}$$

Where,

R = rate of recharge (LT^{-1})

S_y = specific yield, ($M^0L^0T^0$)

Dh = Δh = water table rise, (L)

Dt = Δt = time within which rise dh takes place, (T)

The value of R obtained above can be multiplied by areal extent of aquifer to get recharge in terms of volume per unit time.

A time lag occurs between the arrival of water and its redistribution to the other components like base flow, groundwater evaporation and net sub-surface flow from an area. WTF method can be applied over longer time intervals (seasonal or annual) to estimate the change in subsurface storage. Healy *et al*., (2002) reported that the WTF method for estimation of groundwater recharge was applied as early as the 1920s (Meinzer, 1923; Meinzer and Stearns, 1929) and since then has been used in numerous studies.

The method is quite simple as no assumptions are made on the mechanism by which water reaches to groundwater. The method has some disadvantages also. Water table fluctuation method is applicable to only unconfined aquifers and the method cannot account for steady rate of recharge. This means, if the rate of recharge from an area is equal to rate of drainage, water levels will not change and WTF method will predict no recharge. Other difficulties arise in calculation of specific yield values.

Many researchers have tried this method for the estimation of groundwater recharge. Allison *et al*., (1990) employed water table fluctuation method for estimation of artificial recharge in southern Australia. They observed groundwater levels that were steadily increasing at 0.1 m/year following clearing of native vegetation. Assuming a specific yield of 0.2 this corresponds to an increase in recharge of 20 mm/year. This value was found consistent with the recharge estimated by other independent methods.

Comprehensive reviews on the groundwater recharge estimation methods that are based on groundwater level data were presented by Healy and Cook (2001). They concluded that WTF method that uses specific yield and variations in water table level over time might be the most widely used method for the estimation of groundwater recharge.

2.3.2 Water budget method

The water budget methods are those that are based on water budget equation. The water budget of a basin can be stated as

$$P + Q_{on} = ET + Q_{off} + \Delta S \qquad \ldots\ldots\ldots\ldots(2.3)$$

Where,

P = precipitation (and may also include irrigation) (mm/day)

Q_{on} and Q_{off} = water flow onto and off the site (surface flow, interflow and groundwater flow) (mm/day)

ET = evapotranspiration (mm/day) and

ΔS = change in storage (mm/day).

Based on the above water balance equation, Schict and Walton (1961) formulated the budget equation for recharge estimation as:

$$R = \Delta S^{gw} + ET^{gw} + \left(Q^{gw}_{off} - Q^{gw}_{on}\right) + Q^{bf} \qquad \text{……………….. (2.4)}$$

Where,

R = recharge

ΔS^{gw} = change in subsurface storage

Q^{bf} = base flow

ET^{gw} = evaporation from groundwater and

$Q^{gw}_{off} - Q^{gw}_{on}$ = net surface flow from the basin

In above model all other parameters, except R, can be measured or estimated. This method can be adopted for wide range of spatial and temporal scales. However, major limitation of this approach is that the accuracy of the recharge estimates depends on the accuracy with which other components of the water balance equation are measured (Scanlon *et al*., 2002).

2.3.3 Darcy's law

Darcy's law states that fluid flux; such as recharge in an aquifer system can be calculated if both the head gradients and hydraulic conductivities are known. Darcy's law is used to calculated recharge (R) in the saturated zone according to the following equation:

$$R = -\frac{K(\theta)dH}{dz} = -K(\theta)\frac{d}{dz}(h+z) = -K(\theta)\left(\frac{dh}{dz}+1\right) \qquad \text{……….………. (2.5)}$$

Where,

K(θ) = hydraulic conductivity at the ambient water content,

H = total head, and

h = metric potential head

z = horizontal distance between the two points where hydraulic head is measured

Application of Darcy's law requires measurements or estimates of the vertical total head gradient and the unsaturated hydraulic conductivity at the ambient soil-water content. The method has been applied in many studies under arid and semiarid conditions (Enfield *et al*., 1973; Sammis *et al*., 1982; Stephens and Knowlton 1986) and also under humid conditions (Ahuja and El-Swaify 1979; Steenhuis *et al*., 1985; Kengni *et al*., 1994); Normand *et al*., 1997).

In the areas where thick unsaturated zone exists in uniform porous media the value of metric potential head can be assumed to be 1. (unit-gradient assumption)(Gardner, 1964; Childs, 1969; Chong *et al.*, 1981 and Sisson, 1987). The unit-gradient assumption removes the need to measures the metric pressure gradient and sets recharge equal to the hydraulic conductivity at the ambient water content.

2.3.4 Empirical relationships

Empirical relationships can also be developed between groundwater recharge and rainfall based on seasonal groundwater balance studies. Kumar and Seethapathi (2000) made one such attempt for Upper Ganga Canal command area. An empirical relationship was suggested for estimation of the ground water recharge by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression techniques. The relation between rainfall and recharge is shown by the equation as

$$R = 0.63\ (P - 15.28)^{0.76} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

Where,

R = recharge (m)

P = precipitation (m)

The above equation is based on Chaturvedi (1973) formula for Ganga-Yamuna doab.

2.3.5 Groundwater models

Recharge measurements in the field still contain an appreciable amount of uncertainty and much study on the subject is ongoing (Sanford, 2002). Along with the variety of approaches used to make measurements in the field, investigators have used groundwater models in estimating recharge. Models can also be used to predict distribution of recharge in temporal and spatial scales based on the geologic properties and rate of recharge.

Groundwater flow and contaminant transport models are being extensively used in the studies related to groundwater systems. Groundwater flow models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface. These calculations are referred to as simulations. The simulation of groundwater flow requires a thorough understanding of the hydro-geologic characteristics of the site (DEQ, 2001-2004).

The accuracy of model predictions depends upon successful calibration and verification of the model in determining groundwater flow directions, and transport of contaminants. In relation with groundwater models, Sanford (2002) has highlighted two important issues. As recharge is a fundamental component of the groundwater models, while reviewing one must assess how recharge is *represented* in the groundwater models and how recharge is *estimated* using groundwater models. Use of groundwater models is very fruitful. The analysis proposed by artificial recharge scheme has been improved by groundwater modeling exercises (Peters, 1998); Latinopoulos, 1981).

2.3.6 Tracer techniques

Recently, the techniques based on the heat or chemical isotopic tracers are gaining much importance in the estimation of groundwater recharge. Measuring the concentration of the environment tracers that indicate groundwater age has been increasingly popular approach in this field. Number of articles and research papers about application and theories of isotopic methods for characterizing groundwater and recharge are available. In the field of groundwater, isotopic tracers provide a powerful investigative tool. Coplen (993) reported that another major technological growth area has been in the application of isotopic analysis to groundwater hydrology, wherein isotopic measurements are being used to help interpret and define groundwater flow paths, ages, recharge areas, leakage, and interactions with surface water.

Datta (1999) used the signatures of ^{18}O isotopes to investigate groundwater occurrence and recharge in the National Capital Territory (NCT) of Delhi. These signatures revealed that groundwater in well of Delhi area are a mixture of varying proportions of different water sources and the aquifer in the area does not constitute a homogeneous system in lateral extent.

Due to large uncertainties involved in the measurement of individual parameters of each method, many researchers (Healy and Cook, 2002, Scanlon *et al*., 2002) have suggested that it is highly beneficial to apply multiple methods of estimation to arrive at somewhat reliable results.

McCartney and Houghton (1998) used three independent methods for the computation of groundwater recharge on the Channel Island of Jersey. These are (a) chloride balance, (b) stream base flow analysis, and (c) rainfall-recharge-runoff simulation. All three methods produced reasonably consistent results, indicating that long-term recharge is 16-19% of average annual rainfall, and results of modeling indicate that groundwater abstraction may have exceeded recharge in 5 out of 28 years.

2.4 Estimation of groundwater recharges rate and potential

Groundwater recharge rate, which is the rate at which the water table is replenished (during rainfall, irrigation or from seepage from surface water bodies), it is the single most important parameter one needs to know in developing the groundwater resource. It is also important as one of the important inputs into groundwater management models and in the studies of contamination and pollution of groundwater resources and determination of safe dumping sites for wastes.

In order to represent recharge effectively in a groundwater model, one must consider both the processes that control the rate of recharge and objectives of the modeling study (Sanford, 2002). The factors that control the rate of recharge are related to hydrologic landscape of the aquifer system. The three main factors in the hydrologic landscape that control water flow are classified by winter (2002) as climate, topology and geologic framework.

Proper assessments of groundwater recharge and potential are the two factors of paramount importance in the management of groundwater resources in optimal manner. Gee *et al*., (1994) studied the recharge potential under three distinct and different climatic and soil conditions. All three sites showed increased water storage with time when soils are coarse textured and plants are removed from the surface, the rate of increase was found to be influenced by climatic variables such as precipitation, radiation, temperature and wind. Recharge from bare sandy soil was estimated as of the order of 10 to >50% of the annual precipitation.

Brand (2003) assessed the potential for artificial recharge in the upper black squirrel creek basin, Colorado, using chloride mass balance techniques for the quantification of natural recharge. He investigated other aquifer properties like lithology by drilling test holes; percolation rates by conducting constant head bore hole percolation testing. Infiltration rates (analogous to vertical hydraulic conductivities) were calculated using the methodology developed by Bouwer *et al*., (1998). The chloride mass balance analysis revealed that natural recharge rate to the aquifer was approximately 5.2 cm per year.

Ali and Turner (1997) put forth an innovative idea for the recharge of groundwater in Eastern Goldfields of Western Australia. They proposed to investigate the feasibility of harvesting the periodically available surface water resources in the region that accumulate in natural impoundments such as salt lakes, and artificially recharging them into shallow aquifers for later recovery and use, provided the aquifer used for the recharge was having sufficient storage potential.

Smith (1968) established a criterion for the estimation of the recharge potential of the aquifer based on the parameters like thickness and areal extent of the aquifer, minimum economical withdrawal rate; as well as the limits of the turbidity, temperature, and mineral and bacteriological quality of the recharge water. These recharge criteria were applied to areas of Illinois where aquifers were known to exist. Estimates show large potential for artificial recharge in to the surface sands and gravel aquifers of the state.

Kaledhonkar *et al*., (2003) carried out a case study on artificial groundwater recharge through recharge tube wells constructed in the bed of old *Sirsa* canal bed in the North-Eastern region of the state of Haryana. Location for the tube wells were selected based on the electrical resistivity surveys. Performance of the recharge wells was evaluated based on the water level observations in the grid of observation wells installed on one side of the canal. The recharge tube wells performed well with an average recharge rate of 10.5 lps for individual well, which was reasonably good.

2.5 Assessment of rechargeable runoff

In order to augment the depleting ground water resources, it is essential that the surplus monsoon runoff that flows into the sea is conserved and recharged to augment ground water resources. Ground water storage that could be feasible has been estimated as 214 Billion Cubic Meters (BCM) of which 160 Billion Cubic Meters is considered retrievable. The Central Ground Water Board (CGWB) has prepared the master plan for artificial recharge to ground water for all states in the country. Out of total geographical area of 3287263 sq. km. of the country, an area of 448760 sq. km. has been identified feasible for artificial recharge. The total quantity of surplus monsoon runoff that can be recharged, works out to be 36.4 BCM. The master plan envisages number of artificial recharge and water conservation structures around 39 lakh in the country at an estimated cost of Rs. 24500 crores.

Runoff is an important parameter in the watershed management and in flood prone areas necessitating flood control measures. Reliable prediction of runoff from an un-gauged watershed is tedious and time consuming. However, this problem can be well circumvented by Soil Conservation Service Curve Number method of runoff prediction. Curve Number (CN) is a quantitative descriptor of the land use/land cover and soil characteristics of a watershed and is commonly assigned values based on information acquired from field surveys and/or interpretation of aerial photographs. Remote Sensing and Geographic Information System technique can be used effectively to generate the land use/land cover and change detection map for evaluating the changes in an area.

Tiwari *et al*. (1991) reported that, the observed volume of runoff and that estimated using remote sensing and GIS technique have close correlation and the coefficient of correlation was found to be 0.80. Many researchers (Slack and Welch, 1980, Pandey and Sahu, 2002) have utilized the satellite data to estimate the USDA Soil Conservation Service Runoff Curve Number. To arrive at any optimal artificial recharge scheme for a basin, assessment of rechargeable runoff stays as a factor of prime importance. Surface runoff, which is highly variable and of short duration, does not occur during peak demand periods. Because there are no reservoirs, the runoff is lost by evaporation from shallow playas.

Biwalkar and Taneja (2003) analyzed the rainfall data and estimated the volume of non-committed surplus runoff for the '*kandi*' area of Punjab. After studying well logs at two different locations, recharge well was suggested as the best suitable means of recharging available surface water in to aquifers owing to the presence of three clay layers above water table which obstructed the percolation of surface water. The least hydraulic conductivity among various layers was found to be the controlling factor for groundwater recharge rate.

Bouwer and Rice (2001) proposed that some form of storage is needed where streams with varying flows are used for artificial recharge and the major runoff events occur in short "bursts", and where recharge system do not have enough capacity to absorb all the high flows at once. Water so stored can later be released slowly to the recharging structure. Turbid floodwaters for artificial recharge of groundwater may best be captured and stored in deep reservoirs where solids can settle to the bottom before water is diverted to the recharge system. The optimum combination of reservoir capacity for capturing the flood flows and of recharge capacity for storing them underground depends on the magnitude of flood flows to be captured, availability of land for storage and recharge, water needs, eco-environmental aspects, economics, and other local conditions.

2.6 Delineation of potential groundwater recharge zones

Identifying aquifer recharge area is important, as any pollution in these areas could affect the cleanliness of the aquifers and the purity of the water that comes from them (Ravella *et al*., 1996). In an effort to develop a better understanding of ground water recharge processes and to identify aquifer recharge areas in the Keene region, Ravella *et al*., (1996) determined soil infiltration rates and soil moisture contents, and monitored soil tension, water table and piezometric head levels over time at selected sites. Sites having high infiltration rate followed by high percolation and good aquifer hydraulic conductivity was selected as potential area for groundwater recharge.

The CGWB has prepared a Manual and subsequently a Guide on Artificial Recharge to Ground Water which provides guidelines on investigation techniques for selection of feasible sites, planning & design of artificial recharge structures, economic evaluation & monitoring of recharge facility. These are of immense use to States/ U.T.s in planning and implementation of artificial recharge and rain water harvesting schemes for augmentation of ground water in various parts of the country.

During the Ninth Five Year Plan, a Central Sector Scheme "Studies on Recharge of Ground Water" was undertaken by the CGWB, in which 165 artificial recharge pilot projects were implemented in 27 States/UTs in coordination with organizations of State governments & NGO / VOs, etc. with 100% central funding. Civil works were done by state implementing agencies under technical guidance of the CGWB. State wise details of pilot artificial recharge and rainwater harvesting projects along with their cost is indicated in Annexure I Efficacy of the recharge structures constructed in different hydrogeological conditions of the country was assessed through impact assessment studies taken after completion of recharge facility and has indicated rise in water levels and sustainability of dug wells/ tube wells locally including other benefits like decrease in soil erosion and improvement in socio-economic status of farmers of benefited zone due with increase in crop production

The decline in water levels indicates that much of the water has been withdrawn from storage and will continue to decline unless groundwater withdrawals are decreased and recharge areas are maintained. Location of groundwater recharge areas is important in developing groundwater management strategies to protect these areas from the negative impacts of land-use (Braun, *et al*., 2001).

Jyothiprakash *et al*. (2003), delineated the potential artificial recharge zones in Agniar-Ambuliar-Southvellar river basin in Tamilnadu through integration of various thematic maps using Arc View GIS. Thematic maps pertaining to geology, permeability, effective soil depth, drainage density, soil texture, water holding capacity and physiography were prepared. Each theme was assigned a weightage depending on its influence on the groundwater recharge. Ranking method was followed for the delineation of the potential recharge areas and final map was prepared showing four different categories of the potential zones for artificial recharge. The study showed that the areas having rapid permeability with higher water holding capacity in alluvium soil are excellent zones for constructing artificial recharge structures.

2.7 Application of models in groundwater studies

The earlier generation of irrigation performance indicators was based on canal flow data. Commonly, they quantify performance in a command area downstream of a discharge measurement device. Remote sensing determinants, such as actual evapo-transpiration, soil water content and crop growth reflect the overall water utilization at a range of scales, up to field level. Crop evapo-transpiration includes water originating from irrigation supply, water from precipitation, groundwater and water withdrawn from the unsaturated zone. Hence, this is a refinement in spatial scale as compared to the classically collected flow measurements, and describes moreover depletion from all water resources. If these possibilities are well implemented, we expect that a new generation of irrigation performance indicators can be quantified in a cost-effective manner. Especially, because satellite measurements pave a way to standardize data collection between different irrigation schemes among different countries at costs which are currently decreasing. These challenges can only turn into a success if irrigation managers are involved in pilot projects and demonstration studies exploring satellite data. W.G.M. Bastiaanssen (2007).

James *et al*., (1980) reported that use of numerical models requires an understanding of the physical problem and field data. To use these models, the hydrologist must assess the merits of alternative numerical methods, evaluate available data, estimate data where missing or absent, and interpret computed results. The review of previous model application can provide valuable insight on how these tasks may be approached. They stated that it may be necessary to modify some of the input data until all observed and predicted ground water table values compare sufficiently well. Parameter estimation techniques are used to modify the initial estimates of input data. They also warned about the misuse of models, like assuming 3D flow and inappropriate grid size, which results in additional work and expense.

James *et al*., (1981) stated that Ground-water modeling is a tool that can help analyze many ground-water problems. Models are useful for reconnaissance studies preceding field investigations, for interpretive studies following the field program and also to estimate future field behavior. In addition to these applications, models are useful for studying various types of flow behavior by examining hypothetical aquifer problems. Before attempting such studies, however, one must be familiar with ground water modeling concepts, model usage and modeling limitations.

Rao and Sharma (1981) derived an equation for the formation of groundwater mounds on recharge from a rectangular area to a finite aquifer. This numerical solution described the actual field response of water table to recharge better than the equations derived for infinite aquifers. They assumed that the aquifer is resting on a horizontal and impermeable base.

Huston (1993) studied the well field, Kabwe, Zambia and reported that the response of water level fluctuations were dependent upon pumping rates and prior rainfall and can be simulated by a simple linear regression model. The rate of dewatering of mine was shown to be dependent upon mine size and antecedent rainfall, and could also be simulated by a multiple linear regression model. Such models can be used for forecasting and control of groundwater systems, where more costly and complex methods cannot be used. He also cautioned about the principal limitation of multiple linear regression models that it needs data collected over a reasonable time span for producing meaningful results.

Viswanathan (1983) used the recursive least squares method to develop linear model, which estimates the daily water level in the borehole, given the rainfall on the same day and up to eight days before. He concluded that soil parameters that determine the infiltration rates are time dependant and their variation can be tracked by introducing "forgetting factor". This factor cutback the memory of the algorithm, hence the parameter values depend on the current values of levels and rainfall than on past values.

Prihar *et al*., (1993) used the water table rise and fall along with the agro-climatic zones to divide the Punjab into agro-climatic irrigation zones. They mentioned that the difference in water supply and water requirement to meet the ET of the crops grown in each irrigation zone and the utilizable water supply exclusive of marginally fit and unfit (for irrigation) ground water supplies, changes in groundwater level would depend upon the balance between water supply and water requirement. The Directorate of Water Resources, Punjab has used the average water table rise and fall in blocks values and the weighted average rise and fall for each irrigation zone. They also reported that the rising water table does not mean that the supply exceeds the demand. Due to brackish groundwater, in certain zones the utilizable supply is less than the total supply that affects the changes in ground water level.

El-Kadi *et al*., (1994) reported that the groundwater modeling is generally hindered by the lack of information about the groundwater system for data preparation and result analysis. Such a lack of information usually demands for use of a tedious iterative methodology within a sensitivity analysis scheme. These kinds of situations were managed by using GIS. They integrated the modeling environment with the GIS as an item in the main menu. The formulation of the groundwater-modeling environment necessitated creation of a spatial mesh with parameter values that were assigned to each element or node of the mesh. They also reported that the aquifer parameters were usually known at a limited number of sampling points. The values assigned to the elements were estimated by interpolation. They also stated that the integrated system that they used was suitable for extracting and interpolating from the point measurements from the maps. Through this, the data can be imported and exported to or from the cells.

Watkins *et al*., (1996) reported that the Geographic Information Systems (GISs) offer data management and spatial analysis capabilities that can be useful in ground-water modeling. They also reported that GIS was used for automatic data collection, systematic model parameter assignment, spatial statistics generation, and the visual display of model results. To utilize these abilities, however, GIS and Ground-water models must be able to communicate with each other. They used the finite difference method that employs rectangular descretization in which the parameter values are entered and the hydraulic heads are computed for each cell. The MODFLOW (3-D Groundwater Model) was linked with the Arc/Info and named as MODFLOWARC, which needs no data transfer programs to be written separately. They assumed that the flow in the aquifer was horizontal. Stacking grid layers was done to specify the interaction between them, which often represent the three dimensional finite difference models.

Harrington (1998) developed a multiple linear regression model of water table response to pumping. Their multiple regression models uses the relationship between the measured water table fluctuations at monitoring wells, records of pumping and runoff to predict the response of the water table for a given amount of pumping and recharge.

Johnson *et al*., (1998), stated that the Numerical models such as MODFLOW, provide an excellent tools to assist in the water resource decision process. A simplified representation of the system may in some cases, be obtained by the development of response functions from numerical models. These functions express temporal relationships between causes and effect at specific points within the aquifer and are developed through simulation. It is also reported that the Numerical models such as MODFLOW can produce predictive simulations of cause and effect when properly calibrated and applied to an area. This process normally, involves comparing results of a series of predictive scenarios with the observations, possibly projecting the current conditions into future. The process is valid and useful; however, it requires at least one simulation and comparison for each problem. They also emphasized about the response function of the aquifer system under different stress conditions. The response functions are analytical expressions, graphs or coefficients that describe the relative response of the aquifer system at a given location to a unit stress.

Manglik and Rai (1998) stated that an accurate estimation of water table fluctuations helps in controlling the changes in groundwater regime by selecting an appropriate scheme of recharging and pumping. Since most of the existing solutions on this subject are based on the assumption of constant rate of recharge, they made an attempt by considering the recharge as a time dependant parameter. The rate of recharge follows approximately a similar pattern of variation with less intensity and little time lag. When recharge rate decreases to a minimum prescribed level, the recharge operation is discontinued for some time and after drying, if necessary, scraping and cleaning of the bottom of the basin. They also demonstrated that the solutions based on the assumption of constant recharge rate failed to predict the declining trend of water table, which is due to the decrease in the recharge rate. Therefore, it would be more appropriate to consider the rate of recharge as time varying. Based on these, they developed an analytical solution to simulate water table variations in response to recharge and withdrawal of groundwater from multiple basins and wells, respectively.

Tain-Shing *et al*., (2001) reported that the interest in restoring the habitat along riparian corridors has necessitated quantifying the interaction between the surface and groundwater conditions, particularly in the lower flow conditions, understanding the transient nature of the river seepage losses and groundwater accretions / depletions is critical in assessing the surface and subsurface riparian environment. They described the application of MODFLOW for simulating the effects of changes in surface water flow on groundwater elevations. They reported that the calibration is initiated with the available data, but the rigorous calibration demands for large data. They also reported that the model is calibrated for steady state and transient state conditions. Since data for the most of the areas are unavailable to conduct rigorous calibration, steady state groundwater elevation is assumed and compared with the existing conditions. Though they are not serving the full calibration purposes, the simulations showed that the model representations were not unreasonable. The sensitivity analysis was conducted for different river flow conditions like flows at 5%, 20%-30% and 60% exceedance levels.

Sakthivadivel and Chawla (2002) studied the behavior of water table and its slope in space and time in Lakhaoti branch command area, a part of Madhya Ganga Canal Project of Uttar Pradesh. A program was developed to take irregularly spaced data and convert it to regularly spaced form to create a surface representation. Using Kriging interpolation method, and using data from 102 irregularly located observation wells, a regularly spaced grid at 2km spacing was created and groundwater elevations were computed and smoothened using a smoothing option. The deeper water table depth was mostly confined to a limited area farther away from the branch canal. Water table along the boundaries of the study area was higher than the middle portion of the area in the initial years. However, in the subsequent years, the gradient from the drains towards the central portion of the study area was either negligible or negative. Canal water supply had not only arrested the lowering of water table but also helped to raise the water table in an incremental fashion over the years. They also reported that the tail reach area has taken longer time than head reach area in responding to canal water recharge. This was primarily because much of the canal water is used in the upstream reach due to inadequate infrastructure for water distribution in the tail reach.

Review of literature presented in the preceding section reveals that, for sustainable utilization of groundwater resource, there is need to estimate the recharge potential of a given area. This necessitates the selection of proper groundwater recharge estimation method based on available data and the conditions prevailing in the study area. Recharge estimation requires careful study and thorough understanding of the recharge processes. Review also suggests that delineation of the potential groundwater recharge zone is one of the most important inputs in the planning process of the groundwater recharge project. Review of literature also suggests that rainfall is the major source of recharge, and to recommend artificial recharge scheme for a basin, assessment of runoff available for the groundwater recharge is an important activity. In the absence of other sources for recharge, volume of runoff is a deciding factor for the type and number of recharge structures required for the artificial groundwater recharge. Review on 'groundwater models for simulation studies' showed that, there are several models available for estimation of groundwater recharge. However, selection of appropriate model depends on the available data and soil and aquifer properties. Based on the review, it can be also said that MODFLOW can be used for the prediction of water table fluctuation resulting from groundwater recharge and pumping.

Chapter 3

Materials and Methods

Chapter-3

MATERIALS AND METHODS

3.1 Detailed Description of Gurgaon District

3.1.1 Introduction

Gurgaon exists since the time of Mahabharata. The city derived its name from the name of Guru Dronacharya. The village was given as *gurudakshina* to him by his students; the Pandavas and hence it came to be known as Guru-gram, which in the course of time got distorted to Gurgaon. It is called the Land of Dronacharya.

Evolution is a process, which marks the starting, and growth of an entity. And Gurgaon has evolved from a mere piece of agricultural land to the suburb of Delhi catering to the ever-growing requirement of the region, be those industrial, commercial, or even residential.

Figure 3.1 Geographic map of India

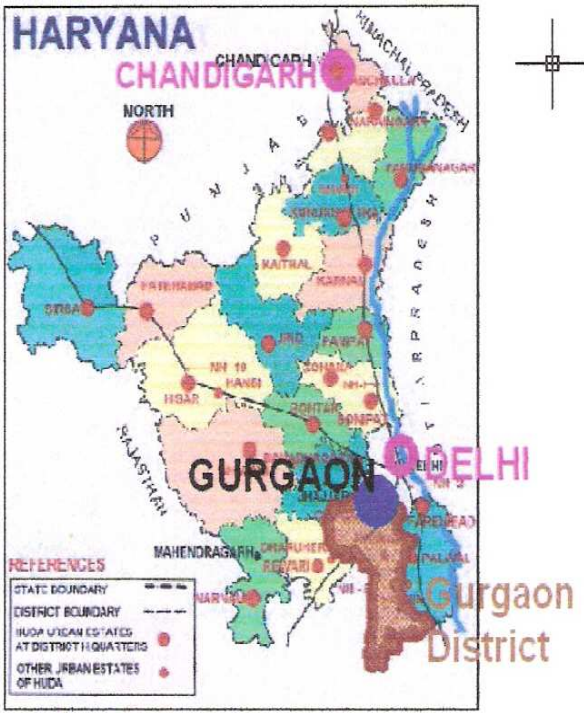


Figure 3.2 Map of Haryana

3.1.2 Location

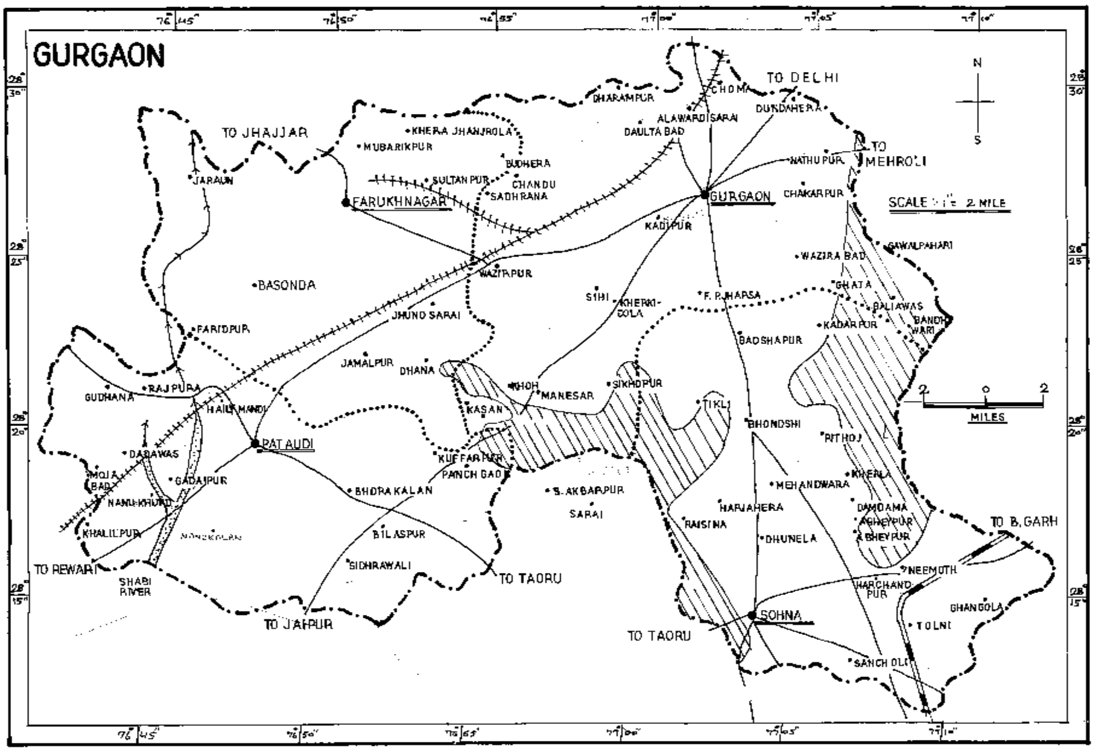


Figure 3.3 Map of Gurgaon district

Gurgaon is about 32kms away from New Delhi, the National Capital of India. It is located at 28.47^o N latitude and 77.03^o E longitude and has an average elevation of 220 meters (721 feet). Gurgaon is the district headquarter town of Gurgaon District in the Haryana State. It is the southernmost district of the state. On its north, it is bounded by the district Rohtak and the Union Territory of Delhi. Faridabad district lies to its east. District shares the boundaries with the states of Uttar Pradesh and Rajasthan from south side and with the state of Rajasthan on its west side. The present Gurgaon district is comprising of four blocks:Pataudi, Sohna, Gurgaon and Farrukhnagar.

According to the 1995 UN census, Delhi is one of the largest cities of the world. The National Capital of India, Delhi, is a city where economic progress related to urbanization is accompanied by tremendous environmental concerns, congestion, and poverty and housing shortages. Delhi's population has increased and reached to 13.5 million. To make city viable to future it was suggested for a planned decentralization to outer areas named as National Capital Region (NCR). The NCR Regional Plan, 2021 of NCR has positioned

Gurgaon as a powerful growth node to attract capital functions and activities and help in population dispersal from the national capital. Gurgaon is one of the six towns in the central NCR (CNCR) and as per the projections, Gurgaon shall be the third largest city in the central NCR (CNCR) after the Ghaziabad-Loni complex and the Faridabad-Ballabgarh complex.

The NCR Regional Plan has envisaged Gurgaon as a metro centre in Central NCR and shall have a high level of physical, social and economic infrastructure, better than obtaining in the capital. This shall include an intra-urban mass transportation system as well as strong transport and communication linkages with Delhi, other metro centers and other NCR towns.

3.2 Geo-morphological features of Gurgaon District

The Natural resources of an area like slope, soil type, drainage vegetation etc, form an important part of land management. The rapid urban growth has led to the intensified land use creating a fast deterioration in the environmental quality. So the conservation of natural resources should be the first priority while considering the growth and development. This includes least modification of the natural topography; minimum cut and fills, non-disruption of the natural drainage pattern and protection of forested areas. In case of Gurgaon it becomes critical to plan the building interventions while considering the strong topographical features and natural resources the region comprises of.

3.2.1 Topography

Gurgaon district possesses a varied topography having ridges, valleys and drainage channels. The district is situated in the transitional zone of the Ganga Plains in the north and the Aravalli Hills in the south. These rocks are one of the oldest mountain systems of the world. The Aravallis are along the western parts of the district and extend up to the Union territory of Delhi in the northeast to the southwest direction. The district comprises of hills and depressions, forming diverse nature of topography. Two ridges - Ferozpur Jhirka - Delhi ridge forms western boundary and the Delhi ridge forms the eastern boundary of the district. The topography in general is slightly undulating

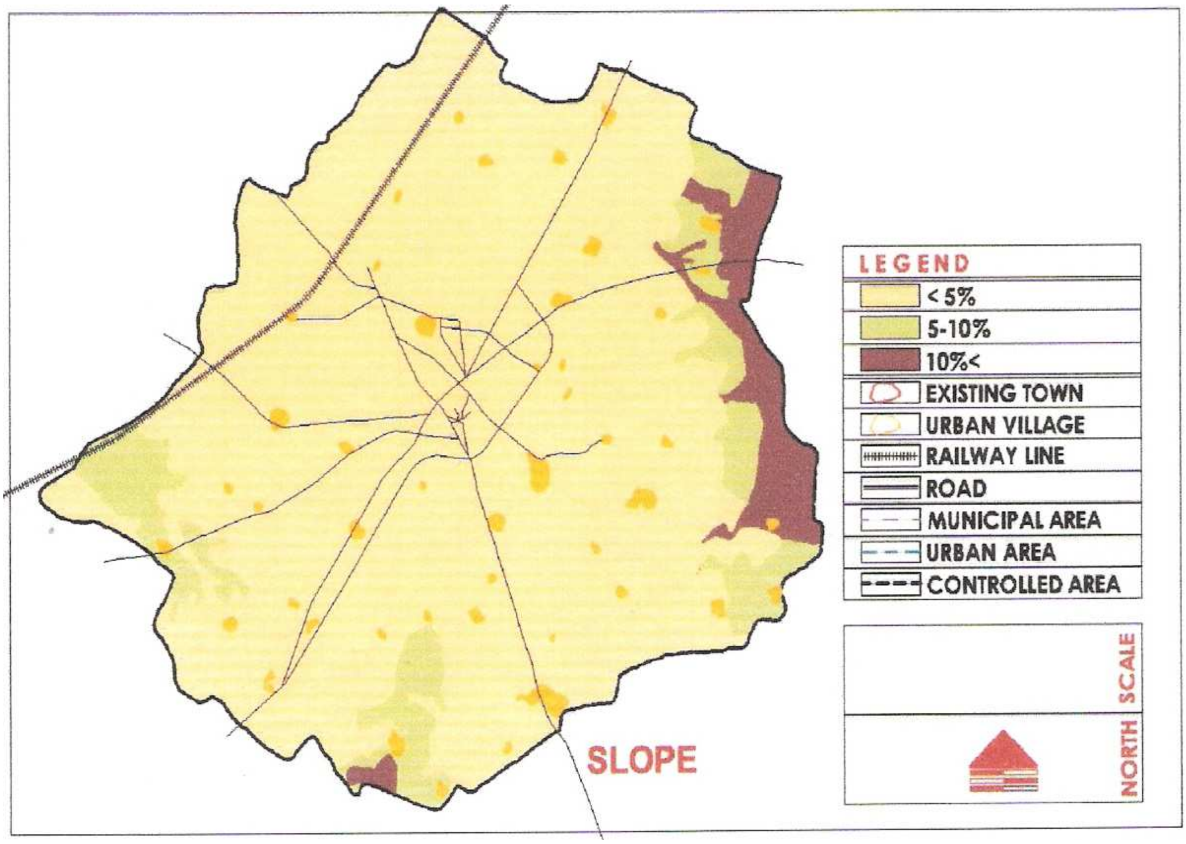


Figure 3.4 Topographic map of Gurgaon District

3.2.2 Landform Characteristics

The district may be divided into four distinct landscapes: -

i. **Aravalli Hills:** They form a part of southeast and very little southwest part of the Sahibi River catchments and are of subdued nature. The MSL ranges from 275 to 325m.

ii. **Foot Hills:** They appear to be old obstacle dunes displaying dissection and very server gully erosion at many places.

iii. **Sahibi Flood Plain:** Major part of the catchments area is composed of plain, levels, bars and basins.

iv. **Aeolian Plain:** This landscape has special significance due to its location in Aeolian activity. Two distinct parts- Aeolian plain and Sand Dunes are dissembled within this region.

3.2.3 Soil Characteristics

The soil is heterogeneous. At most places it is rocky and less fertile.

The residual/ denudation Hills show:

- Low permeability
- High to very high bearing capacity.
- 800-2900 Kg/ sq. cm comprehensive strength.
- Very good foundation characteristics.

Alluvium & Aeolian Sediments Show:

- Cumulative high permeability
- Low bearing capacity.
- 1-2 kg / sq.cm comprehensive strength.
- Poor foundation characteristics.

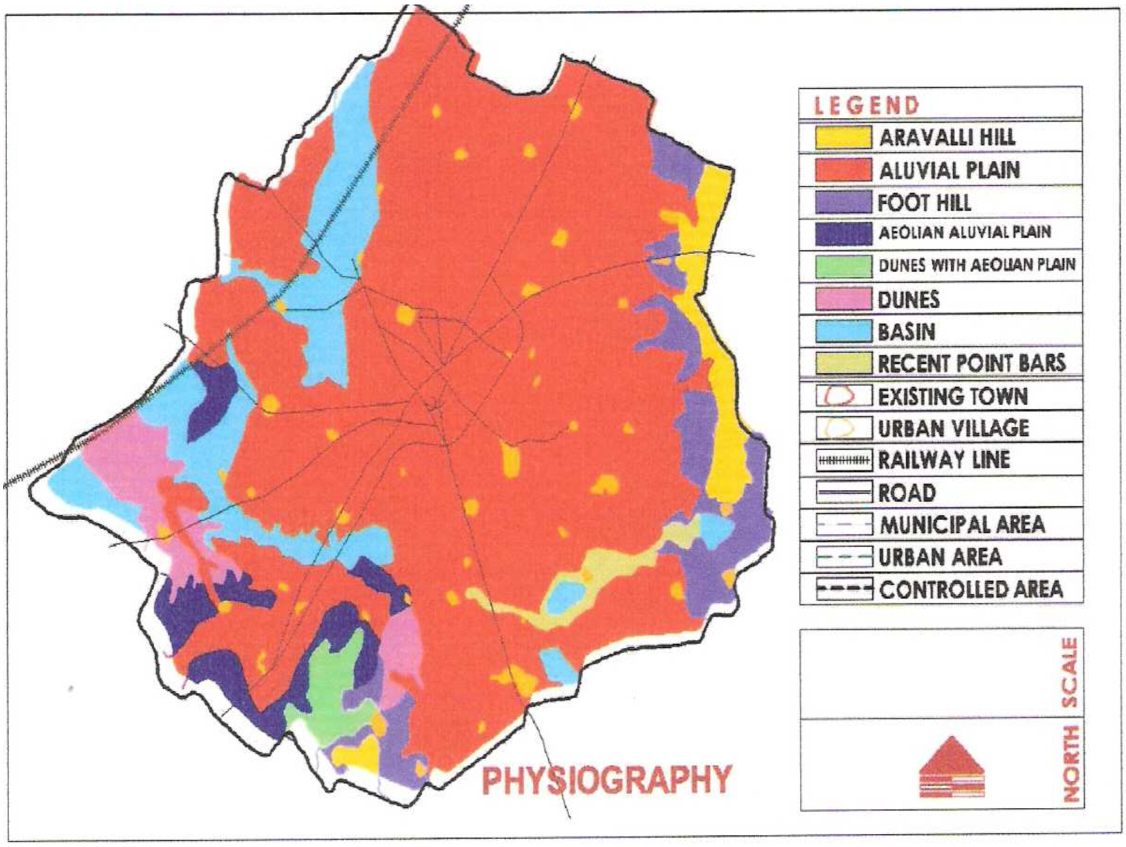


Figure 3.5 Physiographic map of Gurgaon District

Table 3.1 Soil characteristics of Gurgaon District

Physiology	Slope (%)	Soil			Land use	Erosion	Run off (%)
		Depth	Color	Texture			
Aravalli Hill	15-50	Very shallow to shallow	Light Yellowish Brown to Dark Brown	Coarse Loamy 30-35% Rock-out Crops	Sparse Scrubs & grasses	Moderate sheet and Rill	85
Alluvial Plain	0-5	Very Deep	Yellowish Brown to Dark Brown	Coarse Loamy	Cultivated	Slight Sheet	35
Foot Hill	0-10	Very Deep	Light Yellowish Brown to Dark Brown Yellowish	Coarse Loamy	Mostly Cultivated	Very severe Sheet Rill & Gully	60
Aeolian Alluvial Plain	0-3	Very Deep	Dark Yellowish Brown to Brown Yellowish	Coarse Loamy	Cultivated	Slight Wind & Water	30
Dunes with Aeolian Plain	1-5	Very Deep	Dark Yellowish Brown to Brown Yellowish	Sandy	Mostly Cultivated 20-30% barren	Slight Water Moderate to severe Wind	30
Dunes	3-10	Very Deep	Pale Brown to Brownish Yellow	Sandy Occasion-ally Coarse Loamy	Cultivated	Moderate Sheet & Rill	40
Basin	0-3	Very Deep	Yellowish Brown to Dark Grayish Brown	Fine Loamy	Cultivated Grazing	None to Slight	30
Recent Point bars	0-3	Very Deep	Light Yellowish Brown to Dark Brown	Coarse Loamy	Cultivated	Slight Sheet	40

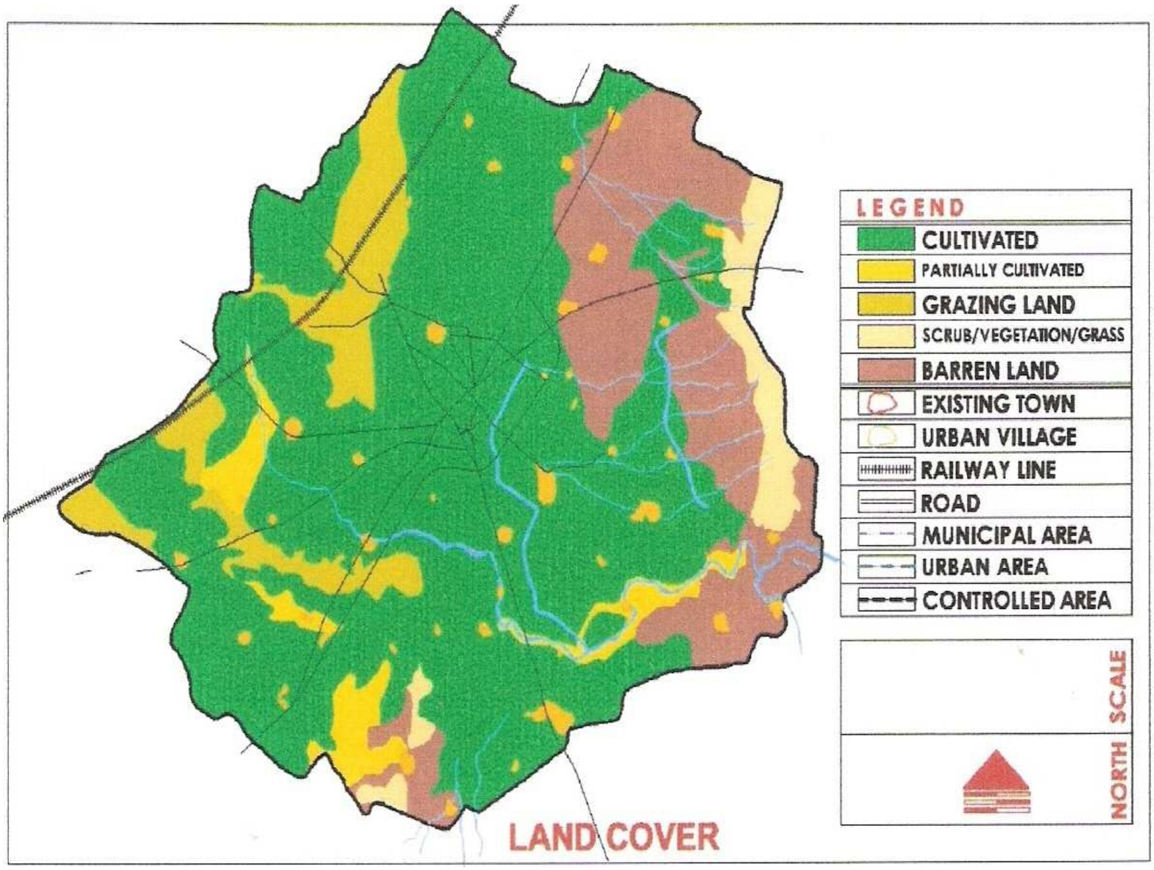


Figure 3.6 Natural Land Cover Map of Gurgaon

3.2.4 Natural Land Cover

The natural land cover is receding due to the increasing population and extensive urban development. The town and its surrounding area are relatively less wooded shrubs. Neem and Shisham are found on both sides of the roads while Kikar is generally found in low-lying areas. Following table shows commonly found vegetation in the area

Table 3.2 commonly found vegetation cover in Gurgaon district

Local Name	Botanical Name
Trees	
Neem	Azadirachta indica
Kikar, Babul	Acacia nilotica
Shisham	Dalbergia sissoo
Safeda	Eucalyptus hybrid
Peepal	Ficus religosa
Semul	Bombax ceiba
Gular	Ficus racemosa
Bargad / Barh	Ficus bengalaenasis
Karir	Capparis deciduas
Dhak	Butea monosperma
Hins	Capparis zeylanica
Lasora	Cordia, dictona
Imli	Tamarindus indica
Papri	Holoptelea integrifolia
Beri	Zizyphus mauratiana
Jhar-beri	Zizyphus nummularia
Jand	Prosopis cineraria
Khajur	Phoenix sylvestris
Shrubs	
Zharberi	Zizyphus nimeleria
Ak	Calctropic procera
Sarkanda	Saccharum munja
Vilayati Ak	Impomea cornea
Grasses	
Bathua	Chenopodiums album
Doob	Cynodon dactylon
Dab	Desmotachua bipinnata
Jawansa	Alhagi camalorum
Anjan	Cencherus ciliaris
Katua	Chenopodium murel
Months	Cyperus rotandus
Sawan	Larisus renidius
Kans	Saccharum spontaneum
Bharond	Cencherus SP
Baysurai	Plachua lanceolata

3.2.5 Normal climatic features of Gurgaon District

General climate of district is characterized by the dryness, hot summer and cold winter except few months of monsoon. The year may be broadly divided into four seasons, viz. winter, summer, rainy period (Monsoon) and Post Monsoon. The winter starts from November to the March. The summer is from March till the end of June. The period from July to mid September is the southwest Monsoon Season. Mid September to end November constitutes the post Monsoon also called as the transition period. Overall climate can be characterized as Hot Tropical to Sub-Tropical climate with high temperature and moisture deficiency for most part of the year.

- **Temperature**

Table 3.3 Variation in monthly maximum and minimum temperature for Gurgaon District

Months	Mean Daily Temp. (^{0}C)		Mean Daily RH (%)		Wind Speed
	Maximum	Minimum	Maximum	Minimum	Km /hr
January	21.4	5.1	75	48	3.7
February	23.5	7.5	69	42	4.5
March	29.8	12.4	60	35	5.5
April	37.1	19.1	45	25	5.8
May	40	23.7	43	28	6.7
June	39.5	26.7	56	39	7.6
July	35	26.1	77	66	6.3
August	33.3	25.1	82	71	3.9
September	34.3	22.8	72	58	4.3
October	33.8	17.6	59	40	3.6
November	28.9	10.7	64	43	3.2
December	23.4	6.1	71	46	3.2

From about the beginning of March, temperature begins to increase rapidly. May and June is the hottest months when the mean daily maximum temperatures are about 41^{0}C. While days are little hotter in May than in June, nights are warmer in June than in May.

From April onwards, hot dust- laden winds locally known as ‘loo’ blows and weather is unpleasant.

Daily mean Maximum Temperature 21.2^{0}C (January) to 40^{0}C in May.

Highest Maximum Temperature 49^{0}C on 10th May 1986.

Lowest Minimum Temp 4.7on 30th December 1972.

- **Altitude**

Plains - 225 to 275m above MSL

Hills - 275 to 326 m above MSL

- **Humidity**

The air is generally dry during the greater part of the year. Humidity is high in the south - west Monsoon Season. April and May are the driest months when the relative humidity in the morning is about 30% and the afternoon less than 20%.

Monsoon Season 77% in morning and 65% in evening hours.

Minimum 43% in May and maximum in August is 82%.

- **Cloudiness**

Heavily clouded or overcast sky generally prevails during the south - west monsoon and for brief spell of one/two days when western disturbances passes. The sky is mostly clear or lightly clouded during rest of the year.

- **Winds**

Winds are generally light but gain force in the summer and Monsoon seasons. During Monsoon season winds are mostly from the east or southeast directions. During rest of the year winds are from the west or north directions.

- **Wind Velocity**

Maximum Speed 7.0 km\hr (May to June)

Minimum Average Speed 3.2 km\hr (Nov. to Dec)

- **Seismicity**

Gurgaon falls in the Seismic Zone - 4 and is considered as High Risk Zone, an earthquake prone area.

3.3 Characterizations of Assessment Units for Ground Water Assessment

A ground water assessment unit is a geographic land area for which ground water assessment is to be carried out with different objectives like estimating the different components of water balance, water table trend analysis, futuristic ground water development or allocation of water for different demand sectors.

3.3.1 Land Delineation

Each state/Union Territory should adopt a particular type of ground water assessment unit. Ground water assessment is also on the basis of a ground water year. The type of ground water assessment unit and ground water unit should be common for all ground water assessment units in a particular State/Union. There are following four types of ground water assessment units

i. Block
ii. Taluka
iii. Mandal
iv. Watershed

The first three types mentioned above are administrative in character, and the last one namely, 'Watershed' is a hydrologic unit. All States/Union Territories are predominantly characterised by either 'Alluvial' terrain or 'Hardrock' terrain. The type of unit to be adopted will depend on the predominant terrain under which a particular State/Union Territory can be characterised. According to Central Ground Water Board guidelines (CGWB, 2010), all States/Union Territories which are predominantly characterised by 'Hardrock' terrain should adopt 'Watershed' as the type of ground water assessment unit and all States/Union Territories which are predominantly characterised by 'Alluvial' terrain should adopt either 'Block' or 'Taluka' as the type of ground water assessment unit. A hydrologic unit like a 'Watershed' as the type of ground water assessment unit is not recommended in the 'Alluvial' terrain for the following reasons.

i. Demarcation of the boundaries of the 'Watershed' in 'Alluvial' terrain is difficult because of the relative flatness of the alluvial areas.

ii. The boundary of a ‘Watershed’ in ‘Alluvial’ terrain will not usually coincide with the ground water divide, as a result of which there is no particular advantage of adopting ‘Watershed’ as the type of ground water assessment unit.

As described in the section 3.2, Gurgaon district fall under alluvial terrain, therefore for the presented research we have adopted block as the assessment unit.

3.3.2 Ground Water Year

India receives rainfall from both South-West and North-East monsoons. The former is more or less consistently active during June to August, and the latter is more or less consistently active during October and November. Any given State/Union Territory is however, characterised by the fact that the quantum of rainfall received from one of these two monsoons is significantly much higher than that from the other. With these considerations in mind, a ground water year for purposes of ground water assessment can be very conveniently considered to comprise of 12 calendar months beginning from the commencement of the predominant monsoon.

3.3.2.1 Seasons within a ground water year

The ground water table is at the lowest level (or, farthest from the ground level) just prior to the onset of the predominant monsoon and reaches a peak (highest level or closest to the ground level) a little before the cessation of the predominant monsoon. Thereafter, the ground water table shows a declining trend with the recession limb having two significant segments. The first segment has a relatively steeper slope and extends to about a month after the cessation of the predominant monsoon. The second segment has a much flatter slope and extends up to the time when the predominant monsoon commences again in the next year. Ground water is usually not developed for irrigation use during the one month period corresponding to the first segment of the recession limb of the water table hydrograph as mentioned above, because of availability of adequate moisture in the root zone during this one month period. Keeping the above considerations in mind, a ground water year can be conveniently sub-divided into the following two seasons:

i. ‘Monsoon Season’ between the commencement of the predominant monsoon and a month after its cessation.
ii. Non-monsoon Season’ covering the rest of the ground water year.

The ‘Monsoon Season’ as defined above does not coincide with the duration of the predominant monsoon as commonly understood on the basis of occurrence of rainfall, but in fact extends to a month after its cessation. Ground water assessment computations will have to be made separately for these two seasons within a ground water year.

3.3.2.2 Pre- monsoon and post- monsoon intervals

Water table data as recorded from a number of observation wells will be made use of in the assessment of ground water. These water table data will have to be recorded during two intervals within a ground water year. These two intervals are referred to as ‘Pre-monsoon’ and ‘Post- monsoon’ intervals. The former corresponds to the calendar month just prior to the ‘Monsoon Season’, and the latter corresponds to the calendar month just after it.

3.3.2.3 Ground water assessment year

The ground water year for which ground water assessment is made and reported is referred to as the ‘Ground Water Assessment Year’. The components of gross ground water draft and recharge from ‘Other Sources’ are computed with reference to the Ground Water Assessment Year’. The component of recharge from ‘Rainfall’ is however a little different in the sense that, the rainfall for which the rainfall recharge is computed is not the rainfall during the ground water assessment year but a ‘Normal Rainfall’ value obtained as the average rainfall over a sufficiently long number of ground water years. The reasons for these are obvious. The components of gross ground water draft and recharge from ‘Other Sources’ primarily result from human interventions, and hence, their current values associated with the ‘Ground Water Assessment Year’ have to be considered. The rainfall on the other hand, is a natural phenomenon which varies considerably from year to year. Hence, it is only appropriate that the recharge from ‘Rainfall’ should be computed with reference to the ‘Normal Rainfall’.

3.4 Recharge Mechanisms and Processes

The downward movement of water is governed by several factors like infiltration rate; vertical permeability of the soil, evapotranspiration, presence of gases in the unsaturated zone, clogging of beds in case of surface spread methods.

If the climatic and soil conditions allow recharge to reach the water table at a rate that is greater than the saturated zone can transmit water away, then permeability of geologic framework controls the rate of recharge. This situation results in conditions of shallow water table. On the other hand, if the saturated zone can transmit more recharge than the climate and soil can provide then the surface factors are limiting and controls the recharge rate. This condition results in relatively deep water table.

Principal recharge mechanisms from various sources of recharge have been conceptually defined by Larner *et al*. (1990) as follows:

i. **Direct recharge:** Water added to the groundwater reservoir in excess of soil moisture and evapotranspiration by direct vertical percolation through the vadose zone is termed as groundwater direct recharge.
ii. **Indirect recharge:** Percolation to the water table through the beds of surface watercourses forms indirect recharge.
iii. **Localized recharge:** An intermediate form of the groundwater recharge resulting from the horizontal surface concentration of water in the absence of well-defined channels.

3.5 Hydraulics of Groundwater Recharge

Differential equations are the basis for development of mathematical formulas describing the flow of groundwater. These equations allow a strict accounting of water flowing in to and out of aquifer. To allow this type of mathematical treatment, certain simplifying assumptions for the boundary conditions must be made. Analytical solutions describing the well recharge are the same as those describing the groundwater withdrawal, except that they describe the accretion of groundwater rather than its depletion. Some of the analytical solutions useful in examining hydraulic effect of artificial recharge are briefly described here.

3.5.1 Steady state conditions

When water is injected in through a well to an aquifer at depth, the resulting mound of water is the mirror image of the cone of depression of that would be caused by an equivalent groundwater withdrawal. The steady state flow equations for pumping wells in confined and unconfined aquifer have been derived in several publications. These equations are the groundwater flow equations in radial co-ordinates. In confined aquifers where no dewatering occurs, the analytical expression for steady state flow is:

$$h_w - h_o = \frac{Q}{2\pi bk} \text{In}\left(\frac{r_o}{r_w}\right) = \frac{Q}{2\pi T} \text{In}\left(\frac{r_o}{r_w}\right) \qquad \text{………..} (3.1)$$

Where; h_o = head above permeable basal boundary at distance r_o form recharge well (L)

h_w = head above permeable basal boundary just outside recharge well (L)

r_o = distance from the recharge well at which h_o is measured (L)

r_w = radius of the well (L)

Q = rate of recharge (L^3T^{-1})

K = aquifer hydraulic conductivity ($L\ T^{-1}$)

b = aquifer thickness (L)

T = kb=transmissivity (L^2T^{-1})

Analysis of unconfined aquifer is simplified by the Dupuit assumption in which head is uniform throughout any vertical section of saturated aquifer. This assumption eliminates the need to consider vertical flow components and equates the elevation of the water table above the base of an aquifer. This assumption gets violated if steep gradient develops near recharge well. The steady state analytical solution for an unconfined aquifer is given by equation no.3.2.

$$h_w^2 - h_o^2 = \frac{Q}{\pi K} \text{In}\left(\frac{r_o}{r_w}\right) \qquad \text{……….…… (3.2)}$$

The variables are the same as defined in confined aquifer case. Equations for both confined and unconfined aquifers can be used to determining the mounding during recharge or maximum rates of recharge, if the required head restrictions are known. However, analysis with steady state flow solution is limited because of its inherent simplifying assumptions, namely that the aquifer fully penetrates an isotropic, homogeneous aquifer and that the flow is radial and that the flow conditions have reached equilibrium and no screen losses occurs.

3.5.2 Transient Conditions

The analytical expression for transient radial flow from a well taping a confined quifer has been derived under the steady state conditions. For a well injecting water at constant rate with the boundary conditions that ($h=h_o$) for ($t=t_o$), and ($h\rightarrow 0$) at ($r\rightarrow\infty$) for $t>0$), the expression appears as

$$s = h_o - h = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-u}\partial u}{u} = \frac{Q}{4\pi T}\, W(u) \qquad \text{..................... (3.3)}$$

Where:

s	= groundwater buildup (L)
h_o	= Initial aquifer head at distance r from the recharge well (L)
h	= head at distance r from recharge well (L)
u	= $r^2S/4Tt$ ($M^0L^0T^0$)
r	= distance from recharge well)L)
S	= aquifer storage coefficient ($M^0L^0T^0$)
T	= aquifer transmissivity (($L^2\ T^{-1}$)
T	= time (T)
Q	= recharge rate (L^3T^{-1})
W (u)	= well function (exponential integral) ($M^0L^0T^0$)

Lohaman, (1972) has given an extensive tabulation of values for the exponential integral for a wide range of u values, which greatly facilitates the solution as long as the estimates of aquifer storage and transmissivity are accurate.

The solution used for transient confined flow can be used for the transient flow in unconfined aquifer provided the mounding is small in relation to aquifer saturated thickness. In thin, unconfined aquifers where mounding is large compared to the aquifer thickness, adjustments must be made to predicted values when the transient solution for confined condition is used. The adjustment to the predicted mound is expressed as

$$s^1 = \sqrt{b^2 - 2bs} - b \qquad \text{……… (3.4)}$$

Where; s^1 is adjusted groundwater built up expected form the unconfined aquifer, s is groundwater build up from the transient flow equation for confined aquifer and b is the saturated thickness of the aquifer. This is also called Jacobs correction.

3.6 Recharge from Irrigation Water Applied By Ground Water Irrigation

Recharge from irrigation water applied by ground water resources was computed for the monsoon and non-monsoon seasons of the ground water assessment year. For both of these periods, two sub-units of each ground water assessment unit a) Non-command area and b) Command area were considered.

The computation of recharge from irrigation water applied by ground water irrigation in a given sub-unit and during a given season involves the following steps to be carried out:

i. Estimation of irrigation water applied by ground water irrigation.
ii. Estimation of average depth to water table below ground level.
iii. Estimation of irrigated area under paddy and non-paddy.
iv. Assigning a return flow factor on the basis of results from ‘b’ and ‘c’ above.
v. Computation of the required recharge on the basis of results from ‘a’ and‘d’ above

3.6.1 Assumptions

The computation of recharge from irrigation water applied by ground water irrigation is based on the following assumptions given by Central Ground Water Board (CGWB):

i. Recharge in hectare meters can be obtained as the product of the following parameters:
    - Irrigation water applied in hectare meters
    - Return flow factor as a fraction
ii. The irrigation water applied as mentioned in ‘a’ above is considered as the gross groundwater draft for irrigation as obtained in Chapter 3. In other words, the transmission losses are considered as nil.
iii. The return flow factor mentioned in ‘a’ above depends only on the following parameters:

- Whether the crop irrigated is paddy or non-paddy.
- Whether the range of depth to water table below ground level is less than 10 metres, between 10 and 25 metres or greater than 25 metres.

iv. The return flow factor mentioned in ‘a’ and ‘c’ above can be assigned a value either on the basis of norms as given in Appendix 6.1 or on the basis of results from documented field studies.

3.6.2 Computational Procedure

First of all, based on the five year average cropping pattern in Kharif, Rabi and Summer season, command and non-command areas were calculated for each block. For monsoon season, Kharif cropping pattern was considered and for non-monsoon season Rabi and Summer cropping was considered.

The gross ground water draft for irrigation, during the monsoon and non-monsoon seasons was calculated using Priestely-Taylor method. For estimation of crop water requirement of different crops grown in Gurgaon district, evapotranspiration of appropriate crop months were utilized. Crop coefficients of various crops were taken from Table 12 of FAO 56 and overall guidelines to calculate crop water requirement were followed as per this report.

The computational scheme recommended by CGWB (2009) requires characterization of the depth to water table below ground level during monsoon and non-monsoon seasons. For this, observation of pre-monsoon and post-monsoon water tables was done and average water table depth below ground was calculated for each block for each computation time step. These water levels were estimated for following three ranges:

i. Less than 10 metres
ii. Between 10 and 25 metres
iii. Greater than 25 metres

The area irrigated by ground water irrigation under paddy and non-paddy crops during monsoon season was estimated according to average cropping pattern. This was required because Paddy requires inundation of water for considerable time in crop growth period which enables for more recharge from this crop irrigation.

The return flow factor for command and non-command areas during monsoon and non-monsoon seasons with reference to ground water irrigation were obtained on the basis of norms as given in Appendix 6.1, of CGWB report 2009. The uses of the norms require the information on depth of water table and irrigated area as discussed earlier. The norms have been presented in Table 3.4 below.

The estimates of irrigation water applied and the estimate of the return flow factor as described earlier were used to compute the recharge from irrigation water from command and non-command areas during monsoon and non-monsoon seasons for every assessment time steps. The computation procedure has been presented in one Table 3.5

Table 3.4 Norms for return flow factor for irrigation as per appendix 6.1 CGWB (2009)

Sl. No.	Type of crop (Paddy / Non - paddy)	Range of depth to water table below ground level (< 10 metres / 10 to 25 metres / > 25 metres)	Return flow factor as a fraction
1	Paddy	< 10 metres	0.45
2	Paddy	10 to 25 metres	0.35
3	Paddy	> 25 metres	0.20
4	Non - paddy	< 10 metres	0.25
5	Non - paddy	10 to 25 metres	0.15
6	Non - paddy	> 25 metres	0.05

Table 3.5 Procedure for calculating recharge from irrigation water applied by ground water

Sl. No.	Description of Item	Monsoon Season		Non-Monsoon
		Paddy	Non-Paddy	
1	Irrigation water applied by ground water irrigation in command area in ha-m	--	--	--
2	Return flow factor for calculating recharge	--	--	--
3	Recharge from irrigation water [1*2] ha-m	--	--	--

-- (The values can be filled up after calculation)

3.7 Recharge Due To Rainfall

Rainfall is major source of recharge for any region. This natural phenomenon shows considerable variations from year to year. Therefore 'Normal Rainfall' obtained as the average rainfall over a sufficiently long number of ground water years was the most appropriate basis for computing rainfall recharge. Thus recharge values calculated using normal rainfall has been used for future predictions and five year average rainfall values has been used for different past scenarios.
The following two methods were employed for computing rainfall recharge:

i. Rainfall infiltration factor method
ii. Water table fluctuation method

The rainfall infiltration factor method was employed in each ground water assessment unit for calculating recharge from command and non-command areas during monsoon and non-monsoon seasons. While water table fluctuation method was employed in each ground water assessment unit for recharge from command and non-command areas during monsoon season as recommended by central ground water board.

Even in the above two cases where the recommended method to be employed was the water table fluctuation method, it was necessary to compute the rainfall recharge by the rainfall infiltration factor method also, because of following reasons :

i. To check reliability of data on depth to water table during pre-monsoon and post-monsoon intervals of a ground water year
ii. The computed rainfall recharge values corresponding to different monsoon season rainfall values through the use of the water balance approach in the water table fluctuation method may be such that all of them are consistently negative or nearly zero. In such a situation, the water table fluctuation method has to be dispensed with, and instead the rainfall infiltration factor method will have to be used.
iii. The rainfall recharge as computed by the water table fluctuation method has to be any way compared with that computed by the rainfall infiltration factor method, and finally the rainfall recharge during monsoon season

will have to be assigned a value on the basis of a set of criteria so as to avoid unreasonably high or low estimates.

The computational procedure for estimating rainfall recharge by the rainfall infiltration factor method for the command and non-command areas during the monsoon as well as non-monsoon seasons essentially comprises of the following steps:

i. Estimating the normal monsoon and the normal non-monsoon season rainfall applicable for the three sub-units
ii. Assigning a rainfall infiltration factor for sub-units
iii. Computing the rainfall recharge during monsoon as well as non-monsoon seasons using results from 'a' and 'b' above

Complete procedure has been presented in Table 3.6.

The estimation of rainfall recharge by the rainfall infiltration factor method is based on the following assumptions:

i. The rainfall recharge in a given sub-unit during a given season is considered to be a linear function of only the quantum of rainfall during that season. The distribution of rainfall within the season is therefore ignored.
ii. The rainfall recharge during the non-monsoon season is considered to be nil if the normal non-monsoon season rainfall is less than or equal 10% of the normal annual rainfall, and is calculated only if that percentage value is greater than 10.
iii. Rainfall recharge in hectare meters can be computed as the product of the following three parameters:
    - Rainfall infiltration factor as a fraction applicable for the sub-unit under consideration
    - Quantum of normal rainfall in meters applicable for the sub-unit and season under consideration
    - Area of the sub-unit under consideration in hectares
iv. The rainfall infiltration factor for the given sub-unit depends only on the following factors
    - Type of terrain (alluvial/ hardrock)

- In the case of alluvial terrain, the geographic location (Indo-gangetic plains and inland areas/ east coast/ west coast)

Other factors like geomorphology, vegetal cover, antecedent moisture status etc., (which may be equally important) have been ignored primarily because of the following reasons:

- the variation of rainfall infiltration factor in quantitative terms with variation in these factors are not widely available
- the specification of norms for assigning rainfall infiltration factors (discussed in the next item) has to be as far as possible simple without sacrificing important considerations

v. The rainfall recharge factor mentioned in'd' above is to be the assigned a value on the basis of norms given in Appendix 8.1 of CGWB (2009). The recommended value given in the norms should be alone made use of unless, results from documented field studies indicate that a different value can be used. In the latter case also, the rainfall infiltration factor assigned should be within the range of the maximum and the minimum values as specified in the norms.

Table 3.6 Procedure for calculating recharge due to rainfall by 'Rainfall Infiltration Factor Method'

Sl.No.	Description	Quantity
1	Area in hectors	--
2	Normal rainfall during	--
	(a) Monsoon (meter)	--
	(b) Non-monsoon (meter)	--
	(c) Is non-monsoon rainfall as percentage of normal annual rainfall greater than 10% (Yes/No)	--
3	Rainfall infiltration factor as fraction	--
4	Rainfall recharge in ha-m during	--
5	(a) Monsoon Season = [1×2(a) ×3]	--
	(b) Non-Monsoon Season = [1×2(b) ×3], if 2(c) is Yes	--

-- (The values can be filled up after calculation)

Table 3.7 Norms for rainfall infiltration factor for alluvial terrain as per Appendix 10.1 CGWB (2009)

Sl. No.	Geographic location	Rainfall infiltration factor as a fraction		
		Recommended value	Maximum value	Minimum value
1	Indo - Gangetic plains and inland areas	0.22	0.25	0.20
2	East coast	0.16	0.18	0.14
3	West coast	0.10	0.12	0.08

3.8 Rainfall Recharge by Water Table Fluctuation Method

The water table fluctuation method was applied for computing rainfall recharge only for the monsoon season, for two sub-units of command and non-command areas within a ground water assessment unit as recommended by CGWB (2009). This method is based on a water balance approach in which of all the components in the water balance equation, the only component which is considered to be unknown is the rainfall recharge. The estimation of this particular component requires the use of the water table fluctuation during the monsoon season.

The computational procedure in the application of the water table fluctuation method for estimating rainfall recharge during the monsoon season in the command area and non-command areas involves the following steps to be carried out:

i. Computing the monsoon season rainfall during the current ground water assessment year as applicable to the sub-unit (blocks in our case).
ii. Computing the water table fluctuation during the monsoon season of the current ground water assessment year as applicable to the sub-unit.
iii. Assigning the specific yield value applicable for the sub-unit.
iv. Application of water balance to compute the rainfall recharge during monsoon season of the current ground water assessment year, i.e., corresponding to the monsoon season rainfall of the current ground water assessment year.
v. Application of a normalization procedure to compute the rainfall recharge during monsoon season corresponding to the normal monsoon season rainfall applicable for the sub-unit.

vi. Compare the estimate of rainfall recharge corresponding to normal monsoon seasons rainfall as obtained in 'e' above with estimate of rainfall recharge obtained by the rainfall infiltration factor method, and finally based on a set of criteria estimate the rainfall recharge during monsoon season in both command and non-command areas of the ground water assessment unit. This is done to avoid unreasonably high or low estimates of rainfall recharge.

Detailed procedure for calculating recharge by water table fluctuation method has been presented in Table 3.6 and norms for specific yield fractions has been given in Figure 3.7. This method has been based on following assumptions as given in the CGWB (2009).

i. The water balance approach followed in the method is essentially a lumped parameter approach. Hence, the spatial variations of individual components in the water balance equation are not considered, and only a single lumped value of each component for the sub-unit (command/ non-command) as a whole is considered.
ii. Some natural net output components in the water balance equation namely, baseflow, flow across the boundaries of the sub-unit, and evaporation from the groundwater reservoir within the sub-unit under consideration are all mostly very difficult to estimate, and are therefore ignored. The implication of this assumption is that, the recharge value computed is not that which is exclusively due to rainfall, but that which is due to a combined effect of rainfall as well as all other factors which have been ignored.
iii. The specific yield of a particular sub-unit is to be assigned a value on the basis of the set of norms given in Appendix 11.1 of CGWB report (2009). The recommended value specified in the norms alone are to be used, unless results from pump tests (each being of duration not less than 24 hours) indicate that, a different value can be used. In the latter case also, the specific yield which is assigned should be within the range of the maximum and minimum values as specified in the norms. These norms also assume that the specific yield depends only on the following factors

- Type of terrain (alluvial/ hardrock)
- In the case of alluvial terrain, the type of alluvium (sandy/ silty/ clayey)
- In the case of hardrock, the rock type.

Table 3.8 Procedure for calculating recharge due to rainfall by water table fluctuation method

Sl.No.	Description	Quantity
1	Area in hectares	--
2	Recharge from other sources in ha-m in monsoon season	--
3	Gross ground water draft in ha-m for 'All Uses' during monsoon season	--
4	Water table fluctuation in meters during monsoon season	--
5	Specific yield as a fraction	--
6	Change in ground water storage in ha-m during monsoon season = [1 × 4 × 5]	--
7	Rainfall recharge by WTF method in ha-m = [6 + 3 - 2]	--
8	Rainfall in mm for which recharge (calculated in step 7) corresponds	--

-- (The values can be filled up after calculation)

Table 3.9 Norms for specific yield fraction for alluvial terrain as per Appendix 11.1 CGWB (2009)

Sl. No.	Type of alluvium	Specific yield as a fraction		
		Recommended value	Maximum value	Minimum value
1	Sandy	0.16	0.20	0.12
2	Silty	0.10	0.12	0.08
3	Clayey	0.06	0.08	0.04

3.9 Identification of Potential groundwater recharge zones

The artificial recharge projects are highly site specific and even the replication of these techniques in the similar areas is based on the local hydro geological and hydrological environment (CGWB, 2000). Following points as recommended by CGWB (2000) were considered for identifying potential recharge areas:

i) The aquifer to be recharged should be unconfined, permeable and sufficiently thick to provide storage space

ii) Surface soil must be permeable enough to maintain high infiltration rate

iii) Vadose zone should be permeable and free from the clay lances, which may cause perched water conditions

iv) Groundwater conditions in the pheratic aquifer should be deep enough to accommodate the water table rise to avoid possible water logging conditions.

v) Aquifer material should have moderate hydraulic conductivity so that recharged water is retained for sufficiently long period of time.

vi) Areas with gently sloping land without gullies or ridges are most suited for surface water spreading technique

vii) When impervious layer overlies deeper aquifers, the infiltration from the surface cannot recharge the subsurface aquifer under the natural conditions. Some structure that punctures such impervious layer may be adopted under this situation.

In addition to above, other favorable areas for groundwater recharge as proposed by CGWB are:

i. Areas where groundwater levels are declining on regular basis,
ii. Areas where substantial amount of aquifer has already been de-saturated,
iii. Areas where availability of groundwater is inadequate in lean months and
iv. Areas where salinity ingress is taking place.

For identification of the potential groundwater recharge zones, it was required to analyze the characteristics of soil and aquifer formations, topography of the area, properties of the unsaturated zone. Using the contour map and information generated through the geo-electrical survey and well logs as described earlier, areas suitable for groundwater recharge structures were identified. Selection of recharge method was based on the infiltration rate and occurrence of clay layer and its thickness below ground level.

3.10 Determination of Different Components of Water Withdrawal

Different components for demand for water were determined based on the standard professional practice in the field. These components were agricultural water requirement, domestic water requirement, industrial water requirement, institutional water requirement, and water requirement for domestic and other animals. Main source of data collection for seasonwise irrigated area, number and type of industries, population, number of animals etc. was statistical abstracts databook published by state government of Haryana. Old Gurgaon district was comprised of nine blocks up to December 2005, after which new Gurgaon district was formulated consisting four blocks. Study period considered for analysis was from 1974 to 2008, therefore all data previous to 2005 were recalculated according to new four block data. Four blocks under new Gurgaon district are Gurgaon, Sohna, Farukhnagar and Sohna. Following section describes the details of each section.

3.10.1 Agricultural Water Requirement

To estimate agricultural water demand first of all irrigated area cropping pattern was determined for both kharif and rabi season. Then agricultural crop water requirement was determined according to guidelines of FAO 56 (Allen, R. G., et al., 1998) and Pristelay-Taylor method of evapotranspiration estimation. In Gurgaon district less than 3% area was irrigated by canal irrigation and remaining area was irrigated by ground water resources. Estimated agricultural water demand was considered as potential water demand. Twenty five percent of total demand in rainy season and eighty percent of total demand in rabi season was assumed to be met by ground water resources.

3.10.1.1 Evapotranspiration Estimation by Priestley-Taylor Method

The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET). Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop factors in the Priestely-Taylor approach. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc), are used to relate ETc to ETo or

$$ETc = Kc\ ETo \qquad \ldots\ldots\ldots\ldots\ldots(3.5)$$

The Priestley-Taylor equation has the form:

$$ET_0 = 1.26\frac{\Delta}{\Delta+\gamma}\frac{R_n-G}{\lambda} \qquad \ldots\ldots\ldots\ldots\ldots (3.6)$$

Where,

ET_0 = Reference Evapotranspiration, mm d^{-1},

R_n = Net radiation, MJ $m^{-2}d^{-1}$

G = Soil heat flux density, MJ $m^{-2}d^{-1}$

λ = Latent heat of vaporization, MJ kg^{-1} = 2.45

Δ = Slope of the saturation vapor pressure temperature relationship, kPa ^{0}C-1

γ = Psychometric constant, kPa $^0C^{-1}$

Net radiation required in this equation was calculated according to standard procedures described in FAO 56 (Crop Evapotranspiration, Guidelines to calculate crop water requirement) using temperature data. The value of the latent heat varies only slightly over normal temperature ranges. For the standardized forms like Priestley-Taylor equation, a single value is taken: λ = 2.45 MJ kg^{-1}

Slope of the Saturation Vapor Pressure Curve (Δ) was calculated as follows

$$\Delta = \frac{2504_{\exp}\left(\frac{17.27\,T}{T+237.2}\right)}{(T+237.3)^2} \qquad \ldots\ldots\ldots\ldots\ldots(3.7)$$

where Δ = slope vapor pressure curve (kPa $^oC^{-1}$)

T = air temperature (^oC)

In 24-hour or bigger time step calculations, Δ is calculated using mean daily air temperature. In hourly calculations T refers to the hourly mean, T_{hr}.

3.10.1.2 Soil Heat Flux Density (G)

The magnitude of the daily or ten-day soil heat flux beneath a fully vegetated grass or alfalfa reference surface is relatively small. Therefore, it is ignored and thus:

$$G_{day} \approx 0 \quad (3.8)$$

On monthly time steps, seasonal warming of soil can be significant. Assuming a constant soil heat capacity of about 2.0 MJ m^{-3} $^0C^{-1}$ and an appropriate soil depth, G for monthly periods is estimated in FAO-56 as:

$$G_{month,i} = 0.07\left(T_{month,i+1} - T_{month,i-1}\right) \quad (3.9)$$

However, since the $T_{month,\ i+1}$ is unknown when the previous line of data are being evaluated for January, the following equation from FAO-56 is used in calculations.

$$G_{month,i} = 0.14\left(T_{month,i} - T_{month,i-1}\right) \quad (3.10)$$

where $T_{month,\ I}$ mean air temperature of month I (^0C),

$T_{month,\ i-1}$ mean air temperature of previous month (^0C),

3.10.2 Domestic Water Requirement

Water requirement for domestic purpose was estimated according to the population multiplied by per day water requirement. Per capita per day water requirement was taken from “Manual of Water Supply and Treatment”. For village area per capita per day water requirement considered was 70 liter and for city areas it was 135 liters.

3.10.3 Industrial Water Requirement

To estimate industrial water requirement first of all data of total number of industries was collected, then it was multiplied by average water requirement of industry. Average water requirement of the industry was estimated according to types of industries located in the area and their daily water requirement according to industry type.

3.10.4 Institutional Water Requirement

Number of institutions for older periods was not recorded separately therefore such data was not available. Hence institutional water requirement was worked out for 2004-08 period and its total percentage to industrial water requirement was worked out. This percentage was around 9%. Therefore institutional water requirement was assumed to be 105 of total industrial water requirement.

3.10.5 Domestic and Other Animal Water Requirement

Water requirement for domestic and other animals living in Gurgaon district was worked out according to population multiplied by per capita per day water requirement. Eleven types of animals were considered for water requirement. Water requirement (per capita per day) considered for cattle, buffalo, and horses was 70 liter, for donkey and mules it was 30 liter, for camel it was 35 liter, for sheep, goat and dog it was 2 liter, for pigs it was 4 liter and for poultry birds it was 1 liter.

Total water requirement was worked out as sum of these five components separately for monsoon season (120 days) and non-monsoon season (245 days).

3.11 Aquifer Parameter Estimation by Using Pumping Tests

The ground water is generally extracted from the aquifers by drilling the wells and using pumps for water lifting. The analysis of flow of ground water towards well was first analyzed by Dupuit in 1863, and later modified by Thiem in 1906. Since then many developments in aquifer constant prediction theories and equations are in use. Two most important parameters namely storage coefficient (S) and transmissibility (T) are required to predict to estimate any ground water related calculations. Values of these two parameters remain constant for any particular type of aquifer. Therefore these two parameters are also called as aquifer constants. The average values of the aquifer constants T and S can be determined by conducting pump tests. The test well is pumped at constant discharge Q and the change in the drawdown with the time in one or more observation wells is measured. The discharge Q is also measured. The values of T and S are obtained by various equations. Following methods are most commonly used for determination of the aquifer constants T and S by conducting pumping tests

i. Theis' Method
ii. Cooper-Jacob Method
iii. Chow's Method

In addition to this Recovery test method is used for determination of T. In this method observations are made in test well (pumping well) itself and therefore there is need of observation well for this method.

For use of all above mentioned methods, values of s (drawdown), t (time), diameter of well (r) is required in addition to Q (discharge). Basic equation used to develop, equations of all these methods is called as convergent series of well function W(u), which is expressed as follows

$$s = -0.5772 - \ln(u) + u - \frac{u^2}{2*2!} + \frac{u^3}{3*3!} - \frac{u^4}{4*4!} + \ldots\ldots\ \ldots\ldots \text{(3.11)}$$

3.11.1 Theis' Method of solution

Theis simplified well function and storage coefficient equations to give following equation $s = \left(\frac{Q}{4\pi T}\right) W(u)$ ……………… (3.12)

where,

W (μ), termed the well function, is a convenient symbolic form of the experimental integral and

$$\frac{r^2}{t} = \left(\frac{4T}{S}\right) u \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.13)}$$

It can be seen that the relation between W(u) and u must be similar to that between s and r^2/t because the terms in parentheses in the two equations are constants. Given this similarity Theis suggested an approximate solution for S and T based on a graphic method of superposition.

A plot on logarithmic paper of W(u) versus u, known as a type curve, is prepared. Values of drawdown are plotted against values of r^2/t on logarithmic paper of the same size as for the type curve. The observed time-drawdown data are superimposed on the type curve, keeping the coordinate axes of the two curves parallel and adjusted until a position is found by trial whereby most of the plotted points of the observed data fall on a segment of the type curve. Any convenient point is then selected, and the coordinates of this match point are recorded. With values of W(u), u, s and r^2/t thus determined, S and T can be obtained from Equations 3.12 and 3.13.

3.11.2 Cooper-Jacob Method of Solution

It was noted by Cooper and Jacob that for small values of r and large values of t, u is small, so that the series terms in Eq. 3.11 become negligible after the first two terms. As a result, the drawdown can be expressed by the asymptote

$$s = \frac{Q}{4\pi T}\left(-0.5772 - In\frac{r^2S}{4Tt}\right) \quad \text{............. (3.14)}$$

Rewriting and changing to decimal logarithms, this reduces to

$$s = \frac{2.30Q}{4\pi T}\, log\, \frac{2.25\, Tt}{r^2\, S} \quad \text{................. (3.15)}$$

Therefore, a plot of drawdown s versus the logarithm of t forms a straight line. Projecting this line to s = 0, where $t = t_0$

$$0 = \frac{2.30\, Q}{4\pi t}\, log\, \frac{2.25Tt_0}{r^2S} \quad \text{..................... (3.16)}$$

and it follows that

$$\frac{2.25\, Tt_0}{r^2S} = 1 \quad \text{.................... (3.17)}$$

resulting in

$$S = \frac{2.25\, Tt_0}{r^2} = 1 \quad \text{..................... (3.18)}$$

A value for T can be obtained by noting that if $t/t_0 = 10$, then $\log t/t_0 = 1$; therefore, replacing s by Δs, where Δs is the drawdown difference per log cycle of t, Eq. 3.15 becomes

$$T = \frac{2.30Q}{4\pi \Delta s} \quad \text{.....................(3.19)}$$

Thus, the procedure is first to solve for T with Eq.3.19 and then to solve for S with Eq.3.18. The straight-line approximation for this method should be restricted to small values of u (u<0.01) to avoid large errors.

3.11.3 Chow Method of Solution

Chow developed a method of solution with the advantages of avoiding curve fitting and being unrestricted in its application. Again, measurements of drawdown in an observation well near a pumped well are made. The observational data are plotted on semi logarithmic paper in the same manner as for the Cooper-Jacob method. On the plotted curve, choose an arbitrary point and note the coordinates, t and s. Next, draw a tangent to the curve at the chosen point and determine the drawdown difference Δs, in feet, per log cycle of time. Compute F(u) from

— ……….. (3.20)

and find the corresponding values of W(u) and u from Figure 3.7

Finally, compute the formation constants T by Eq.3.12 and S by Eq.3.13.

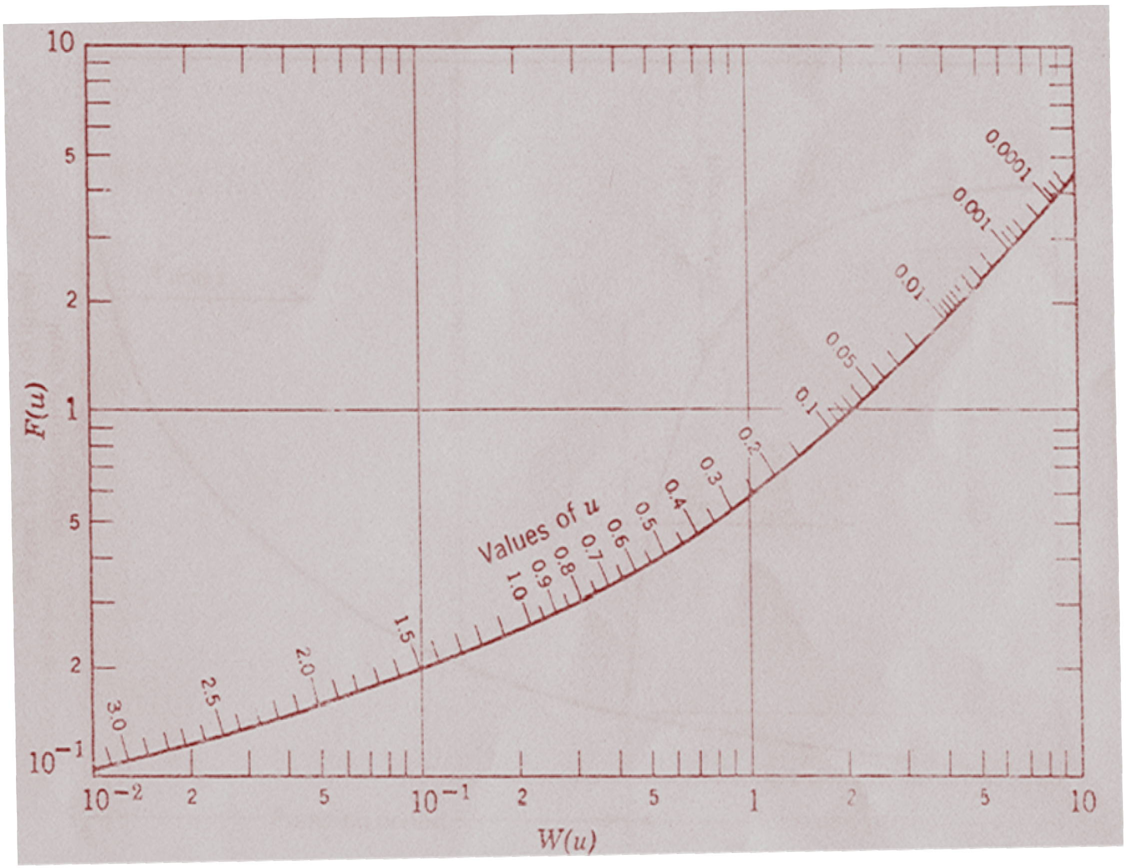


Figure 3.7 Relation among F(u), W(u), and u (Source: Todd, D. K., 2003)

3.11.4 Recovery Test

At the end of a pumping test, when the pump is stopped, the water levels in pumping and observation wells will begin to rise. This is referred to as the recovery of groundwater levels, while measurements of drawdown below the original static water level (prior to pumping) during the recovery period are known as residual drawdown.

It is good practice to measure residual drawdown because analysis of the data enable transmissivity to be calculated, thereby providing an independent check on pumping test results. Also, costs are nominal in relation to the conduct of a pumping test. Furthermore, the rate of recharge Q to the well during recovery is assumed constant and equal to the mean pumping rate, whereas pumping rates often vary and are difficult to control accurately in the field.

If a well is pumped for a known period of time and then shut down, the drawdown thereafter will be identically the same as if the discharge had been continued and a hypothetical recharge well with the same flow were superposed on the discharging well at the instant the discharge is shut down. From this principle Theis showed that the residual drawdown s' can be given as

$$s' = \frac{Q}{4\pi T}[W(u) - W(u)] \quad \text{.............. (3.21)}$$

Where

$$u = \frac{r^2 S}{4Ti} \; and \; u' = \frac{r^2 S}{rT'} \quad \text{................ (3.22)}$$

In addition, it should be noted that measurement of the recovery within a pumped well will provide an estimate of transmissivity even without an observation well. For r small and t' large, the well functions can be approximated by the first two terms of eq. 3.11 so that Eq.3.21 can be written as

$$s' = \frac{2.30Q}{4\pi T} \; log \frac{t}{t'} \quad \text{................ (3.23)}$$

Thus, a plot of residual drawdown s' versus the logarithm of t/t' forms a straight line. The slope of the line equals 2.30Q/4πT so that for Δs', the residual drawdown per log cycle of t/t', the transmissivity becomes

$$T = \frac{2.30Q}{4\pi \Delta s'} \qquad \ldots\ldots\ldots\ldots (3.24)$$

No comparable value of S can be determined by this recovery test method.

3.12 Use of "PROCESSING MODFLOW FOR WINDOWS (PMWIN)" for Sustainable Ground Water Resource Study for Gurgaon

3.12.1 Introduction

Processing Modflow was originally developed for a remediation project of a disposal site in the coastal region of North Germany. It was designed as a pre and postprocessor for the groundwater flow model MODFLOW. PMWIN offer a totally integrated simulation system for modeling groundwater flow and transport processes with MODFLOW-88, MODFLOW-96, PMPATH, MT3D, MT3DMS, MOC3D, PEST and UCODE. It comes complete with a professional graphical pre and postprocessor.

3.12.2 Packages under PMWIN

A brief summary of the various packages under PMWIN is given below and Figure 3.8 shows the details of packages:

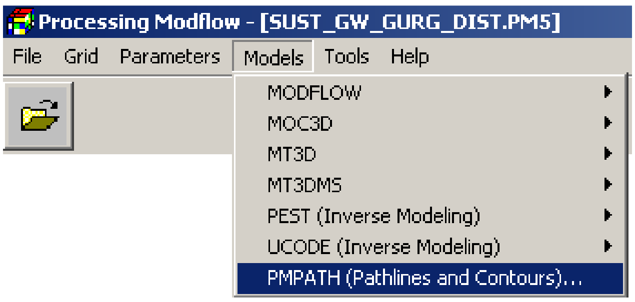


Figure 3.8 Details of Modflow Packages

MODFLOW

MODFLOW (*McDonald and Harbaugh, 1988*) supports the simulation of the effects of wells, rivers, reservoirs, drains, head-dependent boundaries, time-dependent fixed-head boundaries, cut-off walls, compaction and subsidence, recharge and evapotranspiration.

In addition to these standard packages of MODFLOW-96, PMWIN includes the unique Density package for taking into account the density driven flow rates into flow models.

PMPATH

The PMPATH (*Chiang and Kinzelbach, 1994, 1998*) uses a semi-analytical particle tracking scheme to calculates and animates the particle tracking processes simultaneously and provides various on-screen graphical options including head contours, drawdown contours and velocity vectors. Both forward and backward particle-tracking schemes are allowed for steady state and transient flow fields.

MT3D

The MT3D (*Zheng, 1990*) uses a mixed Eulerian-Lagrangian approach to simulate changes in concentration of single species miscible contaminants in groundwater considering advection, dispersion and simple chemical reaction. The chemical reactions included in the model are limited to equilibrium controlled linear or non-linear sorption and first-order irreversible decay or biodegradation.

MT3DMS

The MT3DMS (*Zheng and Wang, 1998*) is a further development of MT3D. The abbreviation MS denotes the Multi- Species structure for accommodating add-on reaction packages. MT3DMS includes three major classes of transport solution techniques, i.e., the standard finite difference method; the particle tracking based Eulerian-Lagrangian methods; and the higher-order finite-volume TVD method. Up to 30 different species can be simulated with PMWIN.

MOC3D

The MOC3D (*Konikow, Goode and Homberger, 1996*) transport model uses the method of characteristics to compute changes in concentration of a single dissolved chemical constituent over time that are caused by advective transport, hydrodynamic dispersion (including both mechanical dispersion and diffusion), mixing or dilution from fluid sources, and mathematically simple chemical reactions, including decay and linear sorption represented by a retardation factor.

PEST and UCODE

The PEST (*Doherty, Brebber and Whyte, 1994*) and UCODE (*Poeter and Hill, 1998*) assist in data interpretation and in model calibration. If there are field or laboratory measurements, PEST and UCODE can adjust model parameters and/or excitation data in order that the discrepancies between the pertinent model-generated numbers and the corresponding measurements are reduced to a minimum. The following model parameters can be automatically calibrated: (1) horizontal hydraulic conductivity or transmissivity; (2) vertical leakance; (3) specific yield or confined storage coefficient; (4) pumping rate of wells; (5) conductance of drain, river, stream or head-dependent cells; (6) recharge flux; (7) maximum evapotranspiration rate; and (8) inelastic storage factor.

3.12.3 MODFLOW: Grid Parameters

MODFLOW, a modular three-dimensional finite difference groundwater flow model developed by the U. S. Geological Survey simulates saturated flow in three dimensions. MODFLOW is probably the most widely used, tested and verified model today because of its versatility and an open structure. The "original" version of MODFLOW-88 was developed by Michael G. McDonald and Arlen W. Harbaugh in 1988. MODFLOW-88 and MODFLOW-96 can simulate the effects of wells, rivers, drains, head-dependent boundaries, recharge and evapotranspiration. Since the publication of MODFLOW numerous investigators have developed various codes. These codes are called packages, models or sometimes simply programs. Packages are integrated with MODFLOW, each package deals with a specific feature of the hydrologic system to be simulated, such as wells, recharge or river. Models or programs can be stand-alone codes or can be integrated with MODFLOW. A standalone model or program communicates with MODFLOW through data files. The advective transport model PMPATH, the solute transport model MT3D, MT3DMS and the parameter estimation programs PEST and UCODE use this approach. The solute transport model MOC3D is integrated with MODFLOW. This code uses MODFLOW as a function for calculating flow fields. MODFLOW is coded in FORTRAN and requires a specific data input format. The major inputs required for running MODFLOW are:

- Model grid size and aquifer's thickness
- Horizontal and vertical hydraulic conductivity of the soil of the model area

- Recharge to aquifers (area and point source)
- Ground water boundary conditions Boundary conditions for the modeled area could be established with a prior knowledge of the area.

The types of boundary conditions MODFLOW uses are:

- Constant head boundary, e.g., a river or a reservoir
- No flow boundary, e.g., an impermeable layer such as mountain bedrock
- Constant flux, e.g., a constant flux of water, such as a stream inlet or ground water recharge from neighboring aquifers.

The major outputs from MODFLOW are the predicted ground water elevation or head for each grid cell in the model along with a water budget (mass balance) for each grid cell. These two outputs can be used as inputs to run MT3D. A step-by-step explanation of the various parameters under MODFLOW package is given below and Figure 3.9 shows the details of the grid parameters.

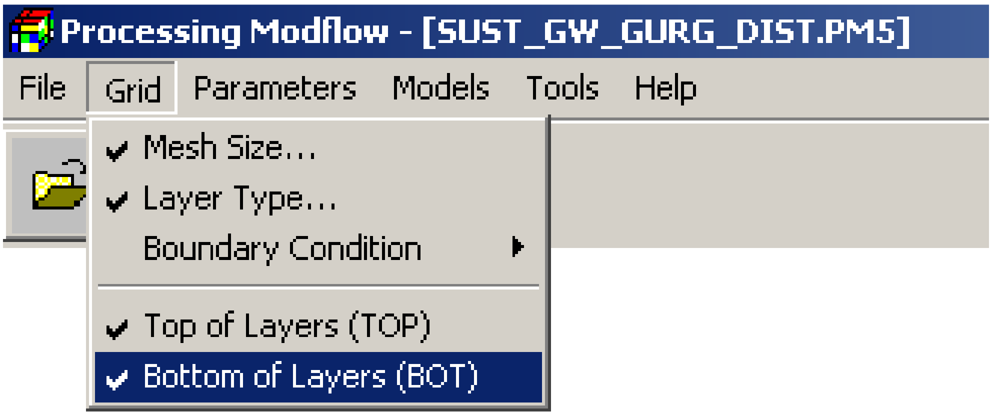


Figure 3.9 Details of the grid parameters.

Mesh Size

MODFLOW uses the block-centered grid in which the model calculates the head at the center of each cell i.e. the node. It is assumed that hydraulic and hydrogeologic properties are uniform over the extent of a cell so that the cell is represented by the node. In MODFLOW the origin of the grid is in the upper left corner of the grid and the layers are numbered from top down. An aquifer system is discretized into a mesh of blocks, or cells, the locations of which are described in terms of rows (I), columns (J), and layers (K) as illustrated in Figure. 3.10. The grid mesh can be uniform, when all the cells have same dimensions, and custom, when cell sizes varies. Although the uniform grid is preferred from a mathematical standpoint, it will often be necessary to design a custom grid. A rule of thumb when designing a custom grid is that the size of a cell, in all three directions (row, column, layer), cannot be more than 1.5 times larger (smaller) than the size of the adjacent cells. This is necessary in order to preserve the mathematical stability of the numerical solution.

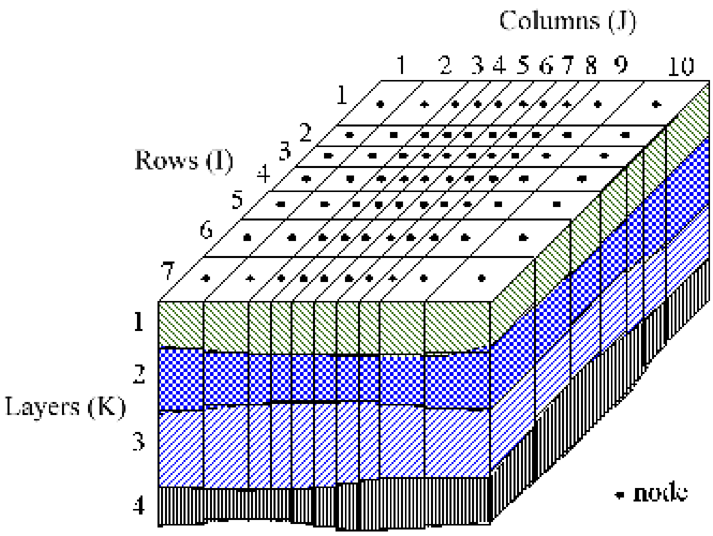


Figure 3.10 Spatial discretization of an aquifer system (after McDonald and Harbaugh)

For formulating mudflow model for Gurgaon district which has area of 1254.62 km^2, depending upon the shape of the district 102 columns and 66 rows mesh size was selected. Out of these total 6732 (102×66) grid cells 3861 cells are being utilized for modeling. Each cell has 570.03 m length and 570.03 m width. Thus each cell area was 324934.20 m^2 and total area under consideration was 1254.57 km^2. Following Figure 3.11 shows the grid view of model (named SUST_GW_GURG_DIST) and lower left side corner shows the cell size in meters.

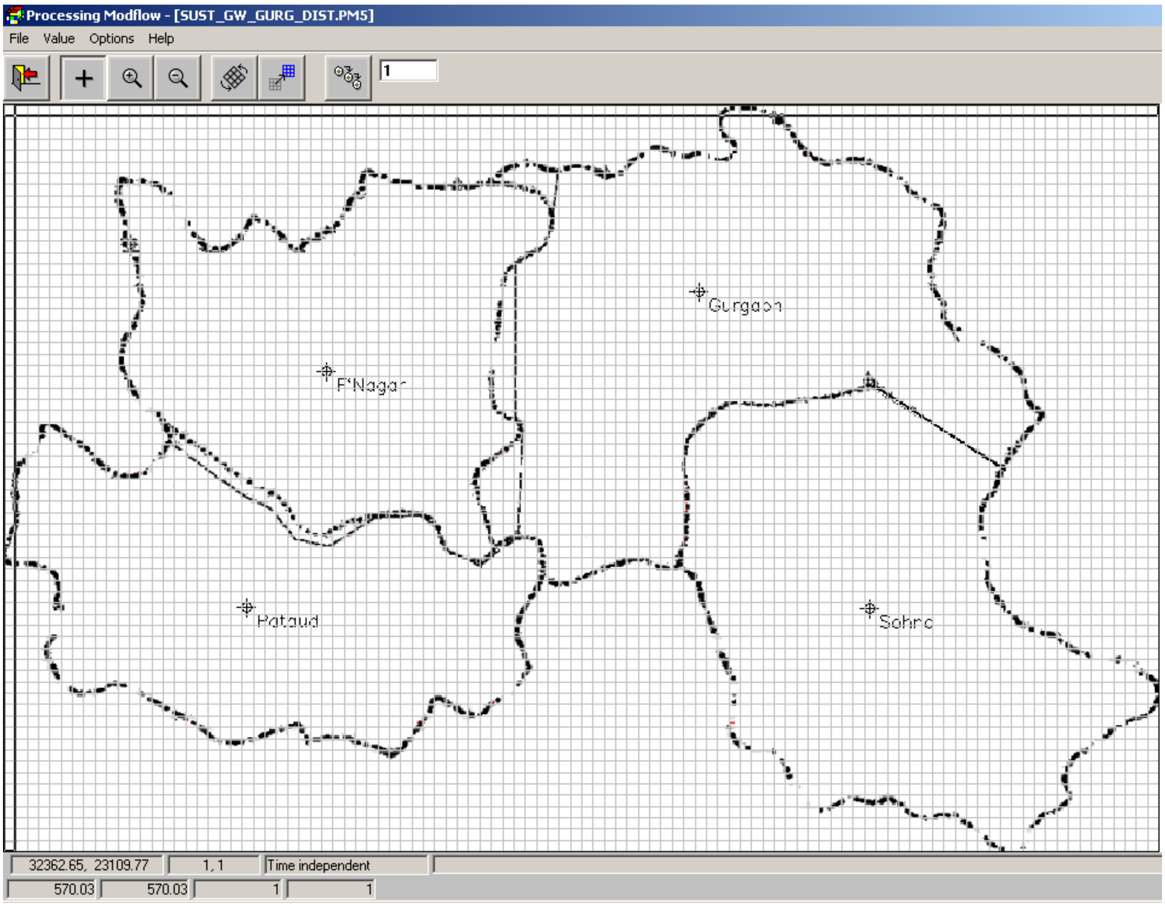


Figure 3.11 Grid view of Modflow model for Gurgaon District (named SUST_GW_GURG_DIST)

Layer Type

There are four basic types of layers in MODFLOW:

- **Type 0:** This layer type is used to simulate confined conditions (layers / aquifers) in which transmissivity of each cell remains constant for the entire simulation time. For transient simulations this layer type requires the confined storage coefficient, which is used to calculate the rate of change in storage.

- **Type 1:** This layer type is used strictly for unconfined conditions and is valid for the first (uppermost) layer only. It requires specific yield for transient conditions. Transmissivity of the layer varies as saturated thickness of the aquifer changes during simulation.

- **Type 2:** This layer type is used when the aquifer alternates between confined and unconfined. However, it is assumed that the saturated thickness remains everywhere a high fraction of the layer thickness so that recalculation of transmissivity is not necessary. In transient simulations it is needed to specify both the storage coefficient for fully saturated confined conditions, and the specific yield for unconfined flow. If the layer completely desaturates, vertical leakage from above ceases.

- **Type 3:** This layer type is also used for confined unconfined transitions. It includes varying transmissivity, which is recalculated at each iteration using hydraulic conductivity and new saturated thickness. Confined storage coefficent and specific yield are both needed for transient simulations. Vertical leakage from above terminates when the layer is completely dry.

The vertical discretization of the Gurgaon district area was represented as single unconfined layer of Type0.

Boundary Condition

i) IBOUND (MODFLOW)

An IBOUND array is required by the flow model MODFLOW. Three types of boundary conditions are possible in IBOUND

• An active cell denoted by 1, in which the hydraulic head is calculated by the model and are free to vary with time.
• A fixed-head cell denoted by -1, in which the hydraulic head is kept fixed at a given value such as aquifer contacts with major surface water features.
• An inactive cell denoted by 0, in which no flow into or out of the cell occurs during the entire time of simulation.
Figure 3.12 shows inactive cells denoted by 0 in grey shade and white colored active cells denoted by 1.

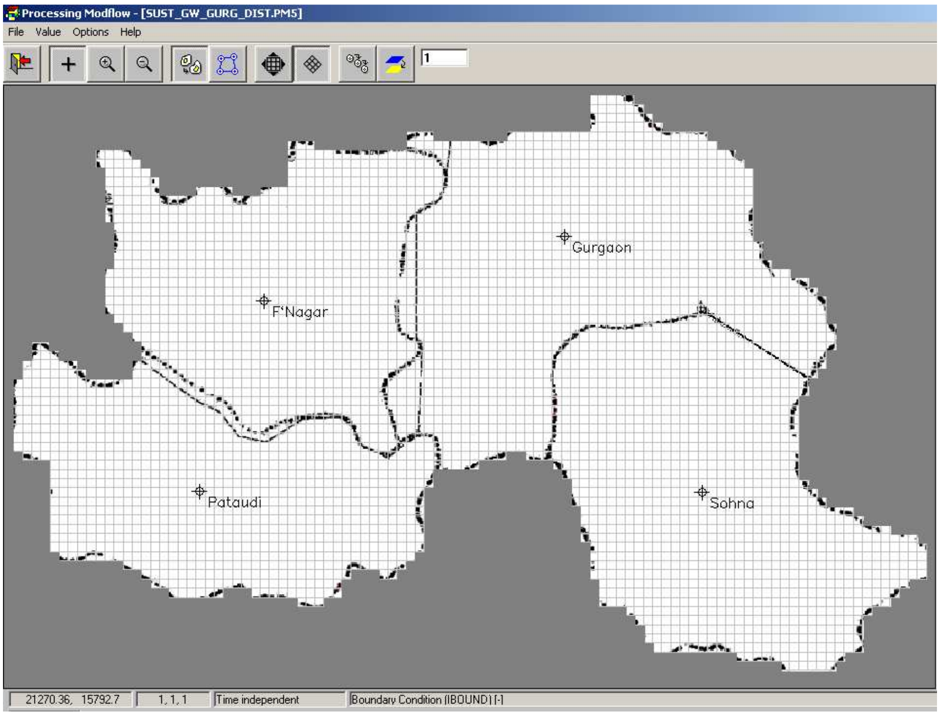


Figure 3.12 Boundary conditions for Gurgaon groundwater Modflow model

ii) ICBUND (MT3D)

An ICBUND array is required by the transport models MT3D and MT3DMS.

• An active concentration cell denoted by 1, in which the concentration varies with time and is calculated by the model.

• A constant concentration cell denoted by -1, in which the concentration is constant.

• An inactive concentration cell denoted by 0, in which no transport simulation takes place at such cells.

Layer Top and Bottom

The elevation of the layer top and bottom is required to calculate aquifer transmissivity, vertical leakage or confined storage coefficient. Original MODFLOW reads the top elevation only for layers of type 2 and 3, and the bottom elevation for layers of type 1or 3. For Gurgaon model top of the model was obtained using natural surface level observations of 75 observation wells (Figure 3.15) spread over the district using digitizer and interpolator tools of the software package of Modflow. Bottom of layer was obtained by considering 60 meters aquifer depth.

3.12.4 MODFLOW: Model Parameters

Following Figure 3.13 shows the details of the model parameters:

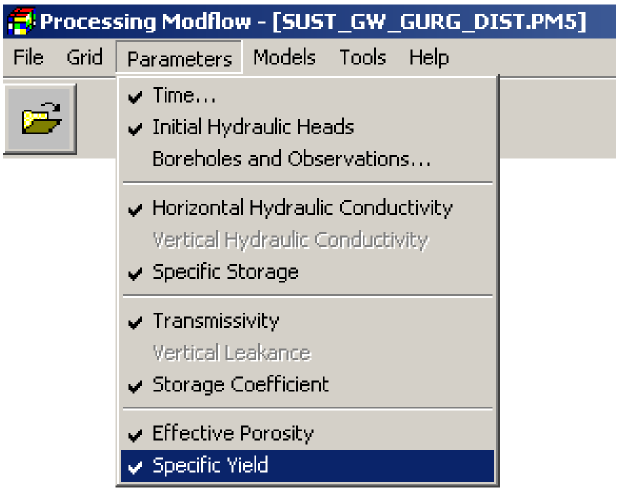


Figure 3.13 Details of the model parameters

i. Time

Time parameters are specified when modeling transient (time dependent) conditions. They include time unit, the length and number of time periods, and the number of time steps. During one time (stress) period all model parameters associated with boundary conditions and various stresses remain constant. A time period is further divided into time steps that are useful for analyzing changes in hydraulic head and drawdown. Time steps do not have to be of same length. Following figure 3.14 shows the actual time parameter description view of the formulated ground water model for Gurgaon district.

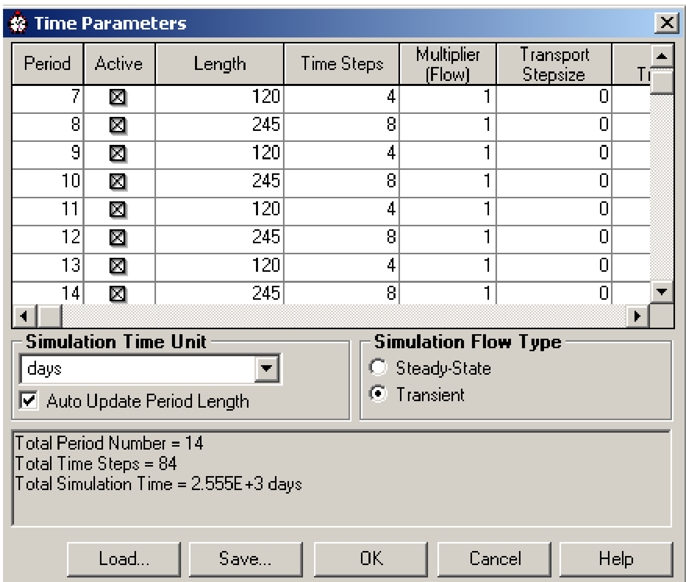


Figure 3.14 Time parameter view of the ground water model for Gurgaon district

For each period of average of five years within study period of 1974 to 2008, water balance was carried out for June of current period to June of next period. In this time period, two stress periods were considered viz. June to September (120 days Monsoon Period) and October to next June (245 days Non-Monsoon Period). Monsoon stress period was simulated at four time steps (end of each month) and non-monsoon period was simulated at eight time steps (end of each month). Thus 1974 to 2008 period was divided into seven five year average time periods, and each period was divided into two stress periods giving total 14 stress periods (7×2) and 84 time steps (7×12).

ii. Initial Hydraulic Heads

MODFLOW requires initial hydraulic heads at the beginning of a flow simulation. For transient flow simulations, the initial heads must be the actual values. For steady-state flow simulations, the initial heads are starting guessed values for the iterative equation solvers. The heads at the fixed-head cells must be the actual values while all other initial heads can be set arbitrarily.

For Gurgaon model initial hydraulic head was obtained using initial depth to water level observations of 75 observation wells (Figure 3.15) spread over the district using digitizer and interpolator tools of the software package of Modflow.

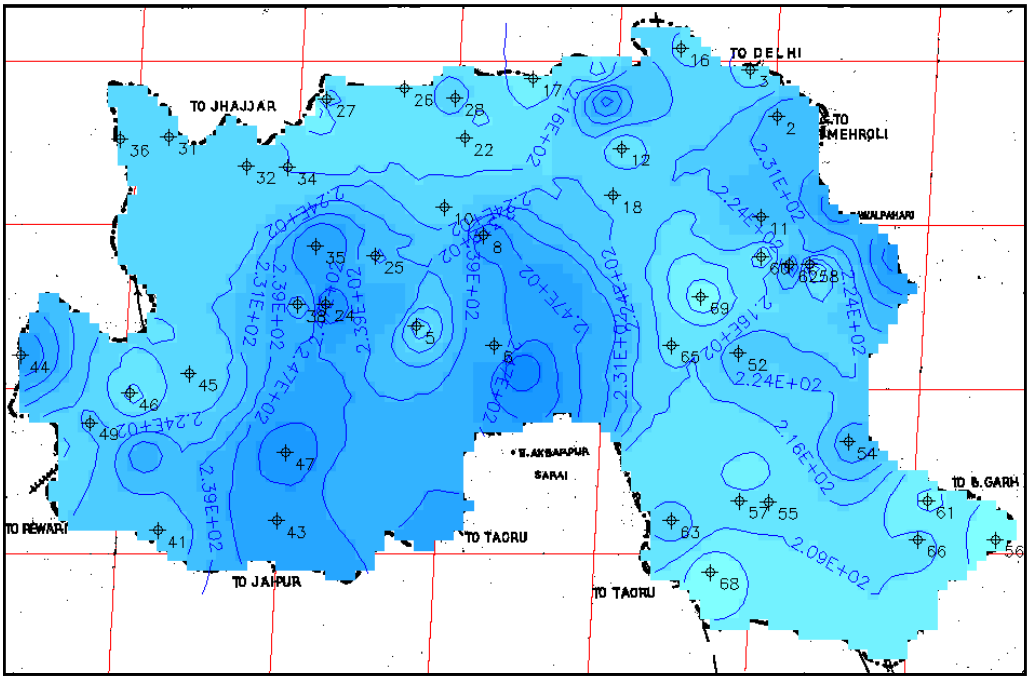


Figure 3.15 Observation wells and initial hydraulic head contours of Modflow model for Gurgaon district.

iii. Horizontal Hydraulic Conductivity and Transmissivity

In MODFLOW the horizontal hydraulic conductivity is the conductivity along the grid rows. The hydraulic conductivity is required for layers of type 1 and 3 (unconfined conditions), and transmissivity is required for layers of type 0 and 2 (confined conditions). Most MODFLOW processors like PMWIN can calculate transmissivity for a layer of any type by multiplying hydraulic conductivity with layer thickness derived from layer top and bottom elevations. For our model we have used horizontal conductivity values found out using pumping tests carried out in various representative locations in Gurgaon district. Details of these test has been given in subsequent section.

iv. Vertical Hydraulic Conductivity and Leakage

For quasi-3D models with more than one layer and for full 3D models, MODFLOW requires the input of the vertical leakage between two layers. Processors such as PMWIN can calculate the vertical leakage for each layer from the layer thickness and the vertical hydraulic conductivity. Unless accurately determined from pumping tests, the vertical hydraulic conductivity is usually assumed and/or calibrated.

v. Storage Terms

Storage coefficient for confined layers (layer type 0, 2, and 3) and specific yield for unconfined layers (layer type 1, 2, 3) are required only for transient simulations. The storage coefficient (S) is the product of the layer thickness (b) and specific storage

vi. Effective Porosity

The volume percentage of a rock or soil sample that consists of interconnected pores through which water can flow is the effective porosity. It is used by transport models, for example PMPATH, MOC3D, MT3D to calculate the average velocity of the flow through the porous medium. For Gurgaon groundwater models we have used CGWB recommended effective porosity value for such areas of 0.16.

3.12.5 MODFLOW Packages

Following figure 3.16 shows the view of packages of Modflow model software.

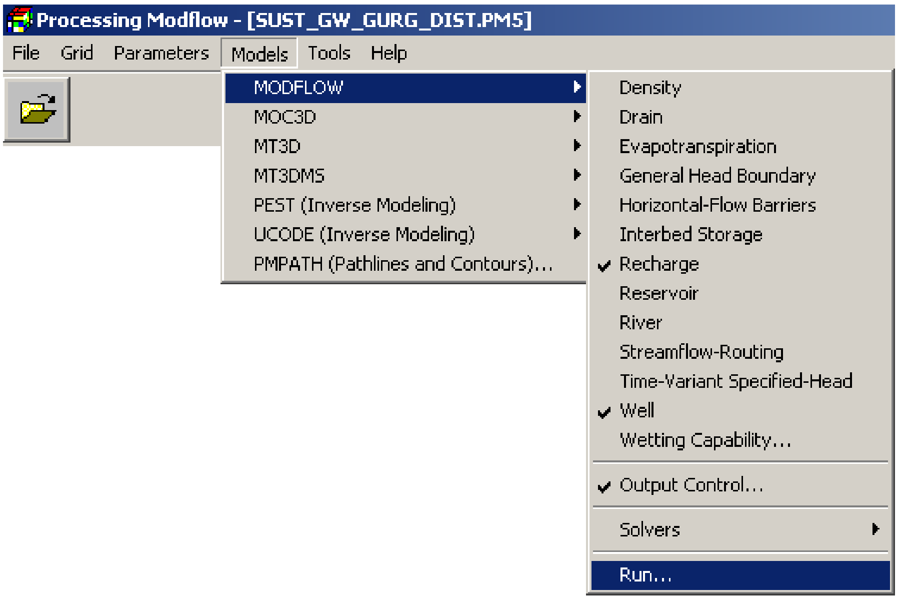


Figure 3.16 Packages of Modflow model software

i. Density Package

In the Density Package developed by Schaars and Van Gerven (1997), the water density of a "density-layer" may differ from cell for cell. During a flow simulation the density-dependent flows will be adapted into the system of flow equations by correcting the hydraulic heads to equivalent fresh water heads (or reference density heads).

ii. Drain Package

The Drain Package simulates both closed and open drains. It is one of the best tools to model springs since the inflow into the drain ceases when the head in the aquifer drops below drain elevation.

iii. Evapotranspiration Package

The Evapotranspiration Package simulates the effects of plant transpiration and direct evaporation in removing water from the saturated groundwater regime. This package shows a linear variation in the water table elevation accounting for the user specified maximum and minimum (zero) depth of evapotranspiration.

iv. General Head Boundary Package

The General Head Boundary Package is used for transient simulations of constant head boundaries since it allows the user to change the head from one time period to another. It can be used to simulate permanent surface water features.

v. Horizontal Flow Barrier Package

The Horizontal-Flow Barrier Package developed by Hsieh and Freckleton (1993), simulates thin low-permeability geologic features, such as vertical faults or slurry walls that impede the horizontal flow of groundwater. These geologic features are approximated as a series of horizontal-flow barriers conceptually situated on the boundaries between pairs of adjacent cells in the finite-difference grid.

vi. Interbed Storage Package

The Interbed Storage Package developed by Leake and Prudic (1991), calculates the water volume released from storage and simulates elastic and inelastic compaction of compressible fine-grained beds in an aquifer due to groundwater extraction. The term “interbed” is used to denote a poorly permeable bed within a relatively permeable aquifer. This package is used only for transient simulations.

vii. Recharge Package

The Recharge Package is typically used to simulate aerial infiltration from precipitation or irrigation. It can also simulate local recharge to ponds. It is flexible in assigning vertical flux to different layers along the vertical.

viii. Reservoir Package

The Reservoir package developed by Fenske, Leake and Prudic (1996) can simulate leakage from reservoirs where the reservoirs are much greater in area than the area represented by individual model cells. More than one reservoir can be simulated using this package.

ix. River Package

The River Package simulates the flow between an aquifer and surface water feature in both directions. It includes riverbed conductance for simulating fine sediment clogging of a river channel. It should not be used for intermittent streams since there is no adjustment for the stream flow and stage once it drops below the channel bottom.

x. Stream flow Routing Package

The Stream flow Routing Package developed by Prudic (1989), simulates interaction between an aquifer and a surface stream accounting for the flow rate in the stream. Flow into or out of the stream stops when the stream dries out. It requires intensive data preparation and more data input than any other package.

xi. Time-Variant Specified-Head Package

The Time-Variant Specified-Head Package developed by Leake and Prudic (1988) is used in transient simulations and allows constant head cells to take on different head values for each time step during a simulation time period.

xii. Well Package

The Well Package simulates both extraction and recharge wells. Negative cell values for the “Recharge rate of the well” are used to indicate pumping wells, while positive cell values indicate injection wells. It assumes full penetration of the layer.

xiii. Block-Centered Flow 2 Package

The Block-Centered Flow 2 Package developed by McDonald, Harbaugh, Orr and Ackerman (1992) allows the simulation of a rising water table into unsaturated (dry) model layers. A typical application is the simulation of the recovery of over stressed aquifer, such as after heavy pumpage, either through artificial recharge or the reduction of stress.

3.12.6 Model Run

After the model parameters are assigned to each cell, to run the model the user must choose one of the solving packages. PMWIN supports four packages (solvers) for solving systems of simultaneous linear equations:

- The Direct Solution (DE45) package,
- The Preconditioned Conjugate-Gradient 2 (PCG2) package,
- The Strongly Implicit Procedure (SIP) package, and
- The Slice-Successive Overrelaxation (SSOR) package.

The number of model runs during calibration will depend on the quantity and quality of available data, desirable accuracy of the model results.

3.12.7 Mathematical Model of MODFLOW

MODFLOW uses the following equations for groundwater flow simulation:

i) Continuity Equation

The method of finite difference with block-centered approach is adopted and the resulting equations are solved using the continuity equation (Eq.3.25) with an assumption that the density of fluid is constant.

$$\sum Qi = SS^{\Delta b} - \Delta V \qquad \text{………… (3.25)}$$

Where,

Q_i = flow rate into the cell (L^3/T),

SS = a term equivalent to specific storage (1/L),

ΔV = change in volume of the cell (L^3), and

Δh = change in head over a time interval (L).

ii) Darcy's Law

$$qi,j - {}^{1}/_{2}, k = KRi,j - {}^{1}/_{2}, k\Delta ci\Delta vk\ \frac{hi,j-1,k-hi,j,k}{\Delta rj-{}^{1}/_{2}} \qquad \text{……… (3.26)}$$

iii) Finite Difference Model

The governing equation is the finite difference model of groundwater flow is given by:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t} \qquad \text{.......... (3.27)}$$

Where, K_{xxx}, K_{yy}, K_{zz} = Hydraulic conductivity along x, y and z

h = total head

W = sources and sinks

S_s = Specific storage

t = time

MODFLOW uses one such numerical method i.e. Finite Difference Method, wherein the continuous system described by equation (3.26) is replaced by a finite set of discrete points in space and time and the partial derivatives are replaced by terms calculated from the differences in head values at these points. The process leads to systems of simultaneous linear algebraic difference equations; their solution yields values of head at specific points and times. These values constitute an approximation to the time varying head distribution that would be given by an analytical solution of the partial difference equation of flow.

Chapter 4

Ground Water Sustainability

Chapter-4
GROUNDWATER SUSTAINABILITY

Since the publication of the Bruntdland Report "Our Common Future" in 1987, sustainable development has been adopted as governing philosophy. Despite the broad acceptance of this philosophy and its recognition on various important meetings, we are witnessing water management practices overstepping ecological limits. Aquifer overexploitation and groundwater mining are reported from all parts of the world. Our study area, Gurgaon district presents same problem and concerns. Unlimited supply of groundwater has led to its unequal and excessive use. However, this use can have diverse and often wide ranging effects on the local and regional hydrology and ecology.

4.1 Overview of important existing challenges for Groundwater Utilization in Gurgaon district

i. **Linkage and Connectivity:** Gurgaon is highly accessible town through Roads, Rails and Airways. The city is just 32 km from New Delhi, the National Capital of India and 285 km from Chandigarh, the State Capital.

ii. **Commercial Potential:** Gurgaon is regarded as the commercial capital of Haryana. It is one of the most sought after destination for MNCs corporate residents and investors as it offers world class standards of living and globally comparable business address in the IT parks and business Centers. Its mounting popularity has inspired the offices to relocate from congested and unhygienic industrial zones of New Delhi to this trendy suburb. Gurgaon's proximity to New Delhi, the National Capital and to the International Airport Delhi makes it a very important city. It is an important NCR town with a fast urbanization trend. The entrepreneur of Delhi found Gurgaon as the nucleus offering a combination of various inputs of land, labor, skill and transport.

iii. **Public-Private Partnership:** The public-Private Partnership concept enacted by the Haryana Government in 1975 brought a revolution in the growth and development in the emerging towns of the state. One such important economic city in Haryana is Gurgaon set in the vicinity of Delhi. The first major residential colony license in Gurgaon given to the foremost developer was in 1981 followed by licenses to M/s Ansal Properties and Industries Ltd. in November 1982, in respect of DLF's Qutub Enclave and Ansals Palam Vihar respectively. Since then about 7000 acres licenses have been granted to various colonizers, which include Group Housing colonies as well as Commercial licenses.

iv. **Residential Potential:** Being in close contact with the cosmopolitan world, the National Capital Delhi, the International Airport, the district is acting as a magnet attracting the residential population. The city offers a wide range of residential properties such as apartments, condominiums, villas, independent floors, duplexes and residential plots to cater to everyone Thousands of professionals have recently made their home in Gurgaon living in apartments in newly constructed colonies and condominiums with world class facilities. The fast growing population with increasing purchasing power has created a huge demand for housing. Quality of life in the privately managed residential estate in Gurgaon remains relatively good due to high standards of security, private parking, common area maintenance and sanitation being the norm.

v. **Industrial Potential:** Gurgaon offers an excellent location to start industry as it is in close contact with cosmopolitan world being close to National capital Delhi. Haryana provides ample choice to an industrialist so far as land is concerned. Industrial land is being continuously developed and allotted to potential entrepreneurs and has been able to attract sizable investment from multinational companies, large business houses, and foreign investors, Non-Resident Indians (NRI) etc. Gurgaon is the home of renowned Maruti Suzuki, India's first small passenger car of International quality. The latest International Industrial Model Township is soon to come into existence with the assistance and guidance from the Japanese. The 600-hector stretch selected for this purpose is adjacent to village Manesar and is situated on the National Highway No. 8 which connects New Delhi to Jaipur and Bombay.

vi. **Basic Financial and Industrial Infrastructure*:*** Haryana's two strongest points- physical infrastructure and Government support are the top two determinants of investment decisions. Further strengthening the infrastructure in order to support the growth process has been accepted by the state as the mainstay of its policy initiatives. A number of projects for development of industrial infrastructure are being implemented. Government support is the main determinants of investment decision in Haryana. The state offers an extremely attractive array of incentives. Therefore Gurgaon has earned global recognition as one of the best IT and ITES destination. The development of Information technology and its extensive use for modern management practices is a part of new Industrial policy.

4.2 Sustainability of Groundwater Resources

The limits how much water can be extracted from a finite groundwater aquifer are economic and environmental (Gleick, 1993). When water is pumped out faster than it is recharged by the natural processes, the water level in the aquifer drops, and the distance the water must travel increases. Eventually, either the energy costs rise to the point that exceeds the value of the water, or the water quality falls below acceptable levels. At this point pumping must cease (Postel,1993).

Although many aspects of what can be called overexploitation are not new in hydrogeology, this concept is still poorly defined and subjected to varying interpretations by different specialists, managers, policy makers and the public. A set of terms, not always fully equivalent are in use for concepts related to overexploitation, such as over-pumping, over-draft, over-development and groundwater mining.

The debates between experts and decision-makers on the management of groundwater resources, as regards the overexploitation of aquifers, are based on two main questions

- How should we assess whether an aquifer is being overexploited, or predict?
- Whether this has happen as a result of planned new exploitation?

Besides this, various questions like is the overexploitation of an aquifer always undesirable, is it permissible or even advantageous under certain situations, and what impact should be anticipated and compensated for? are required to give deep thoughts. Aquifer management, especially of overexploited ones, which deals with a complex interaction between human society and the physical environment, presents an extremely difficult problem of policy design. Establishment of a groundwater management system involves selection among strategies, which variously satisfy competing objectives and criteria. The most suitable policy will include a mix of structural and cognitive measure.

4.2.1 Safe Yield versus Aquifer Overexploitation

Hydro-geologists and ground water managers are concerned about the sustainable economic output when there is excessive groundwater withdrawal. Together with engineers they developed the concept of safe yield. Conversely, overexploitation is largely point of view referring to the consequences of intensive groundwater use, as perceived by environmentalists, sociologists, news media and public in general, and places more emphasis on the adverse or detrimental aspects.

To evaluate a situation that can be termed overexploitation, not only hydrological aspects; have to be taken into account, but also economic, social and political ones, as well as the point of view of the stakeholders and all persons involved (groundwater exploiters, water administrators, water managers, land-use planners, economists, local people and environmentalists).

Overexploitation is a term often used when the rate of abstraction exceeds the so called “safe yield” (or sustainable yield) with the formation of overdraft areas. In another interpretation, undesirable results when the ground water storage cannot be replenished by a natural recharge in a reasonable period of time, or when prolonged abstraction; results in the intrusion of the saline water, or in deterioration of water quality (John, R., 2009). The term groundwater mining is used when conscious and planned abstraction rate exceeds aquifer recharge (UN, 1992).

4.2.2 Safe Yield

Safe yield is defined as the amount of water, which can be taken from the aquifer indefinitely without producing an undesirable result. From a hydrological point of view, the maximum safe yield is equal to the long term mean annual recharge of any origin or, in other words, to the amount of water which under normal circumstances leaves the basin as a natural base flow. According to Romilla John (2009) safe yield should be decided according to

- Potentially exploitable groundwater resources which represent a maximum close to the live storage, and are limited only by technical problem of setting an adequate system of boreholes to utilize the ground water to the maximum and
- Actually exploitable groundwater resources governed by technical, environmental and legal requirements on the minimum base flow and/ or minimum groundwater level.

Safe yield, also called sustainable yield, is considered as the upper limit of exploitation. But Walton (1970) concluded "From the water user's point of view, the so called sustained exploitation means that the water supply has been frozen at a certain level because of the seemingly unfounded apprehensions of a hydrologist".

Safe yield is determined using water balance equations for a representative period of time. The question to be answered is to what extent can the ground water resources be exploited during dry years? Statistical methods can also be applied to determine the safe yield from monitored groundwater table level data or rainfall data, provided that correlation exists. Figure 4.1 shows another approach for determining safe levels of yield.

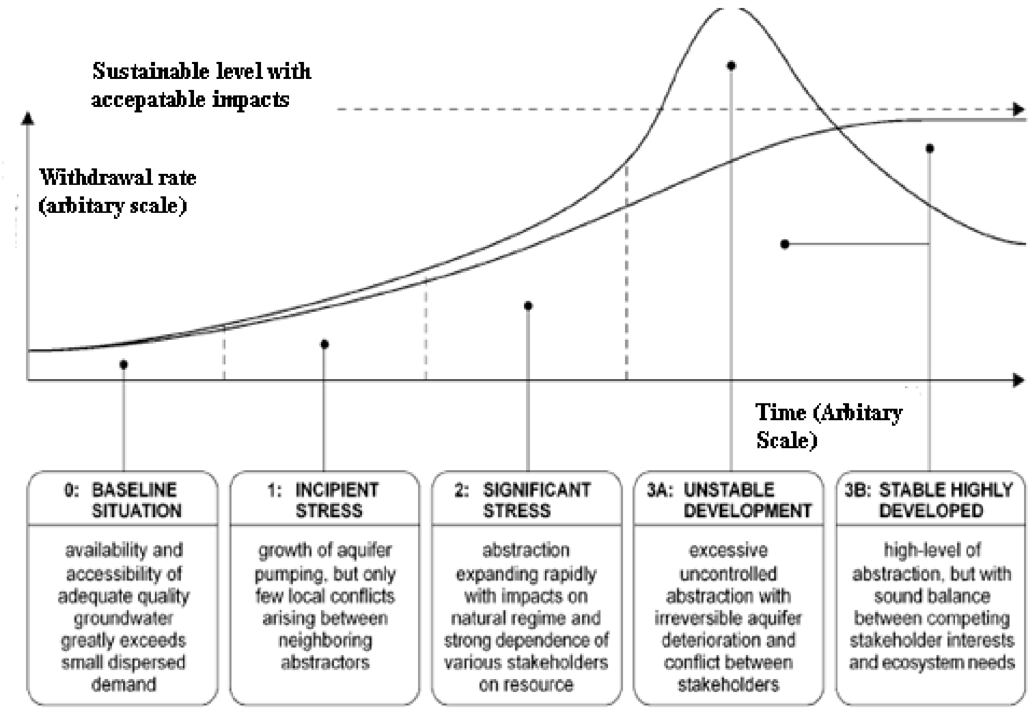


Figure 4.1 Diagram showing sustainable level of resource utilization (Source: Foster, S., 2006)

4.2.3 Aquifer Overexploitation

Effect of aquifer exploitation does not depend on the volume being abstracted only, but also on distribution of withdrawal and well pattern. Thus safe yield of aquifer is complex function that changes with the time. It cannot be considered as a fix value for an aquifer. The problem is complicated with change in natural recharge due to land-use modifications and different form of artificial recharge. Marget (1992) argues that non-equilibrium or an unbalanced regime of an aquifer cannot simply be identified as overexploitation. He proposes that evaluation of overexploitation depends on the agreements on the meaning of undesirable results or adverse situations caused by it. The assessment of overexploitation is relative to the criteria's used, which are themselves linked to the resource management objectives.

Overexploitation is an acceptable policy only if planed with specific aims and as long as negative consequences have been technically evaluated by decision makers and they are economically and socially acceptable. This is the case if groundwater mining is used to induce a cycle of economic development, which will give way to substitution of more expensive water at a later date or to new technology improving the water use. Even so, the issue of intergenerational equity can arise and it has to be considered with due seriousness.

4.3 Management of Aquifers' Utilization

Aquifer management, which deals with a complex interaction between human society and the physical environment, presents an extremely difficult problem of policy design.

If we suppose that aquifers were managed according to the economist's preferred criterion of maximum net return to the entire aquifer, then the rate of abstraction would be the one that gives the maximum Present Net Benefit. The rate obtained would be much lower than the rate at open access equilibrium, thus preserving the aquifer on a sustainable basis and generating a much larger present value of economic return. Economist would then define 'overexploitation' as any pumping rate in excess of that which yields the maximum present value of net benefit. If externalities are included in the analysis, the result for an optimal level of abstraction is similar, but even more restricted, yielding even smaller rate of abstraction. A successful method of managing aquifer exploitation, as a part of regional water resources management, should have the capability of balancing competing demands so that actual operating policies optimize the net benefit to the region.

4.3.1 Causes of aquifer overexploitation

i. Aquifers are typically common pool resources, in which a migratory substractable resource is exploited under an unrestricted rule of capture. Those using the resource are little motivated to pressure its value, and the collective inefficiency of a pumping race is likely to result;
ii. Extensive exploitation of aquifers often imposes unwanted damage to third parties-external costs or “externalities”. External costs are unwanted and uncompensated costs imposed on third parties who do not themselves benefit from the exploitation activity.

4.3.2 Management Strategies of Aquifer

According to the exploitation strategies, three methods of use (of management) of the reserve of an aquifer are therefore conceivable and practicable (John, R., 2009).

i. A strategy of maximum and lasting exploitation of the renewable resources, in a regime of dynamic equilibrium, with average abstraction greater than average recharge, without taking into account seasonal or even possible annual variations. Thus, after a decrease in the initial phase of non-equilibrium, the stabilized reserve is used, usually as a regulatory factor
ii. A strategy of repeated exploitation of the storage in a prolonged unbalanced regime that may be intentional or unintentional in the initial phase. Then, abstraction increasing or stabilized is greater than recharge (even enhanced by boundary effects). A second phase involves reducing abstraction to restore the equilibrium. This equilibrium might be
    - Stabilized, on average, bringing abstraction close to recharge; or
    - In part restored, by reducing abstraction below recharge and sometimes by artificially increasing recharge, and then stabilizing, on average, in this new condition.

iii. A strategy of mining or exhaustion exploitation, with abstraction from the start of operation much greater than the average recharge. In this case depletion of the reserve provides most of the produced water.

4.3.3 Criteria for Assessing Management Strategies

The diversity of hydro-geological conditions and types of aquifers, of rates of recharge and of volumes of recharge, present a large range of possible aquifer developments. Several criteria are appropriate for assessing management strategies:

a) Economic efficiency: most value of output from any given input, ability to maximize net economic returns and in long run dynamic, flexible system, responsive to the changing conditions
b) Equity
c) Security: satisfaction of minimum human needs
d) Liberty: ability to act freely as long as it doesn't interfere with others
e) Avoiding harm

Secondary criteria are:

f) Local control and popular participation
g) Orderly conflict resolution processes
h) Information intensity
i) Ease of monitoring and enforcement
j) Social considerations

4.4 Management of Overexploited Aquifers

We can distinguish two basically different approaches in management of overexploited aquifers:
a) Structural b) Nonstructural.

a) Structural approaches: These generally involve developing some alternative source of water supply. Following two sections can be made for such approaches

Conventional: reservoir or conveyance schemes, conjunctive use of surface and groundwater **Unconventional:** desalination, weather modification through cloud seeding etc.

b) **Nonstructural approaches:** These are policies of demand management which include:
    - Cognitive methods to modify human behavior
    - Institutional arrangements to coordinate activities of individual water users
    - Administrative organizations as a necessary element of institutional arrangements. Incentive and sanction system can influence individual pumper behavior.

Two general types of incentive-based strategies can be employed to influence the behavior of public in an overexploited aquifer:

i. Financial incentives, both positive and negative:
    - Pumping charges or taxes, subsidies
    - Quantity-control approaches: permits, pumping quotas, transferable pumping entitlements, use of water-rights markets;

ii. Monitoring and enforcing pumping controls.

Aquifer exploitation is performed by humans and understanding how people respond to hydrologic facts, economic opportunities, and institutional constraints is important in diagnosing appropriate ground water management policies. Diagnosis and successful resolution of aquifer overexploitation have to be achieved by coordinated interdisciplinary approach.

4.5 Alternatives to Groundwater Mining

- Artificial recharge to aquifer
- Reclamation and reuse of wastewater
- Desalination
- Weather modification
- Demand modification

4.6 Structure and Schemes for Groundwater Sustainability

Activities taken up for sustainability of sources and system are generally aimed at source augmentation for sustained yield and increasing the life span of source. The dividing line in between operation & maintenance and rejuvenation and revitalization of source is very thin and blurred. There is a close linkage between sustained availability of the source and sustained functioning of the system. Under Sustainability, it is envisaged that routine repair works, activities relating to general operation and maintenance will not be taken up and only such activities/ works would be taken up, which lead to increase in sustained yield and augment the source. According to "Guidelines for Implementation of Schemes and Projects on Sustainability" under "Accelerated Rural Water Supply Program", (GOI, 2000), for sustainability (to harvest rainwater and ground water recharge) following works has been suggested.

i. Nalla bunding
ii. Contour bunding
iii. Contour trench
iv. Gully plugging:
v. Check dams
vi. Pits and shafts
vii. Basin/ percolation tanks
viii. Surface Channels
ix. Ground water dams
x. Injection wells
xi. Connector wells
xii. Storage tanks
xiii. Dug well recharge
xiv. De-siliting of tanks
xv. Roof top harvesting
xvi. Inter watershed transfer
xvii. Gabion structure
xviii. Village tanks
xix. Bore hole flooding
xx. Stream augmentation
xxi. Aquifer modification
xxii. Ditch and Furrow
xxiii. Surface spreading
xxiv. Jacket well technique
xxv. Trench-cum-filter bore well technique

Chapter 5

Results and Discussion

Chapter-5

RESULTS AND DISCUSSION

5.1 Rainfall Analysis

To carry out analysis of rainfall first of all block wise annual rainfall quantities were collected from IMD, New Delhi for 1974 to 2008. Using these yearly rainfall quantities, five year average annual rainfall was worked out and same has been shown in Table 5.1.

Table 5.1 Five year average annual rainfall in mm

YEAR	GGN	FNR	PTD	SHN
1974-78	862.0	301.8	329.8	508.8
1979-83	877.6	445.9	537.3	504.1
1984-88	687.4	374.2	427.5	486.7
1989-93	645.4	550.6	456.9	421.8
1994-98	760.1	458.8	595.2	607.8
1999-03	644.4	270.0	451.6	500.6
2004-08	566.4	270.6	549.4	390.0
Normal	**720.5**	**381.7**	**478.3**	**488.5**

To estimate monsoon and non-monsoon rainfall, normal monthly rainfall quantities shown in Table 5.2were analyzed.

Table 5.2 Normal monthly rainfall for Gurgaon district (mm)

Month	Rain, mm	%
January	11.4	2.6
February	10.7	2.4
March	11.6	2.6
April	1.7	0.4
May	23.4	5.3
June	21.3	4.8
July	118.1	26.7
August	151.5	34.2
September	65.4	14.8
October	21.7	4.9
November	0.5	0.1
December	5.1	1.2
Total	**442.4**	
Monsoon	**356.7**	**80.6**
Non-Monsoon	**85.7**	**19.4**

From table 5.2 it was observed that about 80% rainfall was occurring in monsoon season and about 20% rainfall was occurring in non-monsoon season. Using this distribution of rainfall, rainfall quantities were worked out for monsoon and non-monsoon season. Table 5.3 shows the block wise and season wise distribution of rainfall quantities for Gurgaon district

Table 5.3 Block wise and season wise distribution of rainfall quantities for Gurgaon district

YEAR	PTD		GGN		SHN		FNR	
	Monsoon	Non-Monsoon	Monsoon	Non-Monsoon	Monsoon	Non-Monsoon	Monsoon	Non-Monsoon
1974-78	266	64	695	167	410	99	243	58
1979-83	433	104	708	170	406	98	360	86
1984-88	345	83	554	133	392	94	302	72
1989-93	368	89	520	125	340	82	444	107
1994-98	480	115	613	147	490	118	370	89
1999-03	364	87	520	125	404	97	218	52
2004-08	443	106	457	110	314	76	218	52

Rainfall quantities shown in Table 5.3 have been utilized for recharge estimation during monsoon and non-monsoon season caused by rainfall. Figure 5.1 shows the rainfall trend over last 35 years of study period.

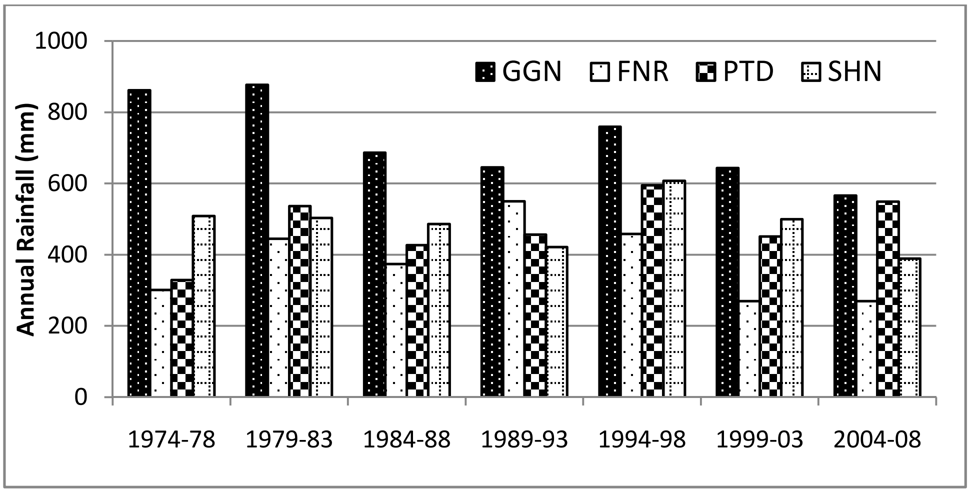


Figure 5.1 Five year average annual rainfall trend over last 35 years (1974-2008)

It can easily be seen from Figure 5.1 that since 1974 total annual quantities of rainfall were reducing for all blocks in Gurgaon district. It can also be seen that total quantities of rainfall were highest for Gurgaon block and lowest for Farukhnagar block.

5.2 Determination of Different Components of Water Withdrawal (Pumping)

Different components for water demand were determined based on the standard professional practice in the field. These components were agricultural water requirement, domestic water requirement, industrial water requirement, institutional water requirement, and water requirement for domestic and other animals. Following section describes the details of each section.

5.2.1 Agricultural Water Requirement

Methodology to estimate agricultural water requirement has been given in section 3.10 of Materials and Methods.

5.2.1.1 Average Irrigated Area Cropping Pattern

For analysis of average cropping pattern, required data was collected from agricultural census of Haryana state for the period 1974 to 2008. As has been discussed in data section previously agricultural census data for 1974 to 2005 has been recalculated for four blocks as new district with four blocks has been formulated from older nine block district in 2005. Table 5.4 and 5.5 shows total area irrigated in different blocks over study period in Kharif and Rabi seasons and Figure 5.2 shows the trend of total existing irrigated area of Gurgaon district over study period and predicted trend for 2025 and 2050.
It was observed from Figure 5.2 that even though total area under irrigation was increasing over years, rate of increase was slowly decreasing over study period. By using prediction equation of trend line, total area under irrigation for year 2025 and 2050 were predicted. Second graph in each row of Figure 5.2 shows the predicted area under irrigation for Gurgaon district.

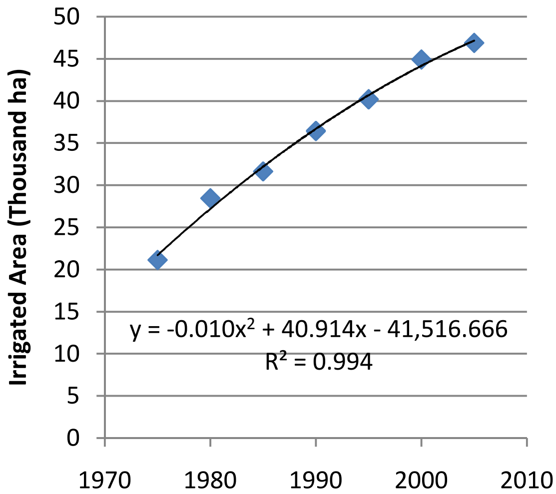
It was revealed from these graphs that total area under irrigation is increasing up to 2025 and then it starts reducing. It was also found out from average cropping pattern over study period that total area under irrigation was high for Rabi season in which farmers are planting different crops using ground water resources. In Gurgaon district, there was less than 3% area under canal irrigation, and mostly agriculture was dependent on ground water resources in Rabi season and on rainfall in Kharif season.

Table 5.4 Average cropping pattern of Gurgaon District in Kharif season over study period

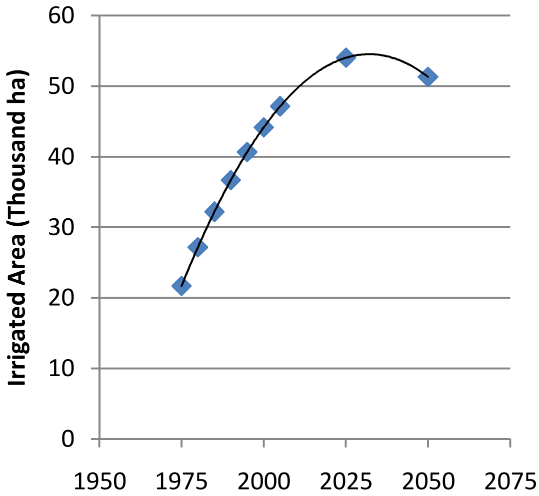
Year	Rice	Jowar	Bajara	Maize	Cotton	Kharif Cereals	Kharif Pulses	S.cane	Spices	Veg. Oil Seed	Total
Pataudi Block											
1977-78	193.1	96.6	2510.5	38.6	38.6	23.2	23.2	38.6	173.8	1506.3	4642.4
1979-83	260.0	130.0	3379.6	52.0	52.0	31.2	31.2	52.0	234.0	2027.8	6249.7
1984-88	289.0	144.5	3757.5	57.8	57.8	34.7	34.7	57.8	260.1	2254.5	6948.5
1989-93	332.9	166.4	4327.4	66.6	66.6	39.9	39.9	66.6	299.6	2596.5	8002.4
1994-98	367.2	183.6	4773.3	73.4	73.4	44.1	44.1	73.4	330.5	2864.0	8826.9
1999-03	410.4	205.2	5335.0	82.1	82.1	49.2	49.2	82.1	369.3	3201.0	9865.6
2004-08	428.3	214.1	5567.9	85.7	85.7	51.4	51.4	85.7	385.5	3340.7	10296.3
2025	493.5	246.8	6415.9	98.7	98.7	59.2	59.2	98.7	444.2	3849.5	11864.4
2050	468.8	234.4	6094.3	93.8	93.8	56.3	56.3	93.8	421.9	3656.6	11269.7
Gurgaon Block											
1977-78	242.1	121.0	3147.2	48.4	48.4	29.1	29.1	48.4	217.9	1888.3	5820.0
1979-83	325.9	163.0	4236.9	65.2	65.2	39.1	39.1	65.2	293.3	2542.1	7834.9
1984-88	362.4	181.2	4710.6	72.5	72.5	43.5	43.5	72.5	326.1	2826.4	8711.0
1989-93	417.3	208.7	5425.1	83.5	83.5	50.1	50.1	83.5	375.6	3255.0	10032.2
1994-98	460.3	230.2	5984.0	92.1	92.1	55.2	55.2	92.1	414.3	3590.4	11065.7
1999-03	514.5	257.2	6688.2	102.9	102.9	61.7	61.7	102.9	463.0	4012.9	12368.0
2004-08	536.9	268.5	6980.1	107.4	107.4	64.4	64.4	107.4	483.2	4188.1	12907.8
2025	618.7	309.4	8043.2	123.7	123.7	74.2	74.2	123.7	556.8	4825.9	14873.7
2050	587.7	293.8	7640.0	117.5	117.5	70.5	70.5	117.5	528.9	4584.0	14128.2
Sohna Block											
1977-78	236.1	118.1	3069.5	47.2	47.2	28.3	28.3	47.2	212.5	1841.7	5676.2
1979-83	317.9	158.9	4132.2	63.6	63.6	38.1	38.1	63.6	286.1	2479.3	7641.4
1984-88	353.4	176.7	4594.2	70.7	70.7	42.4	42.4	70.7	318.1	2756.5	8495.8
1989-93	407.0	203.5	5291.1	81.4	81.4	48.8	48.8	81.4	366.3	3174.6	9784.4
1994-98	448.9	224.5	5836.2	89.8	89.8	53.9	53.9	89.8	404.0	3501.7	10792.4
1999-03	501.8	250.9	6523.0	100.4	100.4	60.2	60.2	100.4	451.6	3913.8	12062.5
2004-08	523.7	261.8	6807.7	104.7	104.7	62.8	62.8	104.7	471.3	4084.6	12589.0
2025	603.4	301.7	7844.5	120.7	120.7	72.4	72.4	120.7	543.1	4706.7	14506.3
2050	573.2	286.6	7451.3	114.6	114.6	68.8	68.8	114.6	515.9	4470.8	13779.2
Farukhnagar Block											
1977-78	208.1	104.0	2704.8	41.6	41.6	25.0	25.0	41.6	187.3	1622.9	5001.8
1979-83	280.1	140.0	3641.3	56.0	56.0	33.6	33.6	56.0	252.1	2184.8	6733.5
1984-88	311.4	155.7	4048.4	62.3	62.3	37.4	37.4	62.3	280.3	2429.0	7486.5
1989-93	358.6	179.3	4662.4	71.7	71.7	43.0	43.0	71.7	322.8	2797.5	8621.9
1994-98	395.6	197.8	5142.8	79.1	79.1	47.5	47.5	79.1	356.0	3085.7	9510.2
1999-03	442.2	221.1	5748.0	88.4	88.4	53.1	53.1	88.4	397.9	3448.8	10629.4
2004-08	461.5	230.7	5998.9	92.3	92.3	55.4	55.4	92.3	415.3	3599.3	11093.3
2025	531.7	265.9	6912.5	106.3	106.3	63.8	63.8	106.3	478.6	4147.5	12782.9
2050	505.1	252.5	6566.0	101.0	101.0	60.6	60.6	101.0	454.6	3939.6	12142.1

Table 5.5 Average cropping pattern of Gurgaon District in Rabi season over study period

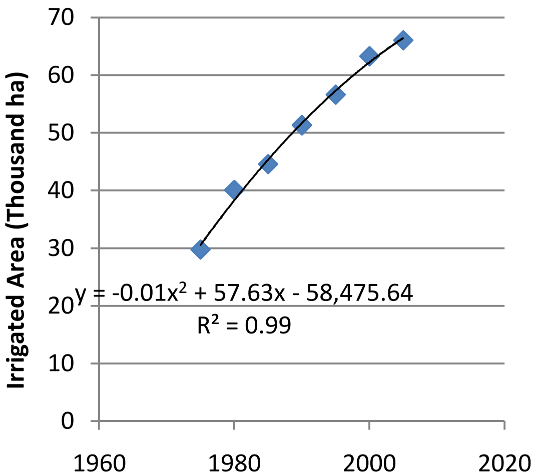
Year	Wheat	Barley	Gram	Rabi Cereals	Rabi Pulses	S.cane	Spices Etc	Vegetables & Oil Seeds	Total
Pataudi Block									
1977-78	5117.5	193.1	38.6	15.4	15.4	38.6	115.9	1004.2	6538.8
1979-83	6889.3	260.0	52.0	20.8	20.8	52.0	156.0	1351.9	8802.6
1984-88	7659.6	289.0	57.8	23.1	23.1	57.8	173.4	1503.0	9786.9
1989-93	8821.3	332.9	66.6	26.6	26.6	66.6	199.7	1731.0	11271.3
1994-98	9730.1	367.2	73.4	29.4	29.4	73.4	220.3	1909.3	12432.5
1999-03	10875.2	410.4	82.1	32.8	32.8	82.1	246.2	2134.0	13895.6
2004-08	11349.9	428.3	85.7	34.3	34.3	85.7	257.0	2227.1	14502.1
2025	13077.7	493.5	98.7	39.5	39.5	98.7	296.1	2566.2	16709.9
2050	12422.1	468.8	93.8	37.5	37.5	93.8	281.3	2437.6	15872.2
Gurgaon Block									
1977-78	6415.5	242.1	48.4	19.4	19.4	48.4	145.3	1258.9	8197.3
1979-83	8636.7	325.9	65.2	26.1	26.1	65.2	195.5	1694.7	11035.4
1984-88	9602.4	362.4	72.5	29.0	29.0	72.5	217.4	1884.2	12269.3
1989-93	11058.8	417.3	83.5	33.4	33.4	83.5	250.4	2170.0	14130.2
1994-98	12198.1	460.3	92.1	36.8	36.8	92.1	276.2	2393.6	15585.9
1999-03	13633.6	514.5	102.9	41.2	41.2	102.9	308.7	2675.3	17420.1
2004-08	14228.7	536.9	107.4	43.0	43.0	107.4	322.2	2792.0	18180.5
2025	16394.8	618.7	123.7	49.5	49.5	123.7	371.2	3217.1	20948.2
2050	15572.9	587.7	117.5	47.0	47.0	117.5	352.6	3055.8	19898.1
Sohna Block									
1977-78	6257.0	236.1	47.2	18.9	18.9	47.2	141.7	1227.8	7994.8
1979-83	8423.3	317.9	63.6	25.4	25.4	63.6	190.7	1652.9	10762.8
1984-88	9365.2	353.4	70.7	28.3	28.3	70.7	212.0	1837.7	11966.2
1989-93	10785.6	407.0	81.4	32.6	32.6	81.4	244.2	2116.4	13781.2
1994-98	11896.8	448.9	89.8	35.9	35.9	89.8	269.4	2334.5	15200.9
1999-03	13296.8	501.8	100.4	40.1	40.1	100.4	301.1	2609.2	16989.9
2004-08	13877.2	523.7	104.7	41.9	41.9	104.7	314.2	2723.1	17731.5
2025	15989.8	603.4	120.7	48.3	48.3	120.7	362.0	3137.6	20430.8
2050	15188.3	573.1	114.6	45.9	45.9	114.6	343.9	2980.3	19406.6
Farukhnagar Block									
1977-78	5513.7	208.1	41.6	16.6	16.6	41.6	124.8	1081.9	7045.0
1979-83	7422.6	280.1	56.0	22.4	22.4	56.0	168.1	1456.5	9484.1
1984-88	8252.5	311.4	62.3	24.9	24.9	62.3	186.8	1619.4	10544.6
1989-93	9504.2	358.6	71.7	28.7	28.7	71.7	215.2	1865.0	12143.9
1994-98	10483.3	395.6	79.1	31.6	31.6	79.1	237.4	2057.1	13394.9
1999-03	11717.1	442.2	88.4	35.4	35.4	88.4	265.3	2299.2	14971.3
2004-08	12228.5	461.5	92.3	36.9	36.9	92.3	276.9	2399.6	15624.8
2025	14090.1	531.7	106.3	42.5	42.5	106.3	319.0	2764.9	18003.4
2050	13383.8	505.0	101.0	40.4	40.4	101.0	303.0	2626.2	17100.9



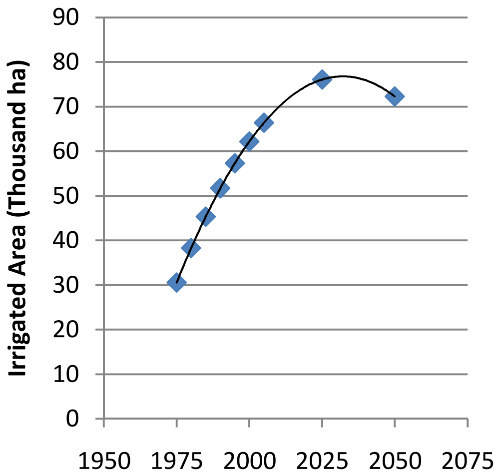
Existing Irrigated Area in Kharif



Predicted Irrigated Area in Kharif



Existing Irrigated Area in Rabi



Predicted Irrigated Area in Rabi

Figure 5.2 Existing and predicted irrigated area of Gurgaon District

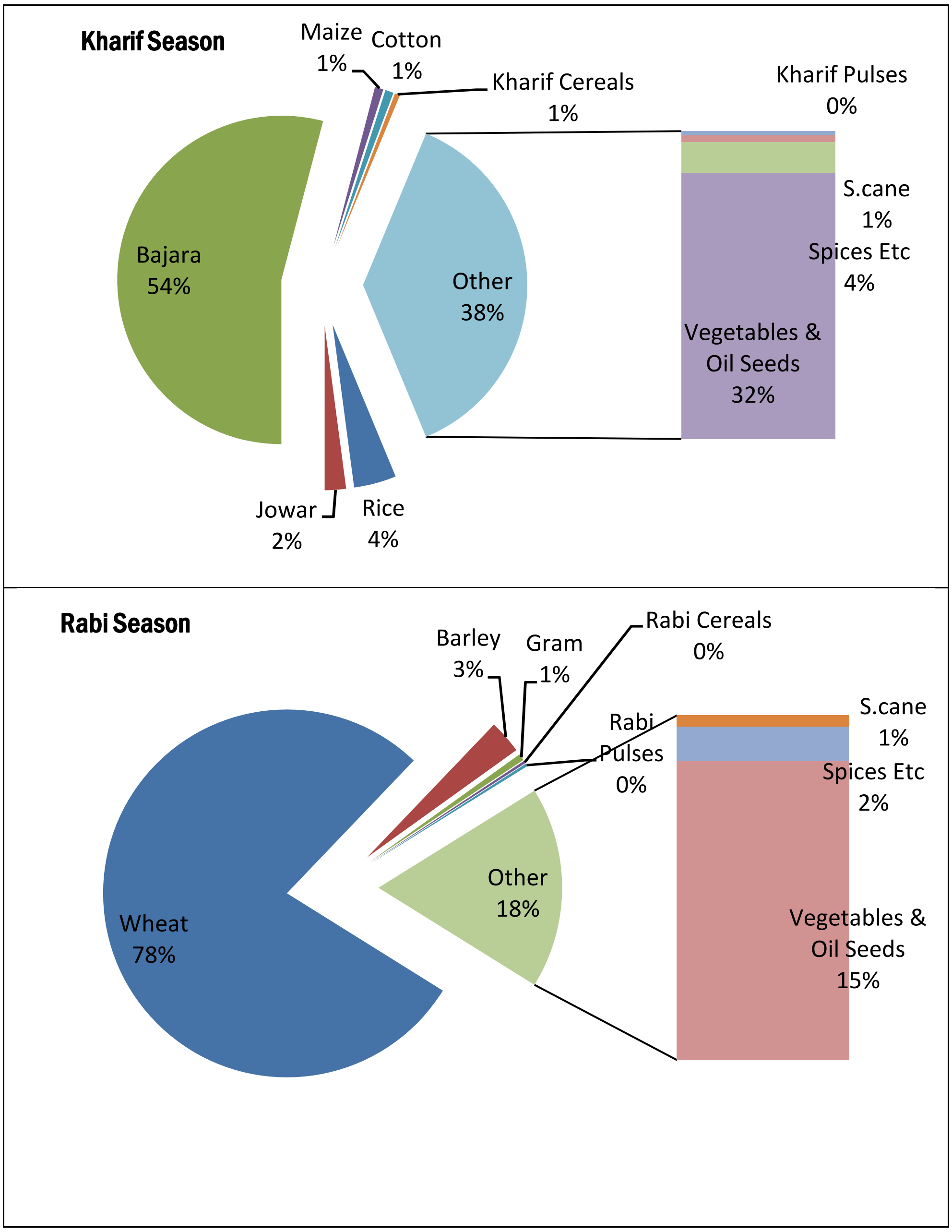


Figure 5.3 Pie chart of average cropping pattern of Gurgaon District over study period

Figure 5.3 shows the pie charts of average cropping pattern of irrigated areas in Kharif and Rabi season for Gurgaon district. It was found out from this graph that during Kharif season major crop was Bajara which occupied about 54% of total area. Next favorable crop of farmers in Gurgaon district after Bajara was vegetable and oil seed crops. This cash crop was grown in slightly more than 30% of total kharif irrigated area. It is also important to note that rice crop was found to be grown in almost 4.5% area of total kharif irrigated area.

Rabi cropping pattern of Gurgaon district revealed that during Rabi season, wheat was mostly grown crop followed by vegetables & Rabi oil seeds. Together these two crops comprised about 93 % of total Rabi irrigated area. Remaining crops were grown in merely 7% of total irrigated area. It was also found out that total irrigated area in Kharif season was 36% of total area and 50.5% of total area in Rabi season.

5.2.1.2 Evapotranspiration Estimation by Priestley-Taylor Method

Complete detail of the procedure to estimate evapotranspiration by Priestelay_Taylor method has been given in section 3.10. According to this method net radiation was required to be estimated using sunshine hour data. But this data was not available for longer duration. Hence net radiation has been estimated using temperature data as suggested in FAO 56 (Guidelines to Calculate Crop Water Requirement, Allen, R. G., et al., 1998). Table 5.6 shows the values of important parameters in Priestlay-Taylor method. Second last column of this table shows the values of evapotranspiration in mm/day for different months in the year. It was found out from this column that evapotranspiration was maximum for May and June months averaging 15.16 mm/day and evapotranspiration was minimum for January and February months averaging 5.44 mm/day. It was also seen that daily average evapotranspiration values for different month in the year were slightly overestimated by this method due to net radiation estimation using temperature values. But slightly over estimated values were used for agriculture water demand estimation to get sure availability values of water. Last column of Table 5.6 shows the average daily evapotranspiration values for different seasons. It can be seen from this column that average evapotranspiration for Kharif, Rabi and Summer season were 13.32 mm/day, 7.5 mm/day and 10.42 mm/day, respectively. Figure 5.4 shows the trend of evapotranspiration over year. This trend is similar to trend of net radiation due to Sun, which ensures the correct estimation of evapotranspiration.

Table 5.6 Values of different parameters in Priestely-Taylor method for evapotranspiration estimation

Month	T mean °C	Delta kPa/°C	Rns MJ/m²/d	Rnl MJ/m²/d	Rn MJ/m²/d	G MJ/d	ET mm/d	Season Total mm/d
January	13.3	0.099	11.09	4.55	6.54	0.098	4.89	
February	15.5	0.113	13.21	4.60	8.61	1.10	5.99	Summer
March	21.1	0.154	16.55	4.92	11.63	1.76	8.71	10.42
April	28.1	0.221	19.39	5.31	14.08	1.51	12.22	
May	31.9	0.267	19.90	4.57	15.32	0.70	14.79	
June	33.1	0.284	18.03	3.02	15.01	-0.18	*15.54*	Monsoon
July	30.6	0.250	14.85	1.60	13.24	-0.55	*13.76*	13.32
August	29.2	0.234	13.48	1.49	11.99	-0.28	*12.07*	
September	28.6	0.226	14.16	2.44	11.72	-0.49	*11.93*	
October	25.7	0.196	14.13	4.22	9.91	-1.23	10.51	Rabi
November	19.8	0.143	12.25	4.82	7.43	-1.53	7.74	7.50
December	14.8	0.108	10.76	4.76	6.00	-2.77	6.88	
Lattitude	**28.47**							
Longitude	**77.03**							
Altitude	**220**	**m**						
Atm Pressure	**98.72635**	**kPa**						
Gamma	**0.065653**	**kPa/°C**						

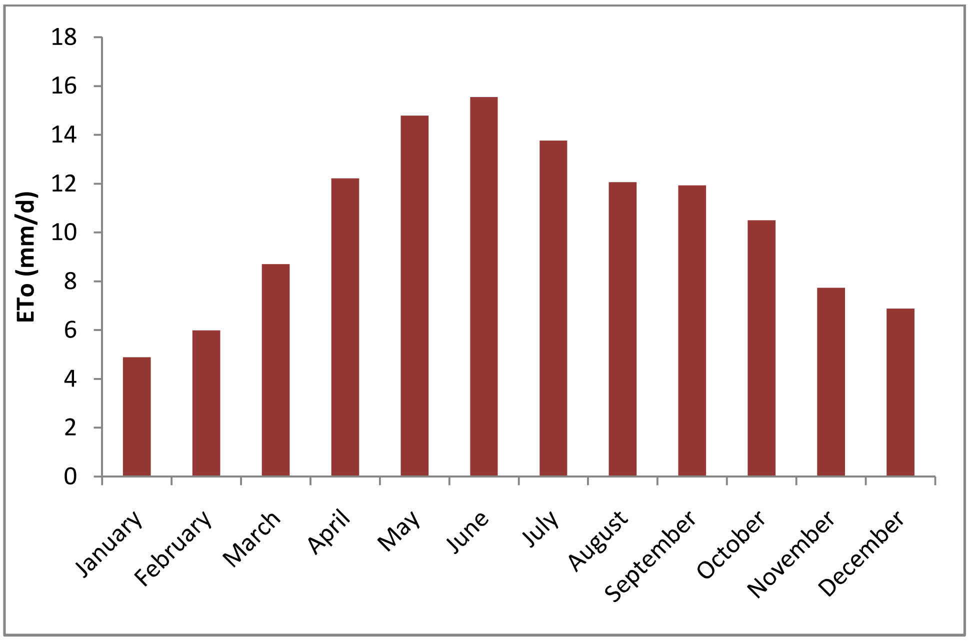


Figure 5.4 Trend of evapotranspiration over year

Table 5.7 Crop coefficients of various Kharif season crops

Crop	Rice	Jowar	Bajara	Maize	Cotton	Kharif Cereals	Kharif Pulses	S.cane	Spices etc.	Veg & Oil Seeds
Kc initial	1.05	0.40	0.40	0.40	0.35	0.30	0.40	0.40	0.70	0.70
Kc mid	1.20	1.10	1.00	1.20	1.20	1.15	1.15	1.25	1.05	1.05
Kc end	0.80	0.55	0.30	0.50	0.60	0.40	0.35	0.75	0.80	0.95
Average	1.02	0.68	0.57	0.70	0.72	0.62	0.63	0.80	0.85	0.90
Duration	120	105	105	120	180	110	110	180	90	90

Table 5.8 Crop coefficients of various Rabi season crops

Crop	Wheat	Barley	Gram	Rabi Cereals	Rabi Pulses	S.cane	Spices etc.	Vegetables & Oil Seeds
Kc initial	0.40	0.40	0.40	0.30	0.40	0.40	0.70	0.70
Kc mid	1.15	1.15	1.00	1.15	1.15	1.25	1.05	1.05
Kc end	0.30	0.30	0.35	0.40	0.35	0.75	0.80	0.95
Average	0.62	0.62	0.58	0.62	0.63	0.80	0.85	0.90
Duration	120	120	110	110	110	180	90	90

5.2.1.3 Agricultural Water Requirement Estimation

Evapotranspiration values given in the table 5.6 are called as reference evapotranspiration values. These values were required to be multiplied by crop coefficient to get crop water requirement. Crop coefficients for all Kharif and Rabi crops were selected from Table 12 of FAO 56 and selected values have been represented in the Table 5.7 for Kharif season and Table 5.8 for Rabi season along with respective crop durations. Resultant values of potential crop water requirement have been shown in Table 5.9 for Kharif season and Table 5.10 for Rabi season.

It can be seen from Table 5.9 that potential crop water requirement for crop in Kharif season grown in 2004-08 in Gurgaon and Sohna block was about 12000 ha.m and Farukhnagar and Pataudi block was about 10000 ha.m. If we consider that 25% of total crop water requirement in Kharif (rainy) season is satisfied by ground water and remaining requirement is satisfied by rainfall then demand for agricultural crop water in Kharif season for Gurgaon and Sohna block would be around 3000 ha.m and for Farukhnagar and Sohna block would be around 2500 ha.m.

Table 5.10 shows the potential agricultural water demand for Rabi season. It was observed from this table that agricultural water demand for crop grown in Rabi season in 2004-08 in Block Gurgaon and Sohna needed about 10000 ha.m water and crop grown in

Farukhnagar and Pataudi block needed about 8500 ha.m water. These water demand quantities can be used for broad planning purpose.

Table 5.9 Potential irrigation water requirement for crops grown in Gurgaon district in Kharif season (ha.m)

Year	Rice	Jowar	Bajara	Maize	Cotton	Kharif Cereals	Kharif Pulses	S.cane	Spices Etc	Veget& Oil Seed	Total
Pataudi Block											
1974-78	314	92	1990	43	66	21	22	74	177	1625	4424
1979-83	422	124	2678	58	89	28	29	100	238	2188	5956
1984-88	470	138	2978	65	99	31	32	111	265	2432	6622
1989-93	541	159	3430	74	114	36	37	128	305	2801	7626
1994-98	597	175	3783	82	126	40	41	141	337	3090	8412
1999-03	667	196	4228	92	141	44	46	157	376	3454	9402
2004-08	696	205	4413	96	147	46	48	164	393	3604	9812
2025	802	236	5085	110	170	54	55	189	453	4153	11306
2050	762	224	4830	105	161	51	52	180	430	3945	10740
Gurgaon Block											
1974-78	393	116	2494	54	83	26	27	93	222	2037	5546
1979-83	530	156	3358	73	112	35	36	125	299	2743	7466
1984-88	589	173	3733	81	125	39	40	139	332	3049	8301
1989-93	678	199	4300	93	143	45	46	160	383	3512	9560
1994-98	748	220	4743	103	158	50	51	177	422	3874	10545
1999-03	836	246	5301	115	177	56	57	197	472	4330	11786
2004-08	873	257	5532	120	185	58	60	206	492	4519	12301
2025	1005	296	6375	138	213	67	69	237	567	5207	14174
2050	955	281	6055	132	202	64	65	225	539	4946	13464
Sohna Block											
1974-78	384	113	2433	53	81	26	26	91	217	1987	5409
1979-83	517	152	3275	71	109	34	35	122	292	2675	7282
1984-88	574	169	3641	79	121	38	39	136	324	2974	8096
1989-93	661	194	4193	91	140	44	45	156	373	3425	9324
1994-98	730	215	4625	100	154	49	50	172	412	3778	10285
1999-03	815	240	5170	112	172	54	56	192	460	4223	11495
2004-08	851	250	5395	117	180	57	58	201	480	4407	11997
2025	981	288	6217	135	207	65	67	231	553	5078	13824
2050	931	274	5905	128	197	62	64	220	526	4824	13131
Farukhnagar Block											
1974-78	338	99	2144	47	72	23	23	80	191	1751	4767
1979-83	455	134	2886	63	96	30	31	107	257	2357	6417
1984-88	506	149	3209	70	107	34	35	119	286	2621	7134
1989-93	583	171	3695	80	123	39	40	138	329	3018	8216
1994-98	643	189	4076	89	136	43	44	152	363	3329	9063
1999-03	719	211	4556	99	152	48	49	170	405	3721	10129
2004-08	750	221	4754	103	159	50	51	177	423	3883	10572
2025	864	254	5478	119	183	58	59	204	488	4475	12182
2050	821	241	5204	113	174	55	56	194	463	4251	11571

Table 5.10 Potential irrigation water requirement for crops grown in Gurgaon district in Rabi season (ha.m)

Year	Wheat	Barley	Gram	Rabi Cereals	Rabi Pulses	S.cane	Spices Etc	Veg&Oil Seeds	Total
Pataudi Block									
1974-78	2840	107	19	8	8	42	66	610	3700
1979-83	3824	144	25	11	11	56	89	821	4981
1984-88	4251	160	28	12	12	62	100	913	5538
1989-93	4896	185	32	14	14	72	115	1052	6378
1994-98	5400	204	35	15	15	79	126	1160	7035
1999-03	6036	228	39	17	17	89	141	1296	7863
2004-08	6299	238	41	17	18	93	147	1353	8206
2025	7258	274	47	20	21	107	170	1559	9456
2050	6894	260	45	19	20	101	161	1481	8982
Gurgaon Block									
1974-78	3561	134	23	10	10	52	83	765	4639
1979-83	4793	181	31	13	14	70	112	1030	6245
1984-88	5329	201	35	15	15	78	125	1145	6943
1989-93	6138	232	40	17	17	90	144	1318	7996
1994-98	6770	255	44	19	19	99	158	1454	8820
1999-03	7567	286	50	21	22	111	177	1625	9858
2004-08	7897	298	52	22	22	116	185	1696	10288
2025	9099	343	60	25	26	134	213	1954	11854
2050	8643	326	57	24	25	127	202	1856	11260
Sohna Block									
1974-78	3473	131	23	10	10	51	81	746	4524
1979-83	4675	176	31	13	13	69	109	1004	6090
1984-88	5198	196	34	14	15	76	122	1116	6771
1989-93	5986	226	39	17	17	88	140	1286	7798
1994-98	6603	249	43	18	19	97	155	1418	8602
1999-03	7380	278	48	20	21	108	173	1585	9614
2004-08	7702	291	50	21	22	113	180	1654	10034
2025	8874	335	58	25	25	130	208	1906	11561
2050	8429	318	55	23	24	124	197	1811	10982
Farukhnagar Block									
1974-78	3060	115	20	8	9	45	72	657	3987
1979-83	4120	155	27	11	12	61	96	885	5367
1984-88	4580	173	30	13	13	67	107	984	5967
1989-93	5275	199	35	15	15	77	123	1133	6872
1994-98	5818	220	38	16	17	85	136	1250	7580
1999-03	6503	245	43	18	18	96	152	1397	8472
2004-08	6787	256	44	19	19	100	159	1458	8842
2025	7820	295	51	22	22	115	183	1680	10188
2050	7428	280	49	21	21	109	174	1595	9677

It was also revealed from Table 5.9 that for year 2025 water demand for agriculture in Kharif was increasing by 2000 ha.m for blocks Pataudi and Farukhnagar and by 4000 ha.m for Gurgaon and Sohna blocks. This signifies that total agricultural demand for water would be increased by 500 ha.m for Pataudi and Farukhnagar blocks and by 1000 ha.m for Gurgaon and Sohna block for year 2025.

Table 5.10 indicates that agricultural water demand in Rabi season for year 2025 would be increased by at least 1000 ha.m for Pataudi and Farukhnagar block and by at least 1500 ha.m for Gurgaon and Sohna block. Thus total agricultural water demand in 2025 Rabi season would be 10000 ha.m for Farukhnagar and Pataudi blocks and 11000 ha.m for Gurgaon and Sohna block.

It is also seen from Table 5.9 and 5.10 that total agricultural water demand in year 2050 would be decreased as total area under agriculture would be decreased.

5.2.2 Domestic Water Requirement

Methodology to estimate domestic water requirement has been given in section 3.10. According to this method total population was required to be multiplied by per capita per day water requirement. As has been mentioned earlier that new Gurgaon district has been formulated in 2005 with four blocks from older nine block district. New district formulated with remaining five blocks was Mewat district. Previous to this Faridabad district has been formulated from older Gurgaon district. So there was possibility of shifting of few villages from one block to another block which might change total population of block. Hence block-wise population was worked out using population density figures of district multiplied by total areas of block.

Table 5.11 shows the total population of different blocks in Gurgaon district. Since 1995 migration of workers and skilled personnel has started towards the Gurgaon (city & block) and it has got impetus since 2000. Hence 2000 onwards there is huge increase in domestic water requirement. Most of the migrated population was and is not accounted for in the census. Therefore there will be surplus demand for domestic water than actually accounted domestic water requirement for Gurgaon block only.

Figure 5.5 shows the trend of population increase from 1971 to 2011. It can be seen from the trend that there is sharp increase in population density since 1990's. Total population is increasing in increasing order. There is no sign of population stagnation in near future in Gurgaon district.

Table 5.11 Population of different blocks in Gurgaon Districts*

Year	Pataudi	Gurgaon	Sohna	Farukhnagar
1976	79860	100116	97643	86042
1981	81650	102360	99831	87970
1986	100238	125662	122558	107997
1991	118826	148965	145286	128024
1996	154212	193327	188551	166150
2001	189598	237688	231817	204275
2006	241782	303109	295622	260499
2011	151030	977162	196562	165877
2025	496524	622464	607088	534961
2050	1022015	1281241	1249594	1101132

***Note: Census 2011 has considerably less area in Pataudi & Farukhnagar blocks and more area in Gurgaon block compared to Census 2001. Pataudi (Old Area- 275.52 sq. km New Area- 177.39 sq. km), Gurgaon (Old-345.43 sq. km, New-738.22 sq. km)**

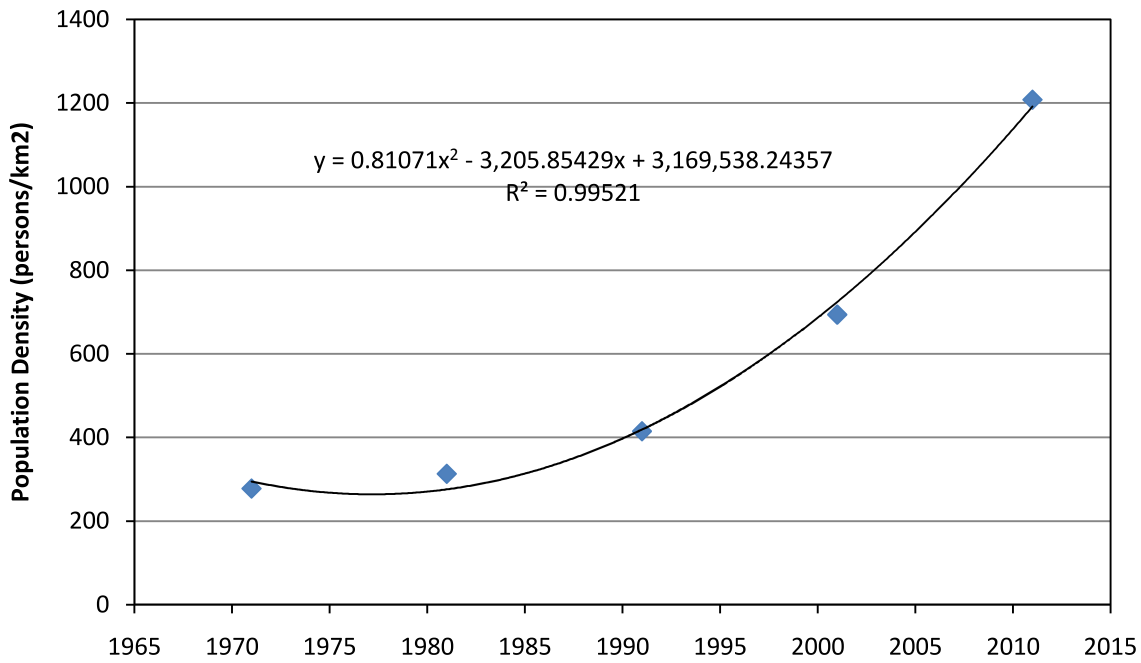


Figure 5.5 Trend of population density increase over period of 1971 to 2011

Table 5.12 Domestic water requirement of Gurgaon District (ha.m)*

	Monsoon Season				Non-Monsoon Season			
Year	**Pataudi**	**Gurgaon**	**Sohna**	**Farukhnagar**	**Patudi**	**Gurgaon**	**Sohna**	**Farukhnagar**
1976	67	162	82	72	137	331	167	148
1981	69	166	84	74	140	339	171	151
1986	84	204	103	91	172	416	210	185
1991	100	241	122	108	204	493	249	220
1996	130	313	158	140	264	639	323	285
2001	159	385	195	172	325	786	398	350
2006	203	491	248	219	415	1003	507	447
2011	310	1583	379	334	633	3232	774	682
2025	417	1829	510	449	852	3735	1041	917
2050	858	2076	1050	925	1753	4238	2143	1888

***Note: Domestic water requirements are adjusted from 2011**

Table 5.12 shows domestic water requirement for four blocks in Gurgaon district from 1976 to 2050 in monsoon and non-monsoon season. Annual total domestic water requirement for Pataudi, Gurgaon, Sohna and Farukhnagar blocks for year 2011 was worked out to be 943, 4815, 1153 and 1016 ha.m, respectively. This water quantity is equivalent to 25.84, 131.92, 31.59 and 27.84 million liter per day (MLD) respectively for Pataudi, Gurgaon, Sohna and Farukhnagar blocks. These are net water quantities required to be delivered at the door step, if we add delivery losses, system efficiency losses, theft of water, illegal use of water for industry then domestic water requirement figure will soar like anything.

5.2.3 Industrial Water Requirement

Methodology to determine industrial water requirement has been given in section 3.10. Following Table 5.13 shows the number of registered factories under different registration rules as well as number of workers. Figure 5.6 shows the existing and future trend of number of industries and workers.

Table 5.13 Number of registered factories and workers in Gurgaon district

Year	Registered Factories Under 2 (m)i	Under 2 (m)ii	U/Section 85 With Power	Without Power	Total	Reg. working Factories	No. of Workers
1975	245	6	93	-	344	517	31735
1980	428	8	127	-	562	918	50571
1985	609	11	147	-	766	1296	65438
1990	717	19	155	-	891	1411	77843
1995	921	10	173	-	1104	1878	113086
2000	1178	10	173	-	1361	2494	144081
2005	1280	11	173	-	1464	2682	166021
2007	1386	11	173	-	1570	2876	196887

Total industrial water requirement for monsoon and non-monsoon season has been given in Table 5.14. It was observed for Gurgaon district that almost all factories are concentrating in Gurgaon city and block. According to types of industries located in different blocks, it was worked out that average water requirement per industry was 50 thousand liter per day. For factories located in Gurgaon block water requirement was increasing in two steps at 1990 and 2000.

Total annual industrial water requirement for Gurgaon, Pataudi, Sohna and Farukhnagar block in 2007 was 11023, 477, 583 and 514 ha.m, respectively. Industrial water requirement for Gurgaon district for year 2007 was worked out to be 12597 ha.m. This water quantity is equivalent to 345 MLD, out of which only Gurgaon block was accounting for 300 MLD.

Existing and future predicted trend of number of industries shows that there will be considerable increase in number of industries in near future. Hence there will be huge industrial water use demand in near future. Calculation indicates that there will be 541.6 MLD water requirement for industry in 2025 for Gurgaon district.

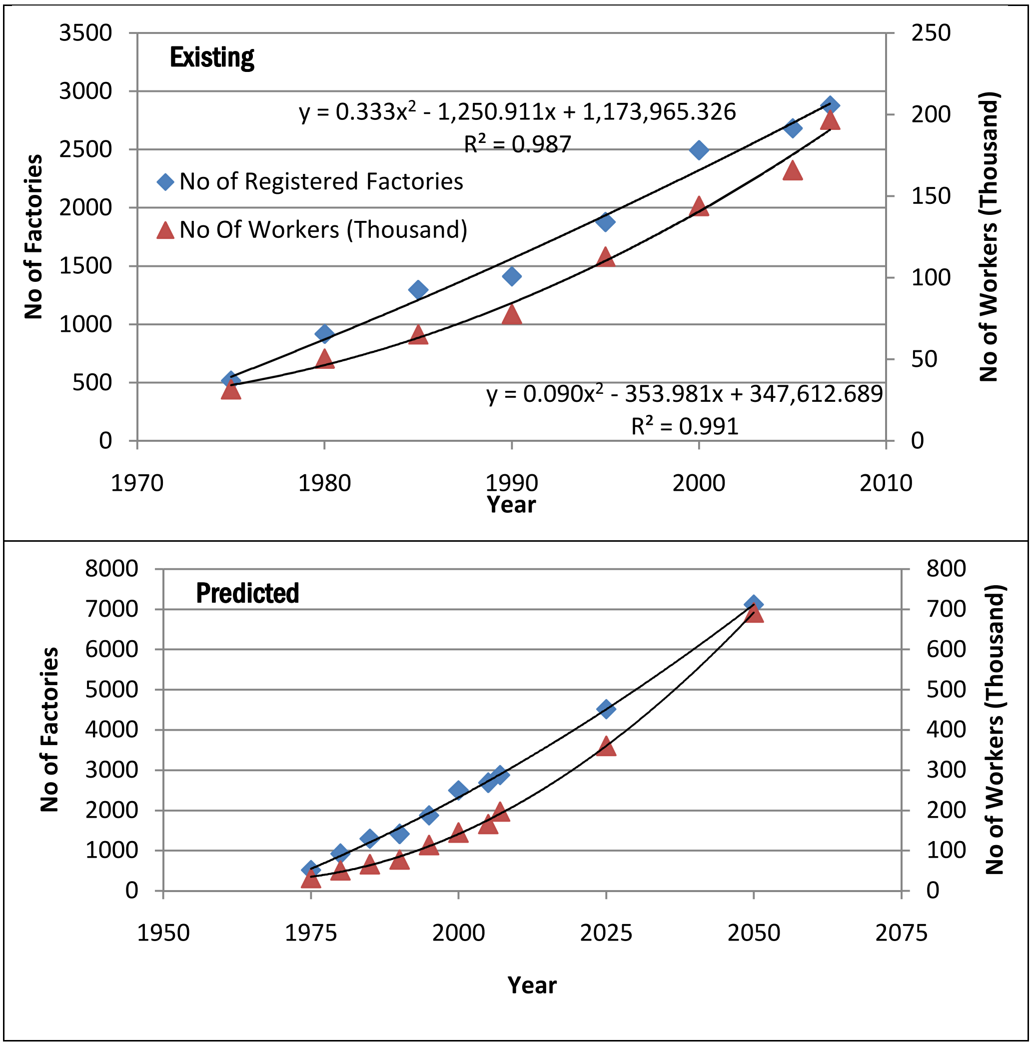


Figure 5.6 Existing & predicted number of registered factories and workers in Gurgaon district

Table 5.14 Industrial water requirement for Gurgaon District (ha.m)

Year	Monsoon				Total	Non-Monsoon				Total
	Gurgaon	Pataudi	Sohna	F'agar		Gurgaon	Pataudi	Sohna	F'agar	
1975	217	28	35	30	310	444	58	70	62	634
1980	385	50	61	54	551	787	102	125	110	1124
1985	544	71	86	76	777	1111	144	176	155	1587
1990	593	77	94	83	847	1210	157	192	169	1728
1995	1577	102	125	110	1915	3220	209	256	225	3910
2000	3142	136	166	147	3591	6415	278	340	299	7332
2005	3379	146	179	158	3862	6899	299	365	322	7885
2007	3624	157	192	169	4142	7399	320	392	345	8456
2025	5686	246	301	265	6499	11610	503	614	542	13268
2050	8969	388	475	418	10250	18311	793	969	854	20927

5.2.4 Institutional Water Requirement

Methodology for estimation of institutional water requirement has been given 3.10. According to this methodology institutional water requirement was worked out as 10% of industrial water requirement. Following table 5.15 shows the institutional water requirement for Gurgaon district.

Table 5.15 Institutional water requirement for Gurgaon District (ha.m)

	Gurgaon	Pataudi	Sohna	F'nagar	Total
Non-Monsoon					
1975	44	6	7	6	63
1980	79	10	12	11	112
1985	111	14	18	16	159
1990	121	16	19	17	173
1995	322	21	26	23	391
2000	642	28	34	30	733
2005	690	30	37	32	788
2007	740	32	39	35	846
2025	1161	50	61	54	1327
2050	1831	79	97	85	2093
Monsoon					
1975	22	3	3	3	31
1980	39	5	6	5	55
1985	54	7	9	8	78
1990	59	8	9	8	85
1995	158	10	13	11	192
2000	314	14	17	15	359
2005	338	15	18	16	386
2007	362	16	19	17	414
2025	569	25	30	27	650
2050	897	39	47	42	1025

Calculation of institutional water requirement indicates that Gurgaon district will need 1266 ha.m water for year 2007 and 1977 ha.m water for year 2025. This water quantity comes out to 34.5 MLD for 2007 and 54.16 MLD for 2025. It can be seen that institutional water requirement quantities are comparable to domestic water requirement and they are little less than domestic water needs.

5.2.5 Water Requirement of Domestic & Other Animals.

Animals in domestic transport or agricultural use forms inseparable parts of human life. Even though water requirement of these animals is equivalent or sometimes more than domestic water requirement of humans, most of planning studies neglect this sector. Hence efforts were made to estimate water requirement for domestic and other animals considering major 11 types of animals for Gurgaon district. Following Table 5.16 shows the total number of animal population and Table 5.17 shows the water requirement. Based on calculations, it was observed that total water requirement for animals was 1260 ha.m (24.4 MLD) for 2005 and it will be 704 ha.m (19.3 MLD) for 2025.

Table 5.16 Total Cattles & poultry birds in Gurgaon district (Thousand)

Year	Cattle	Buffaloes	Horses	Donkey	Mules	Sheep	Goat	Camel	Pigs	Dogs	Total	Poultry
1975	50.5	279.3	0.6	1.0	0.6	20.7	61.7	0.9	7.3	25.5	448.2	27.7
1980	57.0	315.3	0.7	1.1	0.7	23.4	69.7	1.0	8.3	28.8	506.0	204.0
1985	63.5	351.3	0.8	1.2	0.8	26.1	77.7	1.1	9.2	32.1	563.8	380.3
1990	87.8	254.0	1.6	10.7	1.5	42.9	134.6	2.8	39.7	46.0	621.6	600.3
1995	98.8	280.1	1.6	9.2	2.0	53.1	134.3	2.1	51.8	46.4	679.4	645.2
2000	63.4	350.5	0.8	1.2	0.8	26.0	77.5	1.1	9.2	32.0	562.5	952.8
2005	50.2	277.7	0.6	1.0	0.6	20.6	61.4	0.9	7.3	25.4	445.6	1085.3
2025	37.7	208.3	0.5	0.7	0.5	15.4	46.0	0.7	5.5	19.0	334.2	1790.3
2050	28.3	156.2	0.4	0.5	0.4	11.6	34.5	0.5	4.1	14.3	250.7	2671.6

Table 5.17 Blockwise water requirement of domestic & other animals in Gurgaon district (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'nagar	Total
Monsoon					
1975	62	78	76	67	282
1980	70	88	86	76	320
1985	79	99	96	85	359
1990	68	85	83	73	309
1995	75	94	91	81	340
2000	80	100	98	86	365
2005	64	81	79	69	293
2025	51	64	62	55	231
2050	42	52	51	45	189
Non-Monsoon					
1975	126	158	154	136	575
1980	144	180	176	155	654
1985	161	202	197	173	732
1990	138	173	169	149	630
1995	153	191	187	164	695
2000	163	205	200	176	745
2005	131	165	161	141	598
2025	104	130	127	112	472
2050	85	106	104	92	387

5.3 Recharge Due To Irrigation

Detailed methodology for recharge estimation has been given in section 3.7 of materials and methods. Recharge might occur due to two major sources viz. irrigation and rainfall. This section gives the details of recharge due to irrigation which has been calculated according to CGWB, 2009 methodology of return flow factor. Following Tables 5.18 and 5.19 gives information of irrigation and return flow factor as well as results of recharge quantities respectively for monsoon and non-monsoon season.

It can be seen from Table 5.18 that irrigation recharge quantities for blocks Pataudi and Farukhnagar were about 400 ha.m and for blocks Gurgaon and Sohna 500 ha.m for Kharif season of 2004-08. As area under irrigation will increase by 2025, it can be seen that for all blocks recharge quantities will be increased by 75 ha.m. Thus total recharge for 2025 kharif season is expected to reach to 475 ha.m for Pataudi and Farukhnagar blocks and 575 ha.m for Gurgaon and Sohna block.

It was also observed from Table 5.19 that for 2004-08 Rabi period recharge quantities from Pataudi and Farukhnagar block were nearby 1000 ha.m and for Gurgaon and Sohna block they were nearby 1200 ha.m. It was seen that for Rabi period of 2004-08, recharge will increase by almost 200 ha.m for all blocks making total Rabi recharge to the tune of 1200 ha.m for Pataudi and Farukhnagar block and 1400 ha.m for Gurgaon and Sohna block.

Table 5.18 Recharge due to irrigation water applied for crops grown in Gurgaon district in Kharif season

Year	Irrigation (ha.m)		Return Flow Factor		Recharge from Irrig. (ha.m)		
	Paddy	Non-Paddy	Paddy	Non-Paddy	Paddy	Non-Paddy	Total
Pataudi Block							
1974-78	78	1028	0.45	0.25	35	257	292
1979-83	106	1383	0.45	0.25	48	346	393
1984-88	117	1538	0.35	0.15	41	231	272
1989-93	135	1771	0.35	0.15	47	266	313
1994-98	149	1954	0.35	0.15	52	293	345
1999-03	167	2184	0.35	0.15	58	328	386
2004-08	174	2279	0.35	0.15	61	342	403
2025	201	2626	0.35	0.15	70	394	464
2050	190	2494	0.35	0.15	67	374	441
Gurgaon Block							
1974-78	98	1288	0.35	0.15	34	193	228
1979-83	132	1734	0.35	0.15	46	260	306
1984-88	147	1928	0.35	0.15	52	289	341
1989-93	170	2221	0.35	0.15	59	333	392
1994-98	187	2449	0.35	0.15	65	367	433
1999-03	209	2738	0.35	0.15	73	411	484
2004-08	218	2857	0.35	0.15	76	429	505
2025	251	3292	0.35	0.15	88	494	582
2050	239	3127	0.35	0.15	84	469	553
Sohna Block							
1974-78	96	1256	0.45	0.25	43	314	357
1979-83	129	1691	0.45	0.25	58	423	481
1984-88	144	1880	0.45	0.25	65	470	535
1989-93	165	2166	0.35	0.15	58	325	383
1994-98	182	2389	0.35	0.15	64	358	422
1999-03	204	2670	0.35	0.15	71	400	472
2004-08	213	2786	0.35	0.15	74	418	492
2025	245	3211	0.35	0.15	86	482	567
2050	233	3050	0.35	0.15	82	457	539
Farukhnagar Block							
1974-78	85	1107	0.45	0.25	38	277	315
1979-83	114	1490	0.45	0.25	51	373	424
1984-88	127	1657	0.45	0.25	57	414	471
1989-93	146	1908	0.35	0.15	51	286	337
1994-98	161	2105	0.35	0.15	56	316	372
1999-03	180	2353	0.35	0.15	63	353	416
2004-08	187	2455	0.35	0.15	66	368	434
2025	216	2829	0.35	0.15	76	424	500
2050	205	2688	0.35	0.15	72	403	475

Table 5.19 Recharge due to irrigation water applied for crops grown in Gurgaon district in Rabi season

Year	Irrigation ha.m	Return flow factor	Recharge ha.m
Pataudi Block			
1974-78	2960	0.25	740
1979-83	3985	0.25	996
1984-88	4431	0.15	665
1989-93	5103	0.15	765
1994-98	5628	0.15	844
1999-03	6291	0.15	944
2004-08	6565	0.15	985
2025	7565	0.15	1135
2050	7185	0.15	1078
Gurgaon Block			
1974-78	3711	0.15	557
1979-83	4996	0.15	749
1984-88	5554	0.15	833
1989-93	6397	0.15	960
1994-98	7056	0.15	1058
1999-03	7886	0.15	1183
2004-08	8230	0.15	1235
2025	9483	0.15	1422
2050	9008	0.15	1351
Sohna Block			
1974-78	3619	0.25	905
1979-83	4872	0.25	1218
1984-88	5417	0.25	1354
1989-93	6239	0.15	936
1994-98	6881	0.15	1032
1999-03	7691	0.15	1154
2004-08	8027	0.15	1204
2025	9249	0.15	1387
2050	8785	0.15	1318
Farukhnagar Block			
1974-78	3189	0.25	797
1979-83	4293	0.25	1073
1984-88	4774	0.25	1193
1989-93	5498	0.15	825
1994-98	6064	0.15	910
1999-03	6778	0.15	1017
2004-08	7073	0.15	1061
2025	8150	0.15	1223
2050	7742	0.15	1161

5.4 Recharge Due To Rainfall by 'Rainfall Infiltration Factor' Method

Methodology to estimate recharge due to rainfall by rainfall infiltration method has been given in section 3.8. Recharge quantities for different blocks has been estimated by taking average block rainfall of five year for every five year average scenario period and for future prediction of 2025 and 2050 year normal rainfall quantities has been used. Table 5.20 and 5.21 demonstrates the estimates of rainfall recharge respectively for monsoon and non-monsoon season.

It was observed from Table 5.20 that for monsoon season in which almost 80% of total annual rainfall occurs, recharge from rainfall for Pataudi, Gurgaon, Sohna and Farukhnagar blocks was 2868, 3707, 2489 and 1522 ha.m, respectively for 2004-08 average scenario. Nearly one fourth of these quantities were seen to recharge during non-monsoon season. Thus total annual recharge respectively for Pataudi, Gurgaon, Sohna and Farukhnagar blocks were 3557, 4597, 3087 and 1887 ha.m. But under high water withdrawal conditions (exploitation of ground water resources), which was seen in almost all blocks of Gurgaon, non-monsoon recharge might not reach underground water resources. Therefore only dependable recharge quantities will be monsoon recharge. Under normal rainfall condition, recharge from Pataudi, Gurgaon, Sohna and Farukhnagar would be 2499, 4716, 3119, and 2148 ha.m, respectively in Rabi and 3101, 5853, 3871 and 2664 ha.m total annual recharge. Rainfall recharge by rainfall infiltration factor method suggests that under normal rainfall condition recharge from Pataudi, Gurgaon, Sohna and Farukhnagar blocks in Rabi season would be equivalent to 68.5, 129, 85.5 and 58.9 MLD water availability over year if water resources are stored in aquifers.

Table 5.20 Rainfall recharge in Gurgaon District in Monsoon season

Year	Average Rain (mm)	Command Area(ha)	Non-Com. Area(ha)	Return flow ,ha-m CA	NCA	Total
Pataudi Block						
1974-78	266	4642	22910	290	1432	1722
1979-83	433	6250	21302	636	2169	2805
1984-88	345	6949	20603	563	1669	2232
1989-93	368	8002	19550	693	1693	2385
1994-98	480	8827	18725	995	2112	3107
1999-03	364	9866	17686	844	1513	2358
2004-08	443	10296	17256	1072	1796	2868
2025	386	11864	15688	1076	1423	2499
2050	386	11270	16282	1022	1477	2499
Gurgaon Block						
1974-78	695	5820	28723	951	4691	5642
1979-83	708	7835	26708	1303	4441	5744
1984-88	554	8711	25832	1135	3365	4499
1989-93	520	10032	24511	1227	2997	4224
1994-98	613	11066	23477	1594	3381	4975
1999-03	520	12368	22175	1510	2708	4218
2004-08	457	12908	21635	1385	2322	3707
2025	581	14874	19669	2031	2686	4716
2050	581	14128	20415	1929	2787	4716
Sohna Block						
1974-78	410	5676	28010	547	2700	3248
1979-83	406	7641	26045	730	2488	3217
1984-88	392	8496	25190	783	2323	3106
1989-93	340	9784	23902	782	1910	2692
1994-98	490	10792	22894	1243	2637	3879
1999-03	404	12063	21623	1144	2051	3195
2004-08	314	12589	21097	930	1559	2489
2025	394	14506	19180	1343	1776	3119
2050	394	13779	19907	1276	1843	3119
Farukhnagar Block						
1974-78	243	5002	24679	286	1411	1697
1979-83	360	6734	22947	569	1939	2508
1984-88	302	7486	22195	531	1574	2104
1989-93	444	8622	21059	899	2197	3096
1994-98	370	9510	20171	827	1753	2580
1999-03	218	10629	19052	544	975	1518
2004-08	218	11093	18588	569	953	1522
2025	308	12783	16898	925	1223	2148
2050	308	12142	17539	879	1269	2148

Table 5.21 Rainfall recharge in Gurgaon District in Non-Monsoon season

Year	Average Rain (mm)	Command Area(ha)	Non-Com. Area(ha)	Return flow ,ha-m CA	NCA	Total
Pataudi Block						
1974-78	64	6539	21013	98	316	414
1979-83	104	8803	18749	215	459	674
1984-88	83	9787	17765	190	346	536
1989-93	89	11271	16281	234	339	573
1994-98	115	12433	15119	337	410	747
1999-03	87	13896	13656	286	281	566
2004-08	106	14502	13050	363	326	689
2025	93	16710	10842	365	237	602
2050	93	15872	11680	347	255	602
Gurgaon Block						
1974-78	167	8197	26346	322	1034	1356
1979-83	170	11035	23508	441	939	1380
1984-88	133	12269	22274	384	697	1081
1989-93	125	14130	20413	415	600	1015
1994-98	147	15586	18957	539	656	1195
1999-03	125	17420	17123	511	502	1013
2004-08	110	18181	16362	469	422	891
2025	140	20948	13595	689	447	1136
2050	140	19898	14645	655	482	1136
Sohna Block						
1974-78	99	7995	25691	185	595	780
1979-83	98	10763	22923	247	526	773
1984-88	94	11966	21720	265	481	746
1989-93	82	13781	19905	265	382	647
1994-98	118	15201	18485	421	511	932
1999-03	97	16990	16696	387	380	768
2004-08	76	17731	15955	315	283	598
2025	95	20431	13255	456	296	752
2050	95	19407	14279	433	319	752
Farukhnagar Block						
1974-78	58	7045	22636	97	311	408
1979-83	86	9484	20197	193	410	603
1984-88	72	10545	19136	180	326	506
1989-93	107	12144	17537	304	440	744
1994-98	89	13395	16286	280	340	620
1999-03	52	14971	14710	184	181	365
2004-08	52	15625	14056	192	173	366
2025	74	18003	11678	313	203	516
2050	74	17101	12580	297	219	516

5.5 Recharge Due To Rainfall by 'Water Table Fluctuation' Method

Methodology to estimate recharge due to rainfall by water table fluctuation method has been given in section 3.9. Like recharge estimation by rainfall infiltration method, recharge quantities for different blocks has been estimated by taking average block rainfall of five year for every five year average scenario period and for future prediction (2025 and 2050) normal rainfall quantities has been used for water table fluctuation method. For rainfall recharge estimation by water table fluctuation method, first of all blockwise average water table fluctuation, total draft (water withdrawal) and change in ground water storage was worked out and same has been presented in Table 5.22, 5.23 and 5.24. Change in ground water storage was estimated by multiplying total block area and specific yield fraction (CGWB Norm) to the fluctuation. Then rainfall recharge was calculated as sum of blockwise draft and change in water storage. Results of this recharge has been presented in table 5.25

Recharge quantities determined by this procedure were required to be normalized. For normalization of rainfall recharge two methods has been suggested. In first method, percent deviation of average rainfall from normal rainfall was estimated and then ratio of recharge to rainfall was multiplied by normal rainfall. Table 5.26 shows the values of percent deviation from normal rainfall and Table 5.27 shows the normalized recharge values for rainy season. Water table fluctuation method is applicable to calculate rainfall recharge in rainy season only.

According to second method of normalization of rainfall recharge regression analysis was carried out between rainfall and recharge. To carry out this analysis help of Microsoft Excel was taken in which scatter graph was plotted with rainfall on X-axis and recharge on Y-axis. Through scattered points best fit straight line was obtained with regression equation and coefficient of determination (R^2) values. Then using obtained equations and rainfall quantities, normalized rainfall recharge was worked out. Figure 5.7 shows the scatter plots and Table 5.28 shows the normalized rainfall recharge.

Rainfall recharge quantities determined by both the normalization procedures have been compared with Modflow calculated recharge quantities to get realistic method and dependable recharge values.

Table 5.22 Water table fluctuation in Gurgaon district (blockwise)

Year	Water Level in meter		
	June	October	Difference
Pataudi Block			
1974-78	4.68	2.89	1.79
1979-83	7.95	7.45	0.50
1984-88	10.30	10.18	0.12
1989-93	15.89	15.50	0.39
1994-98	18.50	17.75	0.75
1999-03	21.74	20.71	1.03
2004-08	24.26	23.86	0.41
Gurgaon Block			
1974-78	11.94	10.55	1.39
1979-83	12.44	11.82	0.62
1984-88	13.87	13.22	0.66
1989-93	16.74	16.64	0.10
1994-98	18.98	17.79	1.19
1999-03	22.15	21.98	0.18
2004-08	23.22	23.21	0.01
Sohna Block			
1974-78	5.31	4.14	1.17
1979-83	6.14	5.95	0.19
1984-88	8.76	7.85	0.91
1989-93	11.19	10.57	0.62
1994-98	11.72	10.48	1.24
1999-03	13.24	13.00	0.24
2004-08	17.84	18.13	-0.29
Farukhnagar Block			
1974-78	5.18	3.85	1.33
1979-83	6.56	6.24	0.31
1984-88	8.07	7.38	0.69
1989-93	10.73	10.45	0.28
1994-98	11.21	10.11	1.10
1999-03	13.62	13.34	0.28
2004-08	15.27	15.57	-0.29

Table 5.23 Blockwise monsoon season total draft (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'nagar
1974-78	1266	1865	1548	1364
1979-83	1683	2545	2058	1813
1984-88	1896	2976	2318	2043
1989-93	2159	3368	2639	2326
1994-98	2420	4778	2959	2607
1999-03	2739	6888	3349	2951
2004-08	2881	7364	3523	3104

Table 5.24 Change in ground water storage in monsoon season (ha.m)

Year	Pataudi	Gurgaon	Sohna	F'nagar
1974-78	7894	7681	6315	6322
1979-83	2189	3418	1000	1486
1984-88	527	3623	4927	3273
1989-93	1698	564	3342	1323
1994-98	3290	6594	6695	5215
1999-03	4555	980	1302	1315
2004-08	1799	59	-1581	-1394

Table 5.25 Rainfall recharge in monsoon season by water balance method (ha.m)

Year	Pataudi	Gurgaon	Sohna	F'nagar
1974-78	9160	9547	7863	7686
1979-83	3872	5963	3058	3299
1984-88	2423	6599	7245	5316
1989-93	3857	3932	5982	3649
1994-98	5710	11372	9654	7822
1999-03	7294	7869	4652	4267
2004-08	4680	7423	1942	1710

Table 5.26 Percentage deviation of recharge

Year	Rainfall Mm	Recharge ha-m	Deviation %
Pataudi Block			
1974-78	264	9160	-31.11
1979-83	430	3872	12.23
1984-88	342	2423	-10.70
1989-93	366	3857	-4.56
1994-98	476	5710	24.32
1999-03	361	7294	-5.67
2004-08	440	4680	14.76
Gurgaon Block			
1974-78	690	9547	19.72
1979-83	702	5963	21.89
1984-88	550	6599	-4.53
1989-93	516	3932	-10.36
1994-98	608	11372	5.57
1999-03	516	7869	-10.50
2004-08	453	7423	-21.33
Sohna Block			
1974-78	407	7863	4.10
1979-83	403	3058	3.14
1984-88	389	7245	-0.42
1989-93	337	5982	-13.70
1994-98	486	9654	24.36
1999-03	400	4652	2.42
2004-08	312	1942	-20.20
Farukhnagar Block			
1974-78	241	7686	-20.84
1979-83	357	3299	16.96
1984-88	299	5316	-1.85
1989-93	440	3649	44.42
1994-98	367	7822	20.34
1999-03	216	4267	-29.18
2004-08	216	1710	-29.02

Table 5.27 Rainfall recharge by percent deviation normalization procedure

Year	Rainfall mm	Recharge ha-m	Normalized Recharge ha-m
Pataudi Block			
1974-78	264	9160	13296
1979-83	430	3872	3450
1984-88	342	2423	2713
1989-93	366	3857	4041
1994-98	476	5710	4593
1999-03	361	7294	7733
2004-08	440	4680	4079
Normal Rainfall Recharge			**5701**
Gurgaon Block			
1974-78	690	9547	7974
1979-83	702	5963	4892
1984-88	550	6599	6912
1989-93	516	3932	4387
1994-98	608	11372	10772
1999-03	516	7869	8792
2004-08	453	7423	9436
Normal Rainfall Recharge			**7595**
Sohna			
1974-78	407	7863	7553
1979-83	403	3058	2965
1984-88	389	7245	7276
1989-93	337	5982	6931
1994-98	486	9654	7763
1999-03	400	4652	4542
2004-08	312	1942	2434
Normal Rainfall Recharge			**5638**
Farukhnagar			
1974-78	241	7686	9709
1979-83	357	3299	2821
1984-88	299	5316	5416
1989-93	440	3649	2527
1994-98	367	7822	6500
1999-03	216	4267	6025
2004-08	216	1710	2409
Normal Rainfall Recharge			**5058**

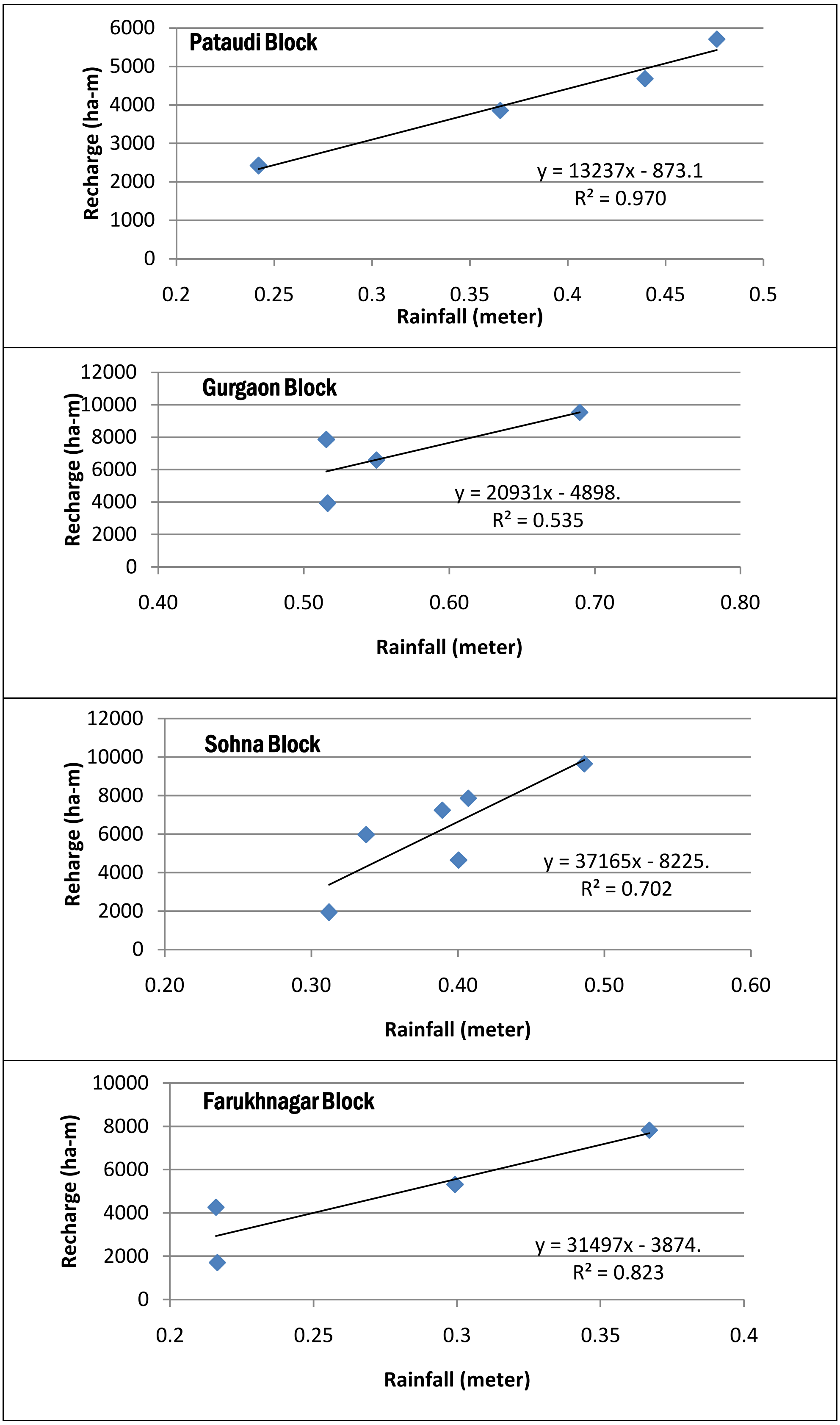


Figure 5.7 Rainfall recharge estimation equations by regression normalization procedure

Table 5.28 Rainfall recharge calculated by water table fluctuation method (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'nagar
1974-78	2620	9536	6903	3731
1979-83	4817	9797	6763	7362
1984-88	3654	6612	6246	5555
1989-93	3966	5909	4316	10000
1994-98	5430	7829	9846	7687
1999-03	3909	5892	6659	2929
2004-08	4945	4586	3370	2944
NMR	4191	7166	6300	5744

5.6 Ground Water Pumping & Recharge Inputs for Modeling

According to methodology given in Section 3.10, total ground water extraction (pumping) has been estimated as sum of five components viz. agricultural water requirement, industrial water requirement, domestic water requirement, institutional water requirement and domestic & other animal water requirement. Also, total recharge was worked out as sum of recharge due to rainfall and irrigation. For rainfall recharge results of rainfall infiltration factor method has been used.

Table 5.29 and 5.30 shows the results of different components of water extraction respectively for monsoon and non-monsoon season for four blocks of Gurgaon district and Table 5.31 & 5.32 shows the results of total ground water extraction for monsoon and non-monsoon seasons. Also, Table 5.33 and 5.34 represents results of components of recharge and total recharge for monsoon and non-monsoon seasons, respectively.

Using results of Table 5.29 to 5.34, inputs required for model viz. pumping and recharge were generated according to season. For monsoon season, net pumping or net recharge was generated by subtracting total pumping from total recharge. If this subtraction is positive then there will be net recharge for that stress period for that block or if subtraction is negative then there will be net pumping for that stress period for that block. Modflow modeling environment require same consistent unit system throughout modeling. We generated all inputs in units of meter for length, and days for time. For model recharge was required to give in units of meter per day and pumping in meter cube per day units. Table 5.35 represents the results of net recharge and net pumping inputs for Modflow model.

Table 5.29 Components of ground water pumping for Gurgaon districts in Monsoon (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'Nagar
Irrigation				
1974-78	1106	1387	1352	1192
1979-83	1489	1867	1821	1604
1984-88	1655	2075	2024	1784
1989-93	1907	2390	2331	2054
1994-98	2103	2636	2571	2266
1999-03	2350	2947	2874	2532
2004-08	2453	3075	2999	2643
2025	2827	3544	3456	3045
2050	2685	3366	3283	2893
Industrial				
1974-78	28	217	35	30
1979-83	50	385	61	54
1984-88	71	544	86	76
1989-93	77	593	94	83
1994-98	102	1577	125	110
1999-03	136	3142	166	147
2004-08	146	3379	179	158
2025	246	5686	301	265
2050	388	8969	475	418
Domestic Use				
1974-78	67	162	82	72
1979-83	69	166	84	74
1984-88	84	204	103	91
1989-93	100	241	122	108
1994-98	130	313	158	140
1999-03	159	385	195	172
2004-08	247	597	302	266
2025	417	1008	510	449
2050	858	2076	1050	925
Domestic & other animals use				
1974-78	62	78	76	67
1979-83	70	88	86	76
1984-88	79	99	96	85
1989-93	68	85	83	73
1994-98	75	94	91	81
1999-03	80	100	98	86
2004-08	64	81	79	69
2025	51	64	62	55
2050	42	52	51	45
Institutional				
1974-78	3	22	3	3
1979-83	5	39	6	5
1984-88	7	54	9	8
1989-93	8	59	9	8
1994-98	10	158	13	11
1999-03	14	314	17	15
2004-08	15	338	18	16
2025	25	569	30	27
2050	39	897	47	42

Table 5.30 Components of ground water pumping for Gurgaon districts in Non-Monsoon (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'Nagar
Irrigation				
1974-78	3384	4242	4137	3646
1979-83	4555	5711	5570	4908
1984-88	5065	6349	6193	5457
1989-93	5833	7313	7132	6285
1994-98	6434	8066	7867	6932
1999-03	7191	9015	8792	7748
2004-08	7505	9409	9176	8086
2025	8648	10841	10573	9317
2050	8214	10297	10043	8850
Industrial				
1974-78	58	444	70	62
1979-83	102	787	125	110
1984-88	144	1111	176	155
1989-93	157	1210	192	169
1994-98	209	3220	256	225
1999-03	278	6415	340	299
2004-08	299	6899	365	322
2025	503	11610	614	542
2050	793	18311	969	854
Domestic Use				
1974-78	137	331	167	148
1979-83	140	339	171	151
1984-88	172	416	210	185
1989-93	204	493	249	220
1994-98	264	639	323	285
1999-03	325	786	398	350
2004-08	504	1219	616	543
2025	852	2059	1041	917
2050	1753	4238	2143	1888
Domestic & other animals use				
1974-78	126	158	154	136
1979-83	144	180	176	155
1984-88	161	202	197	173
1989-93	138	173	169	149
1994-98	153	191	187	164
1999-03	163	205	200	176
2004-08	131	165	161	141
2025	104	130	127	112
2050	85	106	104	92
Institutional				
1974-78	6	44	7	6
1979-83	10	79	12	11
1984-88	14	111	18	16
1989-93	16	121	19	17
1994-98	21	322	26	23
1999-03	28	642	34	30
2004-08	30	690	37	32
2025	50	1161	61	54
2050	79	1831	97	85

Table 5.31 Total ground water pumping for Gurgaon districts in Monsoon (ha-m)

Year	Patudi	Gurgaon	Sohna	F'nagar
1974-78	1266	1865	1548	1364
1979-83	1683	2545	2058	1813
1984-88	1896	2976	2318	2043
1989-93	2159	3368	2639	2326
1994-98	2420	4778	2959	2607
1999-03	2739	6888	3349	2951
2004-08	2925	7470	3577	3152
2025	3565	10871	4359	3841
2050	4012	15359	4905	4323

Table 5.32 Total ground water pumping for Gurgaon districts in Non-Monsoon (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'nagar
1974-78	3711	5220	4537	3998
1979-83	4951	7095	6054	5335
1984-88	5556	8189	6793	5986
1989-93	6348	9309	7761	6839
1994-98	7081	12439	8658	7629
1999-03	7985	17063	9763	8603
2004-08	8469	18381	10355	9125
2025	10156	25800	12417	10942
2050	10924	34784	13356	11769

Table 5.33 Components and total ground water recharge for Gurgaon districts in Monsoon (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'Nagar
Rainfall Infiltration Factor Recharge				
1974-78	1722	5642	3248	1697
1979-83	2805	5744	3217	2508
1984-88	2232	4499	3106	2104
1989-93	2385	4224	2692	3096
1994-98	3107	4975	3879	2580
1999-03	2358	4218	3195	1518
2004-08	2868	3707	2489	1522
2025	2499	4716	3119	2148
2050	2499	4716	3119	2148
Recharge due to irrigation water applied				
1974-78	292	228	357	315
1979-83	393	306	481	424
1984-88	272	341	535	471
1989-93	313	392	383	337
1994-98	345	433	422	372
1999-03	386	484	472	416
2004-08	403	505	492	434
2025	464	582	567	500
2050	441	553	539	475
Total Recharge				
1974-78	2014	5869	3605	2012
1979-83	3198	6050	3698	2931
1984-88	2504	4840	3641	2576
1989-93	2698	4617	3075	3434
1994-98	3452	5408	4302	2952
1999-03	2743	4701	3667	1934
2004-08	3271	4212	2982	1956
2025	2963	5298	3686	2648
2050	2940	5269	3658	2623

Table 5.34 Components and total ground water recharge for Gurgaon districts in Non-Monsoon (ha-m)

Year	Pataudi	Gurgaon	Sohna	F'Nagar
Rainfall Infiltration Factor Recharge				
1974-78	414	1356	780	408
1979-83	674	1380	773	603
1984-88	536	1081	746	506
1989-93	573	1015	647	744
1994-98	747	1195	932	620
1999-03	566	1013	768	365
2004-08	689	891	598	366
2025	602	1136	752	516
2050	602	1136	752	516
Recharge due to irrigation water applied				
1974-78	740	557	905	797
1979-83	996	749	1218	1073
1984-88	665	833	1354	1193
1989-93	765	960	936	825
1994-98	844	1058	1032	910
1999-03	944	1183	1154	1017
2004-08	985	1235	1204	1061
2025	1135	1422	1387	1223
2050	1078	1351	1318	1161
Total Recharge				
1974-78	1154	1912	1685	1205
1979-83	1670	2129	1991	1676
1984-88	1201	1914	2101	1699
1989-93	1338	1974	1583	1569
1994-98	1591	2254	1964	1530
1999-03	1510	2196	1921	1381
2004-08	1674	2125	1802	1427
2025	1737	2559	2139	1739
2050	1680	2488	2070	1677

Table 5.35 Net recharge and net pumping inputs for Modflow model

Year	Time Step	Pataudi	Gurgaon	Sohna	F'nagar
Monsoon Season Recharge (m/day)					
1974-78	1	0.0002262	0.0009660	0.0005088	0.0001819
1979-83	3	0.0004583	0.0008458	0.0004059	0.0003140
1984-88	5	0.0001838	0.0004496	0.0003272	0.0001496
1989-93	7	0.0001632	0.0003012	0.0001077	0.0003111
1994-98	9	0.0003123	0.0001519	0.0003322	0.0000969
1999-03	11	0.0000012	-0.0005276	0.0000786	-0.0002856
2004-08	13	0.0001046	-0.0007860	-0.0001472	-0.0003358
2025		-0.0001821	-0.0013443	-0.0001664	-0.0003349
2050		-0.0003242	-0.0024342	-0.0003086	-0.0004771
Monsoon Season Pumping (m^3/day)					
1974-78	1	0.0000	0.0000	0.0000	0.0000
1979-83	3	0.0000	0.0000	0.0000	0.0000
1984-88	5	0.0000	0.0000	0.0000	0.0000
1989-93	7	0.0000	0.0000	0.0000	0.0000
1994-98	9	0.0000	0.0000	0.0000	0.0000
1999-03	11	0.0000	-171.4394	0.0000	-92.8025
2004-08	13	0.0000	-255.3870	-47.8159	-109.0997
2025		-59.1551	-436.8233	-54.0775	-108.8324
2050		-105.3538	-790.9652	-100.2791	-155.0392
Non-Monsoon Season Pumping (m^3/day), recharge is nil					
1974-78	2	-123.0783	-126.9954	-112.2774	-124.7892
1979-83	4	-157.9493	-190.6515	-159.9617	-163.4935
1984-88	6	-209.6538	-240.9109	-184.7619	-191.5751
1989-93	8	-241.1378	-281.6238	-243.2687	-235.5182
1994-98	10	-264.2797	-391.0443	-263.5306	-272.5560
1999-03	12	-311.6951	-570.8051	-308.7500	-322.7061
2004-08	14	-327.0925	-624.1425	-336.7308	-343.9750
2025		-405.2497	-892.3438	-404.6441	-411.2321
2050		-444.9576	-1239.9953	-444.3546	-450.9472

5.7 Pumping Test Methods for Determination of S and T

Aquifer: water bearing geologic formation which stores water and is capable of transmitting water through its pores at a relatively large rate which is sufficient for economic extraction of ground water by wells. There are two types of aquifers, confined and unconfined. Unconfined aquifer is one in which free surface i.e. water table exists. According to geologic information of Gurgaon districts some of the area doesn't have well defined confined aquifers and some places have sand and gravel formations intermixed with clay and of very small extent and thickness. The unconfined aquifer extends from ground surface up to the impervious stratum underneath. However, only the saturated zone of this aquifer below the water table is of importance in ground water hydrology. Modflow models this situation by considering well observations. Initial hydraulic head is used in Modflow to demarcate the saturated and unsaturated thickness for first run and then according to drawdown, saturated thickness is revised in subsequent runs. Careful study of well information (Appendix A) shows that open wells have depth of 10 to 15 meter and tube wells have depth below 30 to 35 meters. Ground water levels by the end of 2004-08 showed up to 55 meters water withdrawal. Therefore aquifer for Gurgaon district was modeled by considering 60 meter layer thickness for which aquifer transmissivity may vary. Type of aquifer specified for modeling was unconfined/confined mixed layer.

Methodology for determination of aquifer parameters by different methods has been given in Section 3.11 of materials and methods. Table 5.36 to 5.42 shows the data of pumping tests and recovery tests for four villages in Gurgaon districts and Figure 5.8 to 5.11 shows the semi-log graphs prepared using these data for estimation of aquifer parameters. Information of discharge rate (Q), time (t) and diameter of well (r) has been given at the end of pumping test data tables and results of various subsequent parameters required to use in different parameter estimation equation has been given on the semi-log graphs.

Table 5.36 Pump test data for village Pathrerhi Block Pataudi

Time minute	Drawdown ft	Drawdown meter	r^2/t m^2/min	Drawdown meter
0	0.00	0.000		
1	0.25	0.076	58.09	0.076
2	0.46	0.140	29.05	0.140
3	0.63	0.192	19.36	0.192
4	0.82	0.250	14.52	0.250
5	0.95	0.290	11.62	0.290
6	1.13	0.345	9.68	0.345
7	1.29	0.393	8.30	0.393
8	1.46	0.445	7.26	0.445
9	1.62	0.494	6.45	0.494
10	1.75	0.534	5.81	0.534
12	2.04	0.622	4.84	0.622
14	2.29	0.698	4.15	0.698
16	2.54	0.774	3.63	0.774
18	2.78	0.848	3.23	0.848
20	2.98	0.909	2.90	0.909
25	3.42	1.043	2.32	1.043
30	3.48	1.061	1.94	1.061
35	4.19	1.277	1.66	1.277
40	4.50	1.372	1.45	1.372
45	4.75	1.448	1.29	1.448
50	5.00	1.524	1.16	1.524
55	5.21	1.588	1.06	1.588
60	5.38	1.640	0.97	1.640
65	5.52	1.683	0.89	1.683
70	5.67	1.729	0.83	1.729
80	5.84	1.780	0.73	1.780
90	6.00	1.829	0.65	1.829
100	6.15	1.875	0.58	1.875
110	6.25	1.905	0.53	1.905
120	6.34	1.933	0.48	1.933
135	6.40	1.951	0.43	1.951
150	6.44	1.963	0.39	1.963
165	6.48	1.976	0.35	1.976
180	6.52	1.988	0.32	1.988
200	6.57	2.003	0.29	2.003
220	6.59	2.009	0.26	2.009
240	6.59	2.009	0.24	2.009
260	6.59	2.009	0.22	2.009
Q = 80 USGPM		**Q**	**0.302833**	**m^3/min**
r = 25 ft		**r**	**7.621951**	**meter**
t = 260 min				

Table 5.37 Recovery test data for village Pathrerhi Block Pataudi

Time minute t	Time Since pump stop minute t'	Residual Drawdown ft s	Residual Drawdown meter s	t / t'
260	0	6.59	2.009	
261	1	6.42	1.957	261.0
262	2	6.25	1.905	131.0
263	3	6.09	1.857	87.7
264	4	5.92	1.805	66.0
265	5	5.75	1.753	53.0
266	6	5.63	1.716	44.3
267	7	5.50	1.677	38.1
268	8	5.38	1.640	33.5
269	9	5.25	1.601	29.9
270	10	5.13	1.564	27.0
272	12	4.89	1.491	22.7
274	14	4.63	1.412	19.6
276	16	4.42	1.348	17.3
278	18	4.21	1.284	15.4
280	20	4.00	1.220	14.0
285	25	3.50	1.067	11.4
290	30	3.09	0.942	9.7
295	35	2.75	0.838	8.4
300	40	2.44	0.744	7.5
305	45	2.17	0.662	6.8
310	50	1.94	0.591	6.2
315	55	1.75	0.534	5.7
325	65	1.42	0.433	5.0
335	75	1.19	0.363	4.5
345	85	1.02	0.311	4.1
355	95	0.90	0.274	3.7
365	105	0.82	0.250	3.5
380	120	0.67	0.204	3.2
395	135	0.54	0.165	2.9
410	150	0.46	0.140	2.7
425	165	0.38	0.116	2.6
440	180	0.33	0.101	2.4
460	200	0.25	0.076	2.3
480	220	0.17	0.052	2.2
500	240	0.11	0.034	2.1
520	260	0.07	0.021	2.0
540	280	0.04	0.012	1.9
560	300	0.00	0.000	1.9

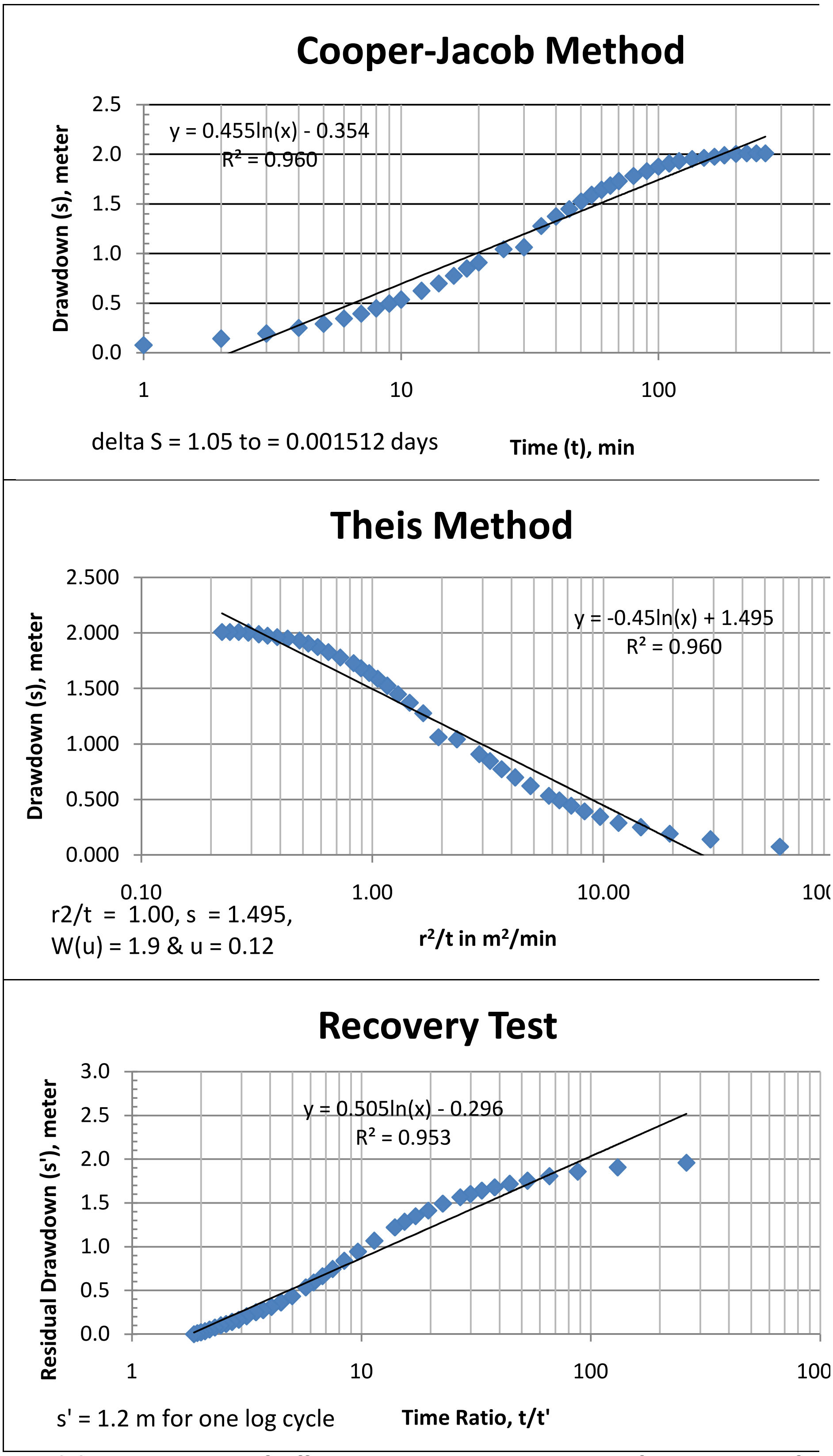


Figure 5.8 Semi-log graphs of different methods to calculate aquifer parameters for Pathrerhi (Pataudi)

Table 5.38 Pump test data for village Jamalpur Block Pataudi

Time minute	Drawdown ft	Drawdown meter	r^2/t m^2/min	Drawdown meter
0	0	0.000		
1	0.38	0.116	148.72	0.116
2	0.71	0.216	74.36	0.216
3	1	0.305	49.57	0.305
4	1.29	0.393	37.18	0.393
5	1.59	0.485	29.74	0.485
6	1.85	0.564	24.79	0.564
7	2.17	0.662	21.25	0.662
8	2.67	0.814	18.59	0.814
9	2.67	0.814	16.52	0.814
10	3.28	1.000	14.87	1.000
12	3.29	1.003	12.39	1.003
14	3.79	1.155	10.62	1.155
16	4.13	1.259	9.30	1.259
18	4.54	1.384	8.26	1.384
20	4.88	1.488	7.44	1.488
25	5.67	1.729	5.95	1.729
30	6.29	1.918	4.96	1.918
35	6.92	2.110	4.25	2.110
40	7.39	2.253	3.72	2.253
45	7.67	2.338	3.30	2.338
50	8	2.439	2.97	2.439
55	8.29	2.527	2.70	2.527
60	8.5	2.591	2.48	2.591
70	8.84	2.695	2.12	2.695
80	9.09	2.771	1.86	2.771
90	9.25	2.820	1.65	2.820
100	9.5	2.896	1.49	2.896
120	9.57	2.918	1.24	2.918
140	9.75	2.973	1.06	2.973
160	9.79	2.985	0.93	2.985
180	9.84	3.000	0.83	3.000
200	9.84	3.000	0.74	3.000
220	9.84	3.000	0.68	3.000
Q =90 USGPM		**Q**	**0.340687**	**m^3/min**
r = 40 ft		**r**	**12.19512**	**meter**
t = 220 min				

Table 5.39 Recovery test data for village Jamalpur Block Pataudi

Time minute t	Time Since pump stop minute t'	Residual Drawdown ft s	Residual Drawdown meter s	t / t'
220	0	9.84	3.000	
221	1	9.54	2.909	221.00
222	2	9.25	2.820	111.00
223	3	8.96	2.732	74.33
224	4	8.71	2.655	56.00
225	5	8.46	2.579	45.00
226	6	8.21	2.503	37.67
227	7	7.96	2.427	32.43
228	8	7.71	2.351	28.50
229	9	7.46	2.274	25.44
230	10	7.25	2.210	23.00
231	11	7	2.134	21.00
232	12	6.79	2.070	19.33
233	13	6.59	2.009	17.92
234	14	6.33	1.930	16.71
235	15	6.21	1.893	15.67
236	16	6.04	1.841	14.75
238	18	5.67	1.729	13.22
240	20	5.34	1.628	12.00
242	22	5	1.524	11.00
244	24	4.71	1.436	10.17
246	26	4.42	1.348	9.46
250	30	3.88	1.183	8.33
255	35	3.25	0.991	7.29
260	40	2.79	0.851	6.50
265	45	2.42	0.738	5.89
270	50	2.09	0.637	5.40
275	55	1.84	0.561	5.00
280	60	1.63	0.497	4.67
285	65	1.42	0.433	4.38
290	70	1.25	0.381	4.14
295	75	1.21	0.369	3.93
300	80	1.17	0.357	3.75
310	90	1.09	0.332	3.44
320	100	1.02	0.311	3.20
330	110	0.98	0.299	3.00
340	120	0.94	0.287	2.83
360	140	0.88	0.268	2.57
380	160	0.84	0.256	2.38
400	180	0.8	0.244	2.22
420	200	0.75	0.229	2.10
440	220	0.71	0.216	2.00
460	240	0.67	0.204	1.92

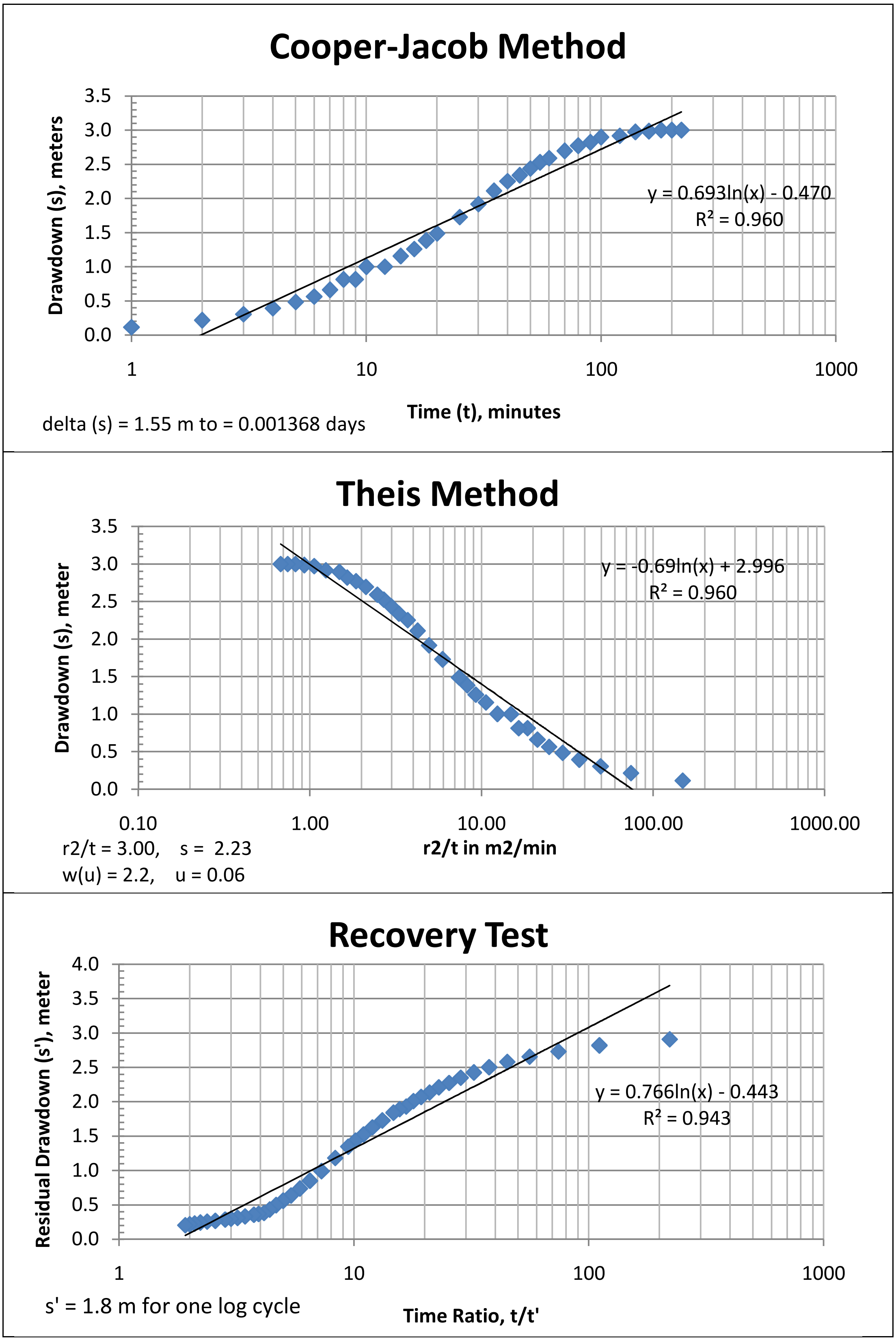


Figure 5.9 Semi-log graphs of different methods to calculate aquifer parameters for Jamalpur (Pataudi)

Table 5.40 Pump Test data for village Isaqi Block Sohna

Time minute	Drawdown meter	r^2/t m^2/min	Drawdown meter
5	0.00	80.00	0.00
10	0.00	40.00	0.00
15	0.02	26.67	0.02
20	0.05	20.00	0.05
25	0.08	16.00	0.08
30	0.12	13.33	0.12
35	0.15	11.43	0.15
40	0.18	10.00	0.18
45	0.22	8.89	0.22
50	0.25	8.00	0.25
55	0.27	7.27	0.27
60	0.27	6.67	0.27
70	0.28	5.71	0.28
80	0.32	5.00	0.32
90	0.32	4.44	0.32
100	0.35	4.00	0.35
110	0.37	3.64	0.37
120	0.40	3.33	0.40
130	0.40	3.08	0.40
140	0.40	2.86	0.40
Q = 139 USGPM	**Q**	**0.526172**	**m^3/min**
r = 20 m	**r**	**20**	**meter**
t = 140 min			

Table 5.41 Recovery test data for village Isaqi Block Sohna

Time minute t	Time Since pump stop minute t'	Residual Drawdown meter s	t / t'
145	5	0.38	29.00
150	10	0.35	15.00
155	15	0.33	10.33
160	20	0.31	8.00
165	25	0.29	6.60
170	30	0.28	5.67
180	40	0.25	4.50
190	50	0.23	3.80
200	60	0.21	3.33
210	70	0.18	3.00
220	80	0.16	2.75
230	90	0.14	2.56
240	100	0.12	2.40
250	110	0.11	2.27
260	120	0.10	2.17
280	140	0.08	2.00
300	160	0.06	1.88
320	180	0.05	1.78
340	200	0.04	1.70
370	230	0.01	1.61

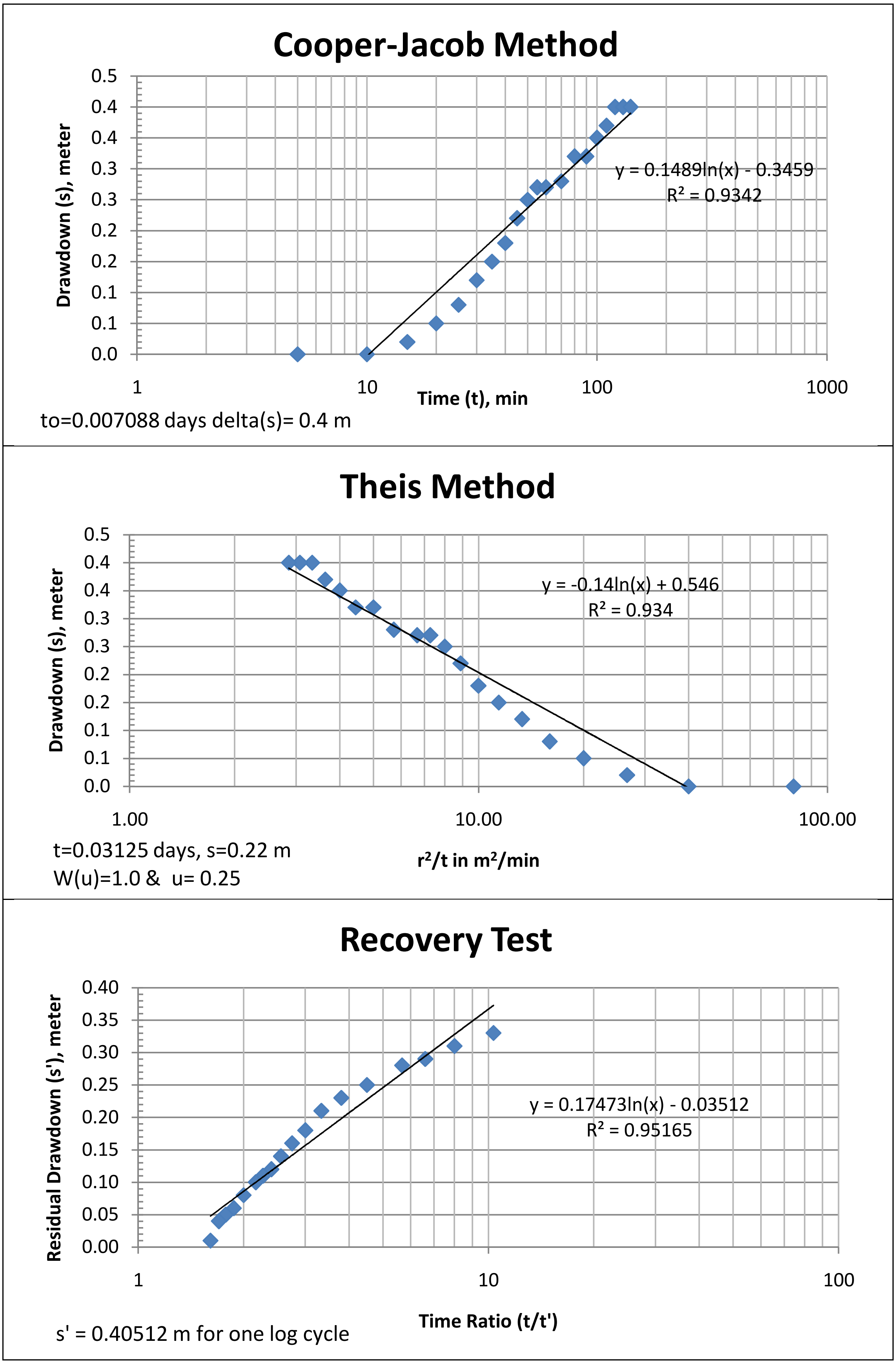
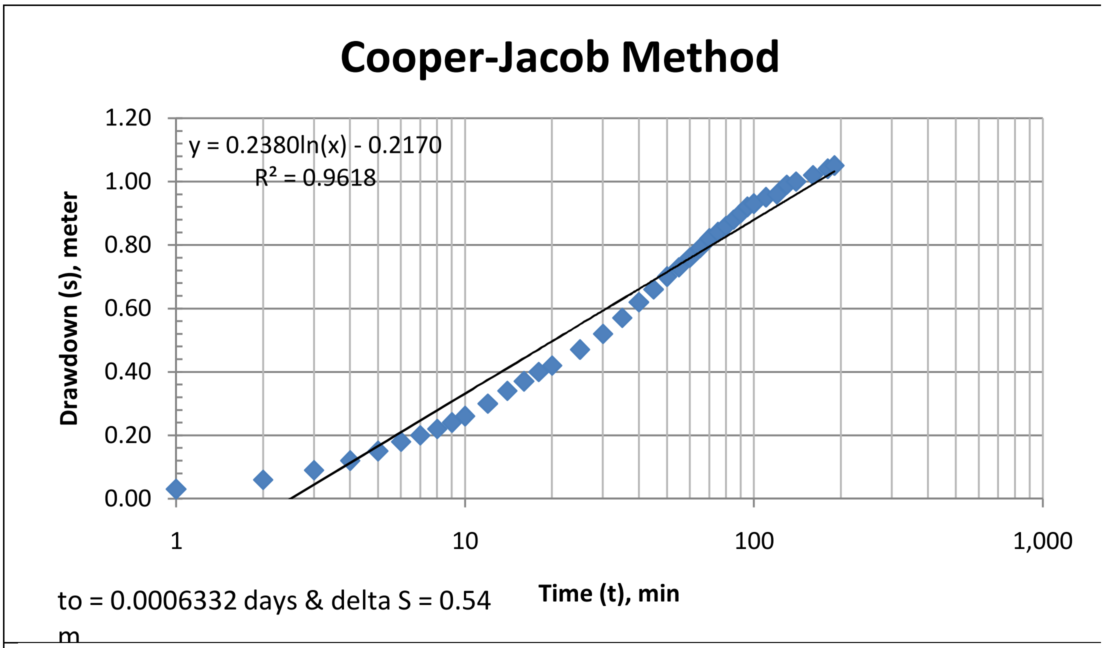


Figure 5.10 Semi-log graphs of different methods to calculate aquifer parameters for Isaqi (Sohna)

Table 5.42 Pump Test data for village Sancoli Block Sohna

Time minute	Drawdown meter	r2/t m2/min	Drawdown meter
0	0		
1	0.03	131.10	0.03
2	0.06	65.55	0.06
3	0.09	43.70	0.09
4	0.12	32.78	0.12
5	0.15	26.22	0.15
6	0.18	21.85	0.18
7	0.20	18.73	0.20
8	0.22	16.39	0.22
9	0.24	14.57	0.24
10	0.26	13.11	0.26
12	0.30	10.93	0.30
14	0.34	9.36	0.34
16	0.37	8.19	0.37
18	0.40	7.28	0.40
20	0.42	6.56	0.42
25	0.47	5.24	0.47
30	0.52	4.37	0.52
35	0.57	3.75	0.57
40	0.62	3.28	0.62
45	0.66	2.91	0.66
50	0.70	2.62	0.70
55	0.73	2.38	0.73
60	0.76	2.19	0.76
65	0.79	2.02	0.79
70	0.82	1.87	0.82
75	0.84	1.75	0.84
80	0.86	1.64	0.86
85	0.88	1.54	0.88
90	0.90	1.46	0.90
95	0.92	1.38	0.92
100	0.93	1.31	0.93
110	0.95	1.19	0.95
120	0.96	1.09	0.96
130	0.99	1.01	0.99
140	1.00	0.94	1.00
160	1.02	0.82	1.02
180	1.04	0.73	1.04
190	1.05	0.69	1.05
Q = 118.87 USGPM	**Q**	**0.449972**	**m^3/min**
r = 11.45 m	**r**	**7.621951**	**meter**
t = 190 min			



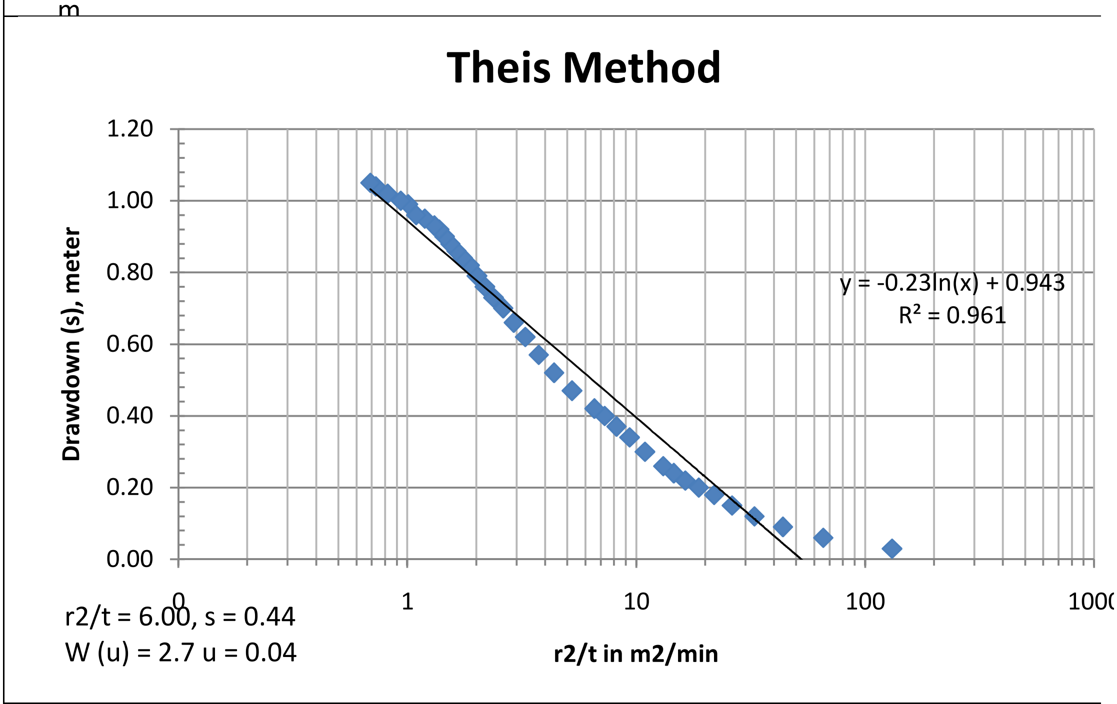


Figure 5.11 Semi-log graphs of different methods to calculate aquifer parameters for Sancholi (Sohna)

Table 5.43 Storage coefficient (S), transmissivity (T), and hydraulic conductivity (k) for Gurgaon district

Aquifer Parameter	Cooper-Jacob Method	Theis Method	Chow Method	Recovery Test	Average
Village:Pathrerhi	**Block: Pataudi**				
Transmissibility (m2/d)	76.11	44.10	61.40	66.51	62.03
Storage Coefficient	0.00	0.01	0.01	-	0.01
Hydraulic Conductivity (m/d)	1.27	0.74	1.02	1.11	1.03
Village:Jamalpur	**Block: Pataudi**				
Transmissibility (m2/d)	58.01	33.14	49.67	49.88	47.68
Storage Coefficient	0.00	0.01	0.00	-	0.00
Hydraulic Conductivity (m/d)	0.97	0.55	0.83	0.83	0.79
Village:Isaqi	**Block: Sohna**				
Transmissibility (m2/d)	347.15	328.27	301.47	342.31	329.80
Storage Coefficient	0.01	0.01	0.02		0.02
Hydraulic Conductivity (m/d)	5.79	5.47	5.02	5.71	5.50
Village:Sancholi	**Block: Sohna**				
Transmissibility (m2/d)	219.91	223.95	198.89	-	214.25
Storage Coefficient	0.02	0.01	0.02	-	0.02
Hydraulic Conductivity (m/d)	3.67	3.73	3.31	-	3.57

Transmissibility is equal to the discharge rate at which water is transmitted through a unit width of an aquifer under unit hydraulic gradient. It can be obtained as a product of hydraulic conductivity (also called as coefficient of permeability) and thickness of aquifer. By using pumping tests we obtained values of transmissibility and using transmissibility and thickness of aquifer, we obtained hydraulic conductivity which is required for Modflow. Hydraulic conductivity is the discharge per unit area of soil mass under unit hydraulic gradient. Therefore it is one of the important parameters.

Table 5.43 shows that average transmissibility was varying from 62.03 to 329.8 m^2/day with average of 163.44 m^2/day. Corresponding values of hydraulic conductivity were varying from 1.03 to 5.5 m/day with average of 2.72 m/day. Therefore it was decided to use this range of hydraulic conductivity values to be used for calibration of model. Storage coefficient was varying from 0.004 to 0.02 with an average of 0.011.

5.8 Calibration and Validation of Groundwater Model for Gurgaon District

Description of Modflow and ground water model for Gurgaon in Modflow environment has been given in detail in section 3.12 of materials and methods. Total Gurgaon district area of 1254.62 km^2 was modeled using 102 column and 66 rows making total grid cell number of 6732. Each grid cell had 570.03 m length by 570.03 m width making 324934.20 m^2 area. Out of total 6732 grid cells, 3861 cells were coming within the boundary of Gurgaon district. Cells coming inside the boundary were indicated by type 1 cells for which head or drawdown may vary. Cells outside the district boundary were indicated by type 0 cells signifying no flow cells. Figure 3.15 (Materials & Methods) shows this boundary condition. Ground water observation well data for about 75 wells was available for the analysis. Table A-1 in Appendix A shows the detail information of the wells and Figure 3.18 shows the geographic locations of these wells. It can be seen from Figure 3.18 that these wells are evenly spread all over the geographic area of Gurgaon district. Out of total 75 wells, data of five wells was not considered for analysis because of non-availability of sufficient long duration data for comparison or non-availability of natural surface level or any such reasons. Therefore using observation of natural surface level of 70 wells, surface level elevation of Gurgaon district was created. For this, help of digitization and interpolation tool of Modflow Version 5.3.1 © Chiang, W. H. and Kinzellbach, W., 1991-2001 was taken. Modflow is one the most robust ground water modeling tool used all over the world. This is open source model and can be downloaded from (http://www.pmwin.net). Various interpolation options are available with the Modflow which are required to test for the accuracy for any particular area representation. We tried all interpolation methods available in the Modflow viz. Shepard's Inverse Distance Method, Akima's Bivariate Method, Renka's Triangulation Method and Kriging Method. We found out that Akima's Bivariate method and Kriging Method was working best to represent actual natural surface elevations of Gurgaon district. Figure 5.12 shows the surface contours of Gurgaon district along with locations of observation wells.

To understand the water budget of four blocks of Gurgaon district, available data from 1974 to 2008 was divided in to five year average periods. Thus total seven five year average periods were formed. Water budget is typically seen from June of any current period to the June of next period called as water year. We followed the same trend.

Within each water year, input value changes at two times viz. end of monsoon period and at the end of post-monsoon period. Therefore seven average five year scenarios were divided into 14 stress periods. Table 5.44 shows details of such periods.

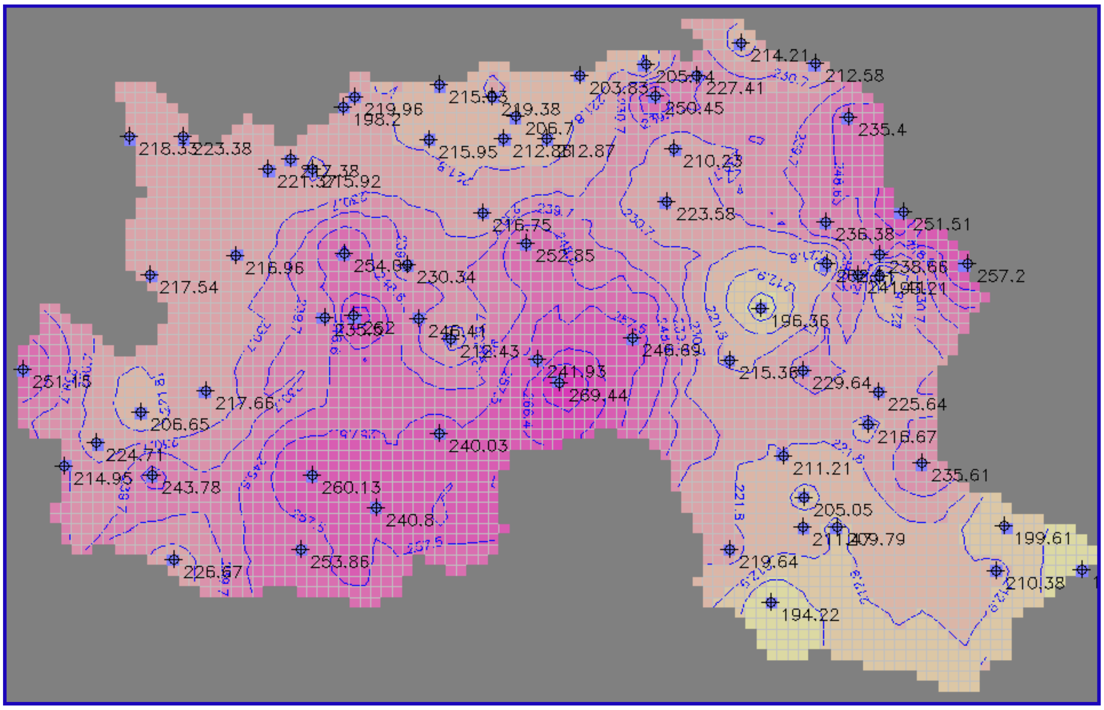


Figure 5.12 Natural surface elevations of observation wells and contours of Gurgaon district

Table 5.44 Information of actual periods, stress periods, total days and cumulative days in the model

Period	Season	Time Step	Total Days	Cumulative Total
1974-78	Monsoon	1	120	120
	Non-Monsoon	2	245	365
1979-83	Monsoon	3	120	485
	Non-Monsoon	4	245	730
1984-88	Monsoon	5	120	850
	Non-Monsoon	6	245	1095
1989-93	Monsoon	7	120	1215
	Non-Monsoon	8	245	1460
1994-98	Monsoon	9	120	1580
	Non-Monsoon	10	245	1825
1999-03	Monsoon	11	120	1945
	Non-Monsoon	12	245	2190
2004-08	Monsoon	13	120	2310
	Non-Monsoon	14	245	2555
Zone 1 =	**Gurgaon Block**			
Zone 2 =	**Sohna Block**			
Zone 3 =	**Farukhnagar Block**			
Zone 4 =	**Pataudi Block**			

Then input of model parameters storage coefficient (0.011) and effective porosity (0.16) were specified and transmissivity was specified as the model calculated value. Model is typically calibrated by testing various values of hydraulic conductivity and specific yield against the observed drawdown. Model should be calibrated using fewer observations and validated against large number of observations. According to previous results available with us (section 4.11) hydraulic conductivity values were varying from 1.03 to 5.5 m/day with average of 2.72 m/day. We were also having observation of 14 stress periods therefore observations at the end of four stress periods were used for calibration and results were tested against remaining observations. Observed values of drawdown have been calculated using actual observations of depth to water table observations (Table A-2 to A-5 in Appendix A). Using these tables, cumulative drawdown was calculated and same has been presented in Table A-6 to A-9 of Appendix A. Block wise average of all these drawdown have been used for analysis as draft of individual wells was not available. It can be seen from Table A-6 to A-9 that each average reading of drawdown for Gurgaon, Farukhnagar, Sohna and Pataudi blocks represents average of 18, 19, 23 and 10 observation wells. Following Table 5.45 shows observed drawdown for four blocks in Gurgaon District.

Table 5.45 Observed season-end drawdown for Gurgaon district for period 1974-2008 (meter)

Period	Month	Cum. Days	Gurgaon	Sohna	Pataudi	F'Nagar
1974-78	June	0	0.00	0.00	0.00	0.00
	Oct	120	-1.39	-1.42	-1.79	-1.33
1979-83	June	365	-0.19	0.50	1.24	0.32
	Oct	485	-0.81	0.31	0.74	0.01
1984-88	June	730	1.33	2.12	2.51	1.83
	Oct	850	0.68	1.21	2.39	1.15
1989-93	June	1095	4.07	2.97	7.43	4.39
	Oct	1215	3.49	2.35	7.05	4.11
1994-98	June	1460	5.49	3.34	8.94	4.33
	Oct	1580	4.29	2.10	8.19	3.23
1999-03	June	1825	8.80	3.96	9.45	6.17
	Oct	1945	8.62	3.72	9.33	5.93
2004-08	June	2190	9.16	5.34	12.63	8.00
	Oct	2310	9.28	5.66	12.29	9.91

Then model was calibrated to match the observed drawdown with model calculated drawdown using different values of hydraulic conductivity and specific yield. It was observed that model give best results when hydraulic conductivity was 1.22 m/s and specific yield for Farukhnagar, Gurgaon, Sohna and Pataudi blocks of 0.14, 0.09, 0.075 and 0.065, respectively. Specific yield is the ratio of volume of water in an aquifer which can be extracted by the force of gravity (or by pumping from wells) to the total volume of the saturated aquifer. It can be seen from calibrated values of specific yield that about 14% of water can be drained from Farukhnagar block, 9 % from Gurgaon block,7.5 % from Sohna block, followed by 6.5% of Pataudi block under the force of gravity.

Stress period of monsoon season was simulated for four times each at the end of four months and stress period of non-monsoon season was simulated for eight times each at the end of month. Table 5.46 shows the monthly drawdown and Table 5.47 shows the drawdown at the end of season for each stress period. Figure 5.13 also shows the monthly drawdown for four blocks in Gurgaon district for period 1974-2008.

Figure 5.14 shows the comparison of observed drawdown and Modflow model calculated drawdown. It can be seen from these graphs that there was excellent correlation between calculated and observed drawdown for all blocks in Gurgaon district. Correlation coefficient (R) of observed and calculated drawdown was 0.964, 0.919, 0.901 and 0.92 respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks. Coefficient of determination (R^2, shown on graph) was 0.93, 0.844, 0.812 and 0.846 respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks. It was revealed from these graphs that model predictions were very close to the reality and they were showing the good results of water balance for existing periods. Therefore formulated model can be used for future prediction also.

Table 5.46 Modflow calculated monthly drawdown for Gurgaon district for period 1974-2008

Days	Gurgaon	Sohna	Pataudi	F'Nagar
30	-0.21	-0.29	0.18	0.03
60	-0.45	-0.56	0.30	0.05
90	-0.70	-0.84	0.38	0.08
120	-0.98	-1.11	0.41	0.11
151	-0.68	-0.89	0.89	0.35
181	-0.39	-0.67	1.34	0.59
212	-0.12	-0.44	1.78	0.83
243	0.15	-0.22	2.20	1.06
273	0.41	0.01	2.62	1.30
304	0.66	0.24	3.03	1.53
334	0.91	0.47	3.43	1.77
365	1.15	0.70	3.82	2.00
395	0.85	0.48	3.65	2.00
425	0.54	0.27	3.46	1.99
455	0.23	0.06	3.28	1.99
485	-0.08	-0.15	3.10	1.99
516	0.08	0.01	3.35	2.16
546	0.25	0.16	3.60	2.33
577	0.41	0.32	3.85	2.50
608	0.58	0.47	4.10	2.67
638	0.74	0.63	4.35	2.84
669	0.90	0.79	4.59	3.01
699	1.06	0.95	4.84	3.18
730	1.22	1.11	5.08	3.35
760	1.04	0.94	5.02	3.38
790	0.85	0.77	4.95	3.40
820	0.66	0.60	4.88	3.43
850	0.47	0.43	4.81	3.45
881	0.68	0.62	5.12	3.64
911	0.90	0.82	5.44	3.82
942	1.11	1.01	5.76	4.01
973	1.32	1.21	6.08	4.19
1003	1.54	1.40	6.39	4.38
1034	1.75	1.60	6.71	4.56
1064	1.96	1.80	7.03	4.74
1095	2.18	2.00	7.35	4.93
1125	2.04	1.92	7.28	4.91
1155	1.90	1.84	7.22	4.90
1185	1.77	1.77	7.16	4.88
1215	1.63	1.69	7.10	4.86
1246	1.89	1.97	7.46	5.07
1276	2.15	2.24	7.82	5.28
1307	2.41	2.51	8.18	5.49
1338	2.67	2.79	8.55	5.70
1368	2.93	3.06	8.91	5.91

..........Continued

Table 5.46 Continued

Days	Gurgaon	Sohna	Pataudi	F'Nagar
1399	3.19	3.34	9.27	6.12
1429	3.45	3.62	9.63	6.32
1460	3.71	3.89	9.99	6.53
1490	3.63	3.73	9.86	6.56
1520	3.54	3.57	9.73	6.58
1550	3.46	3.41	9.60	6.61
1580	3.38	3.25	9.47	6.63
1611	3.76	3.55	9.86	6.86
1641	4.13	3.86	10.26	7.09
1672	4.51	4.16	10.66	7.32
1703	4.89	4.46	11.05	7.54
1733	5.27	4.77	11.45	7.77
1764	5.65	5.07	11.84	8.00
1794	6.03	5.38	12.24	8.22
1825	6.41	5.69	12.63	8.45
1855	6.56	5.63	12.65	8.55
1885	6.71	5.57	12.66	8.65
1915	6.86	5.52	12.67	8.75
1945	7.01	5.46	12.68	8.85
1976	7.16	5.44	12.70	8.96
2006	7.32	5.41	12.71	9.06
2037	7.47	5.39	12.72	9.16
2068	7.63	5.37	12.73	9.26
2098	7.78	5.34	12.75	9.36
2129	7.94	5.32	12.76	9.47
2159	8.09	5.30	12.77	9.57
2190	8.25	5.27	12.78	9.67
2220	8.49	5.31	12.75	9.77
2250	8.73	5.35	12.71	9.88
2280	8.97	5.38	12.67	9.99
2310	9.21	5.42	12.64	10.10
2341	9.84	5.82	13.12	10.37
2371	10.47	6.22	13.61	10.63
2402	11.10	6.63	14.10	10.90
2433	11.74	7.03	14.58	11.17
2463	12.37	7.43	15.07	11.43
2494	13.01	7.83	15.56	11.70
2524	13.64	8.24	16.04	11.96
2555	14.28	8.64	16.53	12.23

Table 5.47 Modflow calculated season-end drawdown for Gurgaon district for period 1974-2008 (meter)

Days	Gurgaon	Sohna	Pataudi	F'Nagar
120	-0.98	-1.11	0.41	0.11
365	1.15	0.70	3.82	2.00
485	-0.08	-0.15	3.10	1.99
730	1.22	1.11	5.08	3.35
850	0.47	0.43	4.81	3.45
1095	2.18	2.00	7.35	4.93
1215	1.63	1.69	7.10	4.86
1460	3.71	3.89	9.99	6.53
1580	3.38	3.25	9.47	6.63
1825	6.41	5.69	12.63	8.45
1945	7.01	5.46	12.68	8.85
2190	8.25	5.27	12.78	9.67
2310	9.21	5.42	12.64	10.10
2555	14.28	8.64	16.53	12.23

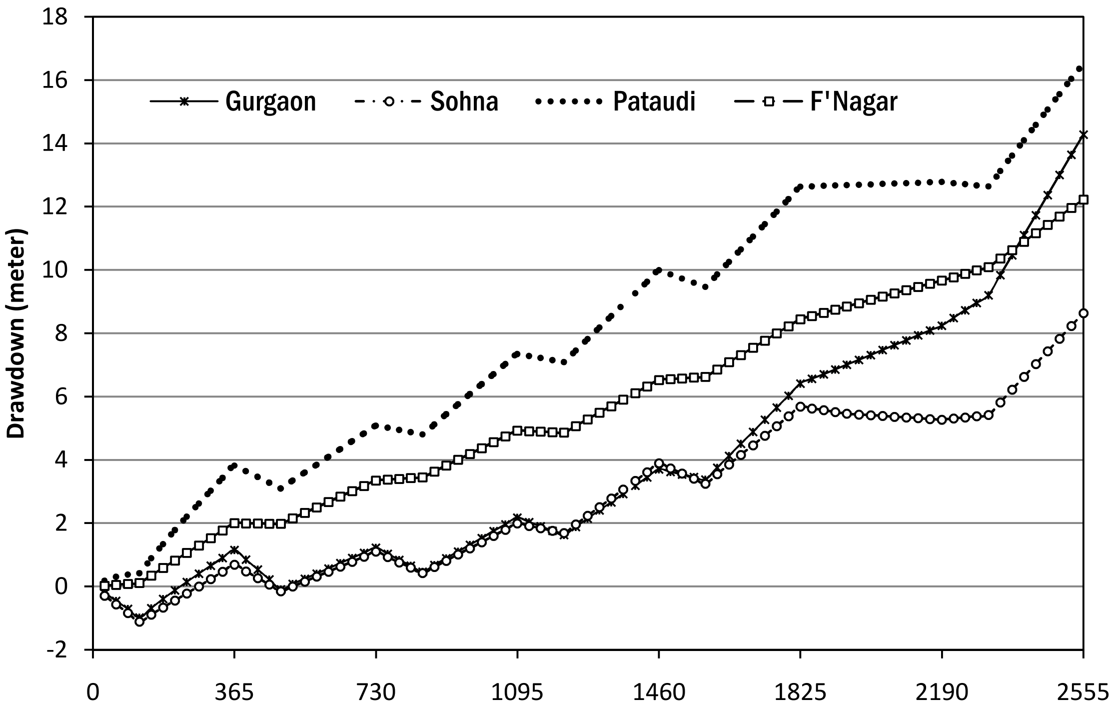


Figure 5.13 Modflow calculated monthly drawdown for four blocks in Gurgaon district for period 1974-2008

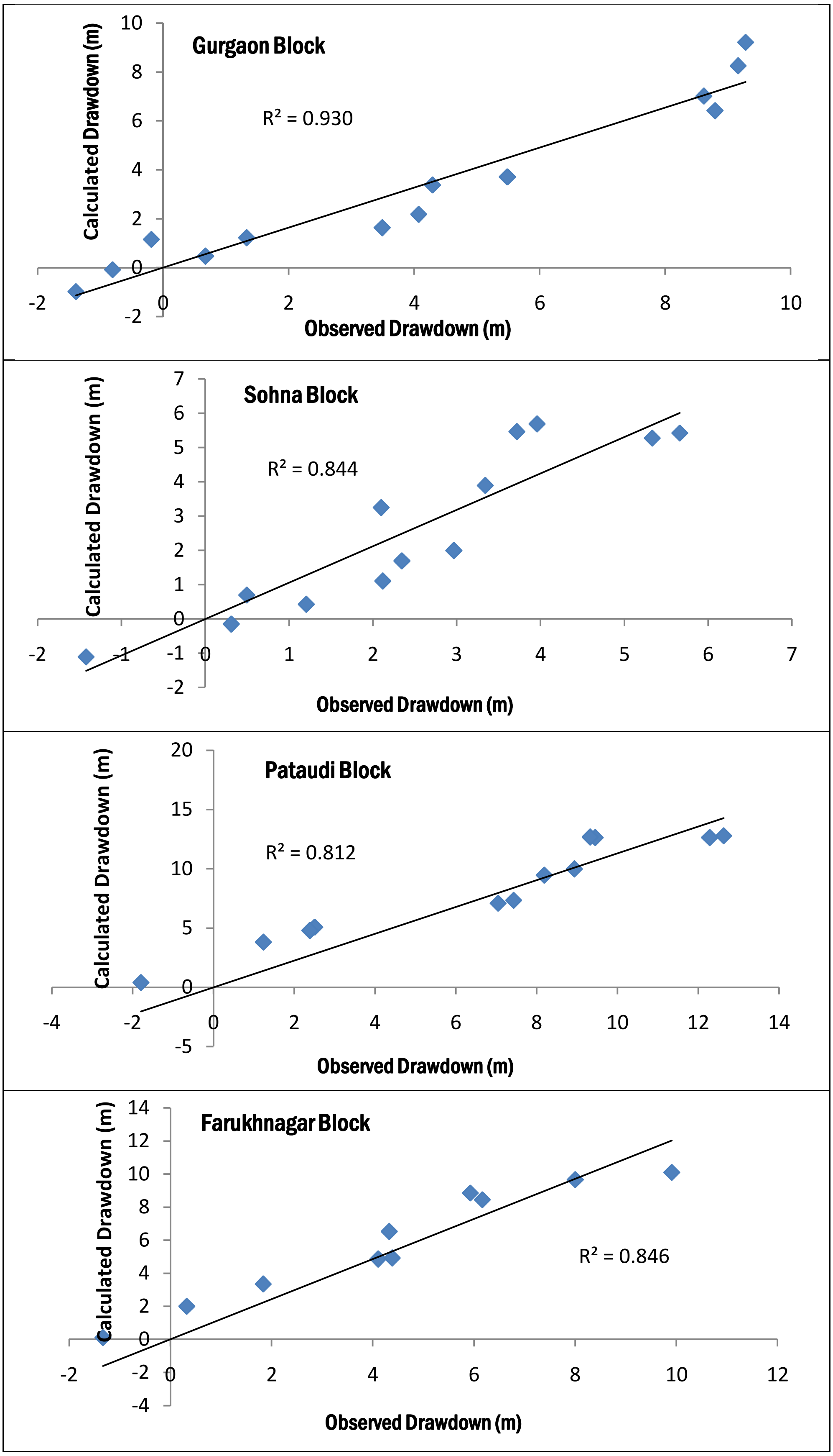


Figure 5.14 Comparison of observed and calculated drawdown for calibration and validation of Modflow model of Gurgaon District

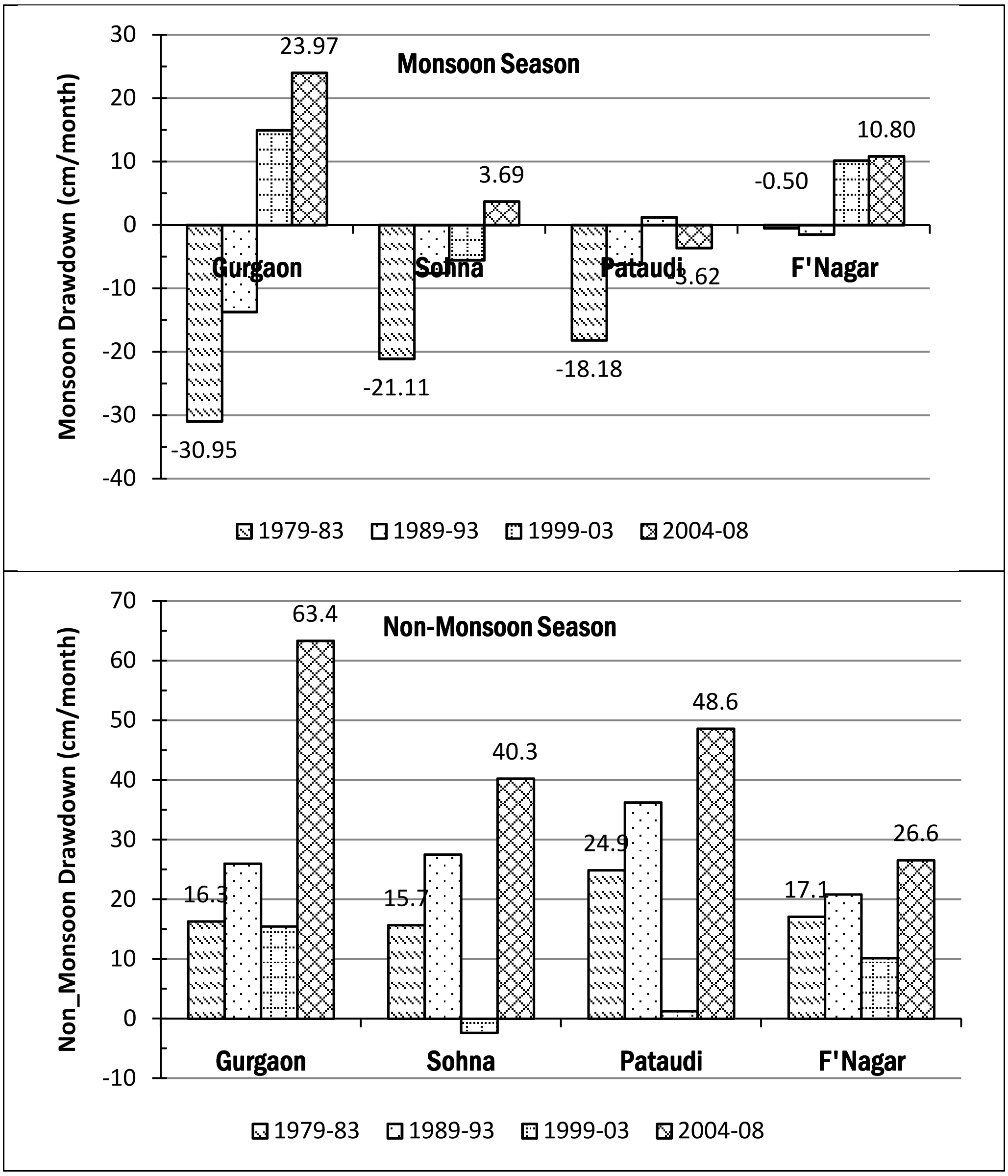


Figure 5.15 Comparison of monthly drawdown for 10 year interval for blocks in Gurgaon District

It was seen from the Table 5.46 that there was maximum drawdown for Pataudi block followed by Gurgaon block, followed by Farukhnagar and Sohna blocks. But close observation of Figure 5.13 reveals that Gurgaon and Sohna blocks had lowest drawdown till end of 1994-98 monsoon seasons. After this drawdown of Gurgaon blocks was increasing considerably till the end of 2004-08 period. Figure 5.15 shows comparison of monthly drawdown (cm/month) for 10 year interval for blocks in Gurgaon district for monsoon and non-monsoon periods. It can be seen from Figure 5.14 that in monsoon season water levels were increasing by almost 31 cm per month in 1974-78 which in 2004-08 were decreasing by almost 24 cm. For Sohna block water levels in monsoon were increasing (at 1974-78) by almost 21 cm per month which were found out to be decreasing (at 2004-08) by 4 cm per month. For Pataudi block rate of increase in water level was observed to be decreasing from 18.2 cm/month in period 1974-78 to 3.62 cm/month in period 2004-08. For Farukhnagar block water levels were increasing at slow pace of 0.5 cm/month in 1974-78 while water level was decreasing by 10.8 cm in 2004-08. Same situation was observed in non-monsoon season and rate of water level decrease was from 16.3 to 63.4 cm/month for Gurgaon block, 15.7 to 40.3 cm/month for Sohna block, 24.9 to 48.6 cm/month for Pataudi block and 17.1 to 26.6 cm/month for Farukhnagar block.

5.9 Five Year Average Water Balance for Gurgaon District for Period 1974-2008

Using calibrated and validated model as well as pumping and recharge inputs (shown in section 5.10), block wise water balance of Gurgaon district was carried out. Appendix – B shows the results of water balance for entire Gurgaon district. Using these results and water balance tool in the Modflow, block wise water balance was worked out and same has been presented in Table 5.48 to 5.61. To analyze these block wise water balances thoroughly, tables of results of water balance of block corresponding to horizontal exchange of the block were prepared. Table 5.62 to 5.69 represents the water balance and horizontal exchange of four blocks.

Table 5.48 Water Balance at the End of 1974-78 Monsoon

TIME STEP 4 OF STRESS PERIOD 1

==

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

==

ZONE 1

FLOW TERM		IN	OUT	IN-OUT
STORAGE		11163.28	327974.00	-316810.72
HORIZ. EXCHANGE		2511.55	16777.46	-14265.91
RECHARGE		331071.22	0.00	331071.22
SUM OF LAYER		344746.06	344751.47	-5.41
DISCREPANCY	[%]	0		

ZONE 2

STORAGE		3801.94	183419.75	-179617.81
HORIZ. EXCHANGE		9267.30	2329.16	6938.14
RECHARGE		172683.69	0.00	172683.69
SUM OF LAYER		185752.92	185748.91	4.02
DISCREPANCY	[%]	0		

ZONE 3

STORAGE		19518.79	83437.84	-63919.05
HORIZ. EXCHANGE		9734.34	1124.12	8610.22
RECHARGE		55314.73	0.00	55314.73
SUM OF LAYER		84567.86	84561.95	5.91
DISCREPANCY	[%]		0.01	

ZONE 4

STORAGE		7965.27	68053.79	-60088.52
HORIZ. EXCHANGE		1962.94	3245.40	-1282.45
RECHARGE		61374.03	0.00	61374.03
SUM OF LAYER		71302.25	71299.19	3.06
DISCREPANCY	[%]	0		

==

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

==

FLOW TERM		IN	OUT	IN-OUT
STORAGE		42449.27	662885.06	-620435.81
WELLS		0.00	0.00	0.00
RECHARGE		620424.06	0.00	620424.06
SUM		**662873.31**	**662885.06**	**-11.75**
DISCREPANCY	[%]	0		

Table 5.49 Water Balance at the End of 1974-78 Non-Monsoon

TIME STEP 8 OF STRESS PERIOD 2

==

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

==

ZONE 1

FLOW TERM		IN	OUT	IN-OUT
STORAGE		284787.88	5228.00	279559.88
HORIZ. EXCHANGE		2053.18	12923.39	-10870.22
WELLS		0.00	268689.72	-268689.72
RECHARGE		0.00	0.00	0.00
SUM OF THE LAYER		286841.06	286841.13	-0.06
DISCREPANCY	[%]	0		

ZONE 2

STORAGE		227804.58	239.03	227565.55
HORIZ. EXCHANGE		7493.70	1629.70	5864.01
WELLS		0.00	233717.08	-233717.08
RECHARGE		289.78	0.00	289.78
SUM OF THE LAYER		235588.06	235585.81	2.25
DISCREPANCY	[%]	0		

ZONE 3

STORAGE		227806.78	456.10	227350.69
HORIZ. EXCHANGE		6022.63	2004.26	4018.38
WELLS		0.00	231373.13	-231373.13
RECHARGE		0.00	0.00	0.00
SUM OF THE LAYER		233829.42	233833.48	-4.06
DISCREPANCY	[%]	0		

ZONE 4

STORAGE		204820.86	0.00	204820.86
HORIZ. EXCHANGE		2537.91	1550.08	987.84
WELLS		0.00	205809.20	-205809.20
RECHARGE		0.00	0.00	0.00
SUM OF THE LAYER		207358.78	207359.28	-0.50
DISCREPANCY	[%]	0		

==

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

==

FLOW TERM		IN	OUT	IN-OUT
STORAGE		945220.06	5923.13	939296.94
WELLS		0.00	939615.63	-939615.63
RECHARGE		289.78	0.00	289.78
SUM		**945509.81**	**945538.75**	**-28.94**
DISCREPANCY	[%]	0		

Table 5.50 Water Balance at The End of 1979-83 Monsoon

TIME STEP 4 OF STRESS PERIOD 3

===

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

===

ZONE 1

FLOW TERM	**IN**	**OUT**	**IN-OUT**
STORAGE	818.93	278303.22	-277484.28
HORIZ. EXCHANGE	1560.87	14701.37	-13140.50
WELLS	0.00	0.00	0.00
RECHARGE	290627.03	0.00	290627.03
SUM OF THE LAYER	293006.84	293004.56	2.28
DISCREPANCY	[%]	0	

ZONE 2

STORAGE	388.00	144774.27	-144386.27
HORIZ. EXCHANGE	7909.61	1400.00	6509.62
WELLS	0.00	0.00	0.00
RECHARGE	137880.95	0.00	137880.95
SUM OF THE LAYER	146178.56	146174.27	4.30
DISCREPANCY	[%]	0	

ZONE 3

STORAGE	4111.89	106151.25	-102039.36
HORIZ. EXCHANGE	8181.60	1122.62	7058.98
WELLS	0.00	0.00	0.00
RECHARGE	94974.83	0.00	94974.83
SUM OF THE LAYER	107268.32	107273.87	-5.55
DISCREPANCY	[%]	-0.01	

ZONE 4

STORAGE	88.77	123819.39	-123730.63
HORIZ. EXCHANGE	1904.02	2332.12	-428.10
WELLS	0.00	0.00	0.00
RECHARGE	124157.34	0.00	124157.34
SUM OF THE LAYER	126150.12	126151.51	-1.39
DISCREPANCY	[%]	0	

===

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

===

FLOW TERM	**IN**	**OUT**	**IN-OUT**
STORAGE	5407.59	653049.13	-647641.56
WELLS	0.00	0.00	0.00
RECHARGE	647645.75	0.00	647645.75
SUM	**653053.31**	**653049.13**	**4.19**
DISCREPANCY	[%]	0	

Table 5.51 Water Balance at the End of 1979-83 Non-Monsoon

TIME STEP 8 OF STRESS PERIOD 4

===

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

===

ZONE 1

FLOW TERM		IN	OUT	IN-OUT
STORAGE		215515.89	3320.13	212195.77
HORIZ. EXCHANGE		1281.17	11872.16	-10590.99
WELLS		0.00	201598.05	-201598.05
RECHARGE		0.00	0.00	0.00
SUM OF THE LAYER		216797.06	216790.34	6.72
DISCREPANCY	[%]		0	

ZONE 2

STORAGE		160713.34	161.49	160551.84
HORIZ. EXCHANGE		6931.75	934.40	5997.35
WELLS		0.00	166545.34	-166545.34
RECHARGE		0.00	0.00	0.00
SUM OF THE LAYER		167645.09	167641.23	3.86
DISCREPANCY	[%]		0	

ZONE 3

STORAGE		148323.94	515.91	147808.02
HORIZ. EXCHANGE		5484.05	1729.30	3754.75
WELLS		0.00	151547.45	-151547.45
RECHARGE		0.00	0.00	0.00
SUM OF THE LAYER		153808.00	153792.67	15.33
DISCREPANCY	[%]		0.01	

ZONE 4

STORAGE		131253.84	0.00	131253.84
HORIZ. EXCHANGE		2221.02	1382.13	838.89
WELLS		0.00	132091.55	-132091.55
RECHARGE		0.00	0.00	0.00
SUM OF THE LAYER		133474.86	133473.67	1.19
DISCREPANCY	[%]		0	

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WATER BUDGET OF THE WHOLE MODEL DOMAIN:

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FLOW TERM		IN	OUT	IN-OUT
STORAGE		655807.50	3997.54	651809.94
WELLS		0.00	651766.94	-651766.94
RECHARGE		0.00	0.00	0.00
SUM		**655807.50**	**655764.50**	**43.00**
DISCREPANCY	[%]	0.01		

Table 5.52 Water Balance at The End of 1984-88 Monsoon

TIME STEP 4 OF STRESS PERIOD 5

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	**IN**	**OUT**	**IN-OUT**
STORAGE	830.19	143786.87	-142956.69
HORIZ. EXCHANGE	1039.72	12503.68	-11463.96
WELLS	0.00	0.00	0.00
RECHARGE	154419.42	0.00	154419.42
SUM OF THE LAYER	156289.33	156290.56	-1.23

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	72.98	116884.40	-116811.41
HORIZ. EXCHANGE	6822.40	889.69	5932.71
WELLS	0.00	0.00	0.00
RECHARGE	110890.70	0.00	110890.70
SUM OF THE LAYER	117786.09	117774.09	11.99

DISCREPANCY [%] 0.01

ZONE 3 IN LAYER 1

STORAGE	5104.36	55670.30	-50565.94
HORIZ. EXCHANGE	6628.17	1262.50	5365.66
WELLS	0.00	0.00	0.00
RECHARGE	45180.91	0.00	45180.91
SUM OF THE LAYER	56913.44	56932.81	-19.36

DISCREPANCY [%] -0.03

ZONE 4 IN LAYER 1

STORAGE	1052.64	51181.77	-50129.13
HORIZ. EXCHANGE	1921.83	1756.24	165.59
WELLS	0.00	0.00	0.00
RECHARGE	49970.11	0.00	49970.11
SUM OF THE LAYER	52944.58	52938.00	6.57

DISCREPANCY [%] 0.01

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	**IN**	**OUT**	**IN-OUT**
STORAGE	7060.18	367522.97	-360462.78
WELLS	0.00	0.00	0.00
RECHARGE	360450.47	0.00	360450.47
SUM	**367510.66**	**367522.97**	**-12.31**

DISCREPANCY [%] 0.00

Table 5.53 Water Balance at the End of 1984-88 Non-Monsoon

TIME STEP 8 OF STRESS PERIOD 6

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	**IN**	**OUT**	**IN-OUT**
STORAGE	264990.06	1018.69	263971.38
HORIZ. EXCHANGE	1006.78	10151.75	-9144.96
WELLS	0.00	254825.92	-254825.92
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	265996.84	265996.34	0.50

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	186904.20	49.93	186854.28
HORIZ. EXCHANGE	6176.77	595.87	5580.90
WELLS	0.00	192435.63	-192435.63
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	193080.97	193081.42	-0.45

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

STORAGE	176119.34	14.73	176104.61
HORIZ. EXCHANGE	3966.42	2267.37	1699.05
WELLS	0.00	177807.08	-177807.08
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	180085.77	180089.19	-3.42

DISCREPANCY [%] 0.00

ZONE 4 IN LAYER 1

STORAGE	173402.20	0.00	173402.20
HORIZ. EXCHANGE	2645.55	780.53	1865.02
WELLS	0.00	175266.75	-175266.75
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	176047.75	176047.28	0.47

DISCREPANCY [%] 0.00

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	**IN**	**OUT**	**IN-OUT**
STORAGE	801414.56	1083.35	800331.19
WELLS	0.00	800295.94	-800295.94
RECHARGE	0.00	0.00	0.00
SUM	**801414.56**	**801379.31**	**35.25**

DISCREPANCY [%] 0.00

Table 5.54 Water Balance at The End of 1989-93 Monsoon

TIME STEP 4 OF STRESS PERIOD 7

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	999.81	94661.66	-93661.85
HORIZ. EXCHANGE	781.78	10671.37	-9889.59
WELLS	0.00	0.00	0.00
RECHARGE	103545.94	0.00	103545.94
SUM OF THE LAYER	105327.52	105333.02	-5.50

DISCREPANCY [%] -0.01

ZONE 2 IN LAYER 1

STORAGE	1320.85	43934.67	-42613.82
HORIZ. EXCHANGE	6432.75	529.12	5903.63
WELLS	0.00	0.00	0.00
RECHARGE	36709.95	0.00	36709.95
SUM OF THE LAYER	44463.54	44463.79	-0.24

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

STORAGE	1218.02	97637.31	-96419.29
HORIZ. EXCHANGE	4486.12	1731.42	2754.70
WELLS	0.00	0.00	0.00
RECHARGE	93652.66	0.00	93652.66
SUM OF THE LAYER	99356.81	99368.73	-11.93

DISCREPANCY [%] -0.01

ZONE 4 IN LAYER 1

STORAGE	400.89	46245.41	-45844.52
HORIZ. EXCHANGE	2224.86	993.59	1231.26
WELLS	0.00	0.00	0.00
RECHARGE	44613.97	0.00	44613.97
SUM OF THE LAYER	47239.72	47239.00	0.71

DISCREPANCY [%] 0.00

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	3939.57	282479.59	-278540.03
WELLS	0.00	0.00	0.00
RECHARGE	278532.88	0.00	278532.88
SUM	**282472.44**	**282479.59**	**-7.16**

DISCREPANCY [%] 0.00

Table 5.55 Water Balance at the End of 1989-93 Non-Monsoon

TIME STEP 8 OF STRESS PERIOD 8

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WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

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ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	306031.13	62.07	305969.06
HORIZ. EXCHANGE	922.17	9051.79	-8129.62
WELLS	0.00	297836.25	-297836.25
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	306953.28	306950.09	3.19

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	247424.94	0.00	247424.94
HORIZ. EXCHANGE	6103.09	303.70	5799.39
WELLS	0.00	253227.38	-253227.38
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	253528.03	253531.08	-3.05

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

STORAGE	218535.58	0.00	218535.58
HORIZ. EXCHANGE	2578.72	2996.94	-418.23
WELLS	0.00	218093.97	-218093.97
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	221114.30	221090.91	23.39

DISCREPANCY [%] 0.01

ZONE 4 IN LAYER 1

STORAGE	198833.56	0.00	198833.56
HORIZ. EXCHANGE	3085.29	336.83	2748.46
WELLS	0.00	201581.47	-201581.47
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	201918.84	201918.30	0.55

DISCREPANCY [%] 0.00

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WATER BUDGET OF THE WHOLE MODEL DOMAIN:

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FLOW TERM	IN	OUT	IN-OUT
STORAGE	970825.38	62.07	970763.31
WELLS	0.00	970719.31	-970719.31
RECHARGE	0.00	0.00	0.00
SUM	**970825.38**	**970781.38**	**44.00**

DISCREPANCY [%] 0.00

Table 5.56 Water Balance at the End of 1994-98 Monsoon

TIME STEP 4 OF STRESS PERIOD 9

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WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

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ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	3429.45	47778.43	-44348.98
HORIZ. EXCHANGE	764.35	8712.53	-7948.18
WELLS	0.00	0.00	0.00
RECHARGE	52295.88	0.00	52295.88
SUM OF THE LAYER	56489.68	56490.95	-1.28

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	0.00	116862.88	-116862.88
HORIZ. EXCHANGE	5499.08	359.38	5139.70
WELLS	0.00	0.00	0.00
RECHARGE	111734.05	0.00	111734.05
SUM OF THE LAYER	117233.13	117222.26	10.88

DISCREPANCY [%] 0.01

ZONE 3 IN LAYER 1

STORAGE	4305.76	35252.03	-30946.27
HORIZ. EXCHANGE	3406.45	1841.25	1565.21
WELLS	0.00	0.00	0.00
RECHARGE	29363.52	0.00	29363.52
SUM OF THE LAYER	37075.73	37093.28	-17.54

DISCREPANCY [%] -0.05

ZONE 4 IN LAYER 1

STORAGE	30.50	85709.83	-85679.34
HORIZ. EXCHANGE	2083.61	840.34	1243.27
WELLS	0.00	0.00	0.00
RECHARGE	84432.38	0.00	84432.38
SUM OF THE LAYER	86546.48	86550.16	-3.69

DISCREPANCY [%] 0.00

==

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

==

FLOW TERM	IN	OUT	IN-OUT
STORAGE	7765.71	285603.56	-277837.84
WELLS	0.00	0.00	0.00
RECHARGE	277826.03	0.00	277826.03
SUM	**285591.75**	**285603.56**	**-11.81**

DISCREPANCY [%] 0.00

Table 5.57 Water Balance at The End of 1994-98 Non-Monsoon

TIME STEP 8 OF STRESS PERIOD 10

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	418159.78	0.00	418159.78
HORIZ. EXCHANGE	1520.10	6186.26	-4666.16
WELLS	0.00	413484.06	-413484.06
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	419679.88	419670.31	9.56

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	270546.81	0.00	270546.81
HORIZ. EXCHANGE	4602.55	313.62	4288.93
WELLS	0.00	274837.53	-274837.53
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	275149.34	275151.16	-1.81

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

STORAGE	255201.06	0.00	255201.06
HORIZ. EXCHANGE	1284.72	3700.00	-2415.28
WELLS	0.00	252772.08	-252772.08
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	256485.78	256472.08	13.70

DISCREPANCY [%] 0.01

ZONE 4 IN LAYER 1

STORAGE	218170.80	0.00	218170.80
HORIZ. EXCHANGE	3051.58	259.06	2792.51
WELLS	0.00	220963.72	-220963.72
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	221222.38	221222.78	-0.41

DISCREPANCY [%] 0.00

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	1162078.80	0.00	1162078.80
WELLS	0.00	1162006.10	-1162006.10
RECHARGE	0.00	0.00	0.00
SUM	**1162078.80**	**1162006.10**	**72.63**

DISCREPANCY [%] 0.01

Table 5.58 Water Balance at The End of 1999-03 Monsoon

TIME STEP 4 OF STRESS PERIOD 11

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WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

==

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	184383.36	4.51	184378.86
HORIZ. EXCHANGE	1726.26	4974.42	-3248.16
WELLS	0.00	181131.17	-181131.17
RECHARGE	0.78	0.00	0.78
SUM OF THE LAYER	186110.39	186110.09	0.30

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	1794.47	30294.45	-28499.98
HORIZ. EXCHANGE	3643.12	500.30	3142.82
WELLS	0.00	1028.64	-1028.64
RECHARGE	26382.44	0.00	26382.44
SUM OF THE LAYER	31820.03	31823.38	-3.35

DISCREPANCY [%] -0.01

ZONE 3 IN LAYER 1

STORAGE	87232.99	184.85	87048.14
HORIZ. EXCHANGE	1359.37	2908.58	-1549.21
WELLS	0.00	85842.26	-85842.26
RECHARGE	361.07	0.00	361.07
SUM OF THE LAYER	88953.43	88935.69	17.74

DISCREPANCY [%] 0.02

ZONE 4 IN LAYER 1

STORAGE	5938.33	7127.84	-1189.51
HORIZ. EXCHANGE	2174.06	519.52	1654.54
WELLS	0.00	464.01	-464.01
RECHARGE	1.95	0.00	1.95
SUM OF THE LAYER	8114.34	8111.37	2.98

DISCREPANCY [%] 0.04

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WATER BUDGET OF THE WHOLE MODEL DOMAIN:

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FLOW TERM	IN	OUT	IN-OUT
STORAGE	279349.44	37611.68	241737.77
WELLS	0.00	268463.53	-268463.53
RECHARGE	26746.25	0.00	26746.25
SUM	**306095.69**	**306075.22**	**20.47**

DISCREPANCY [%] 0.01

Table 5.59 Water Balance at The End of 1999-03 Non-Monsoon

TIME STEP 8 OF STRESS PERIOD 12

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	182607.28	0.00	182607.28
HORIZ. EXCHANGE	2198.50	3672.50	-1474.01
WELLS	0.00	181131.17	-181131.17
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	184805.78	184803.67	2.11

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	7276.87	8172.00	-895.13
HORIZ. EXCHANGE	2752.77	831.32	1921.44
WELLS	0.00	1028.64	-1028.64
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	10029.64	10031.96	-2.32

DISCREPANCY [%] -0.02

ZONE 3 IN LAYER 1

STORAGE	86836.76	76.68	86760.08
HORIZ. EXCHANGE	1502.91	2401.34	-898.43
WELLS	0.00	85842.26	-85842.26
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	88339.67	88320.27	19.40

DISCREPANCY [%] 0.02

ZONE 4 IN LAYER 1

STORAGE	5875.21	5862.61	12.61
HORIZ. EXCHANGE	1440.17	989.18	450.99
WELLS	0.00	464.01	-464.01
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	7315.38	7315.80	-0.41

DISCREPANCY [%] -0.01

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	282596.75	14111.27	268485.47
WELLS	0.00	268463.53	-268463.53
RECHARGE	0.00	0.00	0.00
SUM	**282596.75**	**282574.81**	**21.94**

DISCREPANCY [%] 0.01

Table 5.60 Water Balance at the End of 2004-08 Monsoon

TIME STEP 4 OF STRESS PERIOD 13

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WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

==

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	269932.59	0.00	269932.59
HORIZ. EXCHANGE	2801.30	2884.58	-83.28
WELLS	0.00	269847.94	-269847.94
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	272733.88	272732.50	1.38

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	49724.37	171.14	49553.23
HORIZ. EXCHANGE	2222.25	1008.18	1214.07
WELLS	0.00	50766.68	-50766.68
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	51946.61	51946.00	0.62

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

STORAGE	102042.05	0.00	102042.05
HORIZ. EXCHANGE	1735.16	2608.47	-873.32
WELLS	0.00	101282.85	-101282.85
RECHARGE	101.96	0.00	101.96
SUM OF THE LAYER	103879.16	103891.32	-12.16

DISCREPANCY [%] -0.01

ZONE 4 IN LAYER 1

STORAGE	1054.18	27978.53	-26924.35
HORIZ. EXCHANGE	1156.79	1414.26	-257.47
WELLS	0.00	1056.27	-1056.27
RECHARGE	28244.24	0.00	28244.24
SUM OF THE LAYER	30455.21	30449.06	6.14

DISCREPANCY [%] 0.02

==

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

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FLOW TERM	IN	OUT	IN-OUT
STORAGE	422753.25	28149.67	394603.56
WELLS	0.00	422941.53	-422941.53
RECHARGE	28346.20	0.00	28346.20
SUM	**451099.44**	**451091.19**	**8.25**

DISCREPANCY [%] 0.00

Table 5.61 Water Balance at the End of 2004-08 Non-Monsoon

TIME STEP 8 OF STRESS PERIOD 14

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WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

==

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	655794.88	0.00	655794.88
HORIZ. EXCHANGE	6045.71	1784.28	4261.43
WELLS	0.00	660056.63	-660056.63
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	661840.56	661840.88	-0.31

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	351930.47	0.00	351930.47
HORIZ. EXCHANGE	1626.12	1342.77	283.35
WELLS	0.00	352210.72	-352210.72
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	353556.59	353553.50	3.09

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

STORAGE	325588.03	0.00	325588.03
HORIZ. EXCHANGE	133.97	6887.69	-6753.73
WELLS	0.00	318828.09	-318828.09
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	325722.00	325715.78	6.22

DISCREPANCY [%] 0.00

ZONE 4 IN LAYER 1

STORAGE	271622.44	0.00	271622.44
HORIZ. EXCHANGE	2568.03	359.09	2208.94
WELLS	0.00	273831.66	-273831.66
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	274190.47	274190.75	-0.28

DISCREPANCY [%] 0.00

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WATER BUDGET OF THE WHOLE MODEL DOMAIN:

==

FLOW TERM	IN	OUT	IN-OUT
STORAGE	1604937.90	0.00	1604937.90
WELLS	0.00	1604972.30	-1604972.30
RECHARGE	0.00	0.00	0.00
SUM	**1604937.90**	**1604972.30**	**-34.38**

DISCREPANCY [%] 0.00

Table 5.62 Water balance for Gurgaon block (m^3/day)

Period	Recharge	Pumping	Balance
Monsoon season			
1974-78	344746.06	344751.47	-5.41
1979-83	293006.84	293004.56	2.28
1984-88	156289.33	156290.56	-1.23
1989-93	105327.52	105333.02	-5.50
1994-98	56489.68	56490.95	-1.28
1999-03	186110.39	186110.09	0.30
2004-08	272733.88	272732.50	1.38
Non-Monsoon season			
1974-78	286841.06	286841.13	-0.06
1979-83	216797.06	216790.34	6.72
1984-88	265996.84	265996.34	0.50
1989-93	306953.28	306950.09	3.19
1994-98	419679.88	419670.31	9.56
1999-03	184805.78	184803.67	2.11
2004-08	661840.56	661840.88	-0.31

Table 5.63 Horizontal exchange for Gurgaon block (m^3/day)

Period	Received	Given Out	Balance
Monsoon season			
1974-78	2511.55	16777.46	-14265.91
1979-83	1560.87	14701.37	-13140.50
1984-88	1039.72	12503.68	-11463.96
1989-93	781.78	10671.37	-9889.59
1994-98	764.35	8712.53	-7948.18
1999-03	1726.26	4974.42	-3248.16
2004-08	2801.30	2884.58	-83.28
Non-Monsoon season			
1974-78	2053.18	12923.39	-10870.22
1979-83	1281.17	11872.16	-10590.99
1984-88	1006.78	10151.75	-9144.96
1989-93	922.17	9051.79	-8129.62
1994-98	1520.10	6186.26	-4666.16
1999-03	2198.50	3672.50	-1474.01
2004-08	6045.71	1784.28	4261.43

5.9.1 Water Balance of Gurgaon Block

It can be seen from Table 5.62 that in monsoon season there was almost negative or very little balance water remained in Gurgaon block. Compared to this non-monsoon season was having little water balanced after pumping. It was observed that huge recharge quantities were generated in Gurgaon block based on the rainfall amount. Irrespective to this, there was huge demand for water also. For all periods under analysis, it was seen that recharge and pumping quantities were comparable with each other.

It was revealed from Table 5.63 that there was huge water exchange going out from the Gurgaon block. Gurgaon block was observed to receive water quantities to the tune 764 to 2801 m^3/day depending upon the rainfall in monsoon season. In comparison to this water given out of block were of high order of 4974 to 16777 m^3/day. In non-monsoon season same situation was observed. Gurgaon is situated at higher elevation level (average 241.5 m msl) compared to 220 m average mean sea level of the district. Gurgaon block is bounded by hills on the east side, and south west side. Therefore huge amount of horizontal exchange was seen to occur from Gurgaon block towards Sohna block and upper west side of Farukhnagar side. It can be clearly observed from the water balance of Gurgaon district that availability of water in Gurgaon block was dependent on the horizontal exchange of the water quantities. It was found out from the given out horizontal water quantities that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were reducing irrespective of recharge quantities. Gurgaon block was donating water quantity of 16777 m^3/day in 1974-78. Monsoon period was observed to donate meager 2884 m^3/day water in 2004-08. In non-monsoon season, Gurgaon block was observed to give 12923 m^3/day water in 1974-78 and it was found to give very little 1784 m^3/day water in 2004-08.

Table 5.64 Water balance for Sohna block (m³/day)

Period	Recharge	Pumping	Balance
Monsoon season			
1974-78	185752.92	185748.91	4.02
1979-83	146178.56	146174.27	4.30
1984-88	117786.09	117774.09	11.99
1989-93	44463.54	44463.79	-0.24
1994-98	117233.13	117222.26	10.88
1999-03	31820.03	31823.38	-3.35
2004-08	51946.61	51946.00	0.62
Non-Monsoon season			
1974-78	235588.06	235585.81	2.25
1979-83	167645.09	167641.23	3.86
1984-88	193080.97	193081.42	-0.45
1989-93	253528.03	253531.08	-3.05
1994-98	275149.34	275151.16	-1.81
1999-03	10029.64	10031.96	-2.32
2004-08	353556.59	353553.50	3.09

Table 5.65 Horizontal exchange for Sohna block (m³/day)

Period	Received	Given Out	Balance
Monsoon season			
1974-78	9267.30	2329.16	6938.14
1979-83	7909.61	1400.00	6509.62
1984-88	6822.40	889.69	5932.71
1989-93	6432.75	529.12	5903.63
1994-98	5499.08	359.38	5139.70
1999-03	3643.12	500.30	3142.82
2004-08	2222.25	1008.18	1214.07
Non-Monsoon season			
1974-78	7493.70	1629.70	5864.01
1979-83	6931.75	934.40	5997.35
1984-88	6176.77	595.87	5580.90
1989-93	6103.09	303.70	5799.39
1994-98	4602.55	313.62	4288.93
1999-03	2752.77	831.32	1921.44
2004-08	1626.12	1342.77	283.35

5.9.2 Water Balance of Sohna Block

It can be seen from Table 5.64 that in monsoon season there was almost very little negative or positive balance water remained in Sohna block like Gurgaon block. Compared to this non-monsoon season was having little water deficit after pumping. It was observed that medium recharge quantities were generated in Sohna block based on the rainfall amount. There was huge demand for water irrespective to recharge quantities. For all periods under analysis, it was seen that recharge and pumping quantities were closely tracking each other.

It was revealed from Table 5.65 that there was huge water exchange entering from the Gurgaon block. Sohna block was observed to receive water quantities 2222 to 9267 m^3/day depending upon the rainfall in monsoon season. In comparison to this water quantities received in the block were 1626 to 7493.7 m^3/day, in non-monsoon season. Sohna is situated at the lowest elevation level (block average 216 m msl) compared to 220 m average mean sea level of the district. Sonna block is bounded by hills on the north east side, and south west side. Also, there were outlets for ground water on south-east and south side. Therefore huge amount of horizontal water was seen to come in from Gurgaon and Farukhnagar blocks towards Sohna block. It can be clearly observed from the water balance of Sohna block that water balance was dependent on the horizontal exchange of the water quantities received from other blocks. It was found out from the received horizontal water quantities in Sohna block that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, received quantities were reducing irrespective of recharge quantities. Sohna block was receiving water quantity of 9267 m^3/day in 1974-78 monsoon period was observed to receive 2222 m^3/day water in 2004-08 monsoon. In non-monsoon season, Sohna block was observed to receive 7493 m^3/day in 1974-78 was found to take very little 1626 m^3/day in 2004-08.

Table 5.66 Water balance for Farukhnagar block (m^3/day)

Period	Recharge	Pumping	Balance
Monsoon season			
1974-78	84567.86	84561.95	5.91
1979-83	107268.32	107273.87	-5.55
1984-88	56913.44	56932.81	-19.36
1989-93	99356.81	99368.73	-11.93
1994-98	37075.73	37093.28	-17.54
1999-03	88953.43	88935.69	17.74
2004-08	103879.16	103891.32	-12.16
Non-Monsoon season			
1974-78	233829.42	233833.48	-4.06
1979-83	153808.00	153792.67	15.33
1984-88	180085.77	180089.19	-3.42
1989-93	221114.30	221090.91	23.39
1994-98	256485.78	256472.08	13.70
1999-03	88339.67	88320.27	19.40
2004-08	325722.00	325715.78	6.22

Table 5.67 Horizontal exchange for Farukhnagar block (m^3/day)

Period	Received	Given Out	Balance
Monsoon season			
1974-78	9734.34	1124.12	8610.22
1979-83	8181.60	1122.62	7058.98
1984-88	6628.17	1262.50	5365.66
1989-93	4486.12	1731.42	2754.70
1994-98	3406.45	1841.25	1565.21
1999-03	1359.37	2908.58	-1549.21
2004-08	1735.16	2608.47	-873.32
Non-Monsoon season			
1974-78	6022.63	2004.26	4018.38
1979-83	5484.05	1729.30	3754.75
1984-88	3966.42	2267.37	1699.05
1989-93	2578.72	2996.94	-418.23
1994-98	1284.72	3700.00	-2415.28
1999-03	1502.91	2401.34	-898.43
2004-08	133.97	6887.69	-6753.73

5.9.3 Water Balance of Farukhnagar Block

It can be seen from Table 5.66 that in monsoon season there was almost negative water remained in older periods which were increasing in recent periods. Compared to this non-monsoon season was having little water balanced after pumping. It was observed that huge recharge quantities were generated in Farukhnagar block based on the rainfall amount and irrespective to this, there was huge demand for water also. For all periods under analysis, it was seen that recharge and pumping quantities were matching with each other.

It was revealed from Table 5.67 that there was huge water exchange going out from the Farukhnagar block. Farukhnagar block was observed to receive water quantities ranging from 1360 to 9734 m^3/day depending upon the rainfall in monsoon season and 134 to 6022 m^3/day in non-monsoon season. In comparison to this water given out of block was ranging from 1124 to 2608 m^3/day in monsoon and 1729 to 6888 m^3/day in non-monsoon. Farukhnagar is situated at higher elevation level (average 230.48 m msl) compared to 220 m average mean sea level of the district. Farukhnagar block is bounded by hills on the south-east side. Therefore huge amount of horizontal exchange was seen to occur from Farukhnagar block towards Sohna block via Gurgaon block as well as towards Pataudi block. It can be clearly observed from the water balance of Farukhnagar block that availability of water in Farukhnagar block was dependent on the horizontal exchange of the water quantities. Clear impact on the flow pattern change was observed on the Farukhnagar block. Due to exploitation of water in Gurgaon, Sohna and Pataudi block, water generated and received in the block was seen to go to other blocks. It was found out from the given out horizontal water quantities that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were increasing irrespective of recharge quantities.

Table 5.68 Water balance for Pataudi block (m^3/day)

Period	Recharge	Pumping	Balance
Monsoon season			
1974-78	71302.25	71299.19	3.06
1979-83	126150.12	126151.51	-1.39
1984-88	52944.58	52938.00	6.57
1989-93	47239.72	47239.00	0.71
1994-98	86546.48	86550.16	-3.69
1999-03	8114.34	8111.37	2.98
2004-08	30455.21	30449.06	6.14
Non-Monsoon season			
1974-78	207358.78	207359.28	-0.50
1979-83	133474.86	133473.67	1.19
1984-88	176047.75	176047.28	0.47
1989-93	201918.84	201918.30	0.55
1994-98	221222.38	221222.78	-0.41
1999-03	7315.38	7315.80	-0.41
2004-08	274190.47	274190.75	-0.28

Table 5.69 Horizontal exchange for Pataudi block (m^3/day)

Period	Received	Given Out	Balance
Monsoon season			
1974-78	1962.94	3245.40	-1282.45
1979-83	1904.02	2332.12	-428.10
1984-88	1921.83	1756.24	165.59
1989-93	2224.86	993.59	1231.26
1994-98	2083.61	840.34	1243.27
1999-03	2174.06	519.52	1654.54
2004-08	1156.79	1414.26	-257.47
Non-Monsoon season			
1974-78	2537.91	1550.08	987.84
1979-83	2221.02	1382.13	838.89
1984-88	2645.55	780.53	1865.02
1989-93	3085.29	336.83	2748.46
1994-98	3051.58	259.06	2792.51
1999-03	1440.17	989.18	450.99
2004-08	2568.03	359.09	2208.94

5.9.4 Water Balance of Pataudi Block

It can be seen from Table 5.68 that in monsoon season there were very little water quantities remained after satisfying all needs. Compared to this non-monsoon season was having negative water balanced after pumping. It was observed that medium recharge quantities were generated in Pataudi block based on the rainfall amount and irrespective to this, there was huge demand for water. For all periods under analysis, it was seen that recharge and pumping quantities were following with each other.

It was revealed from Table 5.69 that there was huge water exchange going out as well as coming in Pataudi block. Pataudi block was observed to receive water quantities ranging from 1156 to 2225 m^3/day depending upon the rainfall in monsoon season and 1440 to 3085 m^3/day in non-monsoon season. Pataudi block was also fond to give 519 to 3245 m3/day water quantities in monsoon and 260 to 1600 m3/day water quantities in non-monsoon season. It was seen regarding Pataudi block that in older times Pataudi block was donating larger quantity of water which was seen to reduce over the period of time.

Pataudi block is situated at higher elevation level (average 242.4 m msl) compared to 220 m average mean sea level of the district. Farukhnagar block is bounded by hills on the north side and east side. Therefore huge amount of horizontal exchange was seen to occur from Pataudi block towards district Rewari as well as it was observed to receive water from Farukhnagar block.

It can be clearly observed from the water balance of Pataudi block that availability of water in the block was dependent on the horizontal exchange of the water quantities. Clear impact on the flow pattern change was observed on the Pataudi block. Due to exploitation of water in Gurgaon and Sohna block, water from Farukhnagar was observed to be divided between Pataudi block and Gurgaon block. It was found out from the given out horizontal water quantities that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were decreasing irrespective of recharge quantities.

Table 5.70 Water Balance of Gurgaon District over the Study Period 1974-2008 (m^3/day)

Stress Period	Recharge	Pumping	Balance Water
Monsoon Season			
1	662873.31	662885.06	-11.75
3	653053.31	653049.13	4.19
5	367510.66	367522.97	-12.31
7	282472.44	282479.59	-7.16
9	285591.75	285603.56	-11.81
11	306095.69	306075.22	20.47
13	451099.44	451091.19	8.25
Non-Monsoon Season			
2	945509.81	945538.75	-28.94
4	655807.50	655764.50	43.00
6	801414.56	801379.31	35.25
8	970825.38	970781.38	44.00
10	1162078.80	1162006.10	72.63
12	282596.75	282574.81	21.94
14	1604937.90	1604972.30	-34.38

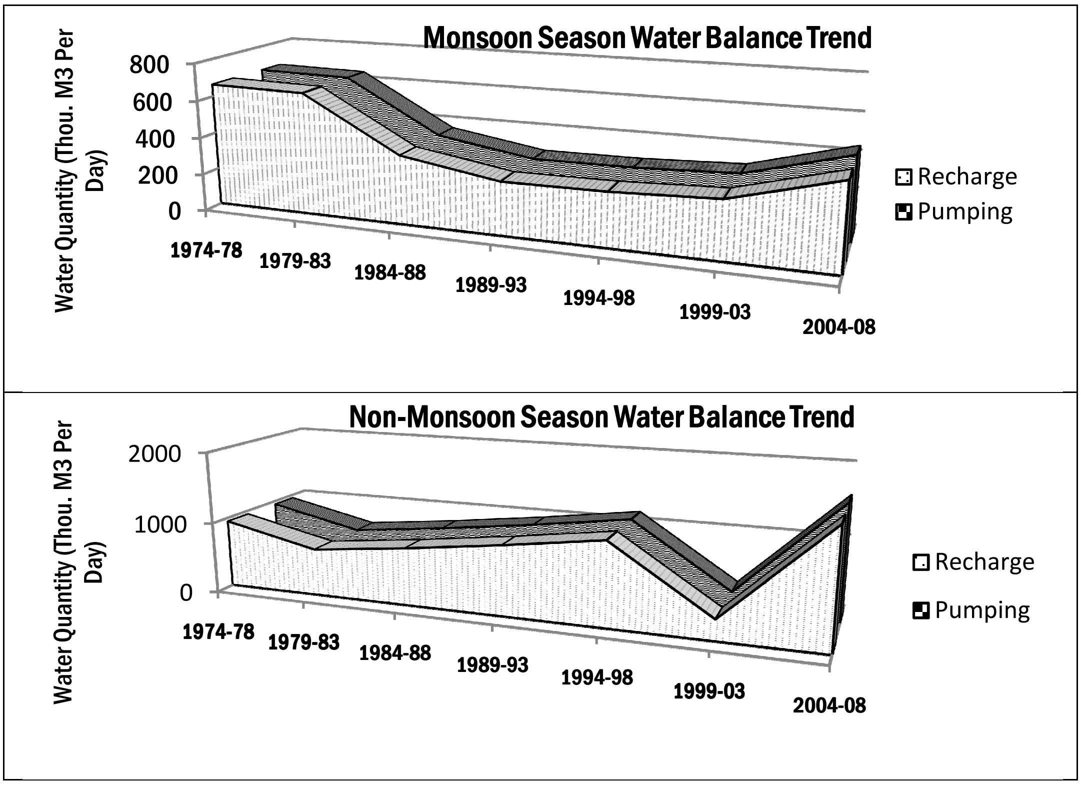

Figure 5.16 Water Balance Trend of Gurgaon District

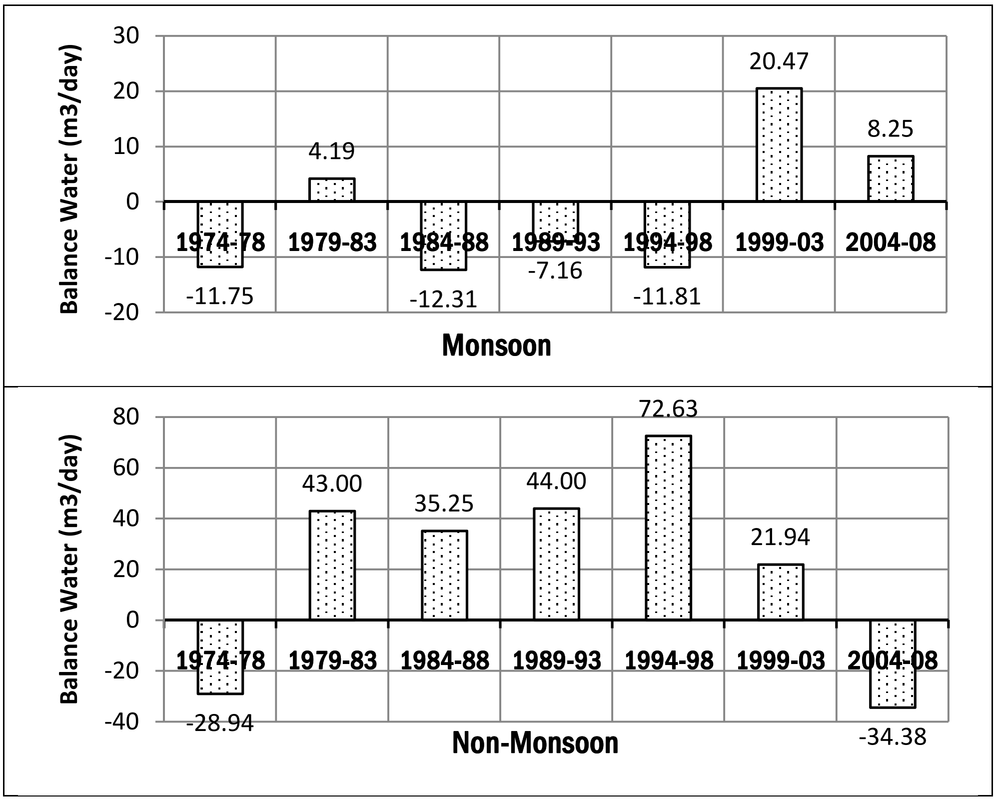

Figure 5.17 Balance water quantities for Gurgaon district over study period (m^3/day)

5.9.5 Water Balance of Gurgaon District

Water balance of entire Gurgaon district has been presented in Table 5.70, trend of water balance and quantities of balance water as bar has been given in Figure 5.16 & 5.17, respectively. Even though generated recharge quantities were huge, equivalent amount of water pumping was seen over the entire study period. Water extraction was huge quantities that remained water quantities were very small either positive or negative in both seasons. Two distinct phases of water balance trend can be clearly identified during study period of 1974 to 2008. In monsoon season, from 1974-78 to 1994-98 there was water deficit and from 1999-03 onwards surplus water quantities were observed. In non-monsoon season exact opposite trend was seen. These water balance trend can be interpreted as in monsoon season, there was delay to reach water quantities to join underground water resources and by the end of season recharge process was becoming complete. Recharge water and horizontal water exchange from adjoining regions was satisfying the needs in non-monsoon season by the end of 1994-98 period. But after 1998, almost all areas were having high demand of water resulting in exploitation of groundwater in such huge quantities that horizontal water exchange has become very less and insignificant. This can be observed from very less remained water quantities of 1999-03 and negative water balance of 2004-08 in non-monsoon season of eight months (245 days).

Water deficit in non-monsoon season presents huge challenge in future water sustainability of the Gurgaon district. All blocks in Gurgaon district except Farukhnagar block had good rainfall in 199-03 and 2004-08 periods. These rainfall quantities were unable to satisfy water requirement over the entire year. Rainfall has shown effect on only monsoon season, in which water balance was little surplus. Unless prohibition on water withdrawal and compulsory recharge in Gurgaon district is implemented, water sustainability of Gurgaon district will be in jeopardy.

5.10 Predicted Water Balance of Gurgaon District for 2025

As has been mentioned in earlier section 3.12 calibrated and validated model of Gurgaon district was used for future prediction of 2025. Trends of different components of water withdrawal were generated and used for future prediction. Details of the trend and other relevant information have been given in Section 3.10 and 5.2 to 5.6. Supreme Court has implemented ban on new tube wells in Gurgaon city and 100 villages surrounding the city since 2010. Gurgaon block still has many villages which were not covered under the prohibition and other three blocks has no ban on tube well construction. Analyzing the data on existing number of tube wells for different blocks and in the district, it was seen that there will not be much impact on agricultural water withdrawal in the district. Withdrawal of water for domestic water use will be lowered after 2010 but these water quantities were very small compared to irrigation water withdrawal. Therefore for Gurgaon block trend of water demand was kept same as calculated for future predictions. For rainfall recharge, normal rainfall quantities of each block have been used.

Table 5.71 and 5.72 shows the Modflow output of predicted block wise water balance of Gurgaon district respectively for monsoon and non-monsoon season of 2025. Corresponding drawdown of the year 2025 have been shown in Table 5.73 and Figure 5.18.

Table 5.71 Blockwise water balance of Gurgaon district for year 2025 Monsoon

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	474769.28	7716.02	467053.25
HORIZ. EXCHANGE	4445.64	10155.01	-5709.38
WELLS	0.00	461335.66	-461335.66
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	479214.94	479206.69	8.25

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	76093.68	19534.05	56559.63
HORIZ. EXCHANGE	6566.88	3053.33	3513.54
WELLS	0.00	60068.52	-60068.52
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	82660.56	82655.90	4.66

DISCREPANCY [%] 0.01

ZONE 3 IN LAYER 1

STORAGE	110479.43	12644.58	97834.84
HORIZ. EXCHANGE	5881.42	2316.42	3565.00
WELLS	0.00	101395.52	-101395.52
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	116360.85	116356.53	4.32

DISCREPANCY [%] 0.00

ZONE 4 IN LAYER 1

STORAGE	60366.72	9142.07	51224.65
HORIZ. EXCHANGE	1571.38	2940.55	-1369.17
WELLS	0.00	49851.23	-49851.23
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	61938.10	61933.84	4.26

DISCREPANCY [%] 0.01

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	721708.69	49036.70	672672.00
WELLS	0.00	672611.94	-672611.94
RECHARGE	0.00	0.00	0.00
SUM	**721708.69**	**721648.63**	**60.06**

DISCREPANCY [%] 0.01

Table 5.72 Blockwise water balance of Gurgaon district for year 2025 Non-Monsoon

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	938016.88	0.00	938016.88
HORIZ. EXCHANGE	8276.82	3166.94	5109.88
WELLS	0.00	943138.94	-943138.94
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	946293.75	946305.88	-12.13

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

STORAGE	424904.81	0.00	424904.81
HORIZ. EXCHANGE	2668.89	3336.12	-667.23
WELLS	0.00	424247.00	-424247.00
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	427573.69	427583.13	-9.44

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

STORAGE	388304.97	0.00	388304.97
HORIZ. EXCHANGE	996.98	7147.53	-6150.55
WELLS	0.00	382153.59	-382153.59
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	389301.97	389301.13	0.84

DISCREPANCY [%] 0.00

ZONE 4 IN LAYER 1

STORAGE	337615.66	0.00	337615.66
HORIZ. EXCHANGE	2850.38	1142.48	1707.90
WELLS	0.00	339323.94	-339323.94
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	340466.03	340466.41	-0.38

DISCREPANCY [%] 0.00

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	2088842.40	0.00	2088842.40
WELLS	0.00	2088856.60	-2088856.60
RECHARGE	0.00	0.00	0.00
SUM	2088842.40	2088856.60	-14.25

DISCREPANCY [%] 0.00

Table 5.73 Blockwise predicted drawdown for Gurgaon district for year 2025

Days	Gurgaon	Sohna	F'Nagar	Pataudi
30	0.56	0.02	0.14	0.37
60	1.09	0.02	0.27	0.68
90	1.60	0.02	0.41	0.94
120	2.10	0.02	0.55	1.16
151	3.06	0.42	0.90	1.87
181	4.02	0.87	1.25	2.55
212	4.97	1.32	1.59	3.22
243	5.90	1.78	1.94	3.87
273	6.84	2.23	2.28	4.52
304	7.76	2.69	2.62	5.16
334	8.69	3.15	2.96	5.79
365	9.61	3.61	3.31	6.41

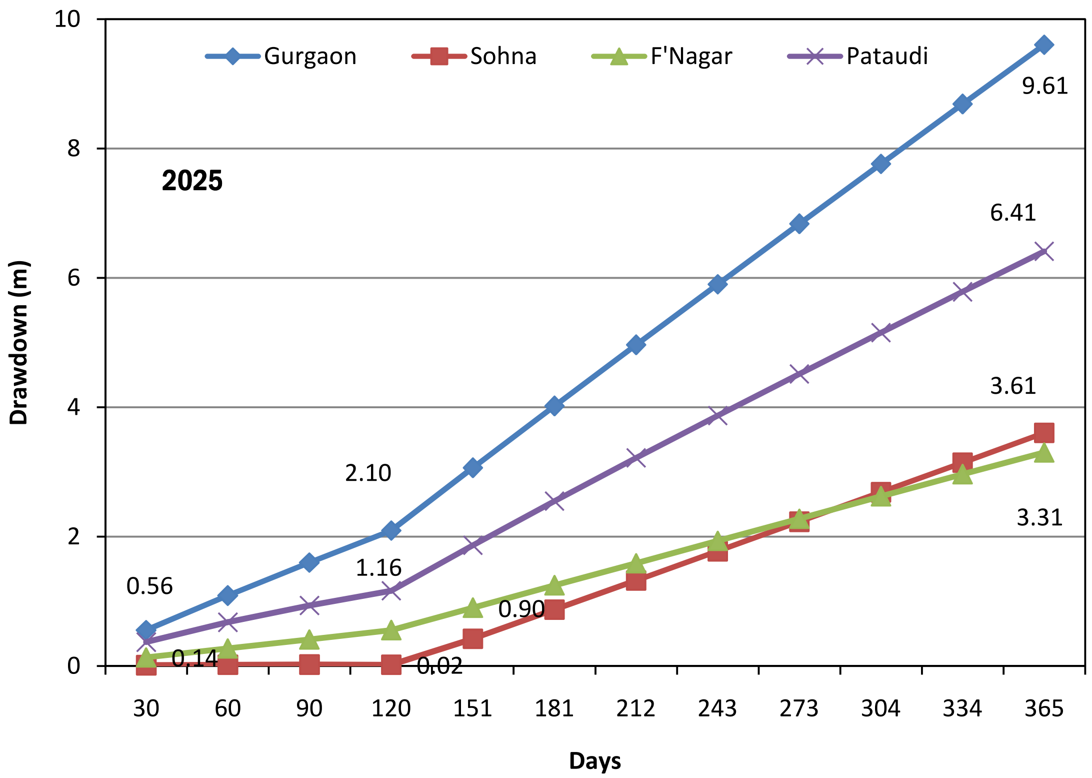

Figure 5.18 Predicted drawdown for Gurgaon district for year 2025 (meter)

It was revealed from Table 5.71 that in 2025 monsoon season all blocks in Gurgaon district will have little water quantities remained after satisfying all needs under normal rainfall condition. Water quantities remained will be very small; to the tune of 4.41

m^3/day for Sohna, Farukhnagar and Pataudi blocks and about 8.25 m^3/day for Gurgaon block. Under normal rainfall condition in monsoon season, horizontal exchange received in Gurgaon block will be 4445.6 m^3/day while it will give out 10155 m^3/day. Sohna block will receive water quantity of 6567 m^3/day and give 3053 m^3/day water quantity. Farukhnagar block will receive horizontal water quantity of 5881 m^3/day and 2316.5 m^3/day water quantities will be given out. Compared to this Pataudi block will get 1571 m^3/day and give 2940.5 m^3/day water quantities.

It can be observed from Table 5.72 that in 2025 non-monsoon season, Farukhnagar and Pataudi block will have little water quantities remained after satisfying all needs and Gurgaon and Sohna blocks will have deficit water budget under normal rainfall condition. Under normal rainfall condition in non-monsoon season, horizontal exchange received in Gurgaon block will be more (8276 m^3/day) and given out water quantity will be less (3167 m^3/day). This signals very high water withdrawal in Gurgaon block in non-monsoon season. Sohna block will receive 2669 m^3/day from other blocks and will give 3336 m^3/day. Farukhnagar block will receive 997 m^3/day horizontal exchange water quantities and 7147 m^3/day water quantity will be given out. Compared to this Pataudi block will get 2850 m^3/day and give 1142 m^3/day water quantities.

Table 5.73 and Figure 5.18 show the monthly drawdown for year 2025. It was observed from Table 5.73 that Gurgaon block will have maximum drawdown of 9.61 meter in 2025 followed by Pataudi block with 6.41 meter. Drawdown of Farukhnagar and Sohna will be lowest in district in 2025 with values of 3.31 and 3.61 meter respectively. Average monthly drawdown in monsoon and non-monsoon will be 51 and 94 cm/month for Gurgaon block. There will be negligible positive drawdown of few millimeters in monsoon season and 45 cm/month drawdown in non-monsoon season for Sohna block. Calculations show that Farukhnagar block will have about 14 cm/month and 34.5 cm/month drawdown in monsoon and non-monsoon season. Pataudi will have second highest drawdown of 26 cm/month in monsoon and about 66cm/month drawdown in non-monsoon season.

5.11 Predicted Water Balance of Gurgaon District for 2050

Prediction scenario for year 2050 has been formulated using the trends described in Section 3.10 and 5.2 to 5.6. Even though lot of development activities, water conservation measures will be taken by 2050 and there will be changes in different policies; long term planning and management activities will need reliable predictions of 2050. Keeping this in mind, scenario of 2050 has been formulated.

Table 5.74 and 5.75 shows the Modflow output of predicted block wise water balance of Gurgaon district respectively for monsoon and non-monsoon season of 2050. Corresponding drawdown of the year 2050 have been shown in Table 5.76 and Figure 5.19.

Analysis of Table 5.74 showed that in 2050 monsoon season all blocks in Gurgaon district except Farukhnagar block has surplus water budget under normal rainfall condition. This surplus quantity was very little. Compared to this, Table 5.75 shows that in 2050 non-monsoon season all blocks in Gurgaon district except Pataudi block has surplus water budget. Even though surplus water quantities were very little considering prolonged period of eight months, surplus water budget has importance. Reduction in total area under irrigation has clear impact on water budget. But if equivalent amount of irrigation water will be required by agro based and other industries then there will be alarming situation in Gurgaon district. By 2050, it was seen that, target block to be considered will be Pataudi block which was showing deficit water budget.

Analysis of horizontal exchange quantities definitely shows the change in underground water flow patterns by 2050. Most affected block in Gurgaon district will be Farukhnagar block. Predictions showed that Farukhnagar block will be forced to give huge amount of water quantities to Gurgaon and Pataudi blocks. Among the receivers, Gurgaon block will have lions share. It was also seen that Sohna block will be also forced to give considerable amount of water to adjoining Mewat district.

Table 5.76 and Figure 5.19 show the monthly drawdown for year 2050. It was observed from Table 5.76 that Gurgaon, Sohna, Farukhnagar and Pataudi blocks will have drawdown of 13.98, 4.24, 3.64 and 7.13 meter, respectively in year 2050.

Table 5.74 Blockwise water balance of Gurgaon district for year 2050 Monsoon

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WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

==

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	839515.38	2963.44	836551.94
HORIZ. EXCHANGE	6145.76	7333.28	-1187.53
WELLS	0.00	835350.63	-835350.63
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	845661.19	845647.38	13.81

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	119416.29	9811.35	109604.94
HORIZ. EXCHANGE	5256.36	3657.50	1598.85
WELLS	0.00	111197.58	-111197.58
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	124672.64	124666.44	6.20

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	151342.03	7578.58	143763.45
HORIZ. EXCHANGE	4412.07	3344.01	1068.06
WELLS	0.00	144844.69	-144844.69
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	155754.11	155767.28	-13.17

DISCREPANCY [%] -0.01

ZONE 4 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	93873.54	3913.19	89960.35
HORIZ. EXCHANGE	1435.52	2914.89	-1479.38
WELLS	0.00	88473.23	-88473.23
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	95309.06	95301.32	7.73

DISCREPANCY [%] 0.01

==

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

==

FLOW TERM	IN	OUT	IN-OUT
STORAGE	1204146.90	24266.57	1179880.20
WELLS	0.00	1179860.90	-1179860.90
RECHARGE	0.00	0.00	0.00
SUM	**1204146.90**	**1204127.50**	**19.38**

DISCREPANCY [%] 0.00

Table 5.75 Blockwise water balance of Gurgaon district for year 2050 Non-Monsoon

==

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

==

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	1296199.60	0.00	1296199.60
HORIZ. EXCHANGE	15522.75	1390.94	14131.81
WELLS	0.00	1310328.00	-1310328.00
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	1311722.40	1311719.00	3.38

DISCREPANCY [%] 0.00

ZONE 2 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	472445.63	0.00	472445.63
HORIZ. EXCHANGE	1141.05	5885.83	-4744.77
WELLS	0.00	467694.31	-467694.31
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	473586.69	473580.13	6.56

DISCREPANCY [%] 0.00

ZONE 3 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	430640.09	0.00	430640.09
HORIZ. EXCHANGE	653.90	11704.48	-11050.58
WELLS	0.00	419586.25	-419586.25
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	431294.00	431290.72	3.28

DISCREPANCY [%] 0.00

ZONE 4 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	371159.91	0.00	371159.91
HORIZ. EXCHANGE	3106.27	1442.74	1663.53
WELLS	0.00	372829.41	-372829.41
RECHARGE	0.00	0.00	0.00
SUM OF THE LAYER	374266.16	374272.16	-6.00

DISCREPANCY [%] 0.00

==

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

==

FLOW TERM	IN	OUT	IN-OUT
STORAGE	2570444.50	0.00	2570444.50
WELLS	0.00	2570442.20	-2570442.20
RECHARGE	0.00	0.00	0.00
SUM	**2570444.50**	**2570442.20**	**2.25**

DISCREPANCY [%] 0.00

Table 5.76 Blockwise predicted drawdown for Gurgaon district for year 2050

Days	Gurgaon	Sohna	F'Nagar	Pataudi
30	0.92	0.04	0.17	0.44
60	1.81	0.09	0.34	0.81
90	2.69	0.15	0.51	1.13
120	3.55	0.21	0.68	1.43
151	4.88	0.70	1.05	2.19
181	6.20	1.20	1.42	2.93
212	7.51	1.70	1.79	3.65
243	8.81	2.21	2.16	4.36
273	10.11	2.71	2.53	5.07
304	11.41	3.22	2.90	5.76
334	12.70	3.73	3.27	6.45
365	13.98	4.24	3.64	7.13

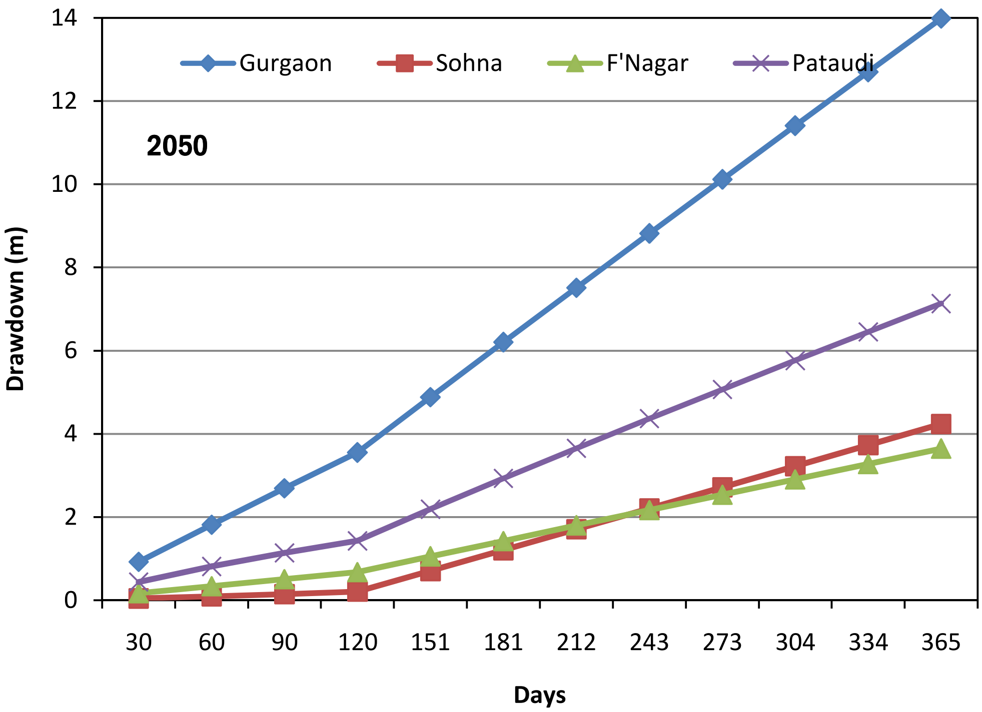


Figure 5.19 Predicted drawdown for Gurgaon district for year 2025 (meter)

5.12 Water Balance of Gurgaon for Normal Rainfall Condition and No Pumping

Instead of formulating different hypothetical scenarios and running model, business as usual (BAU) scenarios of 2025 and 2050 has been formulated in results have been presented in section 5.14 and 5.15. For practical solutions of sustainable water resources of Gurgaon district planning and management activities and to get the base values for comparison, scenario of normal rainfall condition and no-pumping has been formulated. For scenario normal rainfall which was average of past 35 years, 1974 to 2008 (which was study period under consideration also), has been used.

Table 5.77 shows the water balance of four blocks of Gurgaon district for normal rainfall condition and no pumping scenario. Horizontal exchange of water quantities has been shown in Table 5.78 and corresponding drawdown have been shown in Table 5.79.

Analysis of Table 5.77 show that under normal rainfall condition, all blocks in Gurgaon district except Gurgaon block has negative water balance. Even though Gurgaon block was showing positive water budget, surplus quantities were very less compared to pumping. Therefore we can say that almost all blocks might have tendency to store ground water under very deeper layers or water quantities were passed out to the surrounding areas. It was also observed from Table 5.78 that under normal rainfall conditions and no-pumping, only Gurgaon and Pataudi blocks were giving out water. Among these two blocks Gurgaon block (25013 m^3/day) has almost three times bigger donating capacity than Pataudi block (8708 m^3/day), other two blocks viz. Sohna and Farukhnagar were found to receive more water quantities than the given out water quantities. If we compare the exchange quantities of Farukhnagar block (Table 5.68) with normal rainfall no-pumping condition, then it can be said that because of exploitation of ground water in other blocks, there was change in natural flow pattern of Farukhnagar block. Because of high deficits of water quantities in other blocks, more amount of water was found to flow out of Farukhnagar block.

Under normal rainfall condition with no-pumping there will be huge rise in water table of all blocks in Gurgaon district. Increase in water table in monsoon season for Gurgaon, Sohna, Pataudi and Farukhnagar blocks will be 6.14, 5.56, 5.07 and 1.92 meter, respectively. It was also found out that recharge of normal condition rainfall with no-pumping will produce 0.5775, 0.3959, 0.3128 and 0.3799 ha.m/ha water respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks.

Table 5.77 Water balance of Gurgaon district for normal rainfall and no-pimping scenario

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER

ZONE 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	0.00	1639819.50	-1639819.50
HORIZ. EXCHANGE	2416.24	25013.61	-22597.37
WELLS	0.00	0.00	0.00
RECHARGE	1662440.90	0.00	1662440.90
SUM OF THE LAYER	1664857.10	1664833.10	24.00
DISCREPANCY [%]	0		

ZONE 2 IN LAYER 1

STORAGE	0.00	1120278.50	-1120278.50
HORIZ. EXCHANGE	11137.84	2315.92	8821.91
WELLS	0.00	0.00	0.00
RECHARGE	1111447.60	0.00	1111447.60
SUM OF THE LAYER	1122585.50	1122594.40	-8.88
DISCREPANCY [%]	0		

ZONE 3 IN LAYER 1

STORAGE	73.90	795062.94	-794989.06
HORIZ. EXCHANGE	21491.22	293.27	21197.95
WELLS	0.00	0.00	0.00
RECHARGE	773772.50	0.00	773772.50
SUM OF THE LAYER	795337.63	795356.19	-18.56
DISCREPANCY [%]	0		

ZONE 4 IN LAYER 1

STORAGE	0.00	865054.81	-865054.81
HORIZ. EXCHANGE	1286.22	8708.71	-7422.49
WELLS	0.00	0.00	0.00
RECHARGE	872470.13	0.00	872470.13
SUM OF THE LAYER	873756.38	873763.50	-7.13
DISCREPANCY [%]	0		

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	73.90	4420217.00	-4420143.00
WELLS	0.00	0.00	0.00
RECHARGE	4420316.00	0.00	4420316.00
SUM	**4420390.00**	**4420217.00**	**173.00**
DISCREPANCY [%]		0	

Table 5.78 Horizontal exchange of four blocks of Gurgaon district under normal rainfall

Block	Received	Given Out	IN-OUT
Gurgaon	2416.24	25013.61	-22597.37
Sohna	11137.84	2315.92	8821.91
F'Nagar	21491.22	293.27	21197.95
Pataudi	1286.22	8708.71	-7422.49

Table 5.79 Increase in water table due to normal rain and no pumping

Days	Gurgaon	Sohna	Pataudi	F'Nagar
30	1.50	1.40	1.19	0.48
60	3.03	2.79	2.44	0.97
90	4.57	4.17	3.74	1.45
120	6.14	5.56	5.07	1.92

5.13 Effect of Water Conservation and Recharge on Drawdown of Gurgaon District

To give the solution for curbing huge increase in drawdown in Gurgaon district effect of two types of water conservation strategies was tested. In first strategy roof top water harvesting structures combined with recharge structure was considered and for other strategy all types of water conservation structures (check dams, contour bunds, contour ditches, Gabian Structures etc.) were considered. For analysis of effect of these structures, normal rainfall condition was considered.

For roof top water harvesting structure, efficiency of water collection was assumed to be 98% and for recharge structure, efficiency of 80% was considered. For water conservation structures, overall efficiency of 60% was assumed. Area of 100 km^2 (10,000 ha) was considered for both type of strategies as 100 km2 is approximately one third of the each block area. Because of roof top water harvesting and recharge, there will be 0.0010907, 0.000764, 0.000677 and 0.00091437 m/day increase in recharge respectively for Gurgaon, Sohna, Farukhnagar and Pataudi blocks. Because of water conservation structure, there will be 0.0008408, 0.000585, 0.000518 and 0.00069978 m/day increase in recharge respectively for Gurgaon, Sohna, Farukhnagar and Pataudi blocks. These inputs were given separately for each block and increase in water table was worked out. Table

5.80 and 5.81 show the increase in water table under normal rainfall condition due to roof top water harvesting assisted recharge and water conservation structure assisted recharge, respectively.

It can be seen from Table 5.80 that there will be 1.46, 1.22, 1.68 and 0.58 meter rise in water table respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks in monsoon season due to roof top water harvesting done on 100 km^2 equivalent roof top area and water was recharged. It can be also be seen from Table 5.81 that there will be 1.12, 0.94, 1.29 and 0.44 meter rise in water table respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks in monsoon season due to water conservation structure assisted recharge done on 100 km^2 equivalent drainage area and water was recharged.

Table 5.80 Increase in water table due to roof top water harvesting assisted recharge done on 100 km^2

Days	Gurgaon	Sohna	Pataudi	F'Nagar
30	0.37	0.31	0.42	0.14
60	0.73	0.61	0.84	0.29
90	1.10	0.92	1.26	0.43
120	1.46	1.22	1.68	0.58

Table 5.81 Increase in water table due to water conservation structures assisted recharge done on 100 km^2

Days	Gurgaon	Sohna	Pataudi	F'Nagar
30	0.28	0.23	0.32	0.11
60	0.56	0.47	0.64	0.22
90	0.84	0.70	0.96	0.33
120	1.12	0.94	1.29	0.44

5.14 Identification of Potential Groundwater Recharge Zones

For identification of potential ground water recharge, first of all water extraction pattern and water deficit area were identified. For this contours of water drawdown at the end of each five year average period (seven, from 1974-08) was carried out. These contours were then superimposed on the three dimensional mesh wire diagram of water table head of corresponding water withdrawal. For preparation of 3-D diagram help of Surfer was taken.

Human activities, such as ground water withdrawal, irrigation etc. change the natural flow pattern, and these changes must be accounted for in any management decision. Therefore studying the water withdrawal contour diagrams, flow pattern was identified. In addition to this, studying water withdrawal contours and flow pattern, potential sites of water recharge for water conservation schemes on large scale were identified.

Comparing different figures from 5.20 to 5.26, it was observed that at the end of first five year average period (1974-78), most of the areas were having drawdown up to 2 meter and few areas were observed to have drawdown of little more than 2 meters. By the end of period 2004-08, were observed to have drawdown of more than 8 to 10 meters. Figure 5.21 to 5.25 shows the different stages of rapid fall of water levels. In Figure 5.27 major flow directions has been shown and Figure 5.28 shows the potential ideal sites for water conservation structure installations at large scale. From Figure 5.26, it was observed that by the end of 2004-08 periods, all the blocks in Gurgaon district except Farukhnagar block were having very high drawdown. Even though drawdown in Farukhnagar block was comparably less than other blocks, earlier analysis shown in various sections viz. 5.13.3, 5.16 and 5.17, shows that in Farukhnagar block rise or fall of water level were not dependent on the extraction of water alone and horizontal exchange of water plays more important role for this block. Therefore it can be said about all the blocks that these all blocks are rapidly moving towards the closure of underground water resources.

Figure 5.20

WATER TABLE DRAWDOWN CONTOURS FOR GURGAON DISTRICT AT 1974-78 END

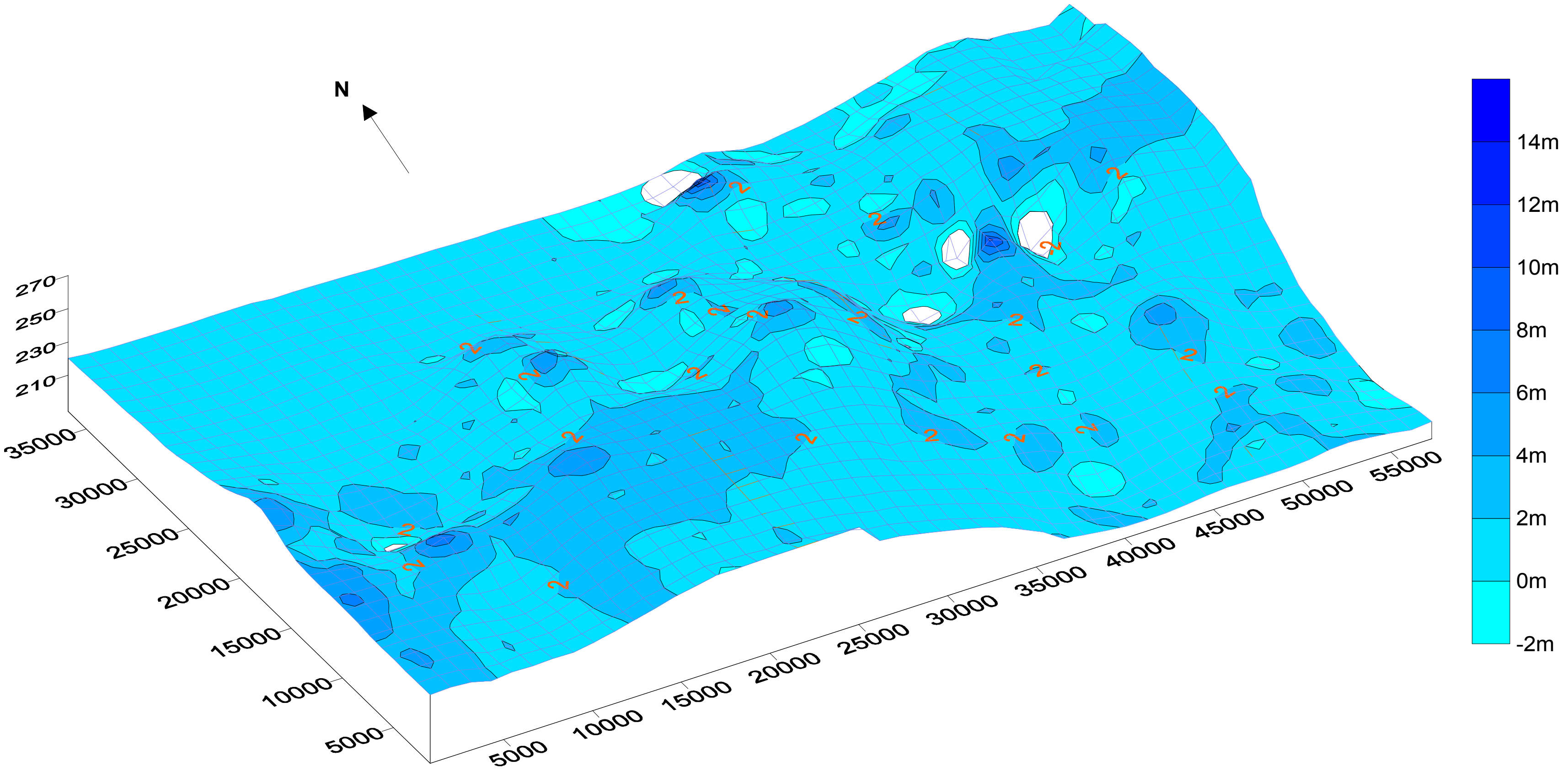


Figure 5.21

WATER TABLE DRAWDOWN CONTOURS FOR GURGAON DISTRICT AT 1979-83 END

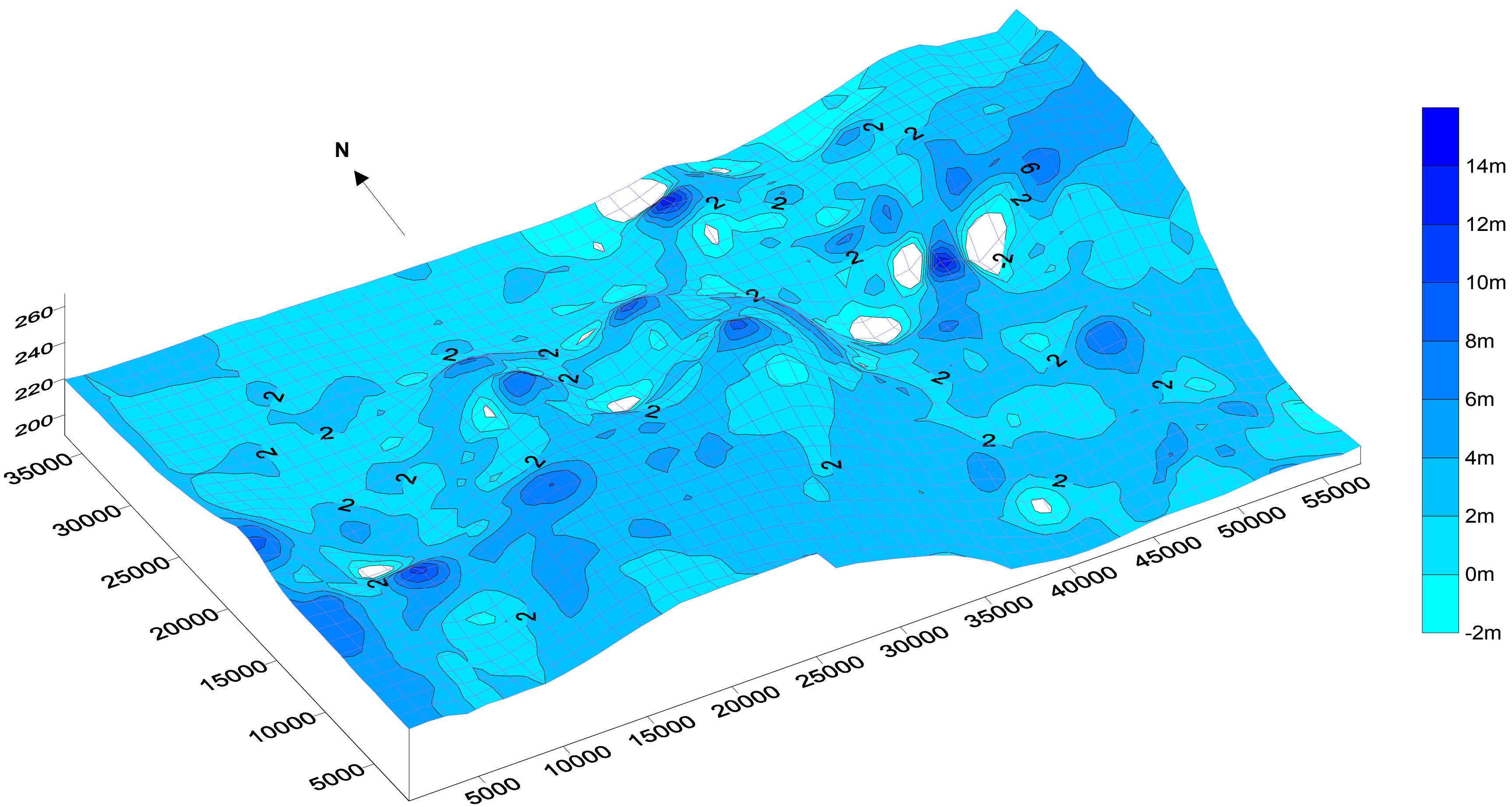


Figure 5.22

WATER TABLE DRAWDOWN CONTOURS FOR GURGAON DISTRICT AT 1984-88 END

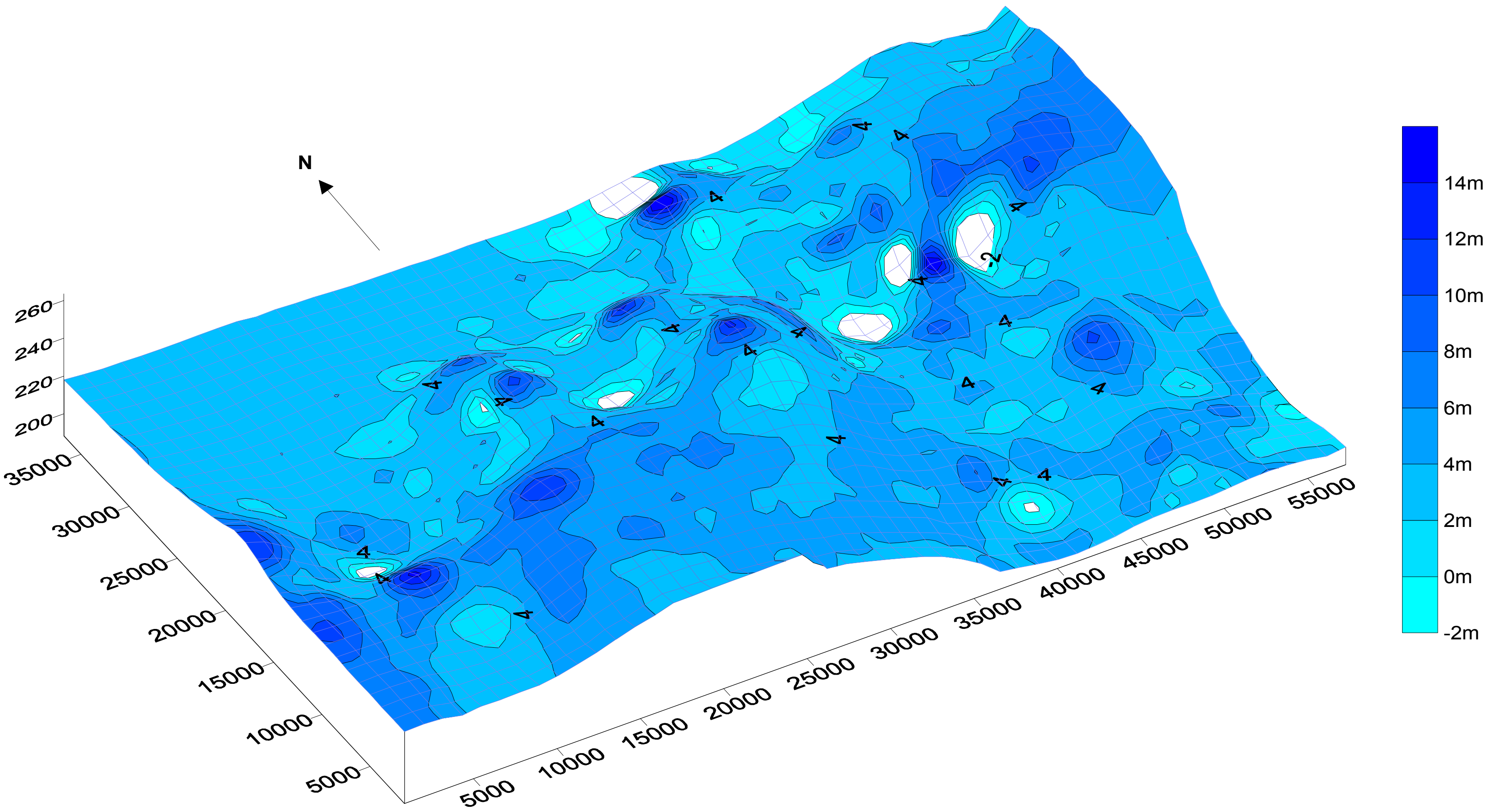


Figure 5.23

WATER TABLE DRAWDOWN CONTOURS FOR GURGAON DISTRICT AT 1989-93 END

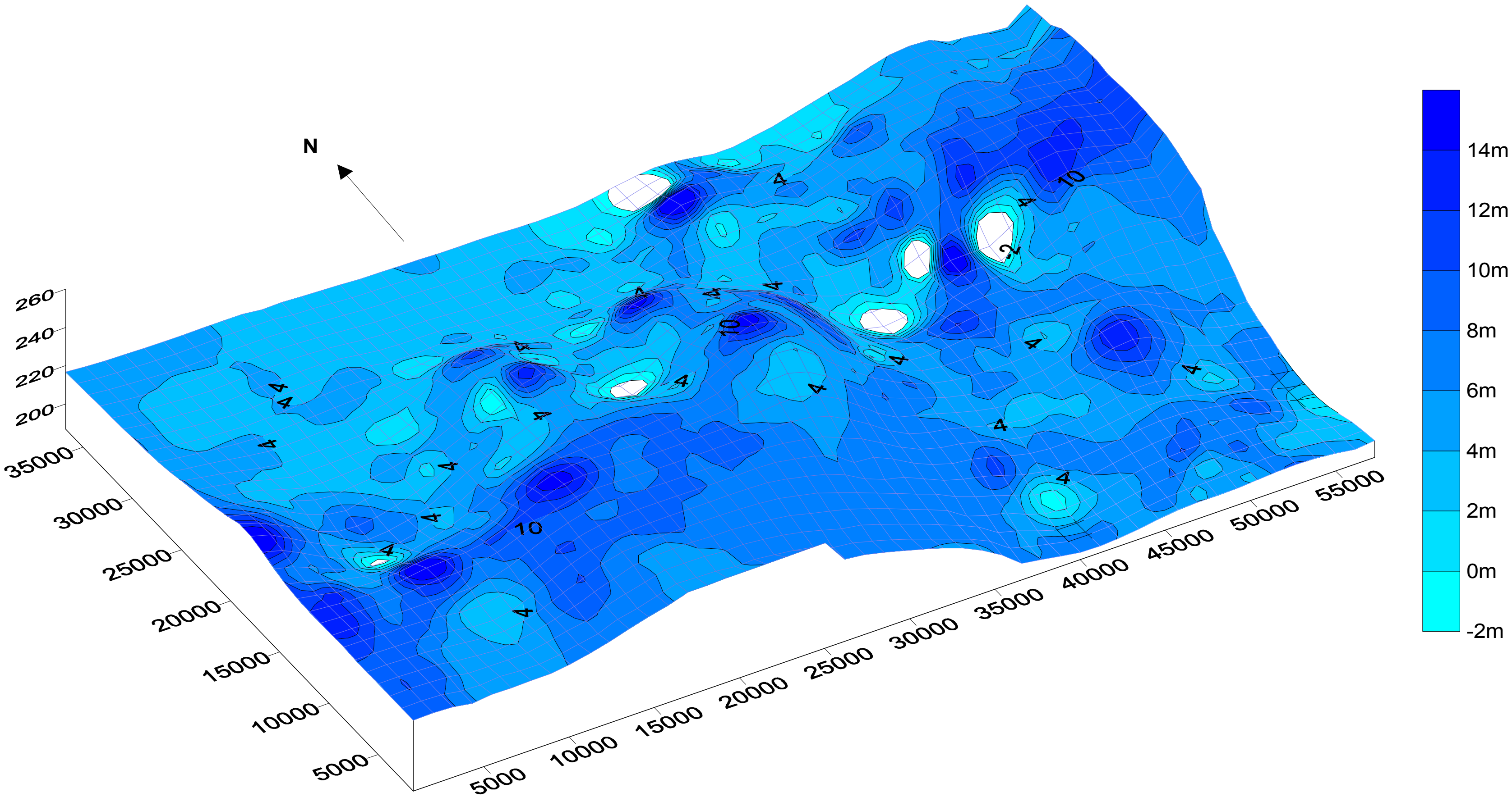


Figure 5.24

WATER TABLE DRAWDOWN CONTOURS FOR GURGAON DISTRICT AT 1994-98 END

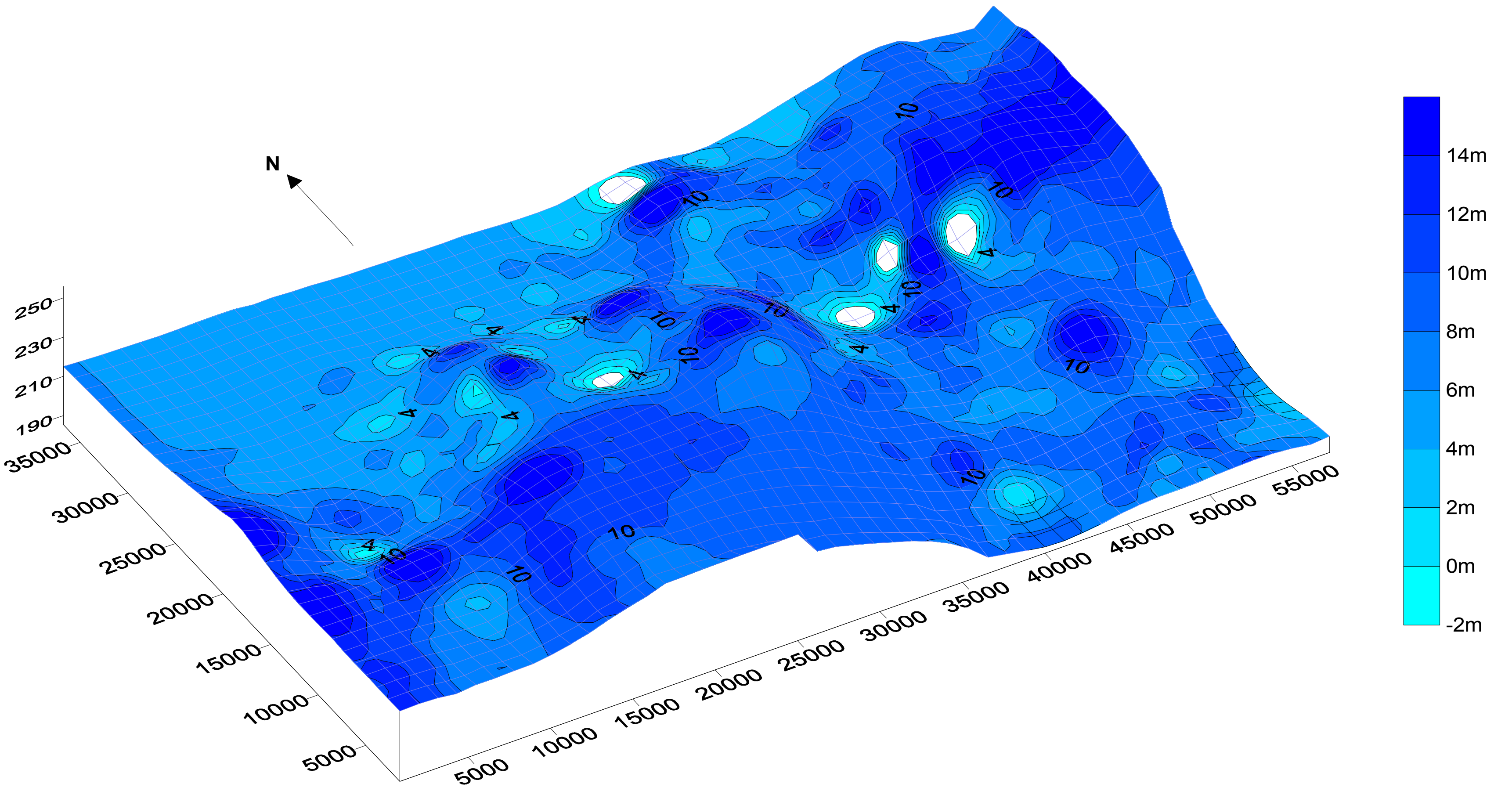


Figure 5.25

WATER TABLE DRAWDOWN CONTOURS FOR GURGAON DISTRICT AT 1999-03 END

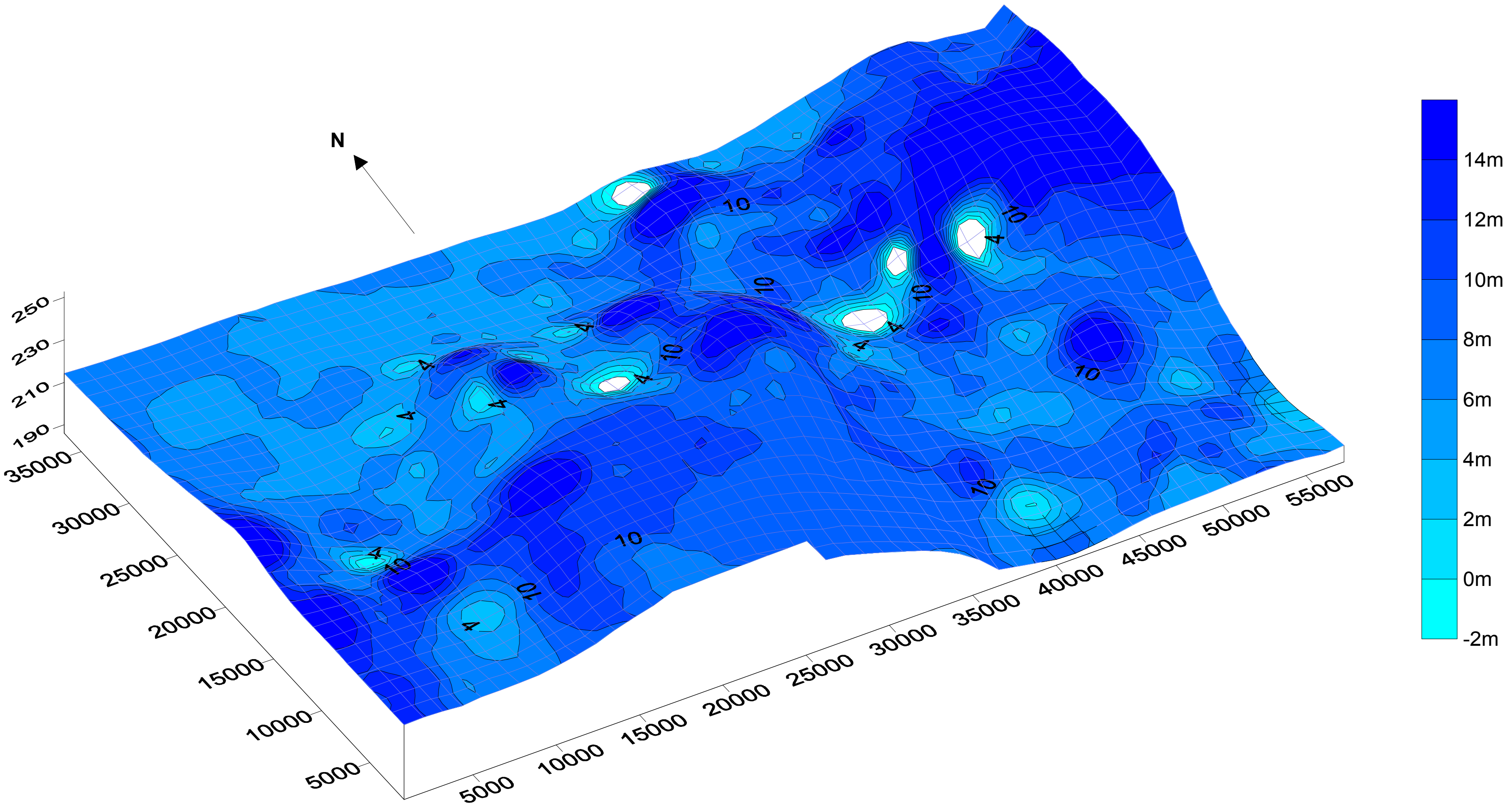


Figure 5.26

WATER TABLE DRAWDOWN CONTOURS FOR GURGAON DISTRICT AT 2004-08 END

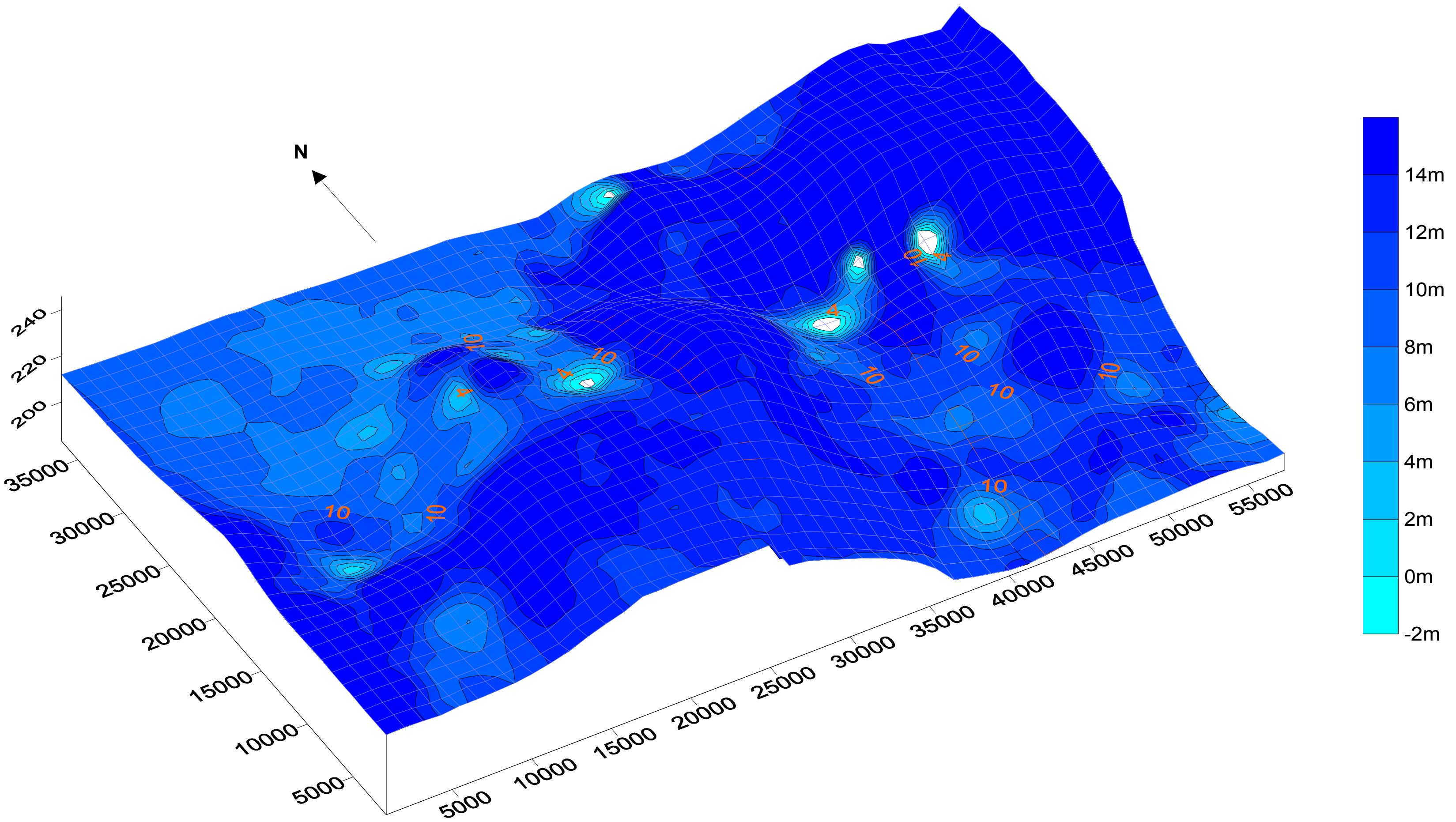


Figure 5.27

GROUNDWATER FLOW DIRECTIONS FOR GURGAON DISTRICT

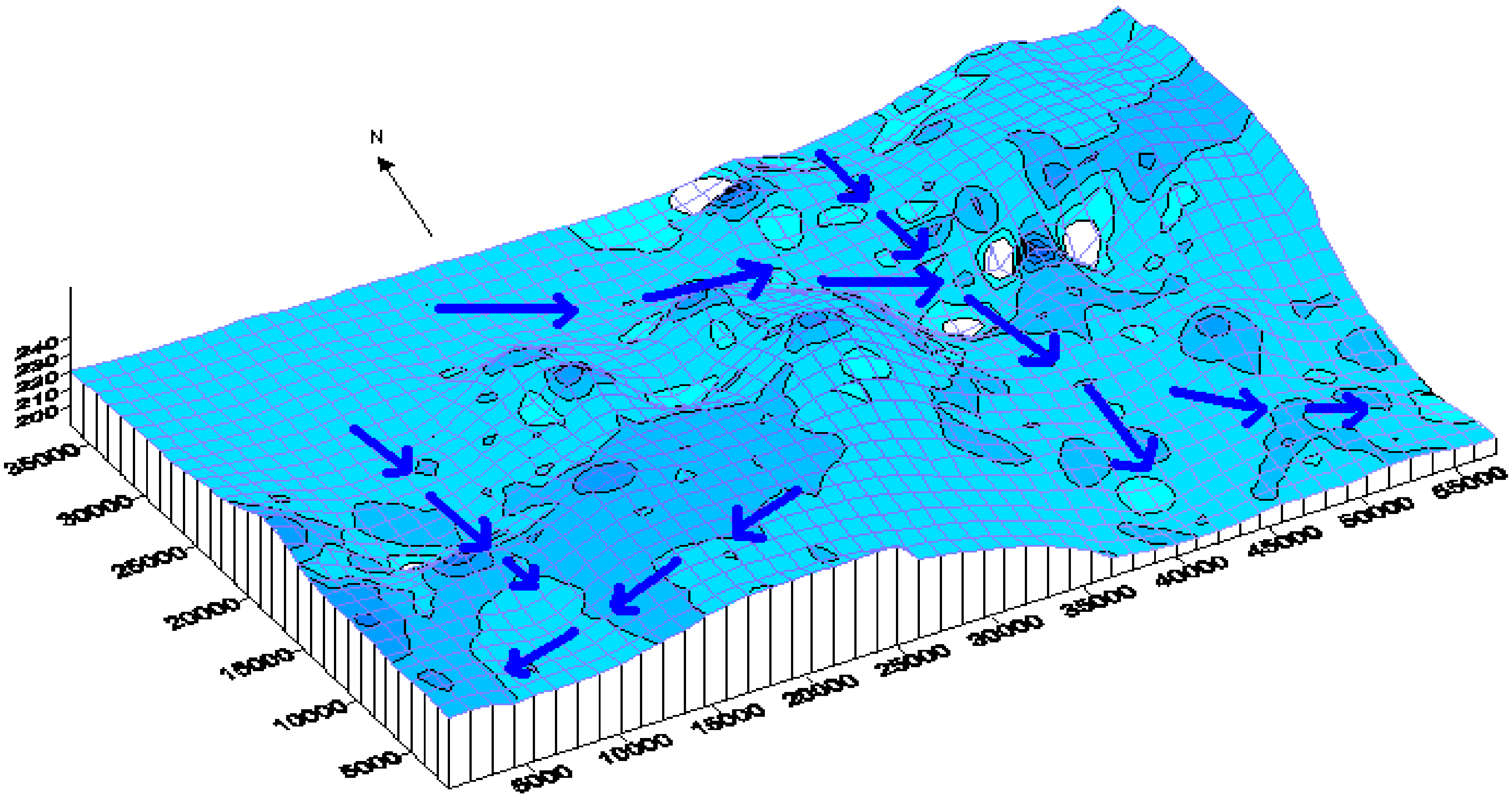
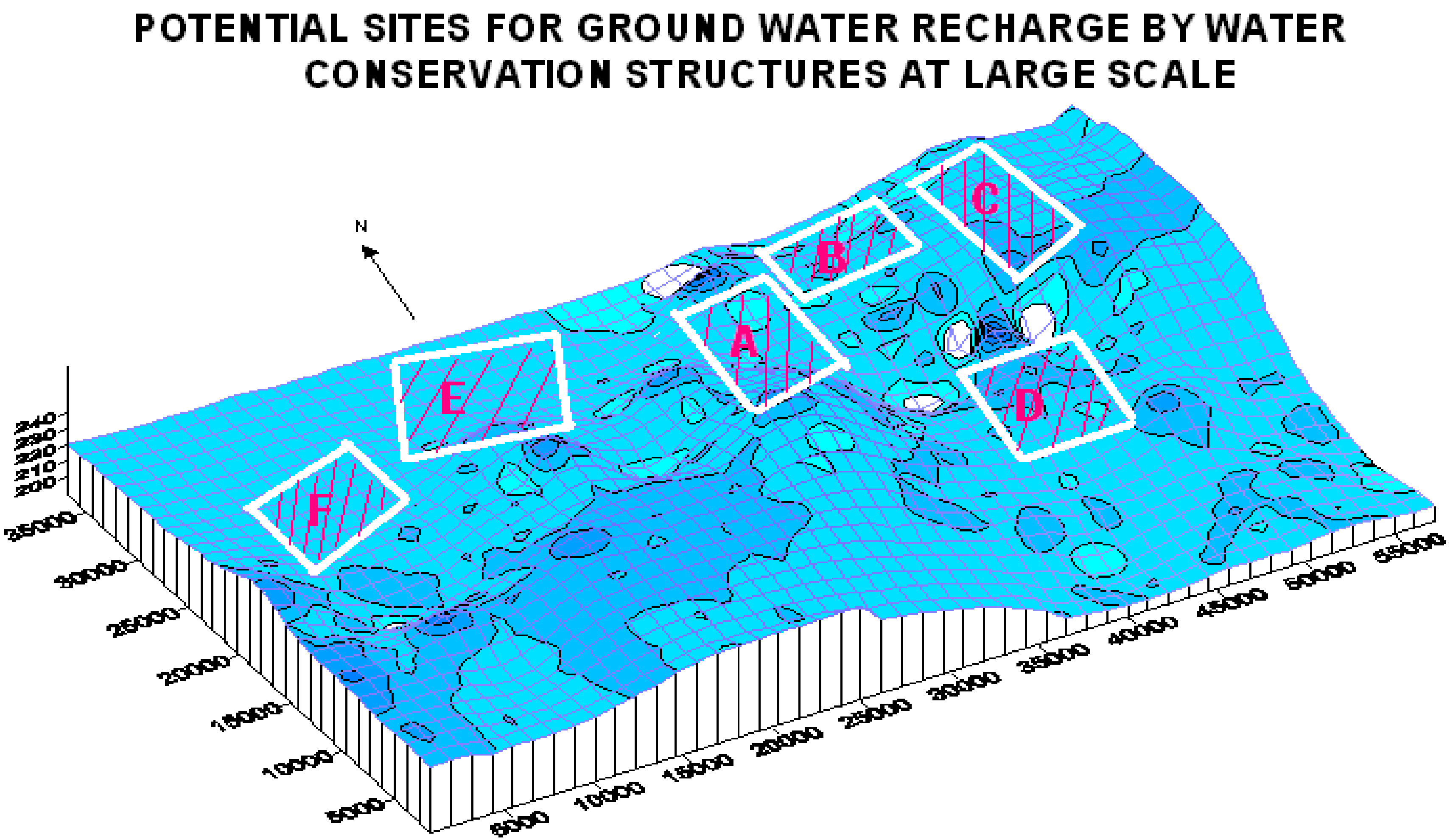


Figure 5.28


POTENTIAL SITES FOR GROUND WATER RECHARGE BY WATER CONSERVATION STRUCTURES AT LARGE SCALE
N
A
B
C
D
E
F
240
230
220
210
200
35000
30000
25000
20000
15000
10000
5000
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000

According to guidelines mentioned in section 3.9, all areas having maximum drawdown can be safely recharged. Therefore areas in all blocks can be considered for recharge sites. Figure 5.28 shows the various potential sites for recharge marked with alphabets. These sites have some specific advantages for water conservation measures.

Site A: This site is located on the water flow path from Farukhnagar to Gurgaon block. Therefore recharge water can be rapidly moved towards underground layers as well as towards Gurgaon block. This flow path was observed to enter Sohna block after Gurgaon block. Therefore advantage of recharge water can be availed by both Gurgaon and Sohna block.

Site B: This site was identified on the flow path of Gurgaon to Sohna block. Water recharge at this site will facilitate entire block as it is located at the Start of Gurgaon block towards Delhi and travels whole block. This is also flow path of Yamuna river recharge lines.

Site C: This site is ideally located on the high hill regions towards the north and north-east side of Gurgaon block. Because of hills water collection will be more and space will be available for recharge sites; as well as this will be ideal site for contour bund or contour trench types of recharge structures.

Site D: This will be ideal site for recharge for Sohna block as it is located on Gurgaon to Sohna flow path and this flow path is travelling across almost all districts. This flow path might have many sub-flow paths also.

Site E: This site has ideal location as it is identified on the major flow path of the district which starts from Farukhnagar block, goes to Gurgaon block and then again enters to Sohna block. Depending upon the recharge quantities these all three blocks may get advantage of recharge.

Site F: This site is identified on the flow path of underground water from Farukhnagar block to Pataudi block. Therefore both these blocks may get the advantage of recharge.

Chapter 6

Conclusion and Recommendation

Chapter-6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

For sustainability of water resources in Gurgaon district, extensive research plan was worked and implemented. Different components for demand for water were determined based on the standard professional practice in the field. These components were agricultural, domestic, industrial, and institutional and water requirement for domestic and other animals. Recharge due to irrigation and rainfall has been estimated in accordance with CGWB (2009) methods. Irrigation recharge has been estimated using return flow factor method and rainfall recharge has been estimated using rainfall infiltration factor method as well as water table fluctuation method. Recharge quantities has been normalized according to standard recommendations of respective methods. Using calculated pumping and recharge quantities inputs for Modflow model were generated.

Total Gurgaon district area of 1254.62 km^2 was modeled using 102 column and 66 rows. Each grid cell had 570.03 m length by 570.03 m width making 324934.20 m^2 areas. Out of total 6732 grid cells, 3861 cells were coming within the boundary of Gurgaon district. To understand the water budget of four blocks of Gurgaon district, available data from 1974 to 2008 was divided in to five year average periods. Thus total seven five year average periods were formed. Modflow model (Version 5.3.1 © Chiang, W. H. and Kinzellbach, W., 1991-2001) has been calibrated using four temporal observations of four blocks and validated for 10 temporal observations of four blocks. Data of 70 tube well observations have been used for calibration and validation. Then model was calibrated to match the observed drawdown with model calculated drawdown using different values of hydraulic conductivity (k) and specific yield (s). Values of aquifer constants viz. k and s have been obtained by the analysis of pumping and recovery test data of four representative villages in Gurgaon district. For each test data, analysis was carried out using Theis Method, Cooper-Jacob Method, Chow Method and Recovery Test Method. Average values of answers by all methods have been used in the analysis.

Calibrated and validated model was used to find out 1974 to 2008 period as well as for future predictions at 2025 and 2050. Existing water was analyzed to understand different component of water pumping, recharge and change in water levels. Various scenarios viz. normal rainfall and no-pumping, roof top water harvesting with recharge and water conservation structure recharge were formulated for sustainable planning and management. 3-D graphical analysis was carried out to understand spatial drawdown patterns, flow patterns as well as to identify potential recharge sites. Following major conclusions were found from the study:

i. Block wise analysis of rainfall has been carried out and presented for future use. Normal annual rainfall in Gurgaon, Farukhnagar, Pataudi and Sohna blocks was 721, 382, 478 and 489 mm, respectively. It was also observed that out of total annual rainfall about 80.62% rainfall was occurring in Monsoon season. Total annual rainfall showed decreasing trend over the span of last 35 years (1974-2008). This situation is alarming for water resources sustainability in the future.

ii. From rigorous review of literature carried out for sustainability of ground water resources for Gurgaon district, it was found out that more than 95% of total requirement of water was from ground water alone. Very high residential and industrial growth as well as growth potential was observed for Gurgaon block in Gurgaon district. Industrial growth has started spreading to other blocks viz. Sohna, Farukhnagar and Pataudi since 2005.

iii. Potential agricultural water demand has been estimated based on Priestely-Taylor method of evapotranspiration calculation. This is significant contribution to the existing knowledge base of demand side management of water resources in Gurgaon district as agriculture is the largest consumer of water.

iv. It was found out from cropping pattern of Gurgaon district that during Kharif season major crop was Bajara which occupied about 54% of total area. Next favorable crop of farmers in Gurgaon district after Bajara was vegetable and oil seed crops. This cash crop was grown in slightly more than 30% of total kharif irrigated area. It is also important to note that rice crop was found to be grown in almost 4.5% area of total kharif irrigated area. Rabi cropping pattern of Gurgaon district revealed that during Rabi season, wheat was mostly grown crop followed by vegetables & Rabi oil seeds. Together these two crops comprised about 93 % of total Rabi irrigated area. Remaining crops were grown in merely 7% of total irrigated area. It was also found out that total irrigated area in Kharif season was 36% of total geographical area and 50.5% of total geographical area in Rabi season.It can be seen from estimations that potential crop water requirement for crop in Kharif season grown in 2004-08 in Gurgaon and Sohna block was about 12000 ha.m and Farukhnagar and Pataudi block was about 10000 ha.m. If we consider that 25% of total crop water requirement in Kharif (rainy) season is satisfied by ground water and remaining requirement is satisfied by rainfall then demand for agricultural crop water in Kharif season for Gurgaon and Sohna block would be around 3000 ha.m and for Farukhnagar and Sohna block would be around 2500 ha.m. Estimations also showed the potential agricultural water demand for crops grown in Rabi season in 2004-08 in Block Gurgaon and Sohna needed about 10000 ha.m water and crop grown in Farukhnagar and Pataudi block needed about 8500 ha.m water. These water demand quantities can be used for broad planning purpose.

v. It was also seen that for year 2025 water demand for agriculture in Kharif was increasing by 2000 ha.m for blocks Pataudi and Farukhnagar and by 4000 ha.m for Gurgaon and Sohna blocks. Thus total agricultural water demand in 2025 Rabi season would be 10000 ha.m for Farukhnagar and Pataudi blocks and 11000 ha.m for Gurgaon and Sohna block.

vi. Trend of population increase from 1971 to 2011indicated that there was sharp increase in population density since 1990's. Total population is increasing in increasing order and there is no sign of population stagnation in near future in Gurgaon district.

vii. Recharge estimation by return flow factor suggest that irrigation recharge quantities for blocks Pataudi and Farukhnagar were about 400 ha.m and for blocks Gurgaon and Sohna 500 ha.m for Kharif season of 2004-08. As area under irrigation will increase by 2025, it can be seen that for all blocks recharge quantities will be increased by 75 ha.m. Thus total recharge for 2025 kharif season is expected to reach to 475 ha.m for Pataudi and Farukhnagar blocks and 575 ha.m for Gurgaon and Sohna block. It was also observed that for 2004-08 Rabi period recharge quantities from Pataudi and Farukhnagar block were nearby 1000 ha.m and for Gurgaon and Sohna block they were nearby 1200 ha.m. It was seen that for Rabi period of 2004-08, recharge will increase by almost 200 ha.m for all blocks making total Rabi recharge to the tune of 1200 ha.m for Pataudi and Farukhnagar block and 1400 ha.m for Gurgaon and Sohna block.

Calculation of recharge due to rainfall by rainfall infiltration method suggest that for monsoon season in which almost 80% of total annual rainfall occurs, recharge from rainfall for Pataudi, Gurgaon, Sohna and Farukhnagar blocks was 2868, 3707, 2489 and 1522 ha.m, respectively for 2004-08 average scenario. Nearly one fourth of these quantities were seen to recharge during non-monsoon season. Thus total annual recharge respectively for Pataudi, Gurgaon, Sohna and Farukhnagar blocks were 3557, 4597, 3087 and 1887 ha.m. But under high water withdrawal conditions (exploitation of ground water resources), which was seen in almost all blocks of Gurgaon, non-monsoon recharge might not reach underground water resources. Therefore only dependable recharge quantities will be monsoon recharge. Under normal rainfall condition, recharge from Pataudi, Gurgaon, Sohna and Farukhnagar would be 2499, 4716, 3119, and 2148 ha.m, respectively in Kharif and 3101, 5853, 3871 and 2664 ha.m respective total annual recharge.

viii. Extensive analysis of pumping and recovery tests data was carried out using four methods viz. Theis Method, Cooper-Jacob Method, Chow Method and Recovery Test Method for determination of transmissibility, specific yield, storage coefficient and hydraulic conductivity. This analysis showed that average transmissibility was varying from 62.03 to 329.8 m^2/day and average transmissibility was 163.44 m^2/day. Corresponding values of hydraulic conductivity were varying from 1.03 to 5.5 m/day with average of 2.72 m/day. Storage coefficient was varying from 0.004 to 0.02 with an average of 0.011. These values have been used for calibration of model.

ix. Precise estimation of water balance of Gurgaon district revealed that there was increase in water level by almost 31 cm per month in 1974-78 which in 2004-08 was decreasing by almost 24 cm per month. For Sohna block water levels in monsoon were increasing (at 1974-78) by almost 21 cm per month which were found out to be decreasing (at 2004-08) by 4 cm per month. For Pataudi block rate of increase in water level was observed to be decreasing from 18.2 cm/month in period 1974-78 to 36.2 cm/month in period 2004-08. For Farukhnagar block water levels were increasing at slow pace of 0.5 cm/month in 1974-78 while water level was decreasing by 10.8 cm in 2004-08. Same situation was observe in non-monsoon season and rate of water level decrease was from 16.3 to 63.4 cm/month for Gurgaon block, 15.7 to 40.3 cm/month for Sohna block, 24.9 to 48.6 cm/month for Pataudi block and 17.1 to 26.6 cm/month for Farukhnagar block.

x. It can be clearly observed from the water balance of Gurgaon block that availability of water in Gurgaon block was dependent on the horizontal exchange of the water quantities. It was found out from the given out horizontal water quantities that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were reducing irrespective of recharge quantities. Gurgaon block was donating water quantity of 16777 m^3/day in 1974-78 monsoon period which was observed to donate meager 2884 m^3/day in 2004-08 monsoon period. In non-monsoon season, Gurgaon block was observed to give 12923 m^3/day in 1974-78 was found to give very little 1784 m^3/day in 2004-08.

xi. It can be clearly observed from the water balance of Sohna block that water balance of this block was dependent on the horizontal exchange of the water quantities received from other blocks. It was found out from the received horizontal water quantities in Sohna block that over the years from 1974 to 2008 that in monsoon and non-monsoon season, received quantities were reducing irrespective of recharge quantities. Sohna block was receiving water quantity of 9267 m^3/day in 1974-78 in monsoon period was observed to receive 2222 m^3/day in 2004-08 monsoon period. In non-monsoon season, Sohna block was observed to receive 7493 m^3/day in 1974-78 and it was found to take very little 1626 m^3/day in 2004-08. .

xii. It can be clearly observed from the water balance of Farukhnagar block that availability of water in Farukhnagar block was dependent on the horizontal exchange of the water quantities. Clear impact on the flow pattern change was observed on the Farukhnagar block. Due to exploitation of water in Gurgaon, Sohna and Pataudi block, water generated and received in the block was seen to go to other blocks. It was found out from the given out horizontal water quantities over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were increasing irrespective of recharge quantities.

xiii. It can be clearly observed from the water balance of Pataudi block that availability of water in the block was dependent on the horizontal exchange of the water quantities. Clear impact on the flow pattern change was also observed on the Pataudi block. Due to exploitation of water in Gurgaon and Sohna block, water from Farukhnagar was observed to be divided between Patadi block and Gurgaon block. It was found out from the given out horizontal water quantities that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were decreasing irrespective of recharge quantities.

xiv. Two distinct phases of water balance trend of Gurgaon district can be clearly identified during study period of 1974 to 2008. In monsoon season, from 1974-78 to 1994-98 there was water deficit water budget and from 1999-03 onwards surplus water budget was observed. In non-monsoon season exact opposite trend was seen. Water deficit in non-monsoon season presents huge challenge in future water sustainability of the Gurgaon district. All blocks in Gurgaon district except Farukhnagar block had good rainfall in 1999-03 and 2004-08 periods. These rainfall quantities were unable to satisfy water requirement over the entire year. Rainfall has shown effect on only monsoon season, in which water balance was little surplus. Unless prohibition on water withdrawal and compulsory recharge in Gurgaon district is implemented, water sustainability of Gurgaon district will be in jeopardy.

xv. Future prediction using Modflow model suggest that in 2025 monsoon season all blocks in Gurgaon district will have little water quantities remained after satisfying all needs under normal rainfall condition. It was also observed that in 2025 non-monsoon season, Farukhnagar and Pataudi block will have little water quantities remained after satisfying all needs and Gurgaon and Sohna blocks will have deficit water budget under normal rainfall condition.

xvi. Future prediction using Modflow model suggest that Gurgaon block will have maximum drawdown of 9.61 meter in 2025 followed by Pataudi block with 6.41 meter. Drawdown of Farukhnagar and Sohna will be lowest in district in 2025 with values of 3.31 and 3.61 meter, respectively. Average monthly drawdown in monsoon and non-monsoon will be 51 and 94 cm/month for Gurgaon block. There will be negligible positive drawdown of few millimeters in monsoon season and 45 cm/month drawdown in non-monsoon season for Sohna block. Calculations show that Farukhnagar block will have about 14 cm/month and 34.5 cm/month drawdown in monsoon and non-monsoon season. Pataudi will have second highest drawdown of 26 cm/month in monsoon and about 66cm/month drawdown in non-monsoon season. These demands are considerably higher than 2004-08 period in both monsoon and non-monsoon period.

xvii. Year 2050 Modflow model prediction for monsoon season indicates that all blocks in Gurgaon district except Farukhnagar block will have surplus water budget under normal rainfall condition. This surplus quantity will be very little.

Compared to this in 2050 non-monsoon season suggest that all blocks in Gurgaon district except Pataudi block will have surplus water budget. Even though surplus water quantities will be very little considering prolonged period of eight months, surplus water budget has importance. Reduction in total area under irrigation will have clear impact on water budget of 2050 monsoon and non-monsoon season. But if equivalent amount of irrigation water will be required by agro based and other industries then there will be alarming situation in Gurgaon district. By 2050, it was seen that, target block to be considered will be Pataudi block which was showing deficit water budget.

xviii. Year 2050 Modflow model prediction for Gurgaon district shows that Gurgaon, Sohna, Farukhnagar and Pataudi blocks will have drawdown of 13.98, 4.24, 3.64 and 7.13 meter, respectively.

xix. Under normal rainfall condition with no-pumping there will be huge rise in water table of all blocks in Gurgaon district. Increase in water table in monsoon season for Gurgaon, Sohna, Pataudi and Farukhnagar blocks will be 6.14, 5.56, 5.07 and 1.92 meter, respectively. It was also found out that recharge of normal condition rainfall with no-pumping will produce 0.5775, 0.3959, 0.3128 and 0.3799 ha.m/ha water respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks. This water quantity is equivalent to 19949, 13337, 9285 and 10470 ha.m respectively for Gurgaon, Sohna, Farukhnagar and Pataudi blocks. Year 2004-08 has calculated water withdrawal of 25851, 13931, 12276 and 11394 ha.m respectively for Gurgaon, Sohna, Farukhnagar and Pataudi blocks.

xx. Scenario of normal rainfall and no-pumping suggest that there will be 1.46, 1.22, 1.68 and 0.58 meter rise in water table respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks in monsoon season due to roof top water harvesting done on 100 km^2 equivalent roof top area and water was recharged. It can be also be seen from this scenario that there will be 1.12, 0.94, 1.29 and 0.44 meter rise in water table respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks in monsoon season due to water conservation structure assisted recharge done on 100 km^2 equivalent drainage area and water was recharged.

Both water conservation scenarios suggest that even one third area of total block area is brought down under water recharge methods, total recharge quantities will not be sufficient to replenish the yearly demand of water. Normal rainfall along with one third of total block area under recharge structures will be able to satisfy only two third of total water demand. Therefore right strategy for sustainability of groundwater resources of Gurgaon district will be to decrease demand and increase recharge simultaneously. Top most water demanding sector viz. agriculture and industry should be supplied with water resources from outside the district areas .

xxi. For effective planning and management activities which will ensure sustainable water development in Gurgaon district, 3-D drawdown contour diagrams were prepared with the help of Surfer program. With the help of these diagrams spatial change in water table, water flow pattern and identification of potential sites for recharge has been carried out and presented for possible future use.

6.2 Recommendation

By extensive analysis of various types of data viz. cropping pattern, population , number and types of industries, animal census, water level observations, geological formations, soil properties, aquifer parameter etc. and use of different methodologies viz. water budgeting, calibration and validation, simulation, normalization, programming, model formulation, scenario generation, graphical analysis, regression etc.; different components of water intake and withdrawal were studied for sustainability of water resources of Gurgaon district. Because of this comprehensive and holistic approach, various facts were revealed which might help for future research, analysis, planning, management as well as policy making. Following points cover these various facts:

i. In older times Gurgaon was considered as the barren land only. Even in this barren land various water courses and drainage networks were present. But with the development of this area to world class city, these networks have been vanished. With the planned development of sewerage water lines older natural sewerage courses has been vanished and benefit of recharge water has been reduced. Therefore modern plans of sewage treatment plants should consider for treating water for recharge purpose .

ii. It was observed that lot of water is flowing out of district through storm water drainage network. These water quantities can be used for domestic and recharge purpose very effectively .

iii. Because of huge water deficits and comparable water table fall in the Gurgaon district, there is need of specific strategy for recording tube well observations in the district. Existing observation wells should be classified according to dominant type of water use in the surrounding area. If such classification is not possible in some areas then special observation wells should be identified or installed for specific type of water use. Main idea behind the classification of observation wells should be evaluation of total draft for specific use in the area.

iv. Existing and new observation wells should identified in accordance to the water flow direction in and among the different blocks of Gurgaon district.

v. For effective planning of natural resources in Gurgaon district, there is need to carry out natural surface elevation as well as land use map at maximum 10 meter by 10 meter grid .

vi. It was observed that water balance of all blocks in Gurgaon district were dependent on the horizontal exchange of water quantities. Therefore for identification of water flow pattern and water quantities in underground layers, there is need of use of modern technologies like tracer technologies .

vii. Agriculture and Industrial water use were the dominant water use sector in the Gurgaon district. For sustainability of water resources arrangement of alternative canal irrigation should be planned for both industrial and agricultural water use.

viii. Water resources of Gurgaon district should be analyzed for surface water and underground water resources together .

ix. Water recharge schemes should be immediately implemented in Gurgaon district not only for the water use in the area but also to stop salt water intrusion in to drinkable water resources. There were some areas identified in the Gurgaon district with salty water and these need special attention .

x. Immediate actions for water recharge should be taken in the area as there is danger of underground water system closure and destruction of natural flow pattern. This will also impose threat to the caving-in of land at many places due to collapse of empty porous aquifers in the region.

References

REFERENCES

1. Agarwal A., (2001), "Drought? Try Capturing the Rain", Briefing Paper for Members of Parliament and State Legislatures. An occasional paper from the Centre for Science and Environment, New Delhi.
2. Ahuja L.R. and El-Swaify S.A., (1979), "Determining soil hydrologic characteristics on a remote forest watershed by continuous monitoring of soil-water pressures, rainfall and runoff", Journal of Hydrology, Vol. 44, pp. 135-47.
3. Ali R. and Turner J.V., (1997), "Artificial recharge of surface water into the paleochannel aquifer systems of the eastern goldfields", Center for Groundwater Studies CSIRO Land and Water, http://www.ciw.csiro.au/research/catchment/ecosystems/projects/kalgoorlie.htm (date of citation 15-1-08)
4. Allison G.B., Cook P.G., Barnett S.R., Walker J.R., Jolly I.D. and Hughes M.W., (1990), "Land clearance and river salinization in the western Murray basin, Australia", Journal of Hydrology, Vol. 9, pp. 1-20.
5. Asano T., (1985), "Artificial Recharge of Groundwater", Buttenworth Publishers, Boston.
6. Ashok R.P.C., (1979), "Onset of Effective monsoon and critical dry spells, a computer based forecasting technique", Water Technology Centre, IARI Publ. New Delhi.
7. Babu R. and Singh D.K., (2003), "Impact analysis of water supply and demand on groundwater behaviours – A Case Study", Journal of Agricultural Engineering, Vol. 40,No.3, pp 51-62.
8. Babu Ram, (1978), "Groundwater management in agriculture", M.Sc. Thesis, Division of Agriculture Engineering, IARI, New Delhi.
9. Baveye P., Vandevivere P., Hoyle B.L., DeLeo P.C. and Sanchez de Lozada, D., (1998), "Environmental impact and mechanisms of biological clogging of saturated soils and aquifer materials", Crit. Rev. Environ. Sci. Technol., CRC press, Vol. 28, No.2, pp 123-191.

10. Bhattacharya A.K., Michael A.M., (2003), "Land Drainage: Principles, Methods and Applications", ISBN: B122006558.

11. Biwalkar N., and Taneja D.S., (2003), "Artificial groundwater recharge in foothill region of Punjab", proc. of XXXVI ISAE annual convention and symposium, CTAE, MPAUT, Udaipur, 29-31.

12. Bouwer H., Rice R.C., (1989), "Effect of water depth in groundwater recharge basins on infiltration rate", Journal of Irrigation Drain Div, Am Soc Civil Eng Vol. 115, No.4, pp 556-568.

13. Bouwer H. (2000), "The recharge of groundwater", Proc of Natural Recharge of groundwater Symp. Temp, Arizona, USA, Arizona Hydro Soc, pp 89-95.

14. Houwer H., Ludke J., Rice R.C. (2001), "Sealing pond bottoms with muddy water", Journal Ecol Engg. Vol. 18, No.2, pp 233-238.

15. Bouwer H. and Rice R.C., (2001), "Capturing floodwater for artificial recharge of groundwater", Proc. 10th Biennial Symp. Artificial recharge of groundwater, Tucson, Arizona, Arizona Hydrological Society, pp 99-106.

16. Bouwer H., (2002), "Artificial recharge of groundwater: Hydrology and engineering", Hydrology journal. Vol.10, pp 121-142.

17. Brand C.C., (2003), "Groundwater recharge potential in the upper black squirrel creek basin, Colorado", Paper presented at the 11th Biennial Symposium on Groundwater Recharge, Phoenix, AZ, June 5-7, 2003.

18. Braun G.M., Norman S. and Roberts S.J., (2001), "Identification of groundwater recharge areas in Waukesha county, Wisconsin for regional aquifer protection, Groundwater Availability Modeling", Hynes Convention Center, The Geological Society of America (GSA), p.312

19. Browe C., Prins K., Kay M. and Heibloem M., (1985), "Irrigation Water Management: Irrigation Methods", Training manual No. 5, Provisional edition, FAO – Food and Agriculture Organization of The United Nations.

20. Catherine C., (2004), "Water resources and groundwater", Lecture Notes, Department of Geology, University of Maryland, http://www.geol.umd.edu/~kate/ (30/6/2004).

21. CGWB, (1994), "Hydro geological framework and Groundwater Resource Potential," Bulandshahr District, Uttar Pradesh, Central Ground Water Board.

22. CGWB, (1995), "Groundwater Resource of India", Central Ground Water Board, Ministry of Water Resources, Govt. of India, Faridabad.

23. CGWB, (1997), "Groundwater estimation methodology", Central Ground Water Board, Ministry of Water Resources, Govt. of India.

24. CGWB, (2000), Annual Report, Ministry of Water Resources, Govt. of India, New Delhi, India.

25. CGWB, (2000), Ground Water Year Book, Uttar Pradesh, (1998-1999), Central Ground Water Board.

26. CGWB, (2009), Reprint Detailed guidelines for implementing ground water estimation methodology, Central Ground Water Board Press. Available online also

27. Chambers Robert ,(1988), "Managing Canal Irrigation", Oxford, England and New Delhi, India: Oxford IBH Publishing Company Pvt. Ltd.

28. Chandrashekharan H. ,(2003), Geoelectrical survey of IARI farms conducted by Dr. H. Chandrashekharan and figures adopted by personal communication with him.

29. Chaturvedi R.S., (1973), "A Note on the Investigation of Ground Water Resources in Western Districts of Uttar Pradesh", Annual Report, U.P. Irrigation Research Institute, pp. 86-122.

30. Childs E.C., (1969), "An introduction to the physical basis of soil water phenomena" Wiley, London.

31. Chong S.K., Green R.E., Ahuja L.R. ,(1981), "Simple *in-situ* determination of hydraulic conductivity by power function descriptions of drainage", Water Resource Res., Vol. 17, pp. 1109-1114.

32. Chow V.T., Maidment D.R. and L.W. Mays., (1988), "Applied Hydrology", McGraw-Hill, 0-07-100174-3.

33. Cook P.L.G., Walker G.R., Brusseli G., Potts I and Dodds A.R., (1992), "The application of electromagnetic techniques to groundwater recharge investigations", Journal of Hydrology Vol.130,pp.201-229.

34. Coplen T.B. ,(1993), "Uses of Environmental Isotopes, in Regional Ground Water Quality", Chap. 10 (Alley, W.A., Ed.), Van Nostrand Reinhold, New York, pp.227-254.

35. Coudrain-Ribtein A., Pratx B., Talbi A. and Jusserand C. ,(1998), " L' evaporation des nappes phreatiques sous climat arid east-alle indipendante de la nature do sol?", CR Aead Sci Paris Sci teree Planet Vol. 326,pp. 159-165.

36. CWC, (2000), "Water and Related Statistics", Central Water Commission, Ministry of Water Resources, Govt. of India, New Delhi, India.

37. Das S.N., Narula K.K. and Laurin R. ,(1992), "Runoff potential indices of watersheds in Tilaiya catchment, Bihar (India) through use of Remote Sensing and implementation of GIS", Journal of Indian society of remote sensing, Vol. 20, No.4.

38. Datta P.S., (1999), "Groundwater Situation in New Delhi: Red Alert", Nuclear Research Laboratory, IARI, New Delhi

39. De Vries, J.J. and Simmers I., (2002), "Groundwater recharge: an overview of processes and challenges", Hydrology journal, Vol. 10,pp. 5-17.

40. DEQ, (2001-2004), "Groundwater modeling, general concepts", Department of environment and quality, Mishingan. Gov http:///www.michigan.gov/ (24/06/2004).

41. Dhawan B.D. ,(1989), "Studies in Irrigation and Water Management", commonwealth Publication, New Delhi, India.

42. Domenico P.A. and Schwartz F. W. ,(1998), "Physical and chemical hydrogeology", John Wiley, Chap 2.

43. Enfield C.G., Hsieh J.J.C., Warrick A.W. ,(1973), " Evaluation of water flux above a deep water table using thermocouple psychrometers", Soil Sci Soc Am Proc Vol.37 ,pp. 968-970.

44. Foster S.S.D., Bath A.H. and Lewis W.J. ,(1982), "The likelihood of active groundwater recharge in the Botswana Kalahari", Journal of Hydrology, Vol. 55,pp. 113-136.

45. Freeze R.A. and Cherry J.A. ,(1979), " Groundwater", Prentice-Hall Inc., Engelwood Cliffs.

46. Garbrecht J., Ogden F.L., DeBarry P.A. and Maidment D.A. ,(2001), “GIS and distributed watershed models. I: Data Coverages and Sources”, Journal of Hydrologic Engineering, Nov./Dec. pp. 506-512.

47. Gardner W.R. ,(1964), “Water movement below the root zone”, In: Proc. 8th Int. congr. Soil Sci., Bucharest, 31 Aug-9 Sept, Rompresfilatelia, Bucharest, pp. 317-320.

48. Gee G.W., Wierenga P.J. ,Andraski B.J., Yound M.H., Frayer M.J. and Rockhold M.L., (1994), “Variations in water balance and recharge potential at three western desert sites”, Soil Sci. Soc. Am. Journal Vol. 58, pp. 63-71.

49. Harrington R.F. ,(1998), “Multiple regression modeling of water table response to pumping and runoff.” Report on fle at Inyo country Water Dept. and Los Angels Dept. of Water and Power, Northern Aquaduct Divisioin.

50. Healy R.W. and Cook P.G. ,(2002), “ Using groundwater levels to estimate recharge”, Hydrology Journal, Vol. 10, pp.19-109.

51. Houston J.F.T. ,(1983), “ Ground-water systems simulation by time-series techniques”, Ground Water, Vol. 21, No.3,pp.301-310.

52. James W.M. and Charles R.F. ,(1980), “ Ground Water Modeling: An overview”, Vol.19, No.2, pp. 108-115.

53. James W.M. and Charles R.F., (1981), “Ground Water Modeling: An overview”, Vol. 18, No.5, pp. 395-403.

54. Johnson S., Gary Cosgrove M. and Joe Spinazolla, (1998), “Use of MODFLOW for development of Response functions”, MODFLOW’98, GOLDEN, CO. International Groundwater Modelling Center and Colorado School of mines. www.if.uidaho.edu/SR3/MODFLOW98.html . 05.12.2002.

55. Jyotiprakash V., Marimuthu G., Murlidharan R. and Senthilkumar N. ,(2003), “Delineation of potential zones for artificial recharge using GIS, Photonirvachak”, Journal of Indian Soc Remote Sensing, Vol. 31. No-1.

56. Kaledhonkar M.J., Singh O.P., Ambast S.K., Tyagi N.K. and Tyagi K.C., (2003), “Artificial groundwater recharge through recharge tube wells: A case study”, IE(I) Journal – AG, Vol. 84, pp. 28-32.

57. Kengni L., Vachaud G., Thony J.L., Laty R., Garino B., Casabianca H., Jame P. and Viscogliosi R. ,(1994), " Field measurements of water and nitrogen losses under irrigated maize", Journal of Hydrology, Vol. 62,pp. 23-46.

58. Kumar P., Tiwari K.N. and Pal D.K. ,(1997), " Establishing SCS runoff curve number form IRS digital database", Journal of Indian Society of Remote Sensing, Vol. 19,No.4,pp. 246-251.

59. Latinopoulos P. ,(1981), "The response of groundwater to artificial recharge schemes", Water Resource Res.,Vol. 17, pp. 1712-1714.

60. Larner D.N. ,(1997), "Groundwater recharge. In: Saether OM, de Caritat P (eds) Geochemical processes, weathering and groundwater recharge in catchments", AA Balkema, Rottrdam, pp. 109-150.

61. Lerner D.N. ,(1990), "Groundwater recharge in urban areas", Journal of Atmospheric Environment, Vol.24,No.1,pp. 29-33.

62. Lerner D.N. ,(2002), "Identifying and quantifying urban recharge: A review", Hydrogeology Journal ,Vol. 10,pp. 143-152.

63. Lerner D.N., Issar A.S., Simmers I. ,(1990), "Groundwater recharge: A guide to understanding and estimating natural recharge", IAH Int. contrib.. Hydrogeol. 8 Heinz Heise, Hannover, pp. 345.

64. "Manual on Water Supply & Treatment", 2009 (3rd Edition), Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, Government of India.

65. Manglik A. and Rai S.N. ,(2002), " Modelling of water table fluctuations in response to time varying and withdrawal", Water Resources Management, Vol. 14,pp. 339-347.

66. McCartney M.P. and Houghton-Carr H.A., (1998), " An assessment of groundwater recharge on the Channel Island of Jersey", Journal-Inst-Water-Environment-Manag. Lavenham, Suffolk, England: Terrence Dalton Ltd. Dec. 12(6): 445-451.

67. Meinger O.E., (1923), "The occurrence of groundwater in United States with a discussion of principles",US Geological Survey Water Supply Paper, 489, pp. 321.

68. Meinger O.E. and Stearns N.D. ,(1929), "A study of groundwater in the Pomperaug Basin, Conn with special reference to intake and recharge" , US Geological Survey Water Supply Pap 597B,pp. 73-146.

69. National Academy of Sciences (1974). More Water for Arid Lands: Promising Technologies and Research Opportunities, Washington DC.

70. Nigam A., Gujja B., Bandyopadhyay J. and Talbot R. ,(1997), " Fresh Water for India's Children: A Draft Report Based on Local Studies", WWF/UNICEF India.

71. Normand B., Recous S., Vachaud G., Kengni L. and Garino B. ,(1997), " Nitrogen-15 tracers combined with tension-neutronic method to estimate the nitrogen balance of irrigated maize", Journal of Soil Science Society Vol. 61,pp. 1508-1518.

72. Pandey V.K., Panda S.N. and Sudhakar S. ,(2002), "Curve Number Estimation for Watershed using Digital Image of IRS-1D LISS-III", http://www. gisdevelopment.net/technology/ (10/9/2003).

73. Prych E.A. ,(1998), "Using chloride and chlorine-36 as soil water tracers to estimate deep percolation at selected locations on the US Department of Energy Hanford site, Washington", US Geological Survey, Water supply paper 2481,pp.67.

74. Querner E.P., (2000), "The effects of Human intervention in the groundwater regime", Groundwater,Vol. 38,pp. 168-171.

75. Rao N.H. and Sarma P.B.S., (1981), "Groundwater recharge from rectangular areas", Groundwater,Vol. 19,No.3,pp. 271-274.

76. Ravella M., Lanceand D. and Allen T. ,(1996), "Potential Aquifer Recharge Locations in the Keene Area", Department of Geology, Mailstop 2001, Keene State College, Keene, NH 03435.

77. Roy S.K., (2001), "Applications of Isotopic Tracers in Water Resource and Environmental Investigations", http://www.enviro-institute.com (22-07-04).

78. Sakhivadivel R. and Chawla A.S., (2002), "Innovations in Conjunctive water management Artificial recharge in Madhya Ganga canal project", IWMI-TATA water policy research program, Annual partners meet 2002.

79. Sanford W., (2002), "Recharge and groundwater models: an overview", Hydrology Journal, Vol.10, pp. 110-120.

80. Sarkar T.K., (1980), "Drainage system design", A drainage plan for the Institute Research Farm, Water Technology Centre, IARI, New Delhi-110012.

81. Scanlon B.R., Healy R.W. and Cook P.G., (2002), "Choosing appropriate techniques for quantifying groundwater recharge", Hydrology Journal, Vol. 10,pp. 18-39.

82. Schicht R.J., Walton W.C., (1961), "Hydrologic budgets for three small watersheds in Illinois", III State Water Survey Rep Invest 40:40.

83. Seckler D., Molden D. and Baker R., (1989), "Water scarcity in the 21st Century", IWMI water brief, International Institute of Water Management, Colombo, Sri Lanka, pp.20.

84. Shah T., Molden, D., Sakhivaddivel R. and Seckler D., (2000), "The Global Groundwater Situation: Overview of Opportunity and Challenges", Monograph, International Institute for Water Management, Colombo, Sri Lanka, pp.20.

85. Sharma P.B.S., Rao N.H. and Sharma R.K., (1979), "Assessment of water resource potential of IARI farm and scope for development", Water Technology Centre, IARI, Technical report No.HYD-V, pp-22.

86. Singh D.K., (2002), "Groundwater Development, Use and Management in India", National Training Program on Watershed Based Water Management for Sustainable Development, October 3-10.

87. Sinha A.K., (1987), "Variations in soil special reflectance related to soil moisture, organic matter and particle size", Journal of the Indian Society of Remote Sensing, Vol.15, No.2.

88. Sisson J.B., (1987), "Drainage from layered field soils: fixed gradient models", Water Resource Res.Vol. 23, pp. 2071-2075.

89. Slack R.B. and Welch R., (1980), "Soil Conservation Service runoff curve number estimates from Landsat data", Water resources bulletin, Vol. 16, No.5.

90. Smith H.F., (1968), "Artificial recharge and its potential in Illinois", Extract of publication No.72 of the IASH Symp of Haifa, pp. 136-142.

91. Soil Conservation Department, (1972), "Handbook of Hydrology", Ministry of Agriculture, Government of India publication, New Delhi.

92. Stanger G., (1995), "Arid zone recharge processes with particular reference to mass balance and isotope estimation in Water Resources Management in Arid Countries", Muscat, Sultanate of Oman, March 1995.

93. Steenhuis T.S., Jackson C.D., Kung S.K. and Brutsaert W., (1985), "Measurement of groundwater recharge in eastern Long Island, New York, USA", Journal of Hydrology Vol. 79, pp. 145-169.

94. Stephens D.B. and Knowelton R.J., (1986), "Soil water movement and recharge through sand at a semiarid site in New Mexico", Water Resource Res Vol. 22, pp. 881-889.

95. Tain-Shing Ma, Deborah L., Hathaway and Adam N. Hobson, (1999), "MODFLOW simulation of transient surface water/Groundwater interactions in a shallow Riparian zone using HEC-2-based water surface profiles", USBR surface-groundwater paper, Contract No: 99-CS-20-2084.

96. Taneja D.S. and Khepar S.D., (1996), "Effect of Artificial groundwater recharge on the aquifer properties using cavity well", Groundwater,Vol. 34,No.2, pp.335-340.

97. Tiwari K.N., Kumar P., Sebastian M. and Pal D.K., (1991), "Hydrologic modeling for runoff determination, remote-sensing techniques", Water Resources Development Vol.7, No.3.

98. Todd D.K., (1980), "Groundwater Hydrology", 2nd edition, John Wiley & Sons, New York, pp. 535.

99. Tyler S.W., Chapman J.B., Conrad S.H., Hammermeister D.P., Blout D.O., Miller J.J., Sully M.J., Ginanni J.M., (1996), "Soil-water flux in the southern Great Basin, United States: temporal and spatial variations", Water Resource Res., Vol. 31, pp. 1491-1499.

100. UNEP. (2000). Sourcebook of Alternative Technologies for Freshwater Augmentation in some countries in Asia, United Nations Environment Programme, Division of Technology, Industry and Economics, International Environmental Technology Centre UNEP, http://www.unep.or.jp/ietc/publications (30/09/2003).

101. Watkins, D.W., McKinney, D.C., Maidment, D.R. and Min-Der Lin. (1996). "Use of geographic information systems in ground water flow modeling", Journal of Water Resources Planning and Management, Vol. 122, No.2, pp. 88-96.

102. Ward R.C. and Robinson M., (1990), "Principles of Hydrology," 3rd Edition London: McGraw-Hill

103. Winter T.C., (2001), "The concepts of Hydrologic Landscapes", Journal of Water Resource Association, Vol. 37, pp. 335-349.

104. World Conservation Union (I.U.C.N.), United Nations Environment Program and Worldwide Fund for Nature (1991), "Caring for the Earth: A Stratergy for Sustainable Living," Earthscan , London.

List of Publications

LIST OF PUBLICATIONS

Published Papers

1. Malik V. K., Singh R. K.and Singh S. K., (2012), "Groundwater modeling with processing MODFLOW for windows (PMWIN), for the water balance study and sustainable recharge site: A case study of Gurgaon district, Haryana, India," International Journal of Application or Innovation in Engineering & Management, Vol. 1, No.1, pp.72-84.
2. Malik V. K., Singh S. K. and Singh R. K., (2012), "Application of processing MODFLOW for windows (PMWIN) for sustainable groundwater resources study for Gurgaon district, Haryana, India," International Journal of Engineering Science and Technology, Vol. 4, No.9, pp. 3988-4002.
3. Singh R. K., Malik V. K. and Singh S. K., (2012),"Groundwater sustainability versus urbanization: a case study from Haryana," Proceedings WARMICE-2012, Sudhir Kumar et al., (eds), I.A.H.-2012.
4. Malik V. K., Singh R. K. and Singh S. K., (2010), "Impact of urbanization on groundwater of Gurgaon district, Haryana, India," International Journal of Rural Development and Management Studies, Vol. 5, No.1, pp. 51-63.
5. Malik V. K., Singh S. K. and Singh R. K., (2010), "Impact of climate change on water resources: a review on global perspectives," Journal of Asian Business Management,Vol. 2, No.1, pp. 33-41.
6. Malik V. K., Singh S. K. and Singh R. K., (2011), "Groundwater scenario of Gurgaon district, Haryana," Proceedings of National Conference on "Sustainable and Innovative Solutions for Water Woes," 28 March 2011, Delhi Technological University, Delhi.
7. Malik V. K., Singh S. K. and Singh R. K., (2011), Review Commentary of the Synthesis Report of IPCC's Fourth Assessment Report (AR4) - "Climate Change 2007 with example of Gurgaon district" Proceedings of International Workshop on "Adaptation and Mitigation Options for Tackling the Impacts of Climate Change on Water Resources," 14th March 2011, ITM University

Papers under preparation

1. Malik V. K., Singh S. K. and Singh R. K., (2012), "Use of Modflow for precise estimation of water balance, recharge and spatial aquifer parameters for Gurgaon district."
2. Malik V. K., Singh S. K. and Singh R. K., (2012), "Impact evaluation of artificial recharge using soil and water conservation structures and roof top harvested water on Gurgaon district."
3. Malik V. K., Singh S. K. and Singh R. K., (2012), "Sustainable solutions for over exploited ground water aquifers of Gurgaon district."

Participation in Conferences, Workshop, Seminars, Training

1. International conference on Biodiversity, Environment and Sustainability Challenges for Future, New Delhi, September 4 to 6, 2008, Organized by University of Delhi.
2. First National Congress on "Role of Woman in Disaster Preparedness" Organized by All India Foundation for Peace and Disaster Management with Delhi Disaster Management Authority, 15-16 December, 2009.
3. Workshop on Information Literacy & Competency, 23rd February 2010, Organized by University of Delhi, Delhi.
4. International Workshop on "Climate Change and Water Resources in South Asia" 8-10 August 2009, Organized by UNESCO, Govt. of India, Columbia University and DTU.
5. Training program on "Open Source Geographic Information System- QUANTUM GIS," April 17-18, 2010 jointly organized by KCube Consultancy Services and TERI University.
6. International workshop on "Adaptation and Mitigation Options for Tackling the Impacts of Climate Change on Water Resources," March 14-15, 2011, Organized by UNESCO and ITM University, Gurgaon.
7. National Seminar on "Sustainable and Innovative Solutions for Water Woes", March 8, 2011 organized by Delhi Technological University and Green Institute for Research & Development.
8. Indo-US Bilateral Workshop on "Global Challenges: Climate Change, Water, Environment and Society", March 5-6, 2012, organized by IUSSTF, ITM, University and Michigan Technological University, USA.

Appendices

Table A 1 Information of wells used for analysis

Well No.	Longitude	Lattitude	Diameter	Depth of Well	Ht. of M. Point	RL of NSL
			m	m	m	m
			Gurgaon Block			
1	77.15	28.40	2.70	21.75	1.85	265.75
2	77.09	28.47	2.42	24.40	1.05	251.40
3	77.08	28.51	2.75	28.30	1.75	227.52
4	77.43	28.33	2.35	15.27	1.45	262.38
5	76.90	28.37	3.50	32.98	1.62	228.61
6	76.94	28.35	2.90	23.75	1.05	257.68
7	77.10	28.41	1.86	31.50	1.05	252.47
8	76.94	28.41	2.05	13.70	0.60	258.35
9	76.99	28.37	1.55	32.15	0.92	260.47
10	76.92	28.42	1.50	11.05	0.65	222.30
11	76.08	28.43	3.30	23.90	0.58	247.90
12	77.50	28.48	0.10	42.16	0.40	225.37
13	76.99	28.50	0.10	24.99	0.37	211.86
14	77.02	28.01	0.10	25.30	0.58	-
15	76.94	28.35	0.10	30.47	0.60	284.25
16	77.03	28.42	2.44	15.20	1.22	219.99
17	76.96	28.51	1.20	17.50	0.70	214.38
18	77.17	28.44	1.32	12.07	0.30	227.38
19	77.13	28.40	-	-	1.15	258.78
20	76.99	28.50	-	-	1.20	211.86
			Farukhnagar Block			
21	76.68	28.41	2.00	12.45	1.20	222.46
22	76.98	28.46	2.20	12.60	0.80	215.31
23	76.89	28.38	2.95	26.30	1.55	255.24
24	76.84	28.37	2.60	17.90	0.60	270.91
25	76.88	28.40	1.90	14.40	0.90	236.24
26	76.95	28.49	2.10	10.84	0.48	220.80
27	76.83	28.48	2.50	12.25	1.00	222.28
28	76.10	28.43	2.70	10.20	0.30	222.48
29	76.95	28.46	1.88	10.88	1.01	218.79
30	76.91	28.48	2.70	10.80	1.30	221.79
31	76.78	28.46	2.40	9.80	0.50	227.00
32	76.82	28.45	2.70	10.40	0.00	228.47
33	76.75	28.40	2.10	14.50	0.90	223.06
34	76.83	28.45	2.70	13.20	0.45	220.52
35	76.81	28.40	2.64	10.08	0.80	258.58
36	76.75	28.46	2.28	10.00	0.60	223.68
37	76.83	28.45	0.10	20.85	-	-
38	76.84	28.37	0.10	36.40	-	-
39	76.83	28.48	0.10	30.00	-	-
40	76.93	28.47	0.10	49.00	-	-

Continued..........

Well No.	Longitude	Lattitude	Diameter m	Depth of Well m	Ht. of M. Point m	RL of NSL m
			Pataudi Block			
41	76.77	28.26	2.50	10.90	0.60	228.62
42	76.97	28.33	2.50	35.70	0.85	259.60
43	76.83	28.27	0.10	21.91	0.75	256.47
44	76.69	28.35	2.35	18.70	0.35	254.40
45	76.75	28.43	0.10	15.54	0.60	224.56
46	76.75	28.33	1.40	17.35	0.70	213.10
47	76.84	28.30	0.10	24.86	0.95	266.53
48	76.23	28.30	0.10	27.19	1.90	250.78
49	76.70	28.32	0.10	26.41	1.10	227.18
50	76.86	28.87	0.10	41.00	1.00	-
51	76.70	28.30	0.10	51.00	1.00	-
			Sohna Block			
52	77.07	28.35	2.90	12.80	0.80	233.64
53	77.34	28.29	2.06	11.00	0.74	211.08
54	77.12	28.31	1.80	9.95	0.66	240.05
55	77.08	28.27	2.63	13.60	1.30	212.49
56	77.21	28.26	2.80	9.29	1.50	195.09
57	77.07	28.28	2.80	14.40	1.30	214.77
58	77.26	28.40	2.54	13.46	1.00	197.86
59	77.10	28.33	2.70	13.00	1.10	220.24
60	77.08	28.40	2.40	12.49	1.06	207.35
61	77.16	28.28	2.10	9.70	0.83	203.88
62	77.10	28.39	1.32	26.88	0.83	256.20
63	77.03	28.21	2.85	24.60	0.50	223.84
64	77.10	28.34	2.80	10.59	0.83	229.55
65	77.03	28.36	3.20	28.04	1.06	221.20
66	77.16	28.26	3.00	8.40	1.00	214.23
67	77.06	28.31	1.85	18.05	0.90	221.64
68	77.05	28.24	2.72	12.30	0.50	197.27
69	77.07	28.25	0.10	29.15	1.50	200.27
70	77.05	28.06	4.00	27.43	0.70	-
71	77.05	28.06	0.10	27.43	-	-
72	77.08	28.30	3.40	14.40	1.20	-
73	77.12	28.29	2.80	8.80	0.87	-
74	77.12	28.37	2.20	15.06	0.70	-
75	77.10	28.31	-	-	-	-

Table A 2 Depth to water table for Gurgaon Block in District Gurgaon (meter)

Well	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
1	GGN	NA		10.91	10.29	10.24	10.19	11.42	11.44	13.33	11.99	13.69	13.01	14.78	14.37
2	GGN	18.34	17.85	17.71	17.59	16.68	15.93	17.92	17.77	20.85	20.31	NA		NA	
3	GGN	16.35	13.89	15.33	15.10	15.29	15.08	20.70	20.62	23.18	24.13	26.72	26.71	NA	
4	GGN	NA		12.05	10.59	11.35	9.98	12.35	12.17	NA		NA		NA	
5	GGN	17.06	16.18	15.60	15.67	20.62	19.36	24.73	24.87	26.93	26.24	28.72	28.25	NA	
6	GGN	15.50	13.69	12.91	12.39	17.29	15.87	21.50	20.66	21.58	18.41	24.12	21.82	27.20	27.20
7	GGN	NA		16.45	15.96	16.75	16.13	18.52	18.37	21.29	21.05	25.77	26.48	NA	
8	GGN	5.44	4.20	5.73	5.58	6.94	6.31	10.83	10.16	10.80	8.83	13.24	13.44	16.40	16.25
9	GGN	NA		15.95	13.62	18.23	16.79	20.25	19.88	21.45	21.00	22.14	22.05	27.86	28.83
10	GGN	6.04	4.38	6.13	5.92	7.25	6.59	8.98	8.95	9.01	7.43	10.23	10.48	NA	
11	GGN	12.29	11.78	14.12	14.10	16.76	16.55	20.82	20.92	20.09	19.91	21.05	21.61	25.15	25.55
12	GGN	15.54	14.43	17.40	17.09	20.38	20.63	26.85	25.40	30.22	30.09	36.98	37.15	36.51	35.46
13	GGN	NA		NA		8.37	7.95	10.38	9.85	10.16	8.40	NA		15.05	15.00
14	GGN	NA		NA		15.26	14.63	17.24	16.48	16.86	13.04	NA		20.73	21.00
15	GGN	NA		15.41	12.24	16.61	16.05	21.44	20.58	19.95	18.18	21.03	20.72	25.28	25.20
16	GGN	7.31	4.87	6.09	6.06	8.32	7.09	NA		NA		NA		NA	
17	GGN	12.46	11.69	10.85	10.97	16.21	15.67	NA		NA		NA		NA	
18	GGN	5.00	3.07	6.46	6.04	7.12	7.07	11.25		NA		NA		NA	
19	GGN	NA		NA		NA		9.48	8.18	NA		NA		NA	
20	GGN	NA		NA		NA		NA		NA		NA		NA	

Table A 3 Depth to water table for Farukhnagar Block in District Gurgaon (meter)

Well No	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
21	FNR	NA		7.07	6.58	7.09	6.72	10.43	9.97	11.66	11.17	12.70	12.65	17.37	18.02
22	FNR	3.16	2.01	4.12	3.67	5.54	4.09	8.31	7.62	9.71	7.73	9.86	9.34	10.81	10.63
23	FNR	NA		12.21	11.78	13.92	13.38	18.79	18.41	20.26	18.68	21.54	21.84	24.53	24.29
24	FNR	8.78	7.16	9.95	9.55	11.34	10.53	14.81	15.08	15.38	15.02	19.28	17.00	NA	
25	FNR	5.89	4.22	6.16	5.90	9.10	8.24	11.70	11.52	11.62	10.69	14.05	13.73	15.20	15.00
26	FNR	5.96	4.58	5.41	5.31	5.08	4.39	6.04	5.33	5.44	4.38	6.70	6.19	7.69	7.74
27	FNR	3.76	2.64	3.62	3.93	10.15	9.55	10.31	9.96	8.34	7.16	8.90	10.44	NA	
28	FNR	3.46	2.38	5.01	5.02	8.46	7.93	9.38	9.68	NA		NA		NA	
29	FNR	NA		8.23	8.06	8.08	7.64	9.72	9.94	8.44	7.68	8.95	11.90	14.79	17.00
30	FNR	NA		7.08	6.13	6.39	5.80	8.47	8.04	8.58	7.55	10.81	10.07	10.33	10.17
31	FNR	4.02	2.42	3.57	3.44	5.70	4.75	9.75	7.50	NA		NA		NA	
32	FNR	6.55	4.97	6.54	6.92	7.34	6.42	8.43	9.35	NA		NA		NA	
33	FNR	NA		6.94	6.21	7.79	8.13	10.50	10.90	12.54	11.62	NA	12.70	14.60	
34	FNR	4.90	3.55	4.20	4.51	8.25	6.39	12.06	11.35	NA		NA		NA	
35	FNR	4.55	3.00	5.09	5.17	7.48	6.33	NA		NA		NA		NA	
36	FNR	6.13	5.53	8.03	7.33	6.73	6.34	NA		NA		NA		NA	
37	FNR	NA		8.48	7.01	8.62	8.68	12.02	11.76	11.64	9.68	13.85	12.55	14.04	13.79
38	FNR	5.03	3.75	6.34	5.89	8.17	7.49	10.97	10.81	10.89	9.96	13.02	11.80	16.38	17.88
39	FNR	NA		NA		NA		NA		NA		23.80	23.25	26.15	25.94
40	FNR	NA		NA		NA		NA		NA		NA		11.40	10.80

Table A 4 Depth to water table for Pataudi Block in District Gurgaon (meter)

Well No	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
41	PTD	2.59	2.10	5.10	3.11	4.96	4.91	8.85	8.38	NA		NA		NA	
42	PTD	NA		20.93	20.75	20.93	20.89	24.72	24.35	26.32	25.81	29.20	29.13	27.77	28.10
43	PTD	3.54	2.59	5.18	3.86	7.18	6.91	14.20	13.99	13.83	13.29	15.89	16.10	21.85	21.49
44	PTD	4.26	1.88	5.68	5.40	7.30	6.30	16.99	16.39	17.61	16.73	21.04	21.13	24.36	23.85
45	PTD	6.58	3.37	7.40	7.46	10.26	10.64	14.82	14.74	NA		24.10	23.48	29.03	28.66
46	PTD	6.41	4.45	8.09	8.30	11.35	11.33	15.70	14.88	16.13	15.37	NA	16.93	20.22	19.57
47	PTD	5.85	4.02	6.05	5.85	11.37	11.37	17.38	16.97	18.76	17.95	20.27	20.45	23.08	22.23
48	PTD	NA		NA		10.88	11.53	16.70	16.33	19.36	18.60	NA	19.11	NA	
49	PTD	3.54	1.81	5.18	4.90	8.45	7.73	13.64	13.51	17.47	16.51	19.95	19.34	22.25	
50	PTD	NA		NA		NA		NA		NA		NA		21.37	19.13
51	PTD	NA		NA		NA		NA		NA		NA		28.44	27.83

Table A 5 Depth to water table for Sohna Block in District Gurgaon (meter)

Well No	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
52	SHN	4.20	2.19	5.47	5.39	6.25	4.91	8.24	7.12	8.37	6.56	10.10	10.54	14.05	15.95
53	SHN	NA		NA		7.35	5.98	9.66	9.28	8.74	6.85	7.82	6.70	NA	
54	SHN	4.64	3.84	4.90	4.49	5.15	4.86	5.32	4.82	5.41	4.36	7.08	6.42	7.88	7.06
55	SHN	3.93	3.13	3.59	3.60	5.78	5.32	8.01	7.47	9.12	8.16	10.18	10.41	NA	
56	SHN	1.81		2.59	2.00	5.06	4.18	6.03	5.27	5.56	4.41	6.49	5.56	6.13	5.71
57	SHN	4.18	3.17	3.43	3.42	6.85	7.19	10.69	9.93	12.31	10.86	12.13	11.76	NA	
58	SHN	5.55	4.31	4.15	4.19	9.28	7.10	6.82	7.60	5.96	3.34	6.31	5.78	8.50	8.23
59	SHN	NA		4.90	3.02	5.40	4.23	8.56	8.22	9.42	8.22	10.40	10.54	16.90	16.95
60	SHN	5.51	4.15	6.59	6.30	8.45	5.63	10.39	8.98	NA		NA		NA	
61	SHN	4.58	3.31	4.57	4.43	5.39	4.21	7.63	6.87	7.97	6.28	8.15	8.26	13.40	12.11
62	SHN	15.21	13.21	14.43	14.80	15.56	14.65	19.04	18.28	20.87	20.23	24.38	24.45	27.79	27.90
63	SHN	4.08	3.81	9.58	10.24	11.96	9.14	17.90	17.40	19.06	20.25	21.76	21.87	30.00	29.50
64	SHN	NA		5.13	4.08	5.35	4.36	7.54	6.76	8.42	6.87	9.51	8.02	NA	
65	SHN	7.31	5.65	8.31	8.45	15.26	15.37	18.90	18.65	20.05	19.56	23.12	23.04	23.90	25.68
66	SHN	4.59	2.93	4.22	4.14	4.37	3.18	5.98	5.48	5.60	3.80	5.40	5.16	7.10	6.67
67	SHN	NA		11.84	12.37	12.70	12.95	16.15	14.78	16.54	14.60	18.31	18.60	22.00	21.50
68	SHN	3.14	1.93	2.59	2.94	9.85	9.11	NA		NA		NA		NA	
69	SHN	5.41	3.53	7.55	6.55	10.71	9.86	15.41	14.52	15.61	14.32	19.55	18.47	22.59	22.19
70	SHN	5.57	2.83	6.66	6.75	8.53	9.39	NA		NA		NA		NA	
71	SHN	NA		NA		16.04	15.40	19.14	18.81	20.30	19.51	21.01	21.56	23.42	23.33
72	SHN	NA		NA		NA		NA		NA		11.55	11.68	15.53	19.80
73	SHN	NA		NA		NA		NA		NA		17.67	17.56	19.77	22.00
74	SHN	NA		NA		NA		NA		NA		13.95	13.65	15.60	17.80
75	SHN	NA		NA		NA		NA		NA		NA		28.70	25.85

Table A 6 Cumulative Drawdown for Gurgaon Block District Gurgaon for 1974-2008 (meter)

Well	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
No.		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
1	GGN	NA	NA	-0.01	-0.63	-0.67	-0.72	0.51	0.53	2.42	1.08	2.78	2.10	3.87	3.46
2	GGN	0.00	-0.49	-0.63	-0.74	-1.66	-2.40	-0.42	-0.57	2.51	1.97	NA	NA	NA	NA
3	GGN	0.00	-2.46	-1.02	-1.25	-1.05	-1.26	4.36	4.27	6.84	7.79	10.37	10.36	NA	NA
4	GGN	NA	NA	0.00	-1.46	-0.70	-2.07	0.30	0.12	NA	NA	NA	NA	NA	NA
5	GGN	0.00	-0.88	-1.46	-1.38	3.56	2.30	7.67	7.81	9.87	9.18	11.66	11.20	NA	NA
6	GGN	0.00	-1.81	-2.58	-3.11	1.79	0.37	6.00	5.16	6.09	2.92	8.62	6.33	11.70	11.70
7	GGN	NA	NA	0.00	-0.49	0.30	-0.32	2.07	1.92	4.85	4.61	9.32	10.04	NA	NA
8	GGN	0.00	-1.24	0.29	0.14	1.50	0.87	5.39	4.72	5.36	3.39	7.81	8.00	10.96	10.81
9	GGN	NA	NA	0.00	-2.34	2.28	0.84	4.30	3.93	5.50	5.05	6.19	6.10	11.91	12.87
10	GGN	0.00	-1.66	0.09	-0.12	1.21	0.55	2.95	2.91	2.98	1.39	4.20	4.44	NA	NA
11	GGN	0.00	-0.51	1.83	1.81	4.47	4.26	8.53	8.63	7.80	7.62	8.76	9.32	12.86	13.26
12	GGN	0.00	-1.11	1.86	1.55	4.84	5.09	11.31	9.86	14.68	14.55	21.44	21.61	NA	NA
13	GGN	NA	NA	NA	NA	0.00	-0.42	2.01	1.47	1.78	0.03	NA	NA	6.68	6.63
14	GGN	NA	NA	NA	NA	0.00	-0.63	1.98	1.22	1.60	-2.23	NA	NA	5.47	5.74
15	GGN	NA	NA	0.00	-3.17	1.20	0.64	6.03	5.17	4.54	2.77	5.62	5.31	9.87	9.79
16	GGN	0.00	-2.44	-1.22	-1.25	1.01	-0.22	NA	NA	NA	NA	NA	NA	NA	NA
17	GGN	0.00	-0.77	-1.61	-1.50	3.75	3.21	NA	NA	NA	NA	NA	NA	NA	NA
18	GGN	0.00	-1.93	1.45	1.04	2.12	2.07	6.25	NA	NA	NA	NA	NA	NA	NA
19	GGN	NA	NA	NA	NA	NA	NA	0.00	-1.30	NA	NA	NA	NA	NA	NA
20	GGN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Average	0.00	-1.39	-0.19	-0.81	1.33	0.68	4.07	3.49	5.49	4.29	8.80	8.62	9.16	9.28

Table A 7 Cumulative Drawdown for Farukhnagar Block District Gurgaon for 1974-2008 (meter)

Well	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
No.		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
21	F'nagar	NA	NA	0.00	-0.50	0.02	-0.35	3.35	2.90	4.59	4.09	5.63	5.58	10.30	10.94
22	F'nagar	0.00	-1.15	0.96	0.51	2.38	0.93	5.15	4.46	6.55	4.57	6.70	6.18	7.65	7.47
23	F'nagar	NA	NA	0.00	-0.43	1.72	1.18	6.59	6.21	8.06	6.48	9.33	9.64	12.33	12.09
24	F'nagar	0.00	-1.61	1.17	0.77	2.56	1.75	6.04	6.30	6.60	6.24	10.50	8.22	NA	10.50
25	F'nagar	0.00	-1.67	0.27	0.01	3.21	2.35	5.82	5.64	5.73	4.81	8.17	7.85	9.32	9.12
26	F'nagar	0.00	-1.38	-0.55	-0.65	-0.88	-1.57	0.08	-0.63	-0.52	-1.58	0.74	0.23	1.73	NA
27	F'nagar	0.00	-1.12	-0.14	0.17	6.39	5.79	6.55	6.20	4.58	3.40	5.14	6.68	NA	NA
28	F'nagar	0.00	-1.08	1.55	1.56	5.00	4.47	5.92	6.22	NA	NA	NA	NA	NA	NA
29	F'nagar	NA	NA	0.00	-0.17	-0.16	-0.59	1.48	1.71	0.21	-0.55	0.72	3.67	6.56	8.77
30	F'nagar	NA	NA	0.00	-0.95	-0.69	-1.29	1.39	0.96	1.50	0.47	3.73	2.99	3.25	NA
31	F'nagar	0.00	-1.60	-0.46	-0.58	1.68	0.72	5.73	3.48	NA	NA	NA	NA	NA	NA
32	F'nagar	0.00	-1.58	-0.01	0.37	0.79	-0.13	1.88	2.80	NA	NA	NA	NA	NA	NA
33	F'nagar	NA	NA	0.00	-0.73	0.85	1.19	3.56	3.96	5.60	4.68	NA	5.76	7.66	NA
34	F'nagar	0.00	-1.35	-0.70	-0.39	3.35	1.49	7.16	6.45	NA	NA	NA	NA	NA	NA
35	F'nagar	0.00	-1.55	0.55	0.62	2.93	1.79	NA	NA	NA	NA	NA	NA	NA	NA
36	F'nagar	0.00	-0.60	1.90	1.20	0.60	0.21	NA	NA	NA	NA	NA	NA	NA	NA
37	F'nagar	NA	NA	0.00	-1.47	0.14	0.20	3.54	3.28	3.16	1.20	5.37	4.07	5.56	5.31
38	F'nagar	0.00	-1.28	1.30	0.86	3.13	2.46	5.94	5.78	5.86	4.93	7.98	6.76	11.35	12.84
39	F'nagar	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.00	9.45	12.35	12.14
40	F'nagar	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Average	0.00	-1.33	0.32	0.01	1.83	1.15	4.39	4.11	4.33	3.23	6.17	5.93	8.00	9.91

Table A 8 Cumulative Drawdown for Sohna Block District Gurgaon for 1974-2008 (meter)

Well	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
No.		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
52	Sohana	0.00	-2.01	1.27	1.19	2.05	0.71	4.04	2.92	4.17	2.36	5.90	6.34	9.85	11.75
53	Sohana	NA	NA	NA	NA	0.00	-1.37	2.31	1.93	1.39	-0.50	0.47	-0.65	NA	NA
54	Sohana	0.00	-0.80	0.26	-0.15	0.51	0.22	0.68	0.18	0.77	-0.28	2.44	1.78	3.24	2.42
55	Sohana	0.00	-0.80	-0.34	-0.33	1.85	1.39	4.08	3.54	5.19	4.23	6.25	6.48	NA	NA
56	Sohana	0.00	NA	0.78	0.19	3.25	2.37	4.22	3.47	3.75	2.60	4.68	3.76	4.32	3.90
57	Sohana	0.00	-1.01	-0.75	-0.75	2.67	3.01	6.51	5.75	8.14	6.68	7.95	7.58	NA	NA
58	Sohana	0.00	-1.24	-1.40	-1.36	3.73	1.55	1.27	2.06	0.41	-2.21	0.76	0.23	2.95	2.69
59	Sohana	NA	NA	0.00	-1.88	0.50	-0.67	3.66	3.32	4.52	3.32	5.50	5.64	0.00	0.05
60	Sohana	0.00	-1.36	1.08	0.79	2.94	0.11	4.88	3.46	NA	NA	NA	NA	NA	NA
61	Sohana	0.00	-1.26	0.00	-0.15	0.81	-0.37	3.06	2.30	3.40	1.71	3.57	3.69	8.83	7.53
62	Sohana	0.00	-2.00	-0.79	-0.41	0.35	-0.56	3.83	3.07	5.66	5.02	9.17	9.24	12.58	12.69
63	Sohana	0.00	-0.27	5.50	6.16	7.88	5.06	0.00	-0.50	1.16	2.35	3.86	3.97	0.00	-0.50
64	Sohana	NA	NA	0.00	-1.05	0.22	-0.77	2.41	1.63	3.29	1.75	4.38	2.89	NA	NA
65	Sohana	0.00	-1.67	1.00	1.14	0.00	0.10	3.64	3.39	4.79	4.30	7.86	7.78	8.64	10.42
66	Sohana	0.00	-1.66	-0.37	-0.45	-0.22	-1.40	1.40	0.89	1.01	-0.79	0.81	0.57	2.51	2.08
67	Sohana	NA	NA	0.00	0.53	0.86	1.12	4.32	2.95	4.70	2.77	6.47	6.76	10.17	9.67
68	Sohana	0.00	-1.21	-0.55	-0.20	6.71	5.97	NA	NA	NA	NA	NA	NA	NA	NA
69	Sohana	0.00	-1.88	2.14	1.14	5.30	4.45	0.00	-0.89	0.20	-1.09	4.14	3.07	7.18	6.78
70	Sohana	0.00	-2.74	1.09	1.18	2.96	3.82	NA	NA	NA	NA	NA	NA	NA	NA
71	Sohana	NA	NA	NA	NA	0.00	-0.64	3.10	2.77	4.26	3.47	4.98	5.52	7.38	7.29
72	Sohana	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00	0.13	3.99	NA
73	Sohana	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00	-0.11	2.10	4.33
74	Sohana	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00	-0.30	1.65	3.85
75	Sohana	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Average	0.00	-1.42	0.50	0.31	2.12	1.21	2.97	2.35	3.34	2.10	3.96	3.72	5.34	5.66

Table A 9 Cumulative Drawdown for Pataudi Block District Gurgaon for 1974-2008 (meter)

Well	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
No.		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
41	Patoudi	0.00	-0.49	2.51	0.52	2.37	2.32	6.26	5.79	NA	NA	NA	NA	NA	NA
42	Patoudi	NA	NA	0.00	-0.18	0.00	-0.04	3.80	3.43	5.40	4.89	8.28	8.20	6.85	7.18
43	Patoudi	0.00	-0.96	1.64	0.32	3.64	3.37	10.66	10.45	10.29	9.74	12.35	12.55	18.31	17.95
44	Patoudi	0.00	-2.37	1.42	1.14	3.04	2.04	12.73	12.13	13.35	12.48	16.78	16.87	20.10	19.59
45	Patoudi	0.00	-3.21	0.83	0.89	3.68	4.06	8.24	8.16	NA	NA	0.00	-0.62	4.93	4.56
46	Patoudi	0.00	-1.96	1.69	1.89	4.95	4.92	9.29	8.47	9.72	8.96	NA	10.52	13.81	13.16
47	Patoudi	0.00	-1.83	0.20	0.00	0.00	0.00	0.00	-0.41	1.39	0.58	2.89	3.07	5.70	4.85
48	Patoudi	NA	NA	NA	NA	0.00	0.65	5.82	5.45	8.47	7.72	NA	8.23	NA	NA
49	Patoudi	0.00	-1.72	1.64	1.36	4.91	4.19	10.10	9.97	13.94	12.97	16.41	15.80	18.71	18.71
50	Patoudi	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
51	Patoudi	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Average	0.00	-1.79	1.24	0.74	2.51	2.39	7.43	7.05	8.94	8.19	9.45	9.33	12.63	12.29

Table A 10 Average Cumulative Drawdown for Gurgaon District for Period 1974-2008 (meter)

Sr	Block	1974-78		1979-83		1984-88		1989-93		1994-98		1999-03		2004-08	
No.		June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct	June	Oct
1	Pataudi	0.00	-1.79	1.24	0.74	2.51	2.39	7.43	7.05	8.94	8.19	9.45	9.33	12.63	12.29
2	Gurgaon	0.00	-1.39	-0.19	-0.81	1.33	0.68	4.07	3.49	5.49	4.29	8.80	8.62	9.16	9.28
3	Sohna	0.00	-1.42	0.50	0.31	2.12	1.21	2.97	2.35	3.34	2.10	3.96	3.72	5.34	5.66
4	F'Nagar	0.00	-1.33	0.32	0.01	1.83	1.15	4.39	4.11	4.33	3.23	6.17	5.93	8.00	9.91

MODFLOW OUPUT FOR PERIOD 1974-2004 CALIBRATION AND VALIDATION MODEL

```
LISTING FILE: output.dat
                UNIT   3

 OPENING bas.dat
 FILE TYPE:BAS   UNIT   1

 OPENING bcf.dat
 FILE TYPE:BCF   UNIT  11

 OPENING oc.dat
 FILE TYPE:OC   UNIT  22

 OPENING wel.dat
 FILE TYPE:WEL   UNIT  12

 OPENING rch.dat
 FILE TYPE:RCH   UNIT  18

 OPENING pcg2.dat
 FILE TYPE:PCG   UNIT  23

 OPENING budget.dat
 FILE TYPE:DATA(BINARY)   UNIT  50

 OPENING heads.dat
 FILE TYPE:DATA(BINARY)   UNIT  51

 OPENING ddown.dat
 FILE TYPE:DATA(BINARY)   UNIT  52

 OPENING mt3d.flo
 FILE TYPE:DATA(BINARY)   UNIT  32
1
MODFLOW
U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL



 THE FREE FORMAT OPTION HAS BEEN SELECTED
    1 LAYERS       66 ROWS      102 COLUMNS
   14 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS

 BAS5 -- BASIC MODEL PACKAGE, VERSION 5, 1/1/95 INPUT READ FROM UNIT  1
 ARRAYS RHS AND BUFF WILL SHARE MEMORY
 INITIAL HEAD WILL BE KEPT THROUGHOUT THE SIMULATION
     60760 ELEMENTS IN X ARRAY ARE USED BY BAS
     60760 ELEMENTS OF X ARRAY USED OUT OF   20000000

 BCF5 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 11
 TRANSIENT SIMULATION
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
 HEAD AT CELLS THAT CONVERT TO DRY= -0.10000E+31
 WETTING CAPABILITY IS NOT ACTIVE
     LAYER  LAYER-TYPE CODE     INTERBLOCK T
     --------------------------------------------
       1         3        0 -- HARMONIC
```

```
    33661 ELEMENTS IN X ARRAY ARE USED BY BCF
    94421 ELEMENTS OF X ARRAY USED OUT OF   20000000

 WEL5 -- WELL PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 12
 MAXIMUM OF 3861 WELLS
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
    15444 ELEMENTS IN X ARRAY ARE USED BY WEL
   109865 ELEMENTS OF X ARRAY USED OUT OF   20000000

 RCH5 -- RECHARGE PACKAGE, VERSION 5, 6/1/95 INPUT READ FROM UNIT 18
 OPTION 1 -- RECHARGE TO TOP LAYER
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
     6732 ELEMENTS IN X ARRAY ARE USED BY RCH
   116597 ELEMENTS OF X ARRAY USED OUT OF   20000000
0PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.1, 6/1/95
 MAXIMUM OF  50 CALLS OF SOLUTION ROUTINE
 MAXIMUM OF  30 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
 MATRIX PRECONDITIONING TYPE :    1
   40428 ELEMENTS IN X ARRAY ARE USED BY PCG
  157025 ELEMENTS OF X ARRAY USED OUT OF*******
1

           BOUNDARY ARRAY FOR LAYER   1
 READING ON UNIT   1 WITH FORMAT: (20I3)

 AQUIFER HEAD WILL BE SET TO -999.99     AT ALL NO-FLOW NODES (IBOUND=0).

            INITIAL HEAD FOR LAYER   1
 READING ON UNIT   1 WITH FORMAT: (20G14.0)

 OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
 HEAD PRINT FORMAT CODE IS   0    DRAWDOWN PRINT FORMAT CODE IS   0
 HEADS WILL BE SAVED ON UNIT  51    DRAWDOWNS WILL BE SAVED ON UNIT  52

      COLUMN TO ROW ANISOTROPY
 READING ON UNIT  11 WITH FORMAT: (1G14.0)

               DELR
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

               DELC
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

         PRIMARY STORAGE COEF FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

        HYD. COND. ALONG ROWS FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)


              BOTTOM FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

        SECONDARY STORAGE COEF FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

               TOP FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)
0
```

SOLUTION BY THE CONJUGATE-GRADIENT METHOD
----
0 MAXIMUM NUMBER OF CALLS TO PCG ROUTINE = 50
MAXIMUM ITERATIONS PER CALL TO PCG = 30
MATRIX PRECONDITIONING TYPE = 1
RELAXATION FACTOR (ONLY USED WITH PRECOND. TYPE 1) = 0.10000E+01
PARAMETER OF POLYMOMIAL PRECOND. = 2 (2) OR IS CALCULATED : 1
HEAD CHANGE CRITERION FOR CLOSURE = 0.10000E-02
RESIDUAL CHANGE CRITERION FOR CLOSURE = 0.10000E-02
PCG HEAD AND RESIDUAL CHANGE PRINTOUT INTERVAL = 1
PRINTING FROM SOLVER IS LIMITED(1) OR SUPPRESSED (>1) = 0
DAMPING PARAMETER = 0.10000E+01
1
STRESS PERIOD NO. 1, LENGTH = 120.0000

NUMBER OF TIME STEPS = 4

MULTIPLIER FOR DELT = 1.000

INITIAL TIME STEP SIZE = 30.00000

0 WELLS

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1

CUMULATIVE VOLUMES L**3 RATES FOR THIS TIME STEP L**3/T
------------------ ------------------------

IN: IN:
--- ---
STORAGE = 7895968.0000 STORAGE = 263198.9380
CONSTANT HEAD = 0.0000 CONSTANT HEAD = 0.0000
WELLS = 0.0000 WELLS = 0.0000
RECHARGE = 18613322.0000 RECHARGE = 620444.0630

TOTAL IN = 26509290.0000 TOTAL IN = 883643.0000

OUT: OUT:
---- ----
STORAGE = 26507662.0000 STORAGE = 883588.7500
CONSTANT HEAD = 0.0000 CONSTANT HEAD = 0.0000
WELLS = 0.0000 WELLS = 0.0000
RECHARGE = 0.0000 RECHARGE = 0.0000

TOTAL OUT = 26507662.0000 TOTAL OUT = 883588.7500

IN - OUT = 1628.0000 IN - OUT = 54.2500

PERCENT DISCREPANCY = 0.01 PERCENT DISCREPANCY = 0.01

```
 1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  1
------------------------------------------------------------------------------

  CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
  ------------------           ------------------------

      IN:                        IN:
      ---                        ---
       STORAGE =   13377024.0000          STORAGE =     182701.8750
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000            WELLS =        0.0000
      RECHARGE =   37226644.0000          RECHARGE =     620444.0630

      TOTAL IN =   50603668.0000          TOTAL IN =     803145.9380

     OUT:                        OUT:
     ----                        ----
       STORAGE =   50600420.0000          STORAGE =     803091.8750
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000            WELLS =        0.0000
      RECHARGE =        0.0000          RECHARGE =        0.0000

     TOTAL OUT =   50600420.0000          TOTAL OUT =     803091.8750

      IN - OUT =      3248.0000          IN - OUT =       54.0625

PERCENT DISCREPANCY =        0.01     PERCENT DISCREPANCY =        0.01

  1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  1
------------------------------------------------------------------------------

  CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
  ------------------           ------------------------

      IN:                        IN:
      ---                        ---
       STORAGE =   17587608.0000          STORAGE =     140352.7810
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000            WELLS =        0.0000
      RECHARGE =   55839964.0000          RECHARGE =     620444.0630

      TOTAL IN =   73427568.0000          TOTAL IN =     760796.8750

     OUT:                        OUT:
     ----                        ----
       STORAGE =   73422696.0000          STORAGE =     760742.5000
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000            WELLS =        0.0000
      RECHARGE =        0.0000          RECHARGE =        0.0000

     TOTAL OUT =   73422696.0000          TOTAL OUT =     760742.5000

      IN - OUT =      4872.0000          IN - OUT =       54.3750

PERCENT DISCREPANCY =        0.01     PERCENT DISCREPANCY =        0.01
1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  1
```

```
------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                IN:
      ---                                ---
       STORAGE =    21022570.0000          STORAGE =      114498.7110
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000              WELLS =         0.0000
      RECHARGE =    74453288.0000          RECHARGE =      620444.0630

      TOTAL IN =    95475856.0000          TOTAL IN =      734942.7500

      OUT:                               OUT:
      ----                               ----
       STORAGE =    95469336.0000          STORAGE =      734887.9380
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000              WELLS =         0.0000
      RECHARGE =         0.0000            RECHARGE =         0.0000

     TOTAL OUT =    95469336.0000         TOTAL OUT =      734887.9380

      IN - OUT =        6520.0000          IN - OUT =         54.8125

PERCENT DISCREPANCY =          0.01     PERCENT DISCREPANCY =          0.01


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                IN:
      ---                                ---
       STORAGE =    51224120.0000          STORAGE =      986173.0630
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000              WELLS =         0.0000
      RECHARGE =    74462160.0000          RECHARGE =         289.7763

      TOTAL IN =   125686280.0000          TOTAL IN =      986462.8130

      OUT:                               OUT:
      ----                               ----
       STORAGE =    96904800.0000          STORAGE =       46872.2305
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =    28774900.0000            WELLS =      939588.5630
      RECHARGE =         0.0000            RECHARGE =         0.0000

     TOTAL OUT =   125679696.0000         TOTAL OUT =      986460.8130

      IN - OUT =        6584.0000          IN - OUT =          2.0000

PERCENT DISCREPANCY =          0.01     PERCENT DISCREPANCY =          0.00
  1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  2
```

```
-----------------------------------------------------------------------------

  CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
  ------------------           ------------------------

      IN:                          IN:
      ---                          ---
        STORAGE =   81179048.0000          STORAGE =     978120.1250
    CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =        0.0000             WELLS =        0.0000
       RECHARGE =   74471032.0000          RECHARGE =      289.7763

       TOTAL IN =   155650080.0000          TOTAL IN =     978409.8750

      OUT:                         OUT:
      ----                         ----
        STORAGE =   98093632.0000          STORAGE =     38818.9570
    CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =   57549800.0000             WELLS =    939588.5630
       RECHARGE =        0.0000         RECHARGE =        0.0000

      TOTAL OUT =   155643424.0000         TOTAL OUT =     978407.5000

       IN - OUT =       6656.0000          IN - OUT =        2.3750

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.00


1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  2
-----------------------------------------------------------------------------

  CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
  ------------------           ------------------------

      IN:                          IN:
      ---                          ---
        STORAGE =  110954440.0000           STORAGE =     972257.6250
    CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =        0.0000             WELLS =        0.0000
       RECHARGE =   74479904.0000          RECHARGE =      289.7763

       TOTAL IN =   185434336.0000          TOTAL IN =     972547.3750

      OUT:                         OUT:
      ----                         ----
        STORAGE =   99102936.0000          STORAGE =     32956.7813
    CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =   86324696.0000             WELLS =    939588.5630
       RECHARGE =        0.0000         RECHARGE =        0.0000

      TOTAL OUT =   185427632.0000         TOTAL OUT =     972545.3750

       IN - OUT =       6704.0000          IN - OUT =        2.0000

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                     IN:
         ---                                     ---
            STORAGE =   140591232.0000            STORAGE =      967732.0630
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =           0.0000
              WELLS =          0.0000               WELLS =           0.0000
           RECHARGE =    74488776.0000            RECHARGE =         289.7763

           TOTAL IN =   215080000.0000            TOTAL IN =      968021.8130

        OUT:                                    OUT:
        ----                                    ----
            STORAGE =    99973656.0000            STORAGE =       28431.7422
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =           0.0000
              WELLS =   115099592.0000              WELLS =      939588.5630
           RECHARGE =          0.0000            RECHARGE =           0.0000

          TOTAL OUT =   215073248.0000           TOTAL OUT =      968020.3130

           IN - OUT =        6752.0000            IN - OUT =           1.5000

PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                     IN:
         ---                                     ---
            STORAGE =   170115520.0000            STORAGE =      964058.1880
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =           0.0000
              WELLS =          0.0000               WELLS =           0.0000
           RECHARGE =    74497648.0000            RECHARGE =         289.7763

           TOTAL IN =   244613168.0000            TOTAL IN =      964347.9380

        OUT:                                    OUT:
        ----                                    ----
            STORAGE =   100731848.0000            STORAGE =       24757.3340
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =           0.0000
              WELLS =   143874496.0000              WELLS =      939588.5630
           RECHARGE =          0.0000            RECHARGE =           0.0000

          TOTAL OUT =   244606336.0000           TOTAL OUT =      964345.8750

           IN - OUT =        6832.0000            IN - OUT =           2.0625

PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                  IN:
         ---                                  ---
          STORAGE =   199545760.0000           STORAGE =      960987.5630
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =          0.0000              WELLS =           0.0000
         RECHARGE =    74506520.0000          RECHARGE =         289.7763

         TOTAL IN =   274052288.0000          TOTAL IN =      961277.3130

        OUT:                                 OUT:
        ----                                 ----
          STORAGE =   101395960.0000           STORAGE =       21685.4023
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =   172649392.0000             WELLS =      939588.5630
         RECHARGE =          0.0000           RECHARGE =           0.0000

        TOTAL OUT =   274045344.0000         TOTAL OUT =      961273.9380

         IN - OUT =        6944.0000          IN - OUT =           3.3750

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  7 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                  IN:
         ---                                  ---
          STORAGE =   228898032.0000           STORAGE =      958441.5000
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =          0.0000              WELLS =           0.0000
         RECHARGE =    74515392.0000          RECHARGE =         289.7763

         TOTAL IN =   303413440.0000          TOTAL IN =      958731.2500

        OUT:                                 OUT:
        ----                                 ----
          STORAGE =   101982168.0000           STORAGE =       19141.4707
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =   201424288.0000             WELLS =      939588.5630
         RECHARGE =          0.0000           RECHARGE =           0.0000

        TOTAL OUT =   303406464.0000         TOTAL OUT =      958730.0630

         IN - OUT =        6976.0000          IN - OUT =           1.1875

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  8 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                               IN:
      ---                               ---
        STORAGE =   258182736.0000          STORAGE =     956235.2500
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =          0.0000             WELLS =          0.0000
       RECHARGE =    74524264.0000         RECHARGE =        289.7763

       TOTAL IN =   332707008.0000         TOTAL IN =     956525.0000

     OUT:                              OUT:
     ----                              ----
        STORAGE =   102500792.0000          STORAGE =      16934.5840
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =   230199184.0000            WELLS =     939588.5630
       RECHARGE =          0.0000          RECHARGE =          0.0000

      TOTAL OUT =   332699968.0000        TOTAL OUT =     956523.1250

       IN - OUT =        7040.0000         IN - OUT =          1.8750

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00


     TIME SUMMARY AT END OF TIME STEP  8 IN STRESS PERIOD  2
            SECONDS     MINUTES      HOURS       DAYS        YEARS
            -----------------------------------------------------------
  TIME STEP LENGTH 2.64600E+06  44100.      735.00      30.625     8.38467E-02
STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0      245.00     0.67077
        TOTAL TIME 3.15360E+07 5.25600E+05  8760.0      365.00     0.99932
1
1
                STRESS PERIOD NO.    3, LENGTH =   120.0000
                ----------------------------------------------

                  NUMBER OF TIME STEPS =     4

                   MULTIPLIER FOR DELT =     1.000

                INITIAL TIME STEP SIZE =   30.00000

   0 WELLS
```

1

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 3

```
------------------------------------------------------------------------------

  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                               IN:
        ---                               ---
         STORAGE =   258934800.0000            STORAGE =      25068.8203
   CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
           WELLS =          0.0000               WELLS =          0.0000
        RECHARGE =    93953456.0000           RECHARGE =     647639.8130

        TOTAL IN =   352888256.0000           TOTAL IN =     672708.6250

       OUT:                              OUT:
       ----                              ----
         STORAGE =   122681320.0000            STORAGE =     672684.3750
   CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
           WELLS =   230199184.0000              WELLS =          0.0000
        RECHARGE =          0.0000            RECHARGE =          0.0000

       TOTAL OUT =   352880512.0000          TOTAL OUT =     672684.3750

        IN - OUT =       7744.0000            IN - OUT =         24.2500

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00
```

1

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 2 IN STRESS PERIOD 3

```
------------------------------------------------------------------------------

  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                               IN:
        ---                               ---
         STORAGE =   259608672.0000            STORAGE =      22462.1973
   CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
           WELLS =          0.0000               WELLS =          0.0000
        RECHARGE =   113382648.0000           RECHARGE =     647639.8130

        TOTAL IN =   372991328.0000           TOTAL IN =     670102.0000

       OUT:                              OUT:
       ----                              ----
         STORAGE =   142783664.0000            STORAGE =     670078.0630
   CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
           WELLS =   230199184.0000              WELLS =          0.0000
        RECHARGE =          0.0000            RECHARGE =          0.0000

       TOTAL OUT =   372982848.0000          TOTAL OUT =     670078.0630

        IN - OUT =       8480.0000            IN - OUT =         23.9375

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 3 IN STRESS PERIOD 3

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                               IN:
        ---                               ---
         STORAGE =   260213904.0000          STORAGE =      20174.2520
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =          0.0000             WELLS =          0.0000
        RECHARGE =   132811840.0000         RECHARGE =     647639.8130

        TOTAL IN =   393025728.0000         TOTAL IN =     667814.0630

       OUT:                              OUT:
       ----                              ----
         STORAGE =   162817360.0000          STORAGE =     667790.0630
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =   230199184.0000            WELLS =          0.0000
        RECHARGE =          0.0000          RECHARGE =          0.0000

       TOTAL OUT =   393016544.0000        TOTAL OUT =     667790.0630

        IN - OUT =        9184.0000         IN - OUT =         24.0000

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 4 IN STRESS PERIOD 3

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                               IN:
        ---                               ---
         STORAGE =   260758832.0000          STORAGE =      18164.1855
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =          0.0000             WELLS =          0.0000
        RECHARGE =   152241040.0000         RECHARGE =     647639.8130

        TOTAL IN =   412999872.0000         TOTAL IN =     665804.0000

       OUT:                              OUT:
       ----                              ----
         STORAGE =   182790768.0000          STORAGE =     665780.2500
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =   230199184.0000            WELLS =          0.0000
        RECHARGE =          0.0000          RECHARGE =          0.0000

       TOTAL OUT =   412989952.0000        TOTAL OUT =     665780.2500

        IN - OUT =        9920.0000         IN - OUT =         23.7500

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

```
      TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD  3
              SECONDS    MINUTES     HOURS      DAYS       YEARS
              -----------------------------------------------------------
  TIME STEP LENGTH 2.59200E+06  43200.     720.00     30.000    8.21355E-02
 STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0     120.00    0.32854
     TOTAL TIME 4.19040E+07 6.98400E+05  11640.     485.00     1.3279
1
1
                 STRESS PERIOD NO.   4, LENGTH =   245.0000
                 ----------------------------------------------

                  NUMBER OF TIME STEPS =     8

                   MULTIPLIER FOR DELT =     1.000

                 INITIAL TIME STEP SIZE =   30.62500

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  4
 -----------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------             ------------------------

       IN:                         IN:
       ---                         ---
        STORAGE =   281354240.0000           STORAGE =     672503.0630
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
         WELLS =         0.0000             WELLS =         0.0000
       RECHARGE =   152241040.0000          RECHARGE =         0.0000

       TOTAL IN =   433595264.0000          TOTAL IN =     672503.0630

      OUT:                          OUT:
      ----                          ----
        STORAGE =   183425232.0000           STORAGE =     20717.1719
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
         WELLS =   250159904.0000            WELLS =     651778.8130
       RECHARGE =         0.0000         RECHARGE =         0.0000

      TOTAL OUT =   433585152.0000          TOTAL OUT =     672496.0000

       IN - OUT =      10112.0000          IN - OUT =         7.0625

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  4
 ---------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3     RATES FOR THIS TIME STEP     L**3/T
   ------------------          ------------------------

      IN:                        IN:
      ---                        ---
       STORAGE =  301897280.0000         STORAGE =     670793.6250
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000            WELLS =        0.0000
      RECHARGE =  152241040.0000         RECHARGE =        0.0000

      TOTAL IN =  454138304.0000         TOTAL IN =     670793.6250

     OUT:                        OUT:
     ----                        ----
       STORAGE =  184007360.0000         STORAGE =      19008.0723
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =  270120640.0000          WELLS =     651778.8130
      RECHARGE =        0.0000         RECHARGE =        0.0000

     TOTAL OUT =  454128000.0000        TOTAL OUT =     670786.8750

      IN - OUT =      10304.0000         IN - OUT =        6.7500

 PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  4
 ---------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3     RATES FOR THIS TIME STEP     L**3/T
   ------------------          ------------------------

      IN:                        IN:
      ---                        ---
       STORAGE =  322392352.0000         STORAGE =     669227.1250
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000            WELLS =        0.0000
      RECHARGE =  152241040.0000         RECHARGE =        0.0000

      TOTAL IN =  474633408.0000         TOTAL IN =     669227.1250

     OUT:                        OUT:
     ----                        ----
       STORAGE =  184541520.0000         STORAGE =      17441.7715
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =  290081376.0000          WELLS =     651778.8130
      RECHARGE =        0.0000         RECHARGE =        0.0000

     TOTAL OUT =  474622912.0000        TOTAL OUT =     669220.5630

      IN - OUT =      10496.0000         IN - OUT =        6.5625

 PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 4 IN STRESS PERIOD 4

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                             IN:
        ---                             ---
            STORAGE =   342844288.0000          STORAGE =      667818.6880
      CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
              WELLS =          0.0000             WELLS =           0.0000
           RECHARGE =   152241040.0000         RECHARGE =           0.0000

           TOTAL IN =   495085312.0000         TOTAL IN =      667818.6880

       OUT:                            OUT:
       ----                            ----
            STORAGE =   185032528.0000          STORAGE =       16032.8984
      CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
              WELLS =   310042112.0000            WELLS =      651778.8130
           RECHARGE =          0.0000         RECHARGE =           0.0000

          TOTAL OUT =   495074624.0000        TOTAL OUT =      667811.6880

           IN - OUT =       10688.0000         IN - OUT =           7.0000

PERCENT DISCREPANCY =            0.00     PERCENT DISCREPANCY =           0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 5 IN STRESS PERIOD 4

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                             IN:
        ---                             ---
            STORAGE =   363256160.0000          STORAGE =      666510.3750
      CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
              WELLS =          0.0000             WELLS =           0.0000
           RECHARGE =   152241040.0000         RECHARGE =           0.0000

           TOTAL IN =   515497216.0000         TOTAL IN =      666510.3750

       OUT:                            OUT:
       ----                            ----
            STORAGE =   185483488.0000          STORAGE =       14724.9971
      CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
              WELLS =   330002848.0000            WELLS =      651778.8130
           RECHARGE =          0.0000         RECHARGE =           0.0000

          TOTAL OUT =   515486336.0000        TOTAL OUT =      666503.8130

           IN - OUT =       10880.0000         IN - OUT =           6.5625

PERCENT DISCREPANCY =            0.00     PERCENT DISCREPANCY =           0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 6 IN STRESS PERIOD 4

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                                IN:
        ---                                ---
          STORAGE =   383630848.0000           STORAGE =      665296.3130
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =          0.0000              WELLS =           0.0000
         RECHARGE =   152241040.0000          RECHARGE =           0.0000

         TOTAL IN =   535871872.0000          TOTAL IN =      665296.3130

       OUT:                               OUT:
       ----                               ----
          STORAGE =   185897264.0000           STORAGE =       13511.0127
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =   349963584.0000             WELLS =      651778.8130
         RECHARGE =          0.0000           RECHARGE =           0.0000

        TOTAL OUT =   535860864.0000         TOTAL OUT =      665289.8130

         IN - OUT =       11008.0000          IN - OUT =           6.5000

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 7 IN STRESS PERIOD 4

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                                IN:
        ---                                ---
          STORAGE =   403972064.0000           STORAGE =      664203.3130
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =          0.0000              WELLS =           0.0000
         RECHARGE =   152241040.0000          RECHARGE =           0.0000

         TOTAL IN =   556213120.0000          TOTAL IN =      664203.3130

       OUT:                               OUT:
       ----                               ----
          STORAGE =   186277552.0000           STORAGE =       12417.8242
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =   369924320.0000             WELLS =      651778.8130
         RECHARGE =          0.0000           RECHARGE =           0.0000

        TOTAL OUT =   556201856.0000         TOTAL OUT =      664196.6250

         IN - OUT =       11264.0000          IN - OUT =           6.6875

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  8 IN STRESS PERIOD  4
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------             ------------------------

      IN:                         IN:
      ---                         ---
       STORAGE =   424281888.0000           STORAGE =     663177.5000
   CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
        WELLS =        0.0000             WELLS =        0.0000
      RECHARGE =   152241040.0000          RECHARGE =        0.0000

      TOTAL IN =   576522944.0000          TOTAL IN =     663177.5000

     OUT:                          OUT:
     ----                          ----
       STORAGE =   186626448.0000           STORAGE =      11392.2998
   CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
        WELLS =   389885056.0000            WELLS =     651778.8130
      RECHARGE =        0.0000          RECHARGE =        0.0000

     TOTAL OUT =   576511488.0000          TOTAL OUT =     663171.1250

      IN - OUT =      11456.0000          IN - OUT =         6.3750

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00




     TIME SUMMARY AT END OF TIME STEP  8 IN STRESS PERIOD  4
            SECONDS     MINUTES      HOURS       DAYS        YEARS
            -----------------------------------------------------------
  TIME STEP LENGTH 2.64600E+06  44100.     735.00     30.625     8.38467E-02
STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0     245.00     0.67077
     TOTAL TIME 6.30720E+07 1.05120E+06  17520.     730.00     1.9986
1
1
                  STRESS PERIOD NO.   5, LENGTH =   120.0000
                  ----------------------------------------------

                   NUMBER OF TIME STEPS =     4

                    MULTIPLIER FOR DELT =     1.000

                  INITIAL TIME STEP SIZE =   30.00000


   0 WELLS
```

```
 1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  5
------------------------------------------------------------------------------

  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

     IN:                               IN:
     ---                               ---
       STORAGE =  424992160.0000          STORAGE =      23675.4668
 CONSTANT HEAD =         0.0000     CONSTANT HEAD =          0.0000
         WELLS =         0.0000             WELLS =          0.0000
      RECHARGE =  163054800.0000         RECHARGE =     360458.5630

      TOTAL IN =  588046976.0000         TOTAL IN =     384134.0310

    OUT:                              OUT:
    ----                              ----
       STORAGE =  198149728.0000          STORAGE =     384109.3130
 CONSTANT HEAD =         0.0000     CONSTANT HEAD =          0.0000
         WELLS =  389885056.0000            WELLS =          0.0000
      RECHARGE =         0.0000          RECHARGE =          0.0000

     TOTAL OUT =  588034816.0000        TOTAL OUT =     384109.3130

      IN - OUT =      12160.0000         IN - OUT =         24.7188

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =        0.01


 1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  5
------------------------------------------------------------------------------

  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

     IN:                               IN:
     ---                               ---
       STORAGE =  425664128.0000          STORAGE =      22398.8691
 CONSTANT HEAD =         0.0000     CONSTANT HEAD =          0.0000
         WELLS =         0.0000             WELLS =          0.0000
      RECHARGE =  173868560.0000         RECHARGE =     360458.5630

      TOTAL IN =  599532672.0000         TOTAL IN =     382857.4380

    OUT:                              OUT:
    ----                              ----
       STORAGE =  209634704.0000          STORAGE =     382832.6880
 CONSTANT HEAD =         0.0000     CONSTANT HEAD =          0.0000
         WELLS =  389885056.0000            WELLS =          0.0000
      RECHARGE =         0.0000          RECHARGE =          0.0000

     TOTAL OUT =  599519744.0000        TOTAL OUT =     382832.6880

      IN - OUT =      12928.0000         IN - OUT =         24.7500

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =        0.01
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  5
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                IN:
         ---                                ---
          STORAGE =   426300960.0000          STORAGE =      21227.9629
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
            WELLS =          0.0000             WELLS =          0.0000
         RECHARGE =   184682320.0000         RECHARGE =     360458.5630

         TOTAL IN =   610983296.0000         TOTAL IN =     381686.5310

        OUT:                               OUT:
        ----                               ----
          STORAGE =   221084592.0000          STORAGE =     381663.0630
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
            WELLS =   389885056.0000            WELLS =          0.0000
         RECHARGE =          0.0000          RECHARGE =          0.0000

        TOTAL OUT =   610969664.0000        TOTAL OUT =     381663.0630

         IN - OUT =      13632.0000          IN - OUT =         23.4688

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.01
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  5
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                IN:
         ---                                ---
          STORAGE =   426905248.0000          STORAGE =      20143.3340
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
            WELLS =          0.0000             WELLS =          0.0000
         RECHARGE =   195496080.0000         RECHARGE =     360458.5630

         TOTAL IN =   622401344.0000         TOTAL IN =     380601.9060

        OUT:                               OUT:
        ----                               ----
          STORAGE =   232501920.0000          STORAGE =     380577.3750
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
            WELLS =   389885056.0000            WELLS =          0.0000
         RECHARGE =          0.0000          RECHARGE =          0.0000

        TOTAL OUT =   622386944.0000        TOTAL OUT =     380577.3750

         IN - OUT =      14400.0000          IN - OUT =         24.5312

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.01
```

```
      TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD  5
             SECONDS     MINUTES      HOURS       DAYS        YEARS
             -----------------------------------------------------------
  TIME STEP LENGTH 2.59200E+06  43200.     720.00     30.000    8.21355E-02
STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0     120.00    0.32854
     TOTAL TIME 7.34400E+07 1.22400E+06  20400.     850.00     2.3272
1
1
                 STRESS PERIOD NO.   6, LENGTH =   245.0000
                 ----------------------------------------------

                  NUMBER OF TIME STEPS =     8

                   MULTIPLIER FOR DELT =     1.000

                 INITIAL TIME STEP SIZE =   30.62500


 3861 WELLS



1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                              IN:
       ---                              ---
         STORAGE =   451608160.0000          STORAGE =      806625.5000
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
           WELLS =          0.0000             WELLS =           0.0000
        RECHARGE =   195496080.0000         RECHARGE =           0.0000

        TOTAL IN =   647104256.0000         TOTAL IN =      806625.5000

      OUT:                             OUT:
      ----                             ----
         STORAGE =   232695072.0000          STORAGE =        6307.0713
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
           WELLS =   414395232.0000            WELLS =      800331.9380
        RECHARGE =          0.0000          RECHARGE =           0.0000

       TOTAL OUT =   647090304.0000        TOTAL OUT =      806639.0000

        IN - OUT =       13952.0000         IN - OUT =         -13.5000

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                             IN:
      ---                             ---
       STORAGE =   476283456.0000          STORAGE =      805723.4380
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
         WELLS =          0.0000             WELLS =           0.0000
      RECHARGE =   195496080.0000         RECHARGE =           0.0000

      TOTAL IN =   671779520.0000         TOTAL IN =      805723.4380

     OUT:                            OUT:
     ----                            ----
       STORAGE =   232860592.0000          STORAGE =        5404.6240
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
         WELLS =   438905408.0000            WELLS =      800331.9380
      RECHARGE =          0.0000          RECHARGE =           0.0000

     TOTAL OUT =   671766016.0000        TOTAL OUT =      805736.5630

      IN - OUT =       13504.0000         IN - OUT =         -13.1250

PERCENT DISCREPANCY =        0.00     PERCENT DISCREPANCY =        0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                             IN:
      ---                             ---
       STORAGE =   500935584.0000          STORAGE =      804967.4380
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
         WELLS =          0.0000             WELLS =           0.0000
      RECHARGE =   195496080.0000         RECHARGE =           0.0000

      TOTAL IN =   696431680.0000         TOTAL IN =      804967.4380

     OUT:                            OUT:
     ----                            ----
       STORAGE =   233002976.0000          STORAGE =        4649.0532
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
         WELLS =   463415584.0000            WELLS =      800331.9380
      RECHARGE =          0.0000          RECHARGE =           0.0000

     TOTAL OUT =   696418560.0000        TOTAL OUT =      804981.0000

      IN - OUT =       13120.0000         IN - OUT =         -13.5625

PERCENT DISCREPANCY =        0.00     PERCENT DISCREPANCY =        0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                                IN:
       ---                                ---
          STORAGE =   525567040.0000          STORAGE =      804292.5630
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
            WELLS =          0.0000             WELLS =           0.0000
         RECHARGE =   195496080.0000         RECHARGE =           0.0000

         TOTAL IN =   721063104.0000         TOTAL IN =      804292.5630

      OUT:                               OUT:
      ----                               ----
          STORAGE =   233124672.0000          STORAGE =        3973.8010
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
            WELLS =   487925760.0000            WELLS =      800331.9380
         RECHARGE =          0.0000          RECHARGE =           0.0000

        TOTAL OUT =   721050432.0000        TOTAL OUT =      804305.7500

         IN - OUT =       12672.0000         IN - OUT =         -13.1875

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =           0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                                IN:
       ---                                ---
          STORAGE =   550182144.0000          STORAGE =      803759.4380
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
            WELLS =          0.0000             WELLS =           0.0000
         RECHARGE =   195496080.0000         RECHARGE =           0.0000

         TOTAL IN =   745678208.0000         TOTAL IN =      803759.4380

      OUT:                               OUT:
      ----                               ----
          STORAGE =   233230032.0000          STORAGE =        3440.1196
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
            WELLS =   512435936.0000            WELLS =      800331.9380
         RECHARGE =          0.0000          RECHARGE =           0.0000

        TOTAL OUT =   745665984.0000        TOTAL OUT =      803772.0630

         IN - OUT =       12224.0000         IN - OUT =         -12.6250

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =           0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                               IN:
         ---                               ---
           STORAGE =   574783616.0000           STORAGE =      803313.1880
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =          0.0000              WELLS =           0.0000
          RECHARGE =   195496080.0000           RECHARGE =           0.0000

          TOTAL IN =   770279680.0000           TOTAL IN =      803313.1880

        OUT:                              OUT:
        ----                              ----
           STORAGE =   233321760.0000           STORAGE =        2995.3484
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =   536946112.0000             WELLS =      800331.9380
          RECHARGE =          0.0000           RECHARGE =           0.0000

         TOTAL OUT =   770267904.0000          TOTAL OUT =      803327.3130

          IN - OUT =       11776.0000           IN - OUT =         -14.1250

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  7 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                               IN:
         ---                               ---
           STORAGE =   599373504.0000           STORAGE =      802934.8130
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =          0.0000              WELLS =           0.0000
          RECHARGE =   195496080.0000           RECHARGE =           0.0000

          TOTAL IN =   794869568.0000           TOTAL IN =      802934.8130

        OUT:                              OUT:
        ----                              ----
           STORAGE =   233401904.0000           STORAGE =        2616.9329
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =   561456256.0000             WELLS =      800331.9380
          RECHARGE =          0.0000           RECHARGE =           0.0000

         TOTAL OUT =   794858176.0000          TOTAL OUT =      802948.8750

          IN - OUT =       11392.0000           IN - OUT =         -14.0625

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  8 IN STRESS PERIOD  6
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                               IN:
      ---                               ---
        STORAGE =   623952832.0000          STORAGE =      802589.6250
  CONSTANT HEAD =           0.0000    CONSTANT HEAD =           0.0000
          WELLS =           0.0000            WELLS =           0.0000
       RECHARGE =   195496080.0000         RECHARGE =           0.0000

       TOTAL IN =   819448896.0000         TOTAL IN =      802589.6250

     OUT:                              OUT:
     ----                              ----
        STORAGE =   233471408.0000          STORAGE =        2269.4958
  CONSTANT HEAD =           0.0000    CONSTANT HEAD =           0.0000
          WELLS =   585966400.0000            WELLS =      800331.9380
       RECHARGE =           0.0000         RECHARGE =           0.0000

      TOTAL OUT =   819437824.0000        TOTAL OUT =      802601.4380

       IN - OUT =       11072.0000         IN - OUT =         -11.8125

PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00




     TIME SUMMARY AT END OF TIME STEP  8 IN STRESS PERIOD  6
              SECONDS     MINUTES      HOURS       DAYS        YEARS
              -----------------------------------------------------------
 TIME STEP LENGTH 2.64600E+06  44100.      735.00      30.625     8.38467E-02
STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0      245.00     0.67077
     TOTAL TIME 9.46080E+07 1.57680E+06  26280.      1095.0      2.9979
1
1
                STRESS PERIOD NO.   7, LENGTH =   120.0000
                ----------------------------------------------

                  NUMBER OF TIME STEPS =     4

                   MULTIPLIER FOR DELT =     1.000

                INITIAL TIME STEP SIZE =   30.00000


   0 WELLS
```

```
1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  7
-----------------------------------------------------------------------------

  CUMULATIVE VOLUMES     L**3     RATES FOR THIS TIME STEP     L**3/T
  ------------------           ------------------------

      IN:                          IN:
      ---                          ---
        STORAGE =  624440064.0000          STORAGE =     16241.3584
  CONSTANT HEAD =        0.0000     CONSTANT HEAD =        0.0000
          WELLS =        0.0000             WELLS =        0.0000
       RECHARGE =  203851792.0000          RECHARGE =    278523.8440

       TOTAL IN =  828291840.0000          TOTAL IN =    294765.1880

     OUT:                         OUT:
     ----                         ----
        STORAGE =  242313888.0000          STORAGE =    294749.2190
  CONSTANT HEAD =        0.0000     CONSTANT HEAD =        0.0000
          WELLS =  585966400.0000             WELLS =        0.0000
       RECHARGE =        0.0000          RECHARGE =        0.0000

      TOTAL OUT =  828280320.0000         TOTAL OUT =    294749.2190

       IN - OUT =      11520.0000          IN - OUT =       15.9688

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.01
```

```
1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  7
-----------------------------------------------------------------------------

  CUMULATIVE VOLUMES     L**3     RATES FOR THIS TIME STEP     L**3/T
  ------------------           ------------------------

      IN:                          IN:
      ---                          ---
        STORAGE =  624905024.0000          STORAGE =     15497.8418
  CONSTANT HEAD =        0.0000     CONSTANT HEAD =        0.0000
          WELLS =        0.0000             WELLS =        0.0000
       RECHARGE =  212207504.0000          RECHARGE =    278523.8440

       TOTAL IN =  837112512.0000          TOTAL IN =    294021.6880

     OUT:                         OUT:
     ----                         ----
        STORAGE =  251134080.0000          STORAGE =    294006.2810
  CONSTANT HEAD =        0.0000     CONSTANT HEAD =        0.0000
          WELLS =  585966400.0000             WELLS =        0.0000
       RECHARGE =        0.0000          RECHARGE =        0.0000

      TOTAL OUT =  837100480.0000         TOTAL OUT =    294006.2810

       IN - OUT =      12032.0000          IN - OUT =       15.4063

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.01
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  7
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                IN:
      ---                                ---
       STORAGE =   625348736.0000          STORAGE =      14789.5059
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
         WELLS =          0.0000             WELLS =          0.0000
      RECHARGE =   220563216.0000         RECHARGE =     278523.8440

      TOTAL IN =   845911936.0000         TOTAL IN =     293313.3440

     OUT:                               OUT:
     ----                               ----
       STORAGE =   259933024.0000          STORAGE =     293297.8750
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
         WELLS =   585966400.0000            WELLS =          0.0000
      RECHARGE =          0.0000          RECHARGE =          0.0000

     TOTAL OUT =   845899392.0000        TOTAL OUT =     293297.8750

      IN - OUT =       12544.0000         IN - OUT =         15.4687

PERCENT DISCREPANCY =          0.00  PERCENT DISCREPANCY =          0.01

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  7
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                IN:
      ---                                ---
       STORAGE =   625772352.0000          STORAGE =      14120.3389
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
         WELLS =          0.0000             WELLS =          0.0000
      RECHARGE =   228918928.0000         RECHARGE =     278523.8440

      TOTAL IN =   854691264.0000         TOTAL IN =     292644.1880

     OUT:                               OUT:
     ----                               ----
       STORAGE =   268711904.0000          STORAGE =     292629.3440
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
         WELLS =   585966400.0000            WELLS =          0.0000
      RECHARGE =          0.0000          RECHARGE =          0.0000

     TOTAL OUT =   854678272.0000        TOTAL OUT =     292629.3440

      IN - OUT =       12992.0000         IN - OUT =         14.8437

PERCENT DISCREPANCY =          0.00  PERCENT DISCREPANCY =          0.01
```

```
      TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD  7
            SECONDS    MINUTES     HOURS      DAYS       YEARS
            -----------------------------------------------------------
  TIME STEP LENGTH 2.59200E+06  43200.      720.00     30.000    8.21355E-02
STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0     120.00    0.32854
     TOTAL TIME 1.04976E+08 1.74960E+06  29160.     1215.0     3.3265
1
1
                 STRESS PERIOD NO.   8, LENGTH =   245.0000
                 ----------------------------------------------

                  NUMBER OF TIME STEPS =     8

                   MULTIPLIER FOR DELT =     1.000

                 INITIAL TIME STEP SIZE =   30.62500

 3860 WELLS

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  8
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3      RATES FOR THIS TIME STEP      L**3/T
   ------------------              ------------------------

       IN:                            IN:
       ---                            ---
         STORAGE =   655540736.0000           STORAGE =      972029.6880
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =          0.0000
          WELLS =         0.0000              WELLS =          0.0000
       RECHARGE =   228918928.0000           RECHARGE =          0.0000

        TOTAL IN =   884459648.0000           TOTAL IN =      972029.6880

      OUT:                             OUT:
      ----                             ----
         STORAGE =   268751456.0000           STORAGE =       1291.8429
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =          0.0000
          WELLS =   615695296.0000              WELLS =      970740.1880
       RECHARGE =         0.0000           RECHARGE =          0.0000

       TOTAL OUT =   884446720.0000          TOTAL OUT =      972032.0000

        IN - OUT =      12928.0000           IN - OUT =         -2.3125

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 2 IN STRESS PERIOD 8
```
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                           IN:
         ---                           ---
             STORAGE =   685299392.0000           STORAGE =      971710.6250
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
               WELLS =          0.0000              WELLS =           0.0000
            RECHARGE =   228918928.0000          RECHARGE =           0.0000

            TOTAL IN =   914218304.0000          TOTAL IN =      971710.6250

          OUT:                          OUT:
          ----                          ----
             STORAGE =   268781216.0000           STORAGE =         971.3349
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
               WELLS =   645424192.0000             WELLS =      970740.1880
            RECHARGE =          0.0000          RECHARGE =           0.0000

           TOTAL OUT =   914205440.0000         TOTAL OUT =      971711.5000

            IN - OUT =       12864.0000          IN - OUT =          -0.8750

 PERCENT DISCREPANCY =            0.00    PERCENT DISCREPANCY =           0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 3 IN STRESS PERIOD 8
```
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                           IN:
         ---                           ---
             STORAGE =   715052224.0000           STORAGE =      971520.1880
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
               WELLS =          0.0000              WELLS =           0.0000
            RECHARGE =   228918928.0000          RECHARGE =           0.0000

            TOTAL IN =   943971136.0000          TOTAL IN =      971520.1880

          OUT:                          OUT:
          ----                          ----
             STORAGE =   268805216.0000           STORAGE =         783.4208
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
               WELLS =   675153088.0000             WELLS =      970740.1880
            RECHARGE =          0.0000          RECHARGE =           0.0000

           TOTAL OUT =   943958272.0000         TOTAL OUT =      971523.6250

            IN - OUT =       12864.0000          IN - OUT =          -3.4375

 PERCENT DISCREPANCY =            0.00    PERCENT DISCREPANCY =           0.00
```

```
 1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  8
-----------------------------------------------------------------------------

  CUMULATIVE VOLUMES    L**3     RATES FOR THIS TIME STEP    L**3/T
  ------------------            ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =   744800960.0000          STORAGE =     971386.4380
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000             WELLS =         0.0000
      RECHARGE =   228918928.0000          RECHARGE =         0.0000

      TOTAL IN =   973719872.0000          TOTAL IN =     971386.4380

     OUT:                          OUT:
     ----                          ----
       STORAGE =   268825088.0000          STORAGE =       648.7385
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =   704881984.0000           WELLS =     970740.1880
      RECHARGE =         0.0000        RECHARGE =         0.0000

     TOTAL OUT =   973707072.0000         TOTAL OUT =     971388.9380

      IN - OUT =      12800.0000          IN - OUT =        -2.5000

PERCENT DISCREPANCY =         0.00    PERCENT DISCREPANCY =         0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  8
 -----------------------------------------------------------------------------

  CUMULATIVE VOLUMES    L**3     RATES FOR THIS TIME STEP    L**3/T
  ------------------            ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =   774546112.0000          STORAGE =     971271.1250
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000             WELLS =         0.0000
      RECHARGE =   228918928.0000          RECHARGE =         0.0000

      TOTAL IN =  1003465020.0000          TOTAL IN =     971271.1250

     OUT:                          OUT:
     ----                          ----
       STORAGE =   268841408.0000          STORAGE =       533.1438
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =   734610880.0000           WELLS =     970740.1880
      RECHARGE =         0.0000        RECHARGE =         0.0000

     TOTAL OUT =  1003452290.0000         TOTAL OUT =     971273.3130

      IN - OUT =      12736.0000          IN - OUT =        -2.1875

PERCENT DISCREPANCY =         0.00    PERCENT DISCREPANCY =         0.00
```

```
1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD  8
---------------------------------------------------------------------------

  CUMULATIVE VOLUMES    L**3     RATES FOR THIS TIME STEP    L**3/T
  ------------------          ------------------------

      IN:                          IN:
      ---                          ---
        STORAGE =  804288000.0000        STORAGE =     971164.5630
    CONSTANT HEAD =        0.0000    CONSTANT HEAD =        0.0000
         WELLS =        0.0000           WELLS =        0.0000
       RECHARGE =  228918928.0000       RECHARGE =        0.0000

       TOTAL IN =  1033206910.0000       TOTAL IN =     971164.5630

     OUT:                          OUT:
     ----                          ----
        STORAGE =  268854464.0000        STORAGE =      425.9517
    CONSTANT HEAD =        0.0000    CONSTANT HEAD =        0.0000
         WELLS =  764339776.0000          WELLS =    970740.1880
       RECHARGE =        0.0000       RECHARGE =        0.0000

      TOTAL OUT =  1033194240.0000       TOTAL OUT =     971166.1250

       IN - OUT =      12672.0000        IN - OUT =       -1.5625

PERCENT DISCREPANCY =        0.00   PERCENT DISCREPANCY =        0.00

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  7 IN STRESS PERIOD  8
---------------------------------------------------------------------------

  CUMULATIVE VOLUMES    L**3     RATES FOR THIS TIME STEP    L**3/T
  ------------------          ------------------------

      IN:                          IN:
      ---                          ---
        STORAGE =  834027584.0000        STORAGE =     971087.6880
    CONSTANT HEAD =        0.0000    CONSTANT HEAD =        0.0000
         WELLS =        0.0000           WELLS =        0.0000
       RECHARGE =  228918928.0000       RECHARGE =        0.0000

       TOTAL IN =  1062946500.0000       TOTAL IN =     971087.6880

     OUT:                          OUT:
     ----                          ----
        STORAGE =  268865152.0000        STORAGE =      349.2609
    CONSTANT HEAD =        0.0000    CONSTANT HEAD =        0.0000
         WELLS =  794068672.0000          WELLS =    970740.1880
       RECHARGE =        0.0000       RECHARGE =        0.0000

      TOTAL OUT =  1062933820.0000       TOTAL OUT =     971089.4380

       IN - OUT =      12672.0000        IN - OUT =       -1.7500

PERCENT DISCREPANCY =        0.00   PERCENT DISCREPANCY =        0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  8 IN STRESS PERIOD  8
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------              ------------------------

      IN:                         IN:
      ---                         ---
       STORAGE =   863765696.0000          STORAGE =     971040.3750
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
        WELLS =         0.0000             WELLS =         0.0000
      RECHARGE =   228918928.0000          RECHARGE =         0.0000

      TOTAL IN =  1092684670.0000          TOTAL IN =     971040.3750

      OUT:                         OUT:
      ----                         ----
       STORAGE =   268874400.0000          STORAGE =       302.0517
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
        WELLS =   823797568.0000            WELLS =     970740.1880
      RECHARGE =         0.0000          RECHARGE =         0.0000

      TOTAL OUT =  1092672000.0000         TOTAL OUT =     971042.2500

      IN - OUT =      12672.0000          IN - OUT =        -1.8750

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00


      TIME SUMMARY AT END OF TIME STEP  8 IN STRESS PERIOD  8
            SECONDS     MINUTES      HOURS       DAYS        YEARS
            -----------------------------------------------------------
  TIME STEP LENGTH 2.64600E+06  44100.     735.00     30.625     8.38467E-02
STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0     245.00     0.67077
     TOTAL TIME 1.26144E+08 2.10240E+06  35040.     1460.0     3.9973
1
1
                STRESS PERIOD NO.   9, LENGTH =   120.0000
                ----------------------------------------------

                 NUMBER OF TIME STEPS =     4

                  MULTIPLIER FOR DELT =     1.000

                INITIAL TIME STEP SIZE =   30.00000


   0 WELLS
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  9
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------               ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =  864167168.0000          STORAGE =      13383.3809
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000             WELLS =        0.0000
      RECHARGE =  237253680.0000          RECHARGE =     277824.8440

      TOTAL IN =  1101420800.0000         TOTAL IN =     291208.2190

     OUT:                           OUT:
     ----                           ----
       STORAGE =  277609248.0000          STORAGE =     291162.0940
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =  823797568.0000           WELLS =        0.0000
      RECHARGE =        0.0000          RECHARGE =        0.0000

     TOTAL OUT =  1101406850.0000        TOTAL OUT =     291162.0940

      IN - OUT =      13952.0000          IN - OUT =        46.1250

PERCENT DISCREPANCY =         0.00    PERCENT DISCREPANCY =         0.02

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  9
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------               ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =  864553536.0000          STORAGE =      12879.7051
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000             WELLS =        0.0000
      RECHARGE =  245588432.0000          RECHARGE =     277824.8440

      TOTAL IN =  1110141950.0000         TOTAL IN =     290704.5630

     OUT:                           OUT:
     ----                           ----
       STORAGE =  286328992.0000          STORAGE =     290658.5310
   CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =  823797568.0000           WELLS =        0.0000
      RECHARGE =        0.0000          RECHARGE =        0.0000

     TOTAL OUT =  1110126590.0000        TOTAL OUT =     290658.5310

      IN - OUT =      15360.0000          IN - OUT =        46.0313

PERCENT DISCREPANCY =         0.00    PERCENT DISCREPANCY =         0.02
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  9
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------            ------------------------

       IN:                          IN:
       ---                          ---
        STORAGE =  864927936.0000          STORAGE =      12479.3604
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
         WELLS =        0.0000            WELLS =        0.0000
       RECHARGE =  253923184.0000          RECHARGE =     277824.8440

       TOTAL IN =  1118851070.0000         TOTAL IN =     290304.2190

      OUT:                          OUT:
      ----                          ----
        STORAGE =  295036736.0000          STORAGE =     290258.6560
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
         WELLS =  823797568.0000            WELLS =        0.0000
       RECHARGE =        0.0000         RECHARGE =        0.0000

      TOTAL OUT =  1118834300.0000         TOTAL OUT =     290258.6560

       IN - OUT =      16768.0000          IN - OUT =       45.5625

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.02


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  9
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------            ------------------------

       IN:                          IN:
       ---                          ---
        STORAGE =  865291584.0000          STORAGE =      12121.5215
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
         WELLS =        0.0000            WELLS =        0.0000
       RECHARGE =  262257936.0000          RECHARGE =     277824.8440

       TOTAL IN =  1127549570.0000         TOTAL IN =     289946.3750

      OUT:                          OUT:
      ----                          ----
        STORAGE =  303733760.0000          STORAGE =     289900.7500
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
         WELLS =  823797568.0000            WELLS =        0.0000
       RECHARGE =        0.0000         RECHARGE =        0.0000

      TOTAL OUT =  1127531260.0000         TOTAL OUT =     289900.7500

       IN - OUT =      18304.0000          IN - OUT =       45.6250

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.02
```

```
      TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD  9
            SECONDS     MINUTES      HOURS       DAYS        YEARS
            -----------------------------------------------------------
  TIME STEP LENGTH 2.59200E+06  43200.      720.00      30.000     8.21355E-02
 STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0      120.00     0.32854
      TOTAL TIME 1.36512E+08 2.27520E+06  37920.      1580.0      4.3258
1
1
                 STRESS PERIOD NO.  10, LENGTH =   245.0000
                 ----------------------------------------------

                  NUMBER OF TIME STEPS =     8

                   MULTIPLIER FOR DELT =     1.000

                 INITIAL TIME STEP SIZE =   30.62500


 3861 WELLS


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 10
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                             IN:
       ---                             ---
         STORAGE =   900879360.0000           STORAGE =     1162050.0000
   CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
           WELLS =          0.0000              WELLS =          0.0000
        RECHARGE =   262257936.0000          RECHARGE =          0.0000

        TOTAL IN =  1163137280.0000          TOTAL IN =     1162050.0000

      OUT:                            OUT:
      ----                            ----
         STORAGE =   303733792.0000           STORAGE =          1.3599
   CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
           WELLS =   859385536.0000             WELLS =     1162057.1200
        RECHARGE =          0.0000           RECHARGE =          0.0000

       TOTAL OUT =  1163119360.0000         TOTAL OUT =     1162058.5000

        IN - OUT =      17920.0000           IN - OUT =         -8.5000

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD 10
 ------------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                IN:
          ---                                ---
            STORAGE =   936467072.0000            STORAGE =     1162048.7500
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =          0.0000               WELLS =          0.0000
           RECHARGE =   262257936.0000           RECHARGE =          0.0000

           TOTAL IN =  1198724990.0000           TOTAL IN =     1162048.7500

         OUT:                               OUT:
         ----                               ----
            STORAGE =   303733792.0000            STORAGE =          0.0000
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =   894973504.0000              WELLS =     1162057.1200
           RECHARGE =          0.0000           RECHARGE =          0.0000

          TOTAL OUT =  1198707330.0000          TOTAL OUT =     1162057.1200

           IN - OUT =       17664.0000           IN - OUT =         -8.3750

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD 10
 ------------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                IN:
          ---                                ---
            STORAGE =   972054848.0000            STORAGE =     1162049.3800
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =          0.0000               WELLS =          0.0000
           RECHARGE =   262257936.0000           RECHARGE =          0.0000

           TOTAL IN =  1234312830.0000           TOTAL IN =     1162049.3800

         OUT:                               OUT:
         ----                               ----
            STORAGE =   303733792.0000            STORAGE =          0.0000
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =   930561472.0000              WELLS =     1162057.1200
           RECHARGE =          0.0000           RECHARGE =          0.0000

          TOTAL OUT =  1234295300.0000          TOTAL OUT =     1162057.1200

           IN - OUT =       17536.0000           IN - OUT =         -7.7500

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD 10
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                              IN:
      ---                              ---
        STORAGE =  1007642620.0000           STORAGE =     1162050.5000
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =           0.0000             WELLS =           0.0000
       RECHARGE =   262257936.0000          RECHARGE =           0.0000

       TOTAL IN =  1269900540.0000          TOTAL IN =     1162050.5000

     OUT:                             OUT:
     ----                             ----
        STORAGE =   303733792.0000           STORAGE =           0.0000
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =   966149440.0000             WELLS =     1162057.1200
       RECHARGE =           0.0000          RECHARGE =           0.0000

      TOTAL OUT =  1269883260.0000         TOTAL OUT =     1162057.1200

       IN - OUT =       17280.0000          IN - OUT =          -6.6250

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD 10
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                              IN:
      ---                              ---
        STORAGE =  1043230340.0000           STORAGE =     1162048.7500
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =           0.0000             WELLS =           0.0000
       RECHARGE =   262257936.0000          RECHARGE =           0.0000

       TOTAL IN =  1305488260.0000          TOTAL IN =     1162048.7500

     OUT:                             OUT:
     ----                             ----
        STORAGE =   303733792.0000           STORAGE =           0.0000
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =  1001737410.0000             WELLS =     1162057.1200
       RECHARGE =           0.0000          RECHARGE =           0.0000

      TOTAL OUT =  1305471230.0000         TOTAL OUT =     1162057.1200

       IN - OUT =       17024.0000          IN - OUT =          -8.3750

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD 10
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                            IN:
       ---                            ---
        STORAGE =  1078818050.0000           STORAGE =     1162049.1200
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
          WELLS =         0.0000             WELLS =         0.0000
       RECHARGE =   262257936.0000          RECHARGE =         0.0000

       TOTAL IN =  1341075970.0000          TOTAL IN =     1162049.1200

      OUT:                           OUT:
      ----                           ----
        STORAGE =   303733792.0000           STORAGE =         0.0000
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
          WELLS =  1037325380.0000             WELLS =     1162057.1200
       RECHARGE =         0.0000          RECHARGE =         0.0000

      TOTAL OUT =  1341059200.0000         TOTAL OUT =     1162057.1200

       IN - OUT =      16768.0000          IN - OUT =        -8.0000

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  7 IN STRESS PERIOD 10
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                            IN:
       ---                            ---
        STORAGE =  1114405760.0000           STORAGE =     1162049.6200
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
          WELLS =         0.0000             WELLS =         0.0000
       RECHARGE =   262257936.0000          RECHARGE =         0.0000

       TOTAL IN =  1376663680.0000          TOTAL IN =     1162049.6200

      OUT:                           OUT:
      ----                           ----
        STORAGE =   303733792.0000           STORAGE =         0.0000
    CONSTANT HEAD =         0.0000       CONSTANT HEAD =         0.0000
          WELLS =  1072913340.0000             WELLS =     1162057.1200
       RECHARGE =         0.0000          RECHARGE =         0.0000

      TOTAL OUT =  1376647170.0000         TOTAL OUT =     1162057.1200

       IN - OUT =      16512.0000          IN - OUT =        -7.5000

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

1

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 8 IN STRESS PERIOD 10

```
-----------------------------------------------------------------------------

 CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
 ------------------                 ------------------------

    IN:                              IN:
    ---                              ---
       STORAGE =  1149993470.0000          STORAGE =    1162049.1200
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
         WELLS =          0.0000             WELLS =          0.0000
      RECHARGE =   262257936.0000         RECHARGE =          0.0000

      TOTAL IN =  1412251390.0000         TOTAL IN =    1162049.1200

   OUT:                             OUT:
   ----                             ----
       STORAGE =   303733792.0000          STORAGE =          0.0000
 CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
         WELLS =  1108501380.0000            WELLS =    1162057.1200
      RECHARGE =          0.0000          RECHARGE =          0.0000

     TOTAL OUT =  1412235140.0000        TOTAL OUT =    1162057.1200

      IN - OUT =       16256.0000         IN - OUT =         -8.0000

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

TIME SUMMARY AT END OF TIME STEP 8 IN STRESS PERIOD 10

```
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
 TIME STEP LENGTH 2.64600E+06  44100.      735.00     30.625     8.38467E-02
STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0     245.00     0.67077
      TOTAL TIME 1.57680E+08 2.62800E+06  43800.      1825.0     4.9966
1
1
```

STRESS PERIOD NO. 11, LENGTH = 120.0000

```
----------------------------------------------

 NUMBER OF TIME STEPS =     4

  MULTIPLIER FOR DELT =    1.000

INITIAL TIME STEP SIZE =   30.00000


 1993 WELLS
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 11
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                                IN:
       ---                                ---
        STORAGE =  1158673660.0000           STORAGE =     289341.2810
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =         0.0000              WELLS =         0.0000
       RECHARGE =   263060336.0000          RECHARGE =      26746.4414

       TOTAL IN =  1421734020.0000          TOTAL IN =     316087.7190

      OUT:                               OUT:
      ----                               ----
        STORAGE =   305161024.0000           STORAGE =      47574.1055
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =  1116555390.0000             WELLS =     268467.7810
       RECHARGE =         0.0000          RECHARGE =         0.0000

      TOTAL OUT =  1421716480.0000         TOTAL OUT =     316041.8750

       IN - OUT =      17536.0000          IN - OUT =         45.8438

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.01


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD 11
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

       IN:                                IN:
       ---                                ---
        STORAGE =  1167331330.0000           STORAGE =     288586.6880
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =         0.0000              WELLS =         0.0000
       RECHARGE =   263862736.0000          RECHARGE =      26746.4414

       TOTAL IN =  1431194110.0000          TOTAL IN =     315333.1250

      OUT:                               OUT:
      ----                               ----
        STORAGE =   306565568.0000           STORAGE =      46818.6055
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =  1124609410.0000             WELLS =     268467.7810
       RECHARGE =         0.0000          RECHARGE =         0.0000

      TOTAL OUT =  1431174910.0000         TOTAL OUT =     315286.3750

       IN - OUT =      19200.0000          IN - OUT =         46.7500

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.01
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD 11
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3      RATES FOR THIS TIME STEP      L**3/T
   ------------------                ------------------------

      IN:                            IN:
      ---                            ---
        STORAGE =  1175971200.0000          STORAGE =      287993.6880
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =          0.0000             WELLS =          0.0000
        RECHARGE =   264665136.0000         RECHARGE =       26746.4414

        TOTAL IN =  1440636290.0000          TOTAL IN =      314740.1250

     OUT:                           OUT:
     ----                           ----
        STORAGE =   307952352.0000          STORAGE =       46226.2227
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =  1132663420.0000            WELLS =      268467.7810
        RECHARGE =          0.0000          RECHARGE =          0.0000

       TOTAL OUT =  1440615810.0000         TOTAL OUT =      314694.0000

        IN - OUT =       20480.0000          IN - OUT =          46.1250

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.01


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD 11
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3      RATES FOR THIS TIME STEP      L**3/T
   ------------------                ------------------------

      IN:                            IN:
      ---                            ---
        STORAGE =  1184595970.0000          STORAGE =      287490.9060
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =          0.0000             WELLS =          0.0000
        RECHARGE =   265467536.0000         RECHARGE =       26746.4414

        TOTAL IN =  1450063490.0000          TOTAL IN =      314237.3440

     OUT:                           OUT:
     ----                           ----
        STORAGE =   309324096.0000          STORAGE =       45724.8359
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
           WELLS =  1140717440.0000            WELLS =      268467.7810
        RECHARGE =          0.0000          RECHARGE =          0.0000

       TOTAL OUT =  1450041600.0000         TOTAL OUT =      314192.6250

        IN - OUT =       21888.0000          IN - OUT =          44.7188

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.01
```

```
     TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD 11
          SECONDS    MINUTES    HOURS     DAYS     YEARS
          -----------------------------------------------------------
 TIME STEP LENGTH 2.59200E+06  43200.    720.00    30.000    8.21355E-02
STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0    120.00    0.32854
    TOTAL TIME 1.68048E+08 2.80080E+06  46680.    1945.0    5.3251
1
1
              STRESS PERIOD NO.  12, LENGTH =   245.0000
              ----------------------------------------------

               NUMBER OF TIME STEPS =     8

                MULTIPLIER FOR DELT =     1.000

              INITIAL TIME STEP SIZE =   30.62500


 1993 WELLS


 1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 12
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------           ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =  1193591040.0000          STORAGE =     293715.2810
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000            WELLS =         0.0000
      RECHARGE =   265467536.0000          RECHARGE =         0.0000

      TOTAL IN =  1459058560.0000          TOTAL IN =     293715.2810

     OUT:                           OUT:
     ----                           ----
       STORAGE =   310097120.0000          STORAGE =      25241.9707
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =  1148939260.0000            WELLS =     268467.7810
      RECHARGE =         0.0000         RECHARGE =         0.0000

     TOTAL OUT =  1459036420.0000          TOTAL OUT =     293709.7500

      IN - OUT =      22144.0000          IN - OUT =          5.5312

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD 12
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                   IN:
      ---                                   ---
       STORAGE =  1202572670.0000           STORAGE =     293279.1560
 CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
         WELLS =          0.0000              WELLS =          0.0000
      RECHARGE =   265467536.0000          RECHARGE =          0.0000

      TOTAL IN =  1468040190.0000          TOTAL IN =     293279.1560

     OUT:                                  OUT:
     ----                                  ----
       STORAGE =   310856800.0000           STORAGE =      24806.2754
 CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
         WELLS =  1157161090.0000             WELLS =     268467.7810
      RECHARGE =          0.0000           RECHARGE =          0.0000

     TOTAL OUT =  1468017920.0000         TOTAL OUT =     293274.0630

      IN - OUT =       22272.0000          IN - OUT =          5.0938

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD 12
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                   IN:
      ---                                   ---
       STORAGE =  1211541630.0000           STORAGE =     292862.9380
 CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
         WELLS =          0.0000              WELLS =          0.0000
      RECHARGE =   265467536.0000          RECHARGE =          0.0000

      TOTAL IN =  1477009150.0000          TOTAL IN =     292862.9380

     OUT:                                  OUT:
     ----                                  ----
       STORAGE =   311603744.0000           STORAGE =      24390.2129
 CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
         WELLS =  1165382910.0000             WELLS =     268467.7810
      RECHARGE =          0.0000           RECHARGE =          0.0000

     TOTAL OUT =  1476986620.0000         TOTAL OUT =     292858.0000

      IN - OUT =       22528.0000          IN - OUT =          4.9375

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 4 IN STRESS PERIOD 12

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                                IN:
        ---                                ---
         STORAGE =  1220498300.0000          STORAGE =     292463.2810
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
           WELLS =         0.0000              WELLS =         0.0000
        RECHARGE =   265467536.0000         RECHARGE =         0.0000

        TOTAL IN =  1485965820.0000         TOTAL IN =     292463.2810

       OUT:                               OUT:
       ----                               ----
         STORAGE =   312338432.0000          STORAGE =      23989.8066
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
           WELLS =  1173604740.0000            WELLS =     268467.7810
        RECHARGE =         0.0000           RECHARGE =         0.0000

       TOTAL OUT =  1485943170.0000        TOTAL OUT =     292457.5940

        IN - OUT =      22656.0000          IN - OUT =         5.6875

PERCENT DISCREPANCY =         0.00   PERCENT DISCREPANCY =         0.00
```

1
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 5 IN STRESS PERIOD 12

```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                                IN:
        ---                                ---
         STORAGE =  1229443070.0000          STORAGE =     292076.1250
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
           WELLS =         0.0000              WELLS =         0.0000
        RECHARGE =   265467536.0000         RECHARGE =         0.0000

        TOTAL IN =  1494910590.0000         TOTAL IN =     292076.1250

       OUT:                               OUT:
       ----                               ----
         STORAGE =   313061248.0000          STORAGE =      23602.5996
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
           WELLS =  1181826560.0000            WELLS =     268467.7810
        RECHARGE =         0.0000           RECHARGE =         0.0000

       TOTAL OUT =  1494887810.0000        TOTAL OUT =     292070.3750

        IN - OUT =      22784.0000          IN - OUT =         5.7500

PERCENT DISCREPANCY =         0.00   PERCENT DISCREPANCY =         0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD 12
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------                 ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =  1238376450.0000          STORAGE =     291700.4690
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =         0.0000            WELLS =         0.0000
      RECHARGE =   265467536.0000         RECHARGE =         0.0000

      TOTAL IN =  1503843970.0000         TOTAL IN =     291700.4690

     OUT:                          OUT:
     ----                          ----
       STORAGE =   313772608.0000          STORAGE =      23227.5801
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =  1190048380.0000            WELLS =     268467.7810
      RECHARGE =         0.0000         RECHARGE =         0.0000

     TOTAL OUT =  1503821060.0000        TOTAL OUT =     291695.3750

      IN - OUT =      22912.0000          IN - OUT =         5.0938

 PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  7 IN STRESS PERIOD 12
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------                 ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =  1247298690.0000          STORAGE =     291336.4060
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =         0.0000            WELLS =         0.0000
      RECHARGE =   265467536.0000         RECHARGE =         0.0000

      TOTAL IN =  1512766210.0000         TOTAL IN =     291336.4060

     OUT:                          OUT:
     ----                          ----
       STORAGE =   314472800.0000          STORAGE =      22863.1973
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =  1198270210.0000            WELLS =     268467.7810
      RECHARGE =         0.0000         RECHARGE =         0.0000

     TOTAL OUT =  1512743040.0000        TOTAL OUT =     291330.9690

      IN - OUT =      23168.0000          IN - OUT =         5.4375

 PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  8 IN STRESS PERIOD 12
 ------------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                     IN:
          ---                                     ---
             STORAGE =  1256210180.0000            STORAGE =     290985.2810
       CONSTANT HEAD =        0.0000         CONSTANT HEAD =        0.0000
               WELLS =        0.0000                 WELLS =        0.0000
            RECHARGE =   265467536.0000           RECHARGE =        0.0000

            TOTAL IN =  1521677700.0000           TOTAL IN =     290985.2810

          OUT:                                    OUT:
          ----                                    ----
             STORAGE =   315162208.0000            STORAGE =      22511.6426
       CONSTANT HEAD =        0.0000         CONSTANT HEAD =        0.0000
               WELLS =  1206492030.0000              WELLS =     268467.7810
            RECHARGE =        0.0000              RECHARGE =        0.0000

           TOTAL OUT =  1521654270.0000          TOTAL OUT =     290979.4380

            IN - OUT =      23424.0000            IN - OUT =        5.8437

 PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00




         TIME SUMMARY AT END OF TIME STEP  8 IN STRESS PERIOD 12
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 2.64600E+06  44100.      735.00      30.625     8.38467E-02
 STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0      245.00     0.67077
         TOTAL TIME 1.89216E+08 3.15360E+06  52560.      2190.0      5.9959
1
1
                            STRESS PERIOD NO.  13, LENGTH =   120.0000
                            ----------------------------------------------

                              NUMBER OF TIME STEPS =     4

                               MULTIPLIER FOR DELT =     1.000

                            INITIAL TIME STEP SIZE =   30.00000


 3032 WELLS
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 13
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                IN:
         ---                                ---
          STORAGE =  1268907010.0000           STORAGE =      423226.8130
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =          0.0000              WELLS =           0.0000
         RECHARGE =   266317920.0000          RECHARGE =       28346.0938

         TOTAL IN =  1535224960.0000          TOTAL IN =      451572.9060

        OUT:                               OUT:
        ----                               ----
          STORAGE =   316020896.0000           STORAGE =       28622.8789
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =  1219180540.0000             WELLS =      422949.9690
         RECHARGE =          0.0000           RECHARGE =           0.0000

        TOTAL OUT =  1535201410.0000         TOTAL OUT =      451572.8440

         IN - OUT =       23552.0000          IN - OUT =       6.2500E-02

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD 13
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                IN:
         ---                                ---
          STORAGE =  1281593340.0000           STORAGE =      422879.0000
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =          0.0000              WELLS =           0.0000
         RECHARGE =   267168304.0000          RECHARGE =       28346.0938

         TOTAL IN =  1548761600.0000          TOTAL IN =      451225.0940

        OUT:                               OUT:
        ----                               ----
          STORAGE =   316869152.0000           STORAGE =       28275.1328
    CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
            WELLS =  1231869060.0000             WELLS =      422949.9690
         RECHARGE =          0.0000           RECHARGE =           0.0000

        TOTAL OUT =  1548738180.0000         TOTAL OUT =      451225.0940

         IN - OUT =       23424.0000          IN - OUT =           0.0000

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD 13
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                   IN:
         ---                                   ---
           STORAGE =  1294270590.0000          STORAGE =     422574.6250
     CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
             WELLS =          0.0000             WELLS =          0.0000
          RECHARGE =   268018688.0000         RECHARGE =      28346.0938

          TOTAL IN =  1562289280.0000         TOTAL IN =     450920.7190
        OUT:                                  OUT:
        ----                                  ----
           STORAGE =   317708256.0000          STORAGE =      27969.9219
     CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
             WELLS =  1244557570.0000            WELLS =     422949.9690
          RECHARGE =          0.0000          RECHARGE =          0.0000

         TOTAL OUT =  1562265860.0000        TOTAL OUT =     450919.8750

          IN - OUT =       23424.0000         IN - OUT =          0.8438

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD 13
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                   IN:
         ---                                   ---
           STORAGE =  1306939390.0000          STORAGE =     422291.6250
     CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
             WELLS =          0.0000             WELLS =          0.0000
          RECHARGE =   268869056.0000         RECHARGE =      28346.0938

          TOTAL IN =  1575808510.0000         TOTAL IN =     450637.7190

        OUT:                                  OUT:
        ----                                  ----
           STORAGE =   318538880.0000          STORAGE =      27687.4238
     CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
             WELLS =  1257246080.0000            WELLS =     422949.9690
          RECHARGE =          0.0000          RECHARGE =          0.0000

         TOTAL OUT =  1575784960.0000        TOTAL OUT =     450637.4060

          IN - OUT =       23552.0000         IN - OUT =          0.3125

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
         TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD 13
            SECONDS     MINUTES      HOURS       DAYS        YEARS
            -----------------------------------------------------------
  TIME STEP LENGTH 2.59200E+06  43200.      720.00      30.000     8.21355E-02
 STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0      120.00     0.32854
      TOTAL TIME 1.99584E+08 3.32640E+06  55440.      2310.0      6.3244
1
1
                STRESS PERIOD NO.  14, LENGTH =   245.0000
                ----------------------------------------------

                 NUMBER OF TIME STEPS =     8

                  MULTIPLIER FOR DELT =     1.000

                INITIAL TIME STEP SIZE =   30.62500


 3861 WELLS


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                             IN:
      ---                             ---
        STORAGE =  1356090620.0000           STORAGE =     1604939.3800
    CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
           WELLS =          0.0000              WELLS =          0.0000
       RECHARGE =   268869056.0000          RECHARGE =          0.0000

        TOTAL IN =  1624959740.0000          TOTAL IN =     1604939.3800

      OUT:                            OUT:
      ----                            ----
        STORAGE =   318538880.0000           STORAGE =          0.0000
    CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
           WELLS =  1306397060.0000             WELLS =     1604929.1300
       RECHARGE =          0.0000          RECHARGE =          0.0000

       TOTAL OUT =  1624935940.0000         TOTAL OUT =     1604929.1300

        IN - OUT =      23808.0000           IN - OUT =         10.2500

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------               ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =  1405241860.0000          STORAGE =    1604939.3800
   CONSTANT HEAD =        0.0000       CONSTANT HEAD =        0.0000
        WELLS =        0.0000              WELLS =        0.0000
      RECHARGE =   268869056.0000          RECHARGE =        0.0000

      TOTAL IN =  1674110980.0000          TOTAL IN =    1604939.3800

     OUT:                            OUT:
     ----                            ----
       STORAGE =   318538880.0000          STORAGE =        0.0000
   CONSTANT HEAD =        0.0000       CONSTANT HEAD =        0.0000
        WELLS =  1355548030.0000           WELLS =    1604929.1300
      RECHARGE =        0.0000          RECHARGE =        0.0000

     TOTAL OUT =  1674086910.0000         TOTAL OUT =    1604929.1300

      IN - OUT =      24064.0000          IN - OUT =       10.2500

PERCENT DISCREPANCY =         0.00    PERCENT DISCREPANCY =         0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------               ------------------------

      IN:                           IN:
      ---                           ---
       STORAGE =  1454393220.0000          STORAGE =    1604940.8800
   CONSTANT HEAD =        0.0000       CONSTANT HEAD =        0.0000
        WELLS =        0.0000              WELLS =        0.0000
      RECHARGE =   268869056.0000          RECHARGE =        0.0000

      TOTAL IN =  1723262210.0000          TOTAL IN =    1604940.8800

     OUT:                            OUT:
     ----                            ----
       STORAGE =   318538880.0000          STORAGE =        0.0000
   CONSTANT HEAD =        0.0000       CONSTANT HEAD =        0.0000
        WELLS =  1404699010.0000           WELLS =    1604929.1300
      RECHARGE =        0.0000          RECHARGE =        0.0000

     TOTAL OUT =  1723237890.0000         TOTAL OUT =    1604929.1300

      IN - OUT =      24320.0000          IN - OUT =       11.7500

PERCENT DISCREPANCY =         0.00    PERCENT DISCREPANCY =         0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                              IN:
      ---                              ---
        STORAGE =  1503544450.0000          STORAGE =     1604939.6300
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =          0.0000             WELLS =          0.0000
       RECHARGE =   268869056.0000         RECHARGE =          0.0000

       TOTAL IN =  1772413440.0000         TOTAL IN =     1604939.6300

     OUT:                             OUT:
     ----                             ----
        STORAGE =   318538880.0000          STORAGE =          0.0000
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =  1453849980.0000            WELLS =     1604929.1300
       RECHARGE =          0.0000          RECHARGE =          0.0000

      TOTAL OUT =  1772388860.0000        TOTAL OUT =     1604929.1300

       IN - OUT =       24576.0000         IN - OUT =         10.5000

 PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                              IN:
      ---                              ---
        STORAGE =  1552695680.0000          STORAGE =     1604939.6300
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =          0.0000             WELLS =          0.0000
       RECHARGE =   268869056.0000         RECHARGE =          0.0000

       TOTAL IN =  1821564670.0000         TOTAL IN =     1604939.6300

     OUT:                             OUT:
     ----                             ----
        STORAGE =   318538880.0000          STORAGE =          0.0000
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =  1503000960.0000            WELLS =     1604929.1300
       RECHARGE =          0.0000          RECHARGE =          0.0000

      TOTAL OUT =  1821539840.0000        TOTAL OUT =     1604929.1300

       IN - OUT =       24832.0000         IN - OUT =         10.5000

 PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                             IN:
         ---                             ---
          STORAGE =  1601847040.0000          STORAGE =     1604941.0000
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
            WELLS =          0.0000             WELLS =          0.0000
         RECHARGE =   268869056.0000         RECHARGE =          0.0000

         TOTAL IN =  1870716160.0000         TOTAL IN =     1604941.0000

        OUT:                            OUT:
        ----                            ----
          STORAGE =   318538880.0000          STORAGE =          0.0000
    CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
            WELLS =  1552151940.0000            WELLS =     1604929.1300
         RECHARGE =          0.0000          RECHARGE =          0.0000

        TOTAL OUT =  1870690820.0000        TOTAL OUT =     1604929.1300

         IN - OUT =       25344.0000         IN - OUT =          11.8750

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  7 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                             IN:
      ---                             ---
        STORAGE =  1650998270.0000          STORAGE =    1604939.3800
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =          0.0000             WELLS =          0.0000
       RECHARGE =   268869056.0000         RECHARGE =          0.0000

       TOTAL IN =  1919867390.0000         TOTAL IN =    1604939.3800

     OUT:                            OUT:
     ----                            ----
        STORAGE =   318538880.0000          STORAGE =          0.0000
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =  1601302910.0000            WELLS =    1604929.1300
       RECHARGE =          0.0000          RECHARGE =          0.0000

      TOTAL OUT =  1919841790.0000        TOTAL OUT =    1604929.1300

       IN - OUT =       25600.0000         IN - OUT =         10.2500

PERCENT DISCREPANCY =          0.00   PERCENT DISCREPANCY =          0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  8 IN STRESS PERIOD 14
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                             IN:
      ---                             ---
        STORAGE =  1700149500.0000          STORAGE =    1604939.8800
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =          0.0000             WELLS =          0.0000
       RECHARGE =   268869056.0000         RECHARGE =          0.0000

       TOTAL IN =  1969018620.0000         TOTAL IN =    1604939.8800

     OUT:                            OUT:
     ----                            ----
        STORAGE =   318538880.0000          STORAGE =          0.0000
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =  1650453890.0000            WELLS =    1604929.1300
       RECHARGE =          0.0000          RECHARGE =          0.0000

      TOTAL OUT =  1968992770.0000        TOTAL OUT =    1604929.1300

       IN - OUT =       25856.0000         IN - OUT =         10.7500

PERCENT DISCREPANCY =          0.00   PERCENT DISCREPANCY =          0.00
```

```
       TIME SUMMARY AT END OF TIME STEP  8 IN STRESS PERIOD 14
            SECONDS     MINUTES      HOURS       DAYS        YEARS
            -----------------------------------------------------------
  TIME STEP LENGTH 2.64600E+06  44100.      735.00      30.625     8.38467E-02
STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0      245.00     0.67077
        TOTAL TIME 2.20752E+08 3.67920E+06  61320.      2555.0     6.9952
1
```

MODFLOW OUTPUT FOR MONTHLY WATER BALANCE FOR GURGAON DISTRICT FOR YEAR 2025

```
LISTING FILE: output.dat
            UNIT   3

 OPENING bas.dat
 FILE TYPE:BAS   UNIT   1

 OPENING bcf.dat
 FILE TYPE:BCF   UNIT  11

 OPENING oc.dat
 FILE TYPE:OC   UNIT  22

 OPENING wel.dat
 FILE TYPE:WEL   UNIT  12

 OPENING rch.dat
 FILE TYPE:RCH   UNIT  18

 OPENING pcg2.dat
 FILE TYPE:PCG   UNIT  23

 OPENING budget.dat
 FILE TYPE:DATA(BINARY)   UNIT  50

 OPENING heads.dat
 FILE TYPE:DATA(BINARY)   UNIT  51

 OPENING ddown.dat
 FILE TYPE:DATA(BINARY)   UNIT  52

 OPENING mt3d.flo
 FILE TYPE:DATA(BINARY)   UNIT  32
1                    MODFLOW
   U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL


 THE FREE FORMAT OPTION HAS BEEN SELECTED
   1 LAYERS       66 ROWS      102 COLUMNS
  2 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS

 BAS5 -- BASIC MODEL PACKAGE, VERSION 5, 1/1/95 INPUT READ FROM UNIT  1
 ARRAYS RHS AND BUFF WILL SHARE MEMORY
 INITIAL HEAD WILL BE KEPT THROUGHOUT THE SIMULATION
    60760 ELEMENTS IN X ARRAY ARE USED BY BAS
    60760 ELEMENTS OF X ARRAY USED OUT OF   20000000

 BCF5 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 11
 TRANSIENT SIMULATION
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
 HEAD AT CELLS THAT CONVERT TO DRY= -0.10000E+31
 WETTING CAPABILITY IS NOT ACTIVE
    LAYER  LAYER-TYPE CODE     INTERBLOCK T
    --------------------------------------------
      1          1        0 -- HARMONIC
    20197 ELEMENTS IN X ARRAY ARE USED BY BCF
```

```
    80957 ELEMENTS OF X ARRAY USED OUT OF   20000000

 WEL5 -- WELL PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 12
 MAXIMUM OF 3861 WELLS
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
    15444 ELEMENTS IN X ARRAY ARE USED BY WEL
    96401 ELEMENTS OF X ARRAY USED OUT OF   20000000

 RCH5 -- RECHARGE PACKAGE, VERSION 5, 6/1/95 INPUT READ FROM UNIT 18
 OPTION 1 -- RECHARGE TO TOP LAYER
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
     6732 ELEMENTS IN X ARRAY ARE USED BY RCH
   103133 ELEMENTS OF X ARRAY USED OUT OF   20000000
0PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.1, 6/1/95
 MAXIMUM OF  50 CALLS OF SOLUTION ROUTINE
 MAXIMUM OF  30 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
 MATRIX PRECONDITIONING TYPE :    1
   40428 ELEMENTS IN X ARRAY ARE USED BY PCG
  143561 ELEMENTS OF X ARRAY USED OUT OF*******
1


            BOUNDARY ARRAY FOR LAYER   1
 READING ON UNIT   1 WITH FORMAT: (20I3)

 AQUIFER HEAD WILL BE SET TO -999.99     AT ALL NO-FLOW NODES (IBOUND=0).


            INITIAL HEAD FOR LAYER   1
 READING ON UNIT   1 WITH FORMAT: (20G14.0)

 OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
 HEAD PRINT FORMAT CODE IS   0    DRAWDOWN PRINT FORMAT CODE IS   0
 HEADS WILL BE SAVED ON UNIT  51    DRAWDOWNS WILL BE SAVED ON UNIT  52


       COLUMN TO ROW ANISOTROPY
 READING ON UNIT  11 WITH FORMAT: (1G14.0)

                 DELR
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

                 DELC
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

         PRIMARY STORAGE COEF FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

        HYD. COND. ALONG ROWS FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

                BOTTOM FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)
```

SOLUTION BY THE CONJUGATE-GRADIENT METHOD
----
0 MAXIMUM NUMBER OF CALLS TO PCG ROUTINE = 50
MAXIMUM ITERATIONS PER CALL TO PCG = 30
MATRIX PRECONDITIONING TYPE = 1
RELAXATION FACTOR (ONLY USED WITH PRECOND. TYPE 1) = 0.10000E+01
PARAMETER OF POLYMOMIAL PRECOND. = 2 (2) OR IS CALCULATED : 1
HEAD CHANGE CRITERION FOR CLOSURE = 0.10000E-02
RESIDUAL CHANGE CRITERION FOR CLOSURE = 0.10000E-02
PCG HEAD AND RESIDUAL CHANGE PRINTOUT INTERVAL = 1
PRINTING FROM SOLVER IS LIMITED(1) OR SUPPRESSED (>1) = 0
DAMPING PARAMETER = 0.10000E+01

1

STRESS PERIOD NO. 1, LENGTH = 120.0000

NUMBER OF TIME STEPS = 4

MULTIPLIER FOR DELT = 1.000

INITIAL TIME STEP SIZE = 30.00000

3860 WELLS

1

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1

CUMULATIVE VOLUMES L**3		RATES FOR THIS TIME STEP L**3/T	
IN:		IN:	
STORAGE =	23599186.0000	STORAGE =	786639.5630
CONSTANT HEAD =	0.0000	CONSTANT HEAD =	0.0000
WELLS =	0.0000	WELLS =	0.0000
RECHARGE =	0.0000	RECHARGE =	0.0000
TOTAL IN =	23599186.0000	TOTAL IN =	786639.5630
OUT:		OUT:	
STORAGE =	3418985.7500	STORAGE =	113966.1950
CONSTANT HEAD =	0.0000	CONSTANT HEAD =	0.0000
WELLS =	20179596.0000	WELLS =	672653.1880
RECHARGE =	0.0000	RECHARGE =	0.0000
TOTAL OUT =	23598582.0000	TOTAL OUT =	786619.3750
IN - OUT =	604.0000	IN - OUT =	20.1875
PERCENT DISCREPANCY =	0.00	PERCENT DISCREPANCY =	0.00

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  1
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                              IN:
         ---                              ---
           STORAGE =    46276136.0000           STORAGE =      755898.3750
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =          0.0000              WELLS =           0.0000
          RECHARGE =          0.0000           RECHARGE =           0.0000

          TOTAL IN =    46276136.0000          TOTAL IN =      755898.3750

        OUT:                             OUT:
        ----                             ----
           STORAGE =     5915767.5000           STORAGE =       83226.0547
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =    40359192.0000             WELLS =      672653.1880
          RECHARGE =          0.0000           RECHARGE =           0.0000

         TOTAL OUT =    46274960.0000         TOTAL OUT =      755879.2500

          IN - OUT =        1176.0000          IN - OUT =          19.1250

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  1
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                              IN:
         ---                              ---
           STORAGE =    68341424.0000           STORAGE =      735509.5000
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =          0.0000              WELLS =           0.0000
          RECHARGE =          0.0000           RECHARGE =           0.0000

          TOTAL IN =    68341424.0000          TOTAL IN =      735509.5000

        OUT:                             OUT:
        ----                             ----
           STORAGE =     7800876.0000           STORAGE =       62836.9492
     CONSTANT HEAD =          0.0000      CONSTANT HEAD =           0.0000
             WELLS =    60538788.0000             WELLS =      672653.1880
          RECHARGE =          0.0000           RECHARGE =           0.0000

         TOTAL OUT =    68339664.0000         TOTAL OUT =      735490.1250

          IN - OUT =        1760.0000          IN - OUT =          19.3750

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
  1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  1
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------            ------------------------

      IN:                         IN:
      ---                         ---
        STORAGE =    89992696.0000          STORAGE =     721709.1250
    CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =         0.0000            WELLS =         0.0000
       RECHARGE =         0.0000         RECHARGE =         0.0000

       TOTAL IN =    89992696.0000         TOTAL IN =     721709.1250

      OUT:                        OUT:
      ----                        ----
        STORAGE =     9271977.0000          STORAGE =      49036.7148
    CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =    80718384.0000            WELLS =     672653.1880
       RECHARGE =         0.0000         RECHARGE =         0.0000

      TOTAL OUT =    89990360.0000        TOTAL OUT =     721689.8750

       IN - OUT =        2336.0000         IN - OUT =        19.2500

 PERCENT DISCREPANCY =         0.00    PERCENT DISCREPANCY =         0.00



      TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD  1
              SECONDS     MINUTES      HOURS       DAYS        YEARS
              -----------------------------------------------------------
  TIME STEP LENGTH 2.59200E+06  43200.     720.00     30.000    8.21355E-02
 STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0     120.00    0.32854
       TOTAL TIME 1.03680E+07 1.72800E+05  2880.0     120.00    0.32854
1
1
                STRESS PERIOD NO.   2, LENGTH =   245.0000
                ----------------------------------------------

                 NUMBER OF TIME STEPS =     8

                  MULTIPLIER FOR DELT =     1.000

                INITIAL TIME STEP SIZE =    30.62500
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------             ------------------------

      IN:                         IN:
      ---                         ---
       STORAGE =   154029200.0000          STORAGE =    2090987.8800
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000             WELLS =         0.0000
      RECHARGE =         0.0000          RECHARGE =         0.0000

      TOTAL IN =   154029200.0000          TOTAL IN =    2090987.8800

     OUT:                         OUT:
     ----                         ----
       STORAGE =     9337670.0000          STORAGE =       2145.0632
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =   144689360.0000             WELLS =    2088848.2500
      RECHARGE =         0.0000          RECHARGE =         0.0000

     TOTAL OUT =   154027024.0000         TOTAL OUT =    2090993.3800

      IN - OUT =       2176.0000          IN - OUT =        -5.5000

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------             ------------------------

      IN:                         IN:
      ---                         ---
       STORAGE =   218043408.0000          STORAGE =    2090260.0000
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =         0.0000             WELLS =         0.0000
      RECHARGE =         0.0000          RECHARGE =         0.0000

      TOTAL IN =   218043408.0000          TOTAL IN =    2090260.0000

     OUT:                         OUT:
     ----                         ----
       STORAGE =     9381038.0000          STORAGE =       1416.1128
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
        WELLS =   208660336.0000             WELLS =    2088848.2500
      RECHARGE =         0.0000          RECHARGE =         0.0000

     TOTAL OUT =   218041376.0000         TOTAL OUT =    2090264.3800

      IN - OUT =       2032.0000          IN - OUT =        -4.3750

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                IN:
         ---                                ---
            STORAGE =   282041472.0000            STORAGE =     2089732.3800
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =          0.0000               WELLS =          0.0000
           RECHARGE =          0.0000            RECHARGE =          0.0000

           TOTAL IN =   282041472.0000            TOTAL IN =     2089732.3800

        OUT:                               OUT:
        ----                               ----
            STORAGE =     9408273.0000            STORAGE =        889.3016
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =   272631328.0000              WELLS =     2088848.2500
           RECHARGE =          0.0000            RECHARGE =          0.0000

          TOTAL OUT =   282039616.0000           TOTAL OUT =     2089737.5000

           IN - OUT =        1856.0000            IN - OUT =         -5.1250

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                IN:
         ---                                ---
            STORAGE =   346025888.0000            STORAGE =     2089286.8800
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =          0.0000               WELLS =          0.0000
           RECHARGE =          0.0000            RECHARGE =          0.0000

           TOTAL IN =   346025888.0000            TOTAL IN =     2089286.8800

        OUT:                               OUT:
        ----                               ----
            STORAGE =     9421893.0000            STORAGE =        444.7269
      CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
              WELLS =   336602304.0000              WELLS =     2088848.2500
           RECHARGE =          0.0000            RECHARGE =          0.0000

          TOTAL OUT =   346024192.0000           TOTAL OUT =     2089293.0000

           IN - OUT =        1696.0000            IN - OUT =         -6.1250

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------
      IN:                              IN:
      ---                              ---
       STORAGE =   410003136.0000          STORAGE =     2089052.7500
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
        WELLS =          0.0000            WELLS =          0.0000
      RECHARGE =          0.0000         RECHARGE =          0.0000

      TOTAL IN =   410003136.0000         TOTAL IN =     2089052.7500

     OUT:                             OUT:
     ----                             ----
       STORAGE =     9428315.0000          STORAGE =        209.7023
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
        WELLS =   400573280.0000           WELLS =     2088848.2500
      RECHARGE =          0.0000         RECHARGE =          0.0000

     TOTAL OUT =   410001600.0000        TOTAL OUT =     2089058.0000

      IN - OUT =        1536.0000         IN - OUT =         -5.2500

PERCENT DISCREPANCY =          0.00   PERCENT DISCREPANCY =          0.00


1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------
      IN:                              IN:
      ---                              ---
       STORAGE =   473975360.0000          STORAGE =     2088888.5000
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
        WELLS =          0.0000            WELLS =          0.0000
      RECHARGE =          0.0000         RECHARGE =          0.0000

      TOTAL IN =   473975360.0000         TOTAL IN =     2088888.5000

     OUT:                             OUT:
     ----                             ----
       STORAGE =     9429696.0000          STORAGE =         45.0965
   CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
        WELLS =   464544256.0000           WELLS =     2088848.2500
      RECHARGE =          0.0000         RECHARGE =          0.0000

     TOTAL OUT =   473973952.0000        TOTAL OUT =     2088893.3800

      IN - OUT =        1408.0000         IN - OUT =         -4.8750

PERCENT DISCREPANCY =          0.00   PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  7 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------
   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------
      IN:                                 IN:
      ---                                 ---
        STORAGE =   537946176.0000          STORAGE =     2088843.3800
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =          0.0000             WELLS =           0.0000
       RECHARGE =          0.0000          RECHARGE =           0.0000
       TOTAL IN =   537946176.0000          TOTAL IN =     2088843.3800

     OUT:                                OUT:
     ----                                ----
        STORAGE =     9429696.0000          STORAGE =           0.0000
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =   528515232.0000             WELLS =     2088848.2500
       RECHARGE =          0.0000          RECHARGE =           0.0000
      TOTAL OUT =   537944960.0000         TOTAL OUT =     2088848.2500
       IN - OUT =       1216.0000          IN - OUT =          -4.8750

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =           0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  8 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------
   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------
      IN:                                 IN:
      ---                                 ---
        STORAGE =   601916992.0000          STORAGE =     2088843.2500
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =          0.0000             WELLS =           0.0000
       RECHARGE =          0.0000          RECHARGE =           0.0000
       TOTAL IN =   601916992.0000          TOTAL IN =     2088843.2500

     OUT:                                OUT:
     ----                                ----
        STORAGE =     9429696.0000          STORAGE =           0.0000
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =           0.0000
          WELLS =   592486208.0000             WELLS =     2088848.2500
       RECHARGE =          0.0000          RECHARGE =           0.0000
      TOTAL OUT =   601915904.0000         TOTAL OUT =     2088848.2500
       IN - OUT =       1088.0000          IN - OUT =          -5.0000

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =           0.00
```

TIME SUMMARY AT END OF TIME STEP 8 IN STRESS PERIOD 2

```
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 2.64600E+06  44100.      735.00      30.625     8.38467E-02
 STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0      245.00     0.67077
         TOTAL TIME 3.15360E+07 5.25600E+05  8760.0      365.00     0.99932
```

MODFLOW OUTPUT FOR MONTHLY WATER BALANCE FOR GURGAON DISTRICT FOR YEAR 2050

```
LISTING FILE: output.dat
              UNIT   3

 OPENING bas.dat
 FILE TYPE:BAS   UNIT   1

 OPENING bcf.dat
 FILE TYPE:BCF   UNIT  11

 OPENING oc.dat
 FILE TYPE:OC   UNIT  22

 OPENING wel.dat
 FILE TYPE:WEL   UNIT  12

 OPENING rch.dat
 FILE TYPE:RCH   UNIT  18

 OPENING pcg2.dat
 FILE TYPE:PCG   UNIT  23

 OPENING budget.dat
 FILE TYPE:DATA(BINARY)   UNIT  50

 OPENING heads.dat
 FILE TYPE:DATA(BINARY)   UNIT  51

 OPENING ddown.dat
 FILE TYPE:DATA(BINARY)   UNIT  52

 OPENING mt3d.flo
 FILE TYPE:DATA(BINARY)   UNIT  32
1                        MODFLOW
    U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL


 THE FREE FORMAT OPTION HAS BEEN SELECTED
    1 LAYERS       66 ROWS       102 COLUMNS
   2 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS

 BAS5 -- BASIC MODEL PACKAGE, VERSION 5, 1/1/95 INPUT READ FROM UNIT  1
 ARRAYS RHS AND BUFF WILL SHARE MEMORY
 INITIAL HEAD WILL BE KEPT THROUGHOUT THE SIMULATION
     60760 ELEMENTS IN X ARRAY ARE USED BY BAS
     60760 ELEMENTS OF X ARRAY USED OUT OF   20000000

 BCF5 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 11
 TRANSIENT SIMULATION
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
 HEAD AT CELLS THAT CONVERT TO DRY= -0.10000E+31
 WETTING CAPABILITY IS NOT ACTIVE
     LAYER  LAYER-TYPE CODE     INTERBLOCK T
     --------------------------------------------
       1          1        0 -- HARMONIC
     20197 ELEMENTS IN X ARRAY ARE USED BY BCF
     80957 ELEMENTS OF X ARRAY USED OUT OF   20000000
```

```
 WEL5 -- WELL PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 12
 MAXIMUM OF 3861 WELLS
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
     15444 ELEMENTS IN X ARRAY ARE USED BY WEL
     96401 ELEMENTS OF X ARRAY USED OUT OF   20000000

 RCH5 -- RECHARGE PACKAGE, VERSION 5, 6/1/95 INPUT READ FROM UNIT 18
 OPTION 1 -- RECHARGE TO TOP LAYER
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 50
      6732 ELEMENTS IN X ARRAY ARE USED BY RCH
    103133 ELEMENTS OF X ARRAY USED OUT OF   20000000
0PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.1, 6/1/95
 MAXIMUM OF  50 CALLS OF SOLUTION ROUTINE
 MAXIMUM OF  30 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
 MATRIX PRECONDITIONING TYPE :    1
   40428 ELEMENTS IN X ARRAY ARE USED BY PCG
  143561 ELEMENTS OF X ARRAY USED OUT OF*******
1

                    BOUNDARY ARRAY FOR LAYER   1
 READING ON UNIT   1 WITH FORMAT: (20I3)

 AQUIFER HEAD WILL BE SET TO -999.99     AT ALL NO-FLOW NODES (IBOUND=0).

                   INITIAL HEAD FOR LAYER   1
 READING ON UNIT   1 WITH FORMAT: (20G14.0)

 OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
 HEAD PRINT FORMAT CODE IS   0    DRAWDOWN PRINT FORMAT CODE IS   0
 HEADS WILL BE SAVED ON UNIT  51    DRAWDOWNS WILL BE SAVED ON UNIT  52

          COLUMN TO ROW ANISOTROPY
 READING ON UNIT  11 WITH FORMAT: (1G14.0)

                         DELR
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

                         DELC
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

             PRIMARY STORAGE COEF FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

            HYD. COND. ALONG ROWS FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)

                        BOTTOM FOR LAYER   1
 READING ON UNIT  11 WITH FORMAT: (20G14.0)
0
```

SOLUTION BY THE CONJUGATE-GRADIENT METHOD

```
                    -------------------------------------------
0                  MAXIMUM NUMBER OF CALLS TO PCG ROUTINE =      50
                     MAXIMUM ITERATIONS PER CALL TO PCG =      30
                        MATRIX PRECONDITIONING TYPE =      1
        RELAXATION FACTOR (ONLY USED WITH PRECOND. TYPE 1) =    0.10000E+01
     PARAMETER OF POLYMOMIAL PRECOND. = 2 (2) OR IS CALCULATED :       1
                  HEAD CHANGE CRITERION FOR CLOSURE =    0.10000E-02
                RESIDUAL CHANGE CRITERION FOR CLOSURE =    0.10000E-02
           PCG HEAD AND RESIDUAL CHANGE PRINTOUT INTERVAL =      1
      PRINTING FROM SOLVER IS LIMITED(1) OR SUPPRESSED (>1) =      0
                          DAMPING PARAMETER =    0.10000E+01
1
```

STRESS PERIOD NO. 1, LENGTH = 120.0000

```
---------------------------------------------

 NUMBER OF TIME STEPS =     4

  MULTIPLIER FOR DELT =     1.000

INITIAL TIME STEP SIZE =   30.00000


 3860 WELLS

1
```

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1

```
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                              IN:
      ---                              ---
        STORAGE =    37619220.0000          STORAGE =     1253974.0000
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =         0.0000              WELLS =         0.0000
       RECHARGE =         0.0000           RECHARGE =         0.0000

       TOTAL IN =    37619220.0000         TOTAL IN =     1253974.0000

     OUT:                              OUT:
     ----                              ----
        STORAGE =     2222802.7500          STORAGE =       74093.4219
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
          WELLS =    35396220.0000            WELLS =     1179874.0000
       RECHARGE =         0.0000           RECHARGE =         0.0000

      TOTAL OUT =    37619024.0000        TOTAL OUT =     1253967.3800

       IN - OUT =       196.0000           IN - OUT =         6.6250

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  1
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                   IN:
         ---                                   ---
             STORAGE =    74492128.0000            STORAGE =     1229097.0000
       CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
               WELLS =          0.0000               WELLS =          0.0000
            RECHARGE =          0.0000            RECHARGE =          0.0000

            TOTAL IN =    74492128.0000           TOTAL IN =     1229097.0000

        OUT:                                  OUT:
        ----                                  ----
             STORAGE =     3699315.0000            STORAGE =       49217.0781
       CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
               WELLS =    70792440.0000              WELLS =     1179874.0000
            RECHARGE =          0.0000            RECHARGE =          0.0000

           TOTAL OUT =    74491752.0000          TOTAL OUT =     1229091.1200

            IN - OUT =        376.0000            IN - OUT =          5.8750

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  1
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                   IN:
         ---                                   ---
             STORAGE =   110908520.0000            STORAGE =     1213879.6300
       CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
               WELLS =          0.0000               WELLS =          0.0000
            RECHARGE =          0.0000            RECHARGE =          0.0000

            TOTAL IN =   110908520.0000           TOTAL IN =     1213879.6300

        OUT:                                  OUT:
        ----                                  ----
             STORAGE =     4719294.0000            STORAGE =       33999.2930
       CONSTANT HEAD =          0.0000       CONSTANT HEAD =          0.0000
               WELLS =   106188656.0000              WELLS =     1179874.0000
            RECHARGE =          0.0000            RECHARGE =          0.0000

           TOTAL OUT =   110907952.0000          TOTAL OUT =     1213873.2500

            IN - OUT =        568.0000            IN - OUT =          6.3750

 PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  1
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                             IN:
      ---                             ---
        STORAGE =   147032912.0000          STORAGE =     1204146.3700
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =          0.0000             WELLS =          0.0000
       RECHARGE =          0.0000          RECHARGE =          0.0000

       TOTAL IN =   147032912.0000         TOTAL IN =     1204146.3700

      OUT:                            OUT:
      ----                            ----
        STORAGE =     5447291.0000          STORAGE =       24266.5664
  CONSTANT HEAD =          0.0000     CONSTANT HEAD =          0.0000
          WELLS =   141584880.0000            WELLS =     1179874.0000
       RECHARGE =          0.0000          RECHARGE =          0.0000

      TOTAL OUT =   147032176.0000        TOTAL OUT =     1204140.6200

       IN - OUT =        736.0000          IN - OUT =          5.7500

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00




      TIME SUMMARY AT END OF TIME STEP  4 IN STRESS PERIOD  1
            SECONDS     MINUTES      HOURS       DAYS        YEARS
            -----------------------------------------------------------
 TIME STEP LENGTH 2.59200E+06  43200.     720.00     30.000    8.21355E-02
STRESS PERIOD TIME 1.03680E+07 1.72800E+05  2880.0     120.00    0.32854
     TOTAL TIME 1.03680E+07 1.72800E+05  2880.0     120.00    0.32854
1
1
                 STRESS PERIOD NO.   2, LENGTH =   245.0000
                 ----------------------------------------------

                  NUMBER OF TIME STEPS =     8

                   MULTIPLIER FOR DELT =     1.000

                 INITIAL TIME STEP SIZE =   30.62500


 3861 WELLS
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                              IN:
      ---                              ---
       STORAGE =   225784496.0000         STORAGE =     2571480.5000
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =           0.0000              WELLS =         0.0000
      RECHARGE =           0.0000           RECHARGE =         0.0000

      TOTAL IN =   225784496.0000           TOTAL IN =     2571480.5000

     OUT:                             OUT:
     ----                             ----
       STORAGE =     5478994.0000         STORAGE =        1035.2001
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =   220304528.0000              WELLS =     2570437.5000
      RECHARGE =           0.0000           RECHARGE =         0.0000

     TOTAL OUT =   225783520.0000          TOTAL OUT =     2571472.7500

      IN - OUT =         976.0000           IN - OUT =           7.7500

 PERCENT DISCREPANCY =        0.00     PERCENT DISCREPANCY =        0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                              IN:
      ---                              ---
       STORAGE =   304522784.0000         STORAGE =     2571046.0000
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =           0.0000              WELLS =         0.0000
      RECHARGE =           0.0000           RECHARGE =         0.0000

      TOTAL IN =   304522784.0000           TOTAL IN =     2571046.0000

     OUT:                             OUT:
     ----                             ----
       STORAGE =     5497401.0000         STORAGE =         601.0370
   CONSTANT HEAD =         0.0000      CONSTANT HEAD =         0.0000
         WELLS =   299024192.0000              WELLS =     2570437.5000
      RECHARGE =           0.0000           RECHARGE =         0.0000

     TOTAL OUT =   304521600.0000          TOTAL OUT =     2571038.5000

      IN - OUT =        1184.0000           IN - OUT =           7.5000

 PERCENT DISCREPANCY =        0.00     PERCENT DISCREPANCY =        0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                      IN:
      ---                                      ---
        STORAGE =   383250176.0000           STORAGE =     2570690.5000
  CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
          WELLS =          0.0000              WELLS =          0.0000
       RECHARGE =          0.0000           RECHARGE =          0.0000

       TOTAL IN =   383250176.0000          TOTAL IN =     2570690.5000

     OUT:                                     OUT:
     ----                                     ----
        STORAGE =     5504885.5000           STORAGE =        244.3887
  CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
          WELLS =   377743840.0000             WELLS =     2570437.5000
       RECHARGE =          0.0000           RECHARGE =          0.0000

      TOTAL OUT =   383248736.0000         TOTAL OUT =     2570682.0000

       IN - OUT =        1440.0000          IN - OUT =          8.5000

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

      IN:                                      IN:
      ---                                      ---
        STORAGE =   461970336.0000           STORAGE =     2570454.0000
  CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
          WELLS =          0.0000              WELLS =          0.0000
       RECHARGE =          0.0000           RECHARGE =          0.0000

       TOTAL IN =   461970336.0000          TOTAL IN =     2570454.0000

     OUT:                                     OUT:
     ----                                     ----
        STORAGE =     5505140.0000           STORAGE =          8.3183
  CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
          WELLS =   456463488.0000             WELLS =     2570437.5000
       RECHARGE =          0.0000           RECHARGE =          0.0000

      TOTAL OUT =   461968640.0000         TOTAL OUT =     2570445.7500

       IN - OUT =        1696.0000          IN - OUT =          8.2500

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =          0.00
```

```
1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                  IN:
         ---                                  ---
             STORAGE =   540690240.0000           STORAGE =     2570445.5000
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
               WELLS =          0.0000              WELLS =          0.0000
            RECHARGE =          0.0000           RECHARGE =          0.0000

            TOTAL IN =   540690240.0000           TOTAL IN =     2570445.5000

          OUT:                                 OUT:
          ----                                 ----
             STORAGE =     5505140.0000           STORAGE =          0.0000
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
               WELLS =   535183136.0000             WELLS =     2570437.5000
            RECHARGE =          0.0000           RECHARGE =          0.0000

           TOTAL OUT =   540688256.0000          TOTAL OUT =     2570437.5000

            IN - OUT =       1984.0000            IN - OUT =          8.0000

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00

1
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  6 IN STRESS PERIOD  2
 ------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

         IN:                                  IN:
         ---                                  ---
             STORAGE =   619410112.0000           STORAGE =     2570445.2500
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
               WELLS =          0.0000              WELLS =          0.0000
            RECHARGE =          0.0000           RECHARGE =          0.0000

            TOTAL IN =   619410112.0000           TOTAL IN =     2570445.2500

          OUT:                                 OUT:
          ----                                 ----
             STORAGE =     5505140.0000           STORAGE =          0.0000
       CONSTANT HEAD =          0.0000      CONSTANT HEAD =          0.0000
               WELLS =   613902784.0000             WELLS =     2570437.5000
            RECHARGE =          0.0000           RECHARGE =          0.0000

           TOTAL OUT =   619407936.0000          TOTAL OUT =     2570437.5000

            IN - OUT =       2176.0000            IN - OUT =          7.7500

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 7 IN STRESS PERIOD 2

```
 ------------------------------------------------------------------------------
   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------            ------------------------
      IN:                         IN:
      ---                         ---
       STORAGE =   698129984.0000          STORAGE =    2570445.2500
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000             WELLS =        0.0000
      RECHARGE =        0.0000          RECHARGE =        0.0000
      TOTAL IN =   698129984.0000         TOTAL IN =    2570445.2500

     OUT:                         OUT:
     ----                         ----
       STORAGE =    5505140.0000          STORAGE =        0.0000
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =   692622464.0000          WELLS =    2570437.5000
      RECHARGE =        0.0000          RECHARGE =        0.0000
     TOTAL OUT =   698127616.0000         TOTAL OUT =    2570437.5000

      IN - OUT =      2368.0000          IN - OUT =        7.7500

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.00
```

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 8 IN STRESS PERIOD 2

```
 ------------------------------------------------------------------------------
   CUMULATIVE VOLUMES     L**3      RATES FOR THIS TIME STEP     L**3/T
   ------------------            ------------------------
      IN:                         IN:
      ---                         ---
       STORAGE =   776849856.0000          STORAGE =    2570445.5000
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =        0.0000             WELLS =        0.0000
      RECHARGE =        0.0000          RECHARGE =        0.0000
      TOTAL IN =   776849856.0000         TOTAL IN =    2570445.5000

     OUT:                         OUT:
     ----                         ----
       STORAGE =    5505140.0000          STORAGE =        0.0000
    CONSTANT HEAD =        0.0000      CONSTANT HEAD =        0.0000
        WELLS =   771342144.0000          WELLS =    2570437.5000
      RECHARGE =        0.0000          RECHARGE =        0.0000
     TOTAL OUT =   776847296.0000         TOTAL OUT =    2570437.5000

      IN - OUT =      2560.0000          IN - OUT =        8.0000

PERCENT DISCREPANCY =        0.00    PERCENT DISCREPANCY =        0.00
```

```
TIME SUMMARY AT END OF TIME STEP  8 IN STRESS PERIOD  2
             SECONDS    MINUTES     HOURS      DAYS      YEARS
             -----------------------------------------------------------
  TIME STEP LENGTH 2.64600E+06  44100.     735.00     30.625    8.38467E-02
STRESS PERIOD TIME 2.11680E+07 3.52800E+05  5880.0     245.00    0.67077
        TOTAL TIME 3.15360E+07 5.25600E+05  8760.0     365.00    0.99932
```