Department of Soil and Water Conservation Engineering,
Dapoli, Maharashtra.

A report on

Simulation of Groundwater Recharge in Priyadarshini Watershed

Submitted by

Er. Anand R. Gattani
(Reg.No.- 17/2005)

College of Agriculture Engg. and Tech., Dapoli

Under the Guidance of

Dr. V.V.S. Gurunadha Rao
Scientist - F

Ground Water Section
National Geophysical Research Institute, Hyderabad

SIMULATION OF GROUNDWATER RECHARGE IN PRIYADARASHINI WATERSHED

A Thesis submitted to the

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

in

SOIL AND WATER CONSERVATION ENGINEERING

by

Anand Radhesham Gattani

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING

COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
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Chairman and Research Guide

Members

(S.B. Nandgude) **Committee Member**	**(M. R. More)** **Committee Member**

(S.M. Kulkarni)
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(K.D. Gharde)
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CANDIDATE'S DECLARATION

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List of Abbreviations

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BCM	Billion Cubic Meter
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DD	Draw down
Div.	Division
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Dr. PDKV.	Dr. Panjabrao Deshmukh Krishi Vidyapeeth
DW	Dug well
Engg.	Engineering
etc	etcetera
et al.	and other
Fig.	Figure
ha	hectare
HP	Horse Power
ICAR	Indian Council of Agricultural Research

i.e.	that is
ICRISAT	International Crop Research Institute for Semi Arid Tropic
Irrg.	Irrigation
J	Journal
m	meter
Mha	million hectares
Maha.	Maharashtra
mm	mili meter
MSL	Mean Sea Level
NGRI	National Geophysical Research Institute
No.	Number
Sci.	Science
SN	Serial number
Soc.	Society
SWC	Soil and Water Conservation
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SD	Standard Deviation
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Research Guide: **Prof. dilip MAHALE**
Department: **Soil and Water Conservation Engineering**

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The water balance was estimated by SWIM computer model, available with National Geophysical Research Institute, Hyderabad. The daily rainfall and pan evaporation data recorded in the study area during year period from 1985-2006 were the main input for this model.

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DW	Dug well
Engg.	Engineering
etc	etcetera
et al.	and other
Fig.	Figure
ha	hectare
HP	Horse Power
ICAR	Indian Council of Agricultural Research

i.e.	that is
ICRISAT	International Crop Research Institute for Semi Arid Tropic
Irrg.	Irrigation
J	Journal
m	meter
Mha	million hectares
Maha.	Maharashtra
mm	mili meter
MSL	Mean Sea Level
NGRI	National Geophysical Research Institute
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I. INTRODUCTION

The earth is sometime called "The blue planet" because from outer space it appears mostly as Blue Ocean. But ocean water is salty, and not easily converted to fresh water. Water is a natural key resource. It constitutes a raw material for agriculture and industry. Through hydropower generation, it is a valuable source of commercial energy. On the earth only 2.8 % water is fresh water. Out of these, only 0.6% of water is groundwater and 2.2% is surface water. However, ground water occurs as the largest (22.6 %) utilizable source of fresh water (Anons, 2003). The hydrologic cycle is complex phenomena involving the precipitation on land or snow melt, evapotranspiration, percolation into ground, runoff as stream flow and storage in surface sources. For efficient water management system, all the above aspects needs to be studied together and their linkages have to be established. So a more scientific approach involving various factors that govern the movement and occurrence of water both on the surface and underground is necessary for judicious planning and management of water resources.

Groundwater is not only an important component of the hydrologic cycle but also most important source of water for drinking, domestic, industrial and agricultural uses. In a densely populated country like India, groundwater resource is of extreme importance. This invisible resource is under stress due to erratic nature of monsoon and excessive use. Proper assessment and management of groundwater is essential to overcome this problem

Average annual rainfall in India, Maharashtra and Konkan is 1194 mm, 1200 mm, and 3500 mm, respectively (Anons, 2006). While availability of groundwater in India and Maharashtra is 431.866 BCM and 37.87 BCM, respectively. The ground water development in India, Maharashtra and Konkan is 41.57%, 37.7% and 10.5%, respectively, (Anons, 2002). The share for fresh water by the industries, power and domestic sectors is expected to increase from 10.7 % in 1990 to 22.5 % in 2025, while that of agriculture will decrease from 89.7 % in 1990 to 77.6 % in 2025. By 2050 energy and industry sector will show much higher proportional water requirement. (Anons, 2005).

Unmindful exploitation and contamination of groundwater demands exigency of thought and action to avert the grave danger of ecological imbalance. Conscious effort with sound scientific understanding of groundwater is the need of hour. Former makes us to focus on studies of ground water movement under various conditions. These conditions are governed by various geological, climatological, morphological and hydrological factors. Studies of these factors and various parameters providing linkages are pre-requisites for understanding and regulating ground water flow and use upto some extent. Watershed based approach to study groundwater movement is considered proper method for scientific study of groundwater as it is natural unit for conservation of natural resources by natures way.

In India, Maharashtra is the third largest state with 30.8 Mha geographical area and 22.5 Mha cultivable land. It is one of the most developed, progressive and industrialized state of India. The state extends between North latitudes 16 º 04' and 22º 01' and East 72º 06' and 80º 09'. Located in the northern center of peninsular India. Maharashtra is surrounded by the Arabian Sea in the west, Gujarat and Madhya Pradesh on the North, Madhya Pradesh in the East and Karnataka and Andhra Pradesh on the South. The Maharashtra is a plateau of plateaux, its western upturned rims rising to form the Sahyadri Range and its slopes gently descending towards the East and Southeast. The Sahyadri Range is the physical backbone of Maharashtra, rising on an average to an elevation of 1000m. It falls in steep cliffs, to the Konkan on the West. The Konkan, lying between the Arabian Sea and the Sahyadri Range is narrow coastal lowland, barely 50 km. wide. Highly dissected and broken, the Konkan alternates between narrow, steep-sided valleys and low laterite plateaux. The entire state broadly falls under tropical monsoon climate. However, its major portion is semi-arid with three distinct seasons rainy (June, July, August, and September), winter (October, November, December and January) and summer (February, March, April and May). There is a considerable variation in monsoon among different parts of the state.

Thousands of years ago, Parsurama (the sixth incarnation of Lord Vishnu), reclaimed the land, that is Konkan today, from the sea. So the tale tells, that the Konkan region has remained unique since then. The geology of the region is also unique because of its reclaimed status. Loose soil, non-uniform strata and unpredictable nature of the earth in the region, extremely heavy rainfall and seismic activity – all these factors characterize the region. Konkan region is long narrow strip on western side of Sahyadri with 720 km. coastline. Konkan region includes Greater Bombay, Thane, Raigad, Ratnagiri, and Sindhudurg districts bounded by Gujarat in North and Goa in South. It is spread between 15º 6' N and 20º 22' N latitude and 72º 39' E and 73º 48' E longitude, covering total geographical area of 3.079 Mha. Konkan region occupies only 10% area and accounts for 46% of the total available water of Maharashtra state. The percent of total irrigated area is 4.63% (Anons, 1997) of the Maharashtra. In contrasts to rest of Maharashtra groundwater resources of this region are underutilized as water table fluctuations is very dramatic. This situation is attributed to peculiar characteristic of soil, land and parent rock of the region. Our effort is to study water resource availability in Konkan, which can be utilized for a regional development. Planning of groundwater and allied activities will be benefited with better scientific knowledge of spatial and temporal groundwater movement. We can also understand how various soil and water conservation measures are affecting journey and destiny of groundwater.

With the increase in demand for water for competing uses, it is difficult to meet the entire demand from a single source and it is a challenge to plan and manage the different water resources. The hydrogeological features such as sub-soil structure, rock formation, lithology and location of water play a crucial role in determining the potential of water storage in groundwater reservoirs. This knowledge and specific information can aid our efforts of integrated watershed development programme. So that we can harvest more benefits of soil and water conservation programme in the region for betterment of society at large.

Now a days, with the development of quantitative hydrogeology, emphasis has been given to forecast the behavior of different rock aquifer systems by studying the drawdowns in the future and the connected problems to determine suitable sites for new wells and optimizing the exploration of the groundwater resources. A numerical groundwater recharge and flow model (MODFLOW) attempts to evolve the regional hydrogeologic framework for recharge simulation modeling. SWIM model is used for calculation of water balance of the selected site, at NGRI, Hydrabad, for the lateritic rock aquifer system. The simulation model has been tested for steady state and transient condition, which has been later, used for prognostic studies.

Model is a tool designed to represent a simplified version of reality. The ultimate value of models of any kind is two folds; one is to understand and reproduce how the modeled system works, and then to predict how the system will respond to future alternative conditions and actions. Groundwater modeling is a tool that can help analyze many groundwater problems. Simulation of groundwater system refers to the construction and operation of a model whose behavior assumes the appearance of the actual aquifer behavior. Models are useful for reconnaissance studies preceding field investigations, for interpretative studies following the field program, and for predictive studies 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 groundwater modeling concepts, model usage, and modeling limitations.

The uses of aquifers are increasing as both sources of water supply and a medium for studying various hazardous wastes. Numerical groundwater modeling is a tool that will aid in studying groundwater problems and can help increase our understanding of groundwater systems. Numerical models have been extensively used for groundwater analysis since mid 1960s, yet confusion and misunderstanding over the application still exists. As a result, some hydrologists have been disillusioned and have overreacted, concluding that models are worthless. On the other extreme are those who have been willing to accept any model results, regardless of whether or not they make hydrologic sense.

Each type of models has both advantages and disadvantages. The selection of a particular approach should be based on the specific aquifer problem addressed. Whichever approach is taken, the final step in modeling a groundwater flow system is to translate the (mathematical) results back to their physical meanings. In addition, these results must be interpreted in terms of both their agreements with their reality and their effectiveness in answering the hydrologic questions that motivated the model study (James, 1981).

The use of model helps to improve the understanding of the hydrogeologic system. Thus, these models are helpful for regulating or developing the groundwater resources in the area of interest. Keeping above point in mind the project entitled “Simulation of groundwater recharge in Priyadarshini watershed.” is undertaken with the following objectives,

1. To determine groundwater recharge using water balance SWIM model.
2. To simulate groundwater recharge using MODFLOW.
3. To assess the impact of soil and water conservation measures on groundwater recharge.

II. REVIEW OF LITERATURE

The research work done in the past on different aspect of groundwater recharging, groundwater recharge modeling, and groundwater recharge estimation by various researchers is briefly reviewed, under different heads as given below:

2.1. Analysis of rainfall for groundwater recharge.
2.2. Simulation of groundwater recharge using various models.
2.3. Impact of soil and water conservation measures on groundwater recharge.

2.1 Analysis of Rainfall for Groundwater Recharge

Beke *et al.* (1993) studied water-table depth, piezometric head and precipitation measured at nine sites in Southern Alberta, Canda, over a period of 28 years to determine the effect of irrigation on long term ground water levels. Irrigation and precipitation, directly recharged the unconfined aquifer. Downward hydraulic heads occurred during the spring and summer seasons and upward ones in the fall-winter period. High water tables were most frequent during May-July, when irrigation water applied and precipitation was high.

Kumar and Seethapathi (2000) studied the rate of natural ground water recharge a pre-requisite for efficient ground water resource management. An empirical relationship has been derived to determine ground water recharge from rainfall in Upper Ganga Canal Command area based upon seasonal ground water balance study carried out for a number of years.

Moon *et al.* (2004) estimated groundwater recharge in National Groundwater Monitoring Network, Korea, a modified water-table fluctuation (WTF) method was developed from the relation between the cumulative WTF and corresponding precipitation records. Applying this method to different types of hydrographs. Each estimated recharge can be considered the maximum value, and therefore, could be used as a cut-off guideline for groundwater development in river basins.

Carter and Driscoll (2006) studied relations between precipitation and yield efficiency used to estimate annual recharge from long-term records of annual precipitation. A series of geographic information system algorithms were used to derive annual estimates for 1000 m X 1000 m grid cell. Resulting estimates of average annual recharge (water years 1950-1998) ranged from 1 cm to 22 cm in Southern black hills and Northwestern black hills in Rapid city, United State. Recharge rates to these aquifers from infiltration of precipitation on outcrops was estimated in the range 0.9 to 18.8 m^3/s during year 1936 to 1995.

Singh *et al.* (2006) studied the recharge rate through a surface drain using the mathematical model correlating runoff with recharge rate. Thirty years of rainfall values in monsoon period were given as input to the model to yield runoff. Recharge in the Raipur link drain, Dist. Ludhiana, Punjab occurring due to runoff was determined. On an average, recharge caused by the runoff in the drain was 3% of the rainfall when the flow detained. The highest value was 7.35% for a single event. The volume of water recharged under detained flow was 4.86 times of that under free flow condition.

Yazaki *et al.* (2006) estimated the water balance in Fuhrengawa Mire, Hokkaido, Japan. Almost identical amount of water that was lost due to evapotranspiration was re-supplied from deeper layers to the surface on sunny days. Conversely, during rainy periods, rain water rapidly infiltrated through unsaturated layers to deeper layers thereby, some fraction of the rainwater was stored in deeper layers or as groundwater. These water movements were attributable to the physical properties of Sphagnum peat, which froms hummocks.

2.2 Simulation of Groundwater Recharge using various Models.

Gupta *et al*. (1979) carried out a model studies of Krishna- Hinton inter- stream region, UP in Alluvial semi- confined aquifer covering an area of 550 km^2 and analyzed by aquifer modeling through electric analog model with the objective of optimal utilization, and simulation of rivers and canals in the aquifer model and evolved a scheme for conjunctive use of surface and groundwater system.

Shelton (1982) conducted the model studies on Deschutes basin covering an area of 27,300km^2, situated at East of the Cascade mountain and South of the Colombian river with the objective of the implementation of groundwater development strategies. Based on storage and transmission characteristics simulated by the model, which demonstrates that, the basin or regional perspectives are necessary to fully utilize groundwater storage in Basalt.

Kent *et al*. (1982) carried out the model studies using finite difference technique in Wasishta River basin covering 284 km^2. The objective of the study was to demonstrate the application of a predictive groundwater potentiometric head model to estimate the probability of irrigation in contrast to that of dry land farming.

Chiew *et al*. (1991) studied the use of an integrated surface and groundwater modeling approach to estimate regional groundwater recharge rates. The daily version of the Monash Rainfall-Runoff Model HYDROLOG, was adapted to represent the surface hydrological process and finite element groundwater model. AQUIFEM-N used to study the groundwater flow. The integrated model was calibrated. The model applied to both the irrigated and non-irrigated areas in the Northern half of the Campaspe river basin in North-Central Victoria, Australia. The integrated model utilizes the important features of the surface and groundwater models. It was useful in evaluating water resource development through better management of the conjunctive use of surface and groundwater.

Narasimha Reddy *et al*. (1991) carried out model studies in Dulapally basin, a Granite terrain, A.P. with the objective of groundwater resource evaluation and suggested for construction of additional water harvesting structures for augmenting the groundwater supply.

Jim Yeh and Peter (1991) carried out the structured approach for calibrating steady state groundwater flow models in the Aver Valley. Two- dimensional numerical models for steady state groundwater flow in porous media have been frequently used to predict groundwater flow and contaminate migration in aquifers. Steady state flow was simulated for the heterogeneous aquifer using the MODFLOW. They concluded that the proposed structured procedure was expected to be useful not only for the manual approach but also for automatic models.

Boonstra and Bhutta (1995) conducted a study for determining the seasonal net recharge in Faisalabad, Pakistan. A numerical groundwater model was developed for the said area and was run in inverse mode to determine the seasonal net recharge. The maximum average net recharge to the aquifer was calculated as 0.6 mm/day during monsoon 1986. The corresponding monsoon rainfall had a return period of 2.8 years.

Hill (1996) has conducted model studies of Yuma basin in Arizona covering an area of 900 km^2 with the objective to assist local agencies in evaluating remedial water management alternative to mitigate the shallow groundwater level problems. The model contains four layers and simulates groundwater pumpage, and percolation from agricultural irrigation, evapotranspiration from spermatophytes and flow in 12 canals, 16 drains, and the Colorado and Gila Rivers. The model predicted that the water management alternative of pumping wells and lining four miles of east main canal would have the greatest impact on lowering groundwater levels. Pumping drainage wells would greatly over shadow any effects from lining the canal. In addition, the model predicted that reducing percolation. From agricultural irrigation within the Yuma valley and on Yuma mesh had significant impacts on groundwater levels.

Gore *et al*. (1998) studied the aquifer modeling which helped to quantify the effect of seepage from ponded water in the water harvesting structures on the groundwater regime in the Wagarwadi watershed. The well-distributed network of 16 observation wells for groundwater monitoring in the watershed has provided the necessary database for groundwater model construction and calibration under steady and transient condition for two hydrological cycles. Furthermore, the observation wells situated below water harvesting structures helped to quantify the effect in terms of seepage component from ponded water in the water harvesting structures, by matching the observed rise in water table through the computed rise in water levels in the model

Abraham and Tiwari. (1999) conducted hydrological studies in lateritic hill slope watershed of Kerala. The watershed characteristics, soil moisture properties and hydrological processes were evaluated. The prominent mechanisms of runoff generation were identified as saturated through flow and saturated source area. A 2D lateral saturated flow model linked with a vertical column model using effective hydraulic conductivity and specific yield can simulate the flow processes in lateritic hill slope watershed. It can predict water table position and the stream flow corresponding to rainfall.

Das and Datta (1999) studied the development of management models for sustainable use of coastal aquifer. There were three multiple management models developed for sustainable use of groundwater in coastal area. The first multiple objective management model was developed for spatial and temporal control of aquifer salinity through planned pumping from locations closest to the ocean boundary. The second multiple objective management model (MOMM) was useful for maximizing sustainable water withdrawal from the aquifer for beneficial uses. The third MOMM was developed for maximizing sustainable water withdrawal from the aquifer for beneficial uses and minimizing the total pumping at locations adjacent to the ocean boundary to control the salinity in the aquifer. The results demonstrated the feasibility of the developed optimization models and also the conflicting nature of the various objectives of coastal aquifer management.

Bekesi and McConchie (1999) studied the groundwater recharge modeling using the Monte Carlo technique for in Manawaty region, New Zealand. Mean annual recharge was calculated at each rainfall station throughout the study area using this technique to randomize soil moisture parameters and approximate the variability of soils. Uncertainty of recharge estimation was expressed as the standard deviation of the mean annual recharge resulting from the Monte Carlo modeling. TECHBASE software was used for this modeling.

Gaur (2001) studied groundwater budget of a 1381 ha watershed comprising predominant cultivable watersheds. The net annual draft through 350 shallow dug wells was predicted as 1.89 million cubic meter (MCM), while the net annual recharge came around 2.058 MCM leaving a groundwater balance of 0.1687 MCM.

Vivoni (2002) found the possibility of enhancing natural aquifer recharge by implementing a variant to time tested hydrologic technologies used for centuries in various arid watersheds. The groundwater model, *MODFLOW*, was used to simulate an idealized catchment where a component of the Branched Aquifer Recharge System *(BARS)* have been suitably modeled. Modeling results suggested that BARS was superior to the homogeneous control case in distributing recharged water to the extraction sites. The simplified modeling of the recharge system discussed, a first step towards combining our current hydrological understanding with hydrologic engineering technology to achieve a sustainable management of water resources in arid environments.

Manglik *et al.* (2004) presented an analytical solution of the linearised Boussinesq equation for the spatio-temporal variation of the water table in an aquifer system. The recharge function was approximated by introducing a number of line segments depending on the nature of variation. The solutions obtained by using finite Fourier sine transform.

Sharma and Bhattacharya (2005) studied the development of model for designing water-harvesting ponds. Study conducted at three sites viz. Dasuya, Indore, and Konas representing low, medium and high rainfall zones for the assumed watershed areas of 5 ha to 100 ha at different probability levels of estimated runoff. Multiple regression models were developed for the design of water harvesting pond capacities. As a result following model was obtained.

$$\mathbf{Y = -27083.2 + 62.988X_1 + 14.18X_2 - 90023.9X_3}$$

$(R^2 = 0.90)$

Y= pond capacity (m^3)

X_1 = total monsoon rainfall (mm), ($672 < X_1 > 1120$)

X_2 = watershed area (ha), ($20 < X_2 > 100$)

X_3 = probability levels, ($0.1 < X_3 > 0.4$)

2.3. Impact of Soil and Water Conservation Measures on Groundwater Recharge

Pandey (1987) studied influence of soil conservation measure on watershed characteristic viz. runoff and sediment yield in Danku sub watershed comprising an area of 7354.23 ha of Mahi-Kadana catchments (Rajasthan). Various soil and water conservation measures like field bunding, check dams, terracing annicuts, and afforastration and pasture development adopted for watershed. Runoff and sediment yield before and after the treatments were studied and compared to a rainfall period of June to October for four

(1976-1979) years. It was observed that peak runoff was reduced by 32.9%. Sediment yield was 0.08 ha m for a runoff of 98.6 ha m, but after 67% area of treatment, the highest sedimentation yield was 0.031 ha m for runoff of 243 ha m.

Mallikarjunappa *et al*. (1992) carried out the study to evaluate nala bunding works under shallow black soil in semi-arid region. Seven nala bunds constructed during the year 1985-86 were chosen for the study. The study was conducted at Chandkavate watershed located in Sindagi Taluka of Bijapur district in the year 1987-88. Average depth of water table for wells under nala bund during August was slightly higher than that of control wells, whereas for the month of September, it was little less as compared to control wells. It was also observed that the average depth of water table for all the entire period of the observation from May to January was 4.57 m against 5.13 m of control wells. The water table in the wells located on the downstream side of nala bunds increased considerably in the open wells for irrigation.

Goel and Singh (1996) studied the impact of soil and water conservation works on groundwater recharge. Analysis of water table data collected form 12 open wells located in the watershed reflected average annual rise in water table. Rise in water level ranges between 2.03 and 17.70 m with an average value of 8m. It also indicated that water remains available in most of the wells throughout the year.

Prasad *et al* (1997) studied the impact of watershed development treatments: *viz.* graded bunds, gully control structures, *in-situ* moisture conservation practices, improved practices of cropping, etc. implemented during February 1986 to 1989 in Chhajawa watershed of Baran District in Rajasthan. Results of the study indicated 7.8% annual runoff as against the 20 to 25% of runoff from untreated arable lands in the region. The number of wells increased from 16 in 1985-86 to 39 in 1992-93 with corresponding increase in area irrigated from 32.5 to 300.4 ha. The average increase in yield of crops was 21.5, 225.9 and 57%, respectively due to graded bunds, improved cropping practices and one irrigation. The cropping intensity increased from 80.5 to 116.8% and the productivity of arable land increased from 670 to 2010 kg ha^{-1} yr^{-1}. The investment in the project was recovered in four years from intense crop production and hence the project was considered economically viable.

Kumar and Warsi. (1998) evaluated the impact of comprehensive water management programs in Yamuna ravine watershed of Ghatampur in Kanpur District of Uttar Pradesh. The impact of various soil and water conservations measures viz. contour bunding, land leveling, & smoothening, gully plugging, contour furrow, vegetative barriers and sunken structures was highly pronounced and resulted in increase of 20-25% in the yield level of crops like wheat, barley Bengal gram pea lentil soybean, in watershed. The wells in the project area also showed groundwater recharge during the operational period.

Phadnavis *et al.* (1998) evaluated water-harvesting structures constructed on shallow black soil in Padalsingi watershed in semi-arid region. Two nala bunds and one percolation tank constructed during the year 1987-88 were selected for this study. The shrinkage percentage was 9.17, which was within safe limits. These structures resulted the rise in water table in open wells situated below the structures.

Pandey *et al.* (1999) studied the groundwater recharge by channel infiltration for EI Barbon Basin, in Baja California, Mexico. The RAINFLO model was used to simulate selected rainfall – runoff events. A mass balance of the Ojas Negros aquifer has determined that the recharge was $18.6 \times 10^6 m^3/yr$ and the withdrawal was $25.1 \times 10^6 m^3/yr$. The overdraft of $6.5 \times 10^6 m^3/yr$ (26%) was the sustainability of irrigated agriculture in the valley. Catchment modeling showed that infrequent storm events from 2 to 100-yr return period can contribute from 14% to 39% of mean annual vertical recharge of aquifer.

Pendke *et al*. (1999) studied the effect of watershed management on increase in groundwater potential. The average four open wells in treated and two open wells in untreated area of watershed for monitoring groundwater fluctuations. The average gravity yield of 2.20 % and 1.21 % was estimated in treated and untreated area, respectively. The increase in gravity yield in treated area over untreated area varies from 71.16 to 94.12 % with an average increase of 86.5 %. The maximum groundwater potential ranged from 21.55 to 122.88 ha-m and 11.99 to 63.70 ha-m in treated and untreated watershed, respectively.

Gitte *et al.* (2002) found that the water conservation measures were effective for rising of water table in observation wells. Located in the middle and lower reach of the watershed. The transmissivity values were found to be in the range of 10 to 40 m^2/day. The specific yield was found to be in the range of 0.01 to 0.03 %. The mean depth of rainwater contributed to groundwater recharge during the year 1998 and 1999 have been estimated as 5.66 cm and 5.10 cm respectively.

Gontia *et al.* (2003) studied the effects of check dams on nalas and gullies and constructed farm ponds for groundwater recharge in Saurashtra region of Gujarat State. During two consecutive drought years1999-2000 and 2000-2001,diverting farm runoff using various types of filters recharged, about 0.2 million-dug wells. More than 14000 check dams and more than 2000 farm pond were constructed with effective storage of 186 Mm^3. which may be helpful in providing drinking water and irrigation water.

Mahale *et al.* (2004) found that an average groundwater recharge in the treated zone was higher than that in untreated zone throughout the year by 2.13m. The structures like continuous contour trenches, bench terraces, the on-stream water harvesting pond, a cement plugs, vegetative barriers and loose boulder structures on the adjoining streams were found to be having beneficial effect on the groundwater level in the down stream area of the watershed.

III. Material and Methods

The research study entitled “Simulation of Groundwater Recharge Modeling in Priyadarshini Watershed” was carried out in Priyadarshini watershed to estimate the groundwater recharge and to assess the impact of soil and water conservation measures on groundwater potential of the area.

The details of the study area, aquifer parameters, water balance components and groundwater modeling approach are discussed in this chapter.

3.1 Basin Features

For this study of groundwater movement, the Priyadarshini watershed with an area of 38.72 hectares was selected. Its topography is hilly, undulating with shallow and stony lateritic soil. Geographically, it is situated at 17°45′N latitude and 73°26′E longitude. Its elevation is 250 m above MSL. The soil type of watershed is lateritic-sandy loam. Climate of Konkan region and selected watershed is warm and humid with an average annual precipitation is 3500 mm. The watershed consist the area under research units of College of Agril. Engineering and Technology, Dapoli. Location map is shown in Fig.3.1. Watershed was divided into five parts on the basis of soil depth. The soil depth varies from 20 cm to 90 cm. Average soil depth in the watershed was 45 cm. Soil depth map is shown in Fig. 3.2. An average slope of watershed is 6.09 %.

3.2 Groundwater Levels

Groundwater occurs in water table conditions of weathered fractured aquifer system. The groundwater level in open wells generally started rising by the end of June and continued upto September. Later it started declining till the last week of May. Three observation wells were selected within the boundary of watershed. Well No. 1, 2, and 3 were used for irrigation and these wells were situated in the treated area i.e. in watershed area, well no. 4 was also comes under the influence of SWC work. It was also used for irrigation purpose. Remaining five wells were used for domestic water supply. This observations and pumping wells are as shown in Fig. 3.3.The depth of water table was in the range 2 to 9 m bgl.

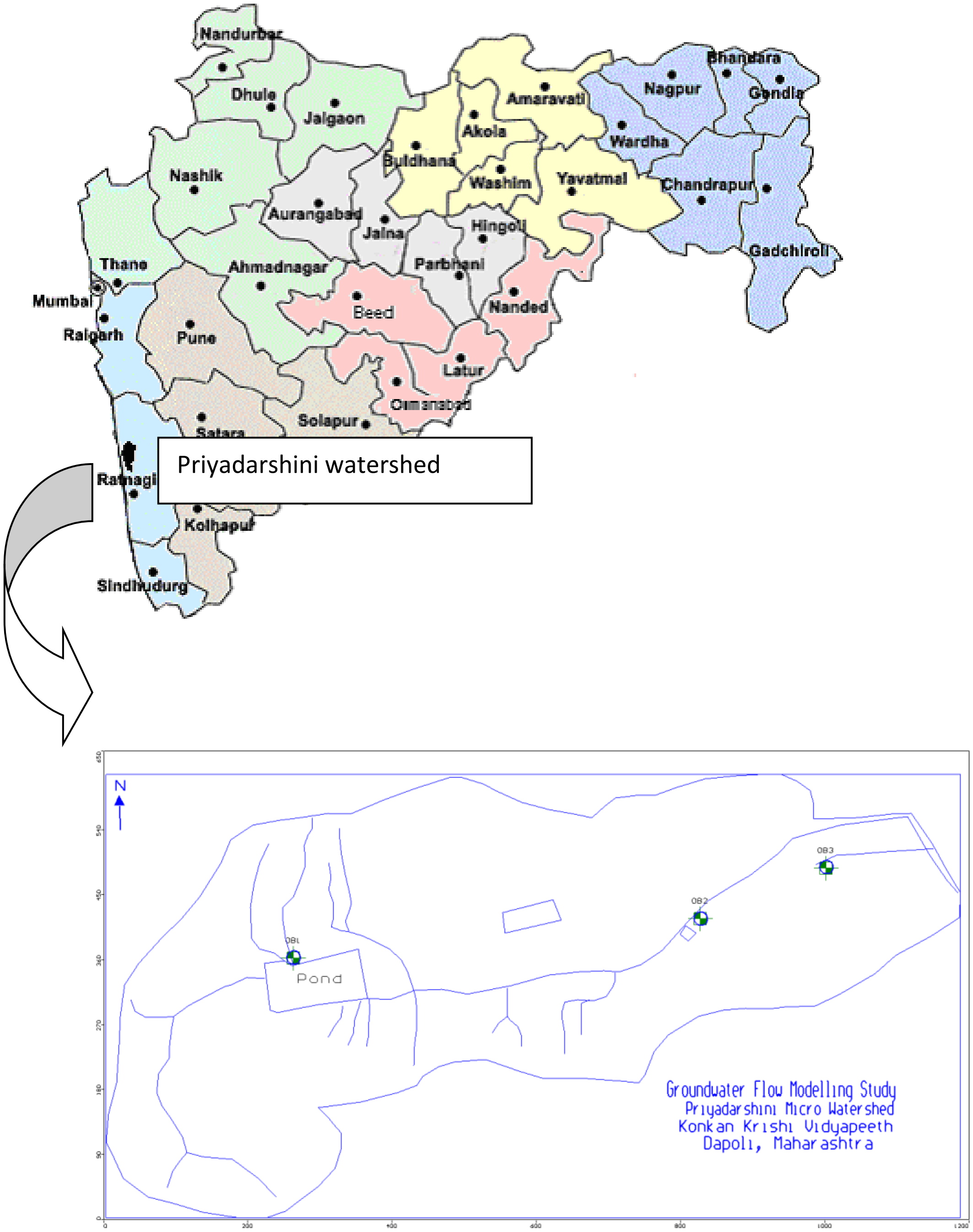


Fig. 3.1 Location Map of Priyadarshini watershed

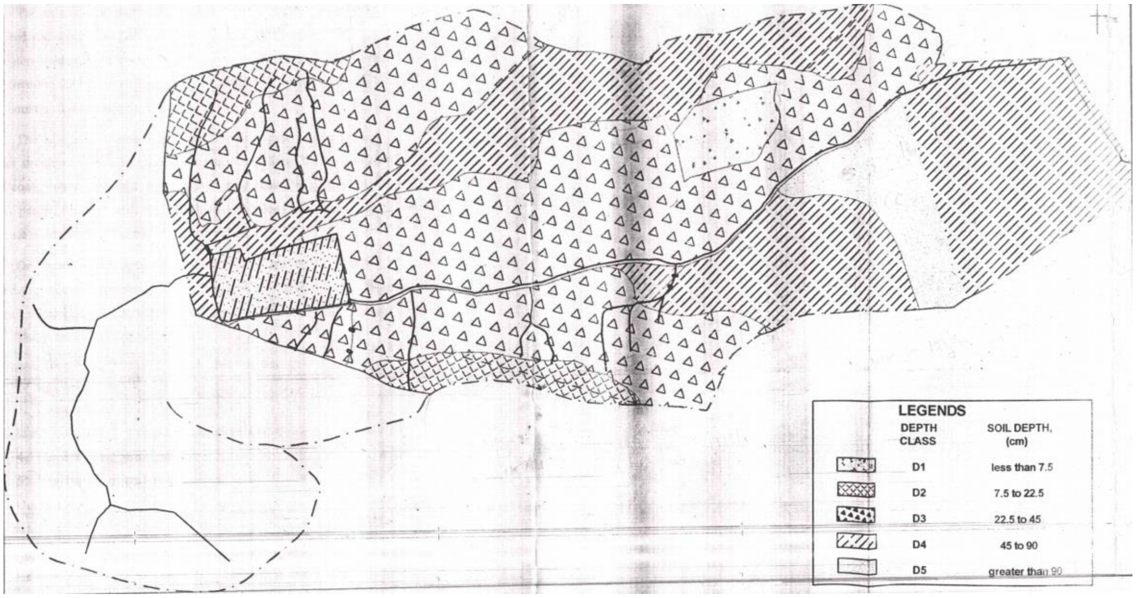


Fig.3.2 Soil depth map of the Priyadarshini watershed

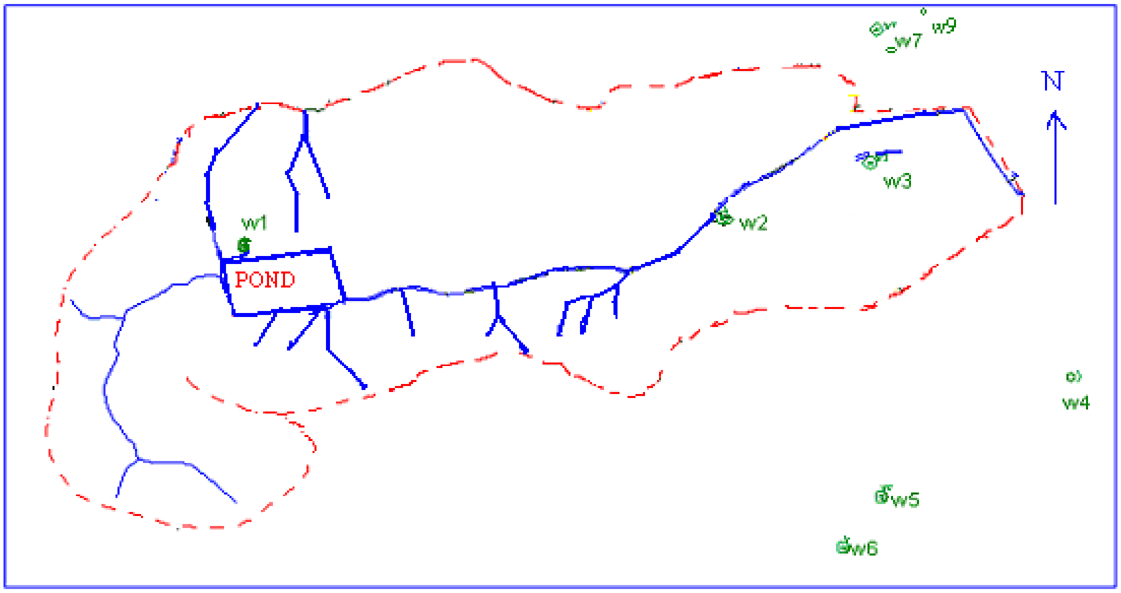


Fig. 3.3 Observation and Pumping wells in Priyadarshini watershed

3.3 Aquifer Parameters

Aquifer parameters like transmissivity and specific yield were estimated by carring out a long duration pumping tests. Pumping test was carried out in the open wells. Pumping test involves pumping out of water at the selected discharge rate for a specific time period. During pumping test pumping water levels were recorded at regular intervals. The time-drawdown and recovery data was interpreted using curve matching procedure (Michel, 2003). Detail procedure of pumping test for estimation of aquifer parameters is given in the Appendix-A.

3.4 Water Balance SWIM Model

SWIM is the software package for simulating water infiltration and movement in soils. Water is added as precipitation and removed by runoff, evaporation and recharge from the soil surface and transpiration by vegetation. The simulator assume that conditions can be treated as horizontally uniform, that flow was described by Richards equation and that soil hydraulic properties can be described by simple functions. Richards’s equation is as fallow.

$$q = - K*dH / dx$$

Where, q is flux density (cm/h), K is hydraulic conductivity (cm/h) and H is hydraulic head (cm) at position x in the direction of flow. Soil physicists describe water flow in soils with Richards’s equation. Solving this equation mathematically is difficult or impossible for many realistic flow problems and so numerical methods have been used extensively. The results, combined with the increased power of computers make numerical solution of Richards equation a powerful practical tool (Ross,1990). SWIM provides a greater number and variety of features are as following.

- Numerical solution of Richards’s equation.
- Ability to handle non-uniform and layered soils.
- Ability to handle unsaturated, saturated and ponded conditions.
- Calculate runoff, evapotranspiration and recharge.
- Allows simultaneous transpiration by several vegetation types.
- Fast and accurate

Daily rainfall and pan evaporation data collected from Agro-meteorological observatory, Department of Agronomy, Dapoli. The daily rainfall data was used to estimate the surface runoff and water availability in the soil zone where as the pan evaporation data was utilized to estimate evaporation and transpiration. Computation of each components of the water balance was discussed below.

SWIM water balance model, its work divided into three steps i.e. preparing an input file, running the simulation and viewing the results. In preparing an input file, it consist simulation time, vegetation type, soil conductance, runoff, soil hydraulic properties, cumulative precipitation and cumulative evaporation. These all file factors value were fed to SWIM model, which are shown in following tables.

3.4.1 Time

Model represents a 365-day water balance. The time factors for the simulation of water of water balance were shown in Table 3.1. Simulation integration time steps are chosen so that the greatest water flux in the system, excluding transpiration will move approximate this amount of water in one time step. A smaller increment gives better accuracy mostly 0.5 cm is taken.

Table: 3.1 Time factor for water balance model

Starting time means simulation-starting time.

Finishing time means simulation-finishing time.

Print interval means simulation results will be output at this interval.

Water increment means simulation integration time steps are chosen so that the greatest water flux in the system, excluding transpiration, will move approximately this amount of water in one time step. A value of 0.5 cm is usually acceptable.

Sr. No.	Time factors	Value
1	Starting time	0 hr.
2	Finishing time	8760 hr.
3	Print interval	24 hr.
4	Water increment	0.5 cm

3.4.2 Vegetation characteristic

The model allows up to four vegetation types to grow together. Each type has certain characteristics that determine its water extraction pattern. The distribution of roots with depth is assumed to be exponential with a fixed depth constant. In Priyadarshini watershed, density of vegetation was more. Different types of trees and grasses were found. For this vegetation has lower minimum xylem potential, is deeper rooted with a lower maximum root length density and almost fully grown a star of the simulation. Soil evaporation was less than the transpiration. The parameter of vegetation as shown in Table3.2

Table: 3.2 Vegetation parameters for water balance model

Sr. No.	Vegetation Parameters	Value
1	Vegetation type	1
2	No. of type want	1
3	Minimum xylem potential	- 250 m
4	Depth constant for roots	50 cm
5	Max. root length density	10 cm/ cm^3
6	Max. fraction of PET	0.5
7	Fraction of above max.	0.2
	at time	0 day
8	Fraction of above max.	0.8
	at time	185 days

A fraction of the total potential evapotranspiration (PET) is assigned to each type, with any left over being used for soil evaporation. The fraction of the potential that a type intercepts is assumed to increase sigmoidally with time. Root length density is assumed to be exponential, with a fixed depth constant.

Minimum xylem potential: A value of –150 m is often used.

Depth constant for roots: The depth at which root length density falls to 37%.

Maximum root length density: At the surface, when fully grown.

Maximum fraction of PET: Fraction of PET intercepted when plants fully grown.

Fraction of maxima at given times: These values define two points on the sigmoid growth curve used for root length density and fraction of PET intercepted. Note that the fractions will be limited to the range 0.001- 0.999.

3.4.3 Conductance

The parameters displayed determine how a thin seal that may grow with time as raindrops fall on it affects water flow through the soil surface. A thicker crust, such as that in the layered soil, can also be simulated in this way. Flow rate through the surface is given by the surface conductance time the potential drop across the layer, whose thickness is assumed negligible. The conductance decreases exponentially with cumulative rainfall energy. The conductance value for this region as shown in Table 3.3

Table: 3.3 Conductance parameters for water balance model

Sr. No.	**Conductance Parameters**	**Value**
1	Initial soil surface conductance	4 / hr.
2	Min. soil surface conductance	0.02 / hr.
3	Precipitation constant	0.05 cm
4	Effectiveness parameter	0.184

The soil may have a thin surface layer that impedes water entry. The water flux through this layer is equal to the surface conductance multiplied by he matric potential difference across the layer. A soil layer of thickness dx and saturated hydraulic conductivity Ks would represent a conductance of Ks/dx at saturation.

To allow for a reduction of surface conductance due to formation of a crust caused by rainfall, the conductance decreases exponentially with cumulative precipitation energy from the given initial value towards the given minimum. Its falls 63% of the way after the given precipitation constant, assuming that the precipitation falls at 25 mm/h. For a different intensity I, the relative energy per unit of precipitation is 1+ E ln (I/Ir), where E is he effectiveness parameter and Ir = 25 mm/h. 'E' usually take 0.184. However, when realistic intensity information is not given (e.g. when daily precipitation is used), set E = 0 so that all precipitation is equally effective in reducing the surface conductance.

3.4.4 Runoff

The parameters displayed determined how water on the soil surface behaves. A certain amount of water can be stored on the surface without running off usually the surface is rough. Here surface storage decreases from 2 cm towards 1 cm. The effectiveness parameter for surface conductance is used here. Runoff parameters values are shown in table 3.4

Table: 3.4 Runoff parameters for water balance model

Sr. No.	**Runoff parameters**	**Value**
1	Initial soil surface storage	4 cm
2	Min. soil surface storage	3 cm
3	Precipitation constant	5 cm
4	Runoff rate factor	2 (cm/hr/ cm^P)
5	Runoff rate power P	2
6	Initial surface water depth	0 cm

Initial soil surface storage, Minimum soil surface storage, Precipitation constant- Runoff occurs when the surface water depth is greater than the surface storage. To allow for a reduction of surface roughness due to rainfall, the storage decreases exponentially with precipitation energy from the given initial value towards the given minimum in exactly the same way as the surface conductance.

Runoff rate factor, Runoff rate power- For a water depth that is dh above the storage, the runoff rate is equal to the given runoff rate factor time dh^P, where P is the given runoff rate power. Initial surface water depth- This allows the simulation to begin with surface ponding.

3.4.5 Soil hydraulic properties

Hydraulic properties together with soil depth and initial metric potential value. The hydraulic properties available including

Thetas: water content at field concentration,

Psie: Air enter potential,

Psi: Initial metric potentials,

b: Minus the slope of straight line approximation, the water retension curve on log- log plot.

Ks: Hydraulic conductivity a field saturation.

Soil depth was made significant effect on the simulation. Increasing the number of soil depth increases accuracy. Hydraulic properties of sandy loam soil as shown in table 3.5

Table: 3.5 Hydraulic properties of sandy loam soil depth unto 900 cm.

Sr. No	**Soil depth (cm)**	**Psi**	**Thetas (θ)**	**Psie**	**b**	**Ks cm/h**
1	0	-300	0.45	-13.78	4.9	5.4
2	30	-300	0.45	-13.78	4.9	5.4
3	90	-300	0.45	-13.78	4.9	5.4
4	150	-300	0.45	-13.78	4.9	5.4
5	300	-300	0.45	-13.78	4.9	5.4
6	700	-300	0.45	-13.78	4.9	5.4
7	900	-300	0.45	-13.78	4.9	5.4

Hydraulic properties

The parameter theta is water content (cm^3/cm^3) at field saturation. If don’t know thetas, use 0.93* porosity.

The parameter b is minus the slope of a straight line approximating the water retention curve on a log- log plot. It ranges, typically, from 2 in sandy soil to 25 in clay soil.

The line pass through the point (thetas, Psie), where Psie may range from –1 cm in sandy soils to –50 cm in clay soil.

Ks is hydraulic conductivity at field saturation. It may vary widely, from many cm/h in sandy soils to mm/day in clay soils. It also has a high spatial variability.

3.4.6 Cumulative rainfall and cumulative evaporation

Cumulative precipitation and cumulative evaporation are given functions of time. Daily precipitation and monthly evaporation values were fed to SWIM water balance model. These two factors were important inputs for water balance calculation. Rainfall and evaporation data was available from 1985 to 2006. Different water balance parameters (runoff, evapotranspiration and recharge) were estimated per year with the help of SWIM model.

Day	Hour	Minute	Cumulative precipitation (mm)
0	0	0	0
365	0	0	2730.7

Table: 3.6 Cumulative precipitation values for the year 2002

Table: 3.7 Cumulative evaporation values for the year 2002

Day	Hour	Minute	Cumulative evaporation (mm)
0	0	0	0
365	0	0	1770

Thus various components of the water balance model like surface runoff, evapotranspiration, soil moisture status were computed and groundwater recharge was estimated using a SWIM software available with NGRI, Hydrabad.

3.5 Groundwater Flow Model

The initial stage in developing the groundwater flow model was to define the region of interest and establish boundary conditions for flow. The following information was used during conceptualization of the groundwater flow regions.

- No flow occurs across the boundaries.
- Recharge of groundwater takes place from top layer of the watershed.
- As the watershed is nearly a streamlet, some out flow may take place.
- Seepage in the study area is an additional input to the watershed recharging system.
- There will be downward leakage to the fractured zone.

The simulated model of Priyadarshini watershed area was divided in to a grid of square blocks with 96 columns and 56 rows and of a 2-layered aquifer model. Each square block dimension was 12.5 m X 12.5 m. The grid is a finite difference block centered grid i.e., node was located at the center of each block. The grid map of Priyadarshini watershed is shown in Fig.3.5 The groundwater recharge due to rainfall enters the weathered fractured aquifer system as vertical flow initially through less permeable weathered zone and later moves slowly as leakage to the underlying fractured zone from where groundwater flow takes place horizontally. The water level data measured at three observation wells during April 2002 were used to prepare initial water level contours. The boundaries of groundwater flow model were visualized in terms of a initial head at down stream node at Eastern side of the watershed, by assuming some groundwater outflow through this node.

The highest water table elevation was in the North Western side of the watershed at 98 m amsl and lowest water table is at an elevation of 87 m amsl at Eastern side of the watershed. The water level data measured at three observation wells during April 2002 was selected as initial water level for steady state model.

Bottom of the First layer (or) surface of the second layer was considered as 20 m below from the topographic surface, and bottom of second layer (or) was considered as 20 m below from bottom of the first layer, which is based on the weathered zone and Fractured zone determined by the geophysical surveys. Hence the total aquifer thickness is 40m. The vertical cross section of aquifer presented in Fig. 3.5.

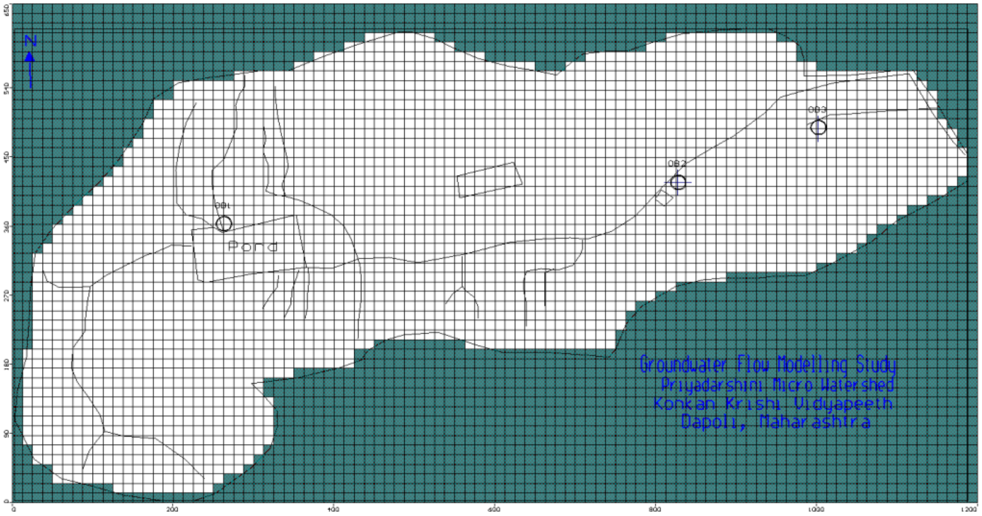


Fig 3.4 Grid map of Priyadarshini watershed

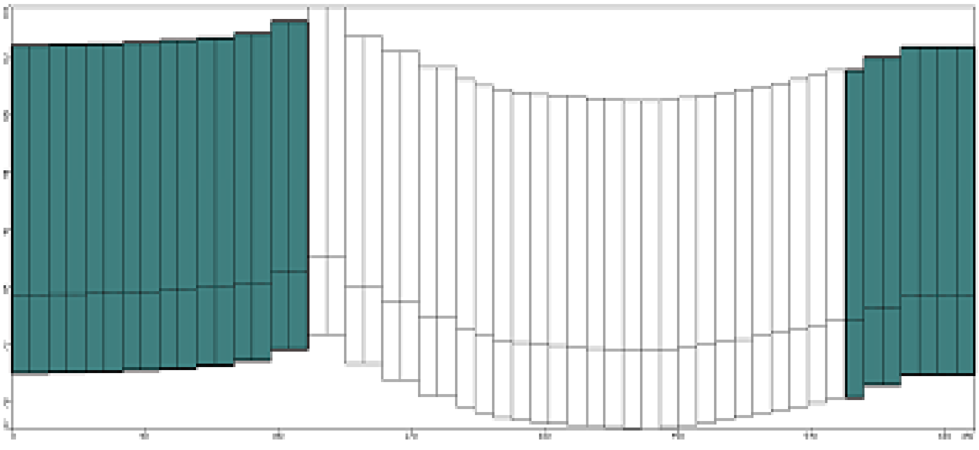


Fig.3.5 Simulated vertical cross section of watershed area along column 54

3.5.1. Numerical approaches

The numerical approaches for solving groundwater flow are based on finite difference integral method. These numerical approaches deal with variability of the flow parameters (hydraulic conductivity, porosity, etc.). The first step in developing a computer flow model is to subdivide the region in terms of cells. This process makes it possible to account for variable nature of provided boundary conditions at node points. A numerical solution of heads was obtained through simulation with a flow model. Velocity values were computed by applying Darcy's equation with calculated hydraulic heads and porosity values. Following boundary conditions were given to MODFLOW for construction of flow model.

The groundwater pumping from the existing wells was assigned as 50 to 250 m^3/day. Recharge at the rate of 8 – 11 % of the rainfall has been considered in the model and fed through recharge package to aquifer system. It was slightly altered in different blocks during model calibration. The recharge of Priyadarshini watershed during the study period is shown in Table 3.8. The outflow towards Eastern part of the study area was simulated as constant head of 87 m (amsl) in the model. The observed heads of three observation wells presented in Table 3.9.

MODFLOW River package is used to incorporate surface water boundary conditions into the groundwater flow model. Rivers, Streams and Lakes contribute to the groundwater system based on the gradient between the surface water body and groundwater regime. The River and aquifer interaction was simulated by assigning water levels and River bed elevations of the Rivers / Streams in study area and assigned River water elevations and River bottom elevation is presented in Table 3.10. The river stage elevation is the elevation of the water surface in River. The River bottom elevation is the elevation of the River/stream bed. Conductance is a numerical parameter that represents the resistance to flow between the surface water body and groundwater.

Priyadarshini watershed has been divided in parts and assigning permeability from 4.4 m/day to 6 m/day in two layers in X and Y directions and approximately 10% of these values were assigned in Z direction. The Permeability distribution in the watershed, layer wise, is given in Table 3.12. Specific storage has been assigned as $5 \times 10^{-5.}$

Table 3.8 Recharge data for Priyadarshini watershed.

Table 3.9 Observation well heads (m) in the study area

Pre-monsoon Period

	Well no.1	**Well no.2**	**Well no.3**
Apr 2002	97.10	89.08	89.17
Apr 2003	97.70	89.58	89.87
Apr 2004	97.50	88.78	89.97
Apr 2005	97.40	88.98	90.17
Apr 2006	98.20	89.11	90.07

Post-monsoon Period:

	Well no.1	**Well no.2**	**Well no.3**
Nov. 2002	99.04	91.73	91.87
Nov. 2003	99.25	91.05	92.77
Nov. 2004	98.64	91.13	93.30
Nov.2005	99.00	91.37	91.57
Nov.2006	98.05	91.93	93.18

Zones	**Recharge (mm/yr)**
1	300
2	325

Table 3.10 Simulated River boundary Conditions in study area

River 1

	River stage Elevation(m, amsl)	**River bottom Elevation (m, amsl)**	**Conductance (m^2/day)**
Starting Point (near Priyadashani Pond)	98	97	25.578
Ending Point (outlet, near CAET College site)	87	86	13.518

Table 3.11 Heads (m) in observation wells in the beginning of April 2002

Well no. 1	97.70
Well no. 2	89.50
Well no. 3	89.80

The **evapotranspiration** for the watershed area was assigned as 30 mm/year.

Table 3.12 Hydraulic Conductivity distribution in the Priyadarshini watershed

Zone	**Zone Parameter values (m/day)**		
	K_x	K_y	K_z
1	6	6	0.6
2	4.4	4.4	0.44

The convex shapes of water table contours indicated an area of groundwater discharge (Todd, 1980). The additional feature of convergence flow lines depicts the discharge and divergence of flow lines indicates an area of recharge. In this groundwater flow model recharge property has been taken as zero in the initial and final stages i.e. at April 2002 and April 2006. For the years between 2002 and 2006 the recharge has been assigned zone wise.

Governing Equation for Flow

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

The “W” term is flow rate per unit volume of aquifer added to or taken from ground-water system. Most interaction between ground water and surface water is lumped into the *W* term

Where,

K_{xx}*, *K_{yy}* and *K_{zz} are the values of hydraulic conductivity along the *x*, *y*, and *z* coordinate axes (L/T)

h is the potentiometric head (L)

W is a volumetric flux per unit volume representing sources and/or sinks of water,

S_S is the specific storage of the porous material (L^{-1});

t is time (T)

For steady state flow, the groundwater flow equations solved once and a single velocity field is applied for all times. The finite difference method replaces the governing differential equations of groundwater flow by a set of differential equations applicable to the system of nodes. The differential equations approximate the first and second order derivatives of flow between node points. When each node in the grid is considered, the result is a system of algebraic equations, which can be solved by matrix method.

Darcy’s law:

$$q_x = K_{xx}\frac{\partial h}{\partial x}$$

$$q_y = K_{yy}\frac{\partial h}{\partial y}$$

$$q_z = K_{zz}\frac{\partial h}{\partial z}$$

The Input section of Visual MODFLOW is used to define:

- the 3D finite difference grid
- pumping well and observation well locations and attributes
- soil properties required for flow and contaminant transport
- boundary conditions for flow and contaminant transport
- particle locations for determining flow path lines
- observation zones for determining flow and mass budgets

3.5.2. WHS (Waterloo Hydrogeologic Solver)

The solver uses a bi-conjugate Gradient stabilized (Bi-CGSTAB) acceleration routine implemented with stone incomplete decomposition for preconditioning of the groundwater flow partial differential equations. The solution of large set of partial differential equations is obtained iteratively through an approximate solution. Because the matrix equation for groundwater flow is initially “ill-conditioned”, effective pre-conditioning of these matrices is necessary for an efficient solution. Two “levels” of factorization are available with the WHS solver. While convergence of the solver requires less iteration with a factorization level of 1, the memory required running the solver increases.

The solver works on a two-tier approach to a solution at one time step. Outer iterations are used to vary the factorized parameter matrix in an approach towards the solution. An outer iteration is where the hydrogeologic parameters of the flow system are updated (i.e., transmissivity, saturated thickness, storability) in the factorized set of matrices. Different levels of factorization allow these matrices to be initialized differently to increase the efficiency of solution and model stability. Inner iterations are used iteratively; solve the matrices created in the outer iteration. Maximum number if outer (non-linear) iterations are 50. Maximum numbers of inner iterations are 500. After outer iteration is completed, the solver checks for the maximum change in the solution at every cell. If the maximum change in the solution is below the set convergence tolerance, then the solution has converged and the solver stops, otherwise a new outer iteration is started. A solution accurate to 0.01 m of head change in the modeled domain is used.

While the head change criterion is used to judge the over all solver convergence, the residual criterion is used to judge the convergence of the inner iterations of the solver. If the change is successive inner iterations is less than the tolerance of .001 m than the solver will proceed with the next outer iteration. Dampening factor for the outer iterations allows the user to reduce the head change calculated during successive outer iteration. Here a dampening factor of 1 was used. This parameter can be used to make a non-convergent solution process more stable such that a solution will be achieved. This will be done by decreasing the damping factor to a value between 0 and 1 (rarely < 0.6). This parameter is similar to “acceleration parameters” used in other solvers. Relative residual criterion is another method of checking for convergence of the inner iterations. It compares the residual from the most recent inner iteration to the residual from the initial inner iteration. Once the most recent inner iteration residual is below the initial inner iteration residual times the relative residual criterion, the current outer iteration is completed, and a new outer iteration will be started (Guiger and Franz, 1996).

3.5.3 Finite difference approximations

At place where the stream bed elevations cut the aquifer system and when the groundwater level become higher than the stream bed the groundwater leaves the aquifer as base flow to stream. This base flow generally occurs during August, September and October months when the entire weathered material becomes saturated with groundwater recharge. Rest of the year the groundwater levels in the watershed generally stand below the stream bed elevations.

The constraints of aquifer modeling in the lateritic porous rock aquifer system is that baised predictions may be obtained if only a sub-region of the basin is artificially isolated for the modeling. For better replications of the flow regime the actual physical limits of the basin must be included in the model making the modeled area very large. It is well known that the aquifer modeling is nothing but the numerical integration of the basic equation of groundwater flow in a set of small areas making the discretization of the domain of interest. Accordingly the first step in any aquifer modeling becomes how to decide the shape, size and portion of the small area. This becomes exclusively a problem of hydrology and of numerical description and data collection on this set of small areas. Numerical integration cames afterwards and different techniques performs this integration in different ways giving very similar results. In other words discretization of space must not be imposed by numerical techniques but by hydrogeology.

In the horizontal plane square meshes of variable size are very convenient to represent aquifer and the size of meshes may be chosen according to the hydrogeologic problem (area of interest, rapid heat changes) with the availability and quantity of data. The whole watershed was divided into 5376 nested square meshes of 12.5 m x 12.5 m size incorporating the boundary conditions. Also the hydraulic behavior of a basin, if considered as a whole, the shape of boundaries, streams, lakes, geologic structures and even location of wells may quite satisfactorily be represented by three variable size nested squares.

Out of 3 observation wells in the watershed only 2 observation wells were considered for construction of well hydrographs from April 2002 to December 2006. The water level configuration of April 2002 has been assumed to be in equilibrium condition of the aquifer model. The water levels between observation wells have been interpolated by taking care of surface topography, waterways and stream channels. Model boundary was kept same as the actual boundary of the watershed.

The average groundwater recharge estimated from water balance model was uniformly fed to all meshes. The draft and transmissivity values were assigned to different meshes. These inputs and output stresses were consider for steady state and transient state condition.

3.5.4 Draft

Withdrawal of groundwater from the aquifer of the watershed was used for the purpose of irrigation, drinking etc. through number of existing wells. The draft was estimated based on well inventory and average running hours of pumps, pumping rate and water requirement of the cropping pattern. For the calculation of unit draft, pump horse power, running hours of pump in different season as shown in Table 3.13 were used. Most of the groundwater draft occurs during post monsoon season from October to February.

Table 3.13 Pumping schedule of observation wells in Priyadarshini watershed.

Well No.	**Pumping Horse power (hp)**	**Kharif June-Sept. (hr/day)**	**Rabi Oct.-Jan. (hr/day)**	**Summer Feb.-June (hr/day)**
Well 1	5	2	5	2.5
Well 2	5	0	2	0
Well 3	5	2.5	3	1

3.6 Flow Boundary Conditions

Visual MODFLOW supports the following groundwater flow boundary condition types

1 Constant Head (CHD)

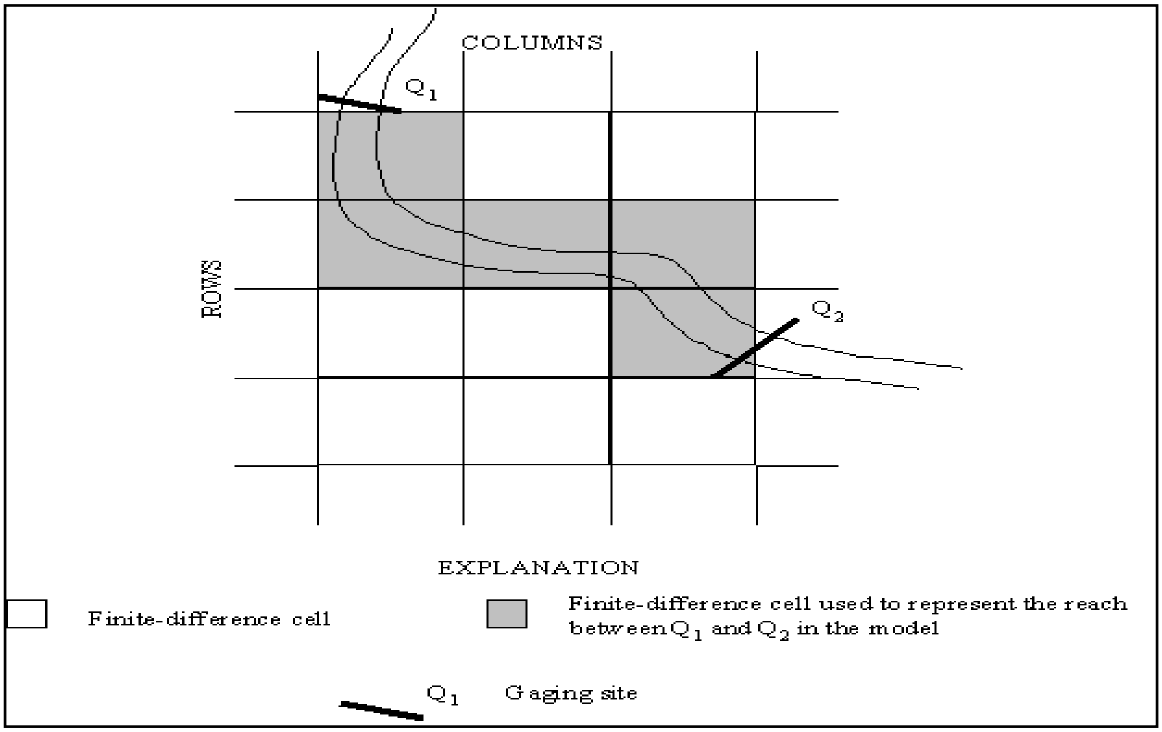
2 River

3 Recharge

3.6.1 Constant head (CHD) boundary condition

The Constant Head boundary condition is used to fix the head value in selected grid cell regardless of the system conditions in the surrounding grid cells, thus acting as an infinite source of water entering the system, or as an infinite sink for water leaving the system. Therefore, Constant Head boundary conditions can have a significant influence on the results of a simulation, and may lead to unrealistic predictions, particularly when used in locations close to the area of interest.

Unlike most other transient MODFLOW boundary condition packages, the CHD package allows the specified heads to be linearly interpolated in time between the beginning and end of each stress period, such that the specified head for a grid cell may change at each time step of a given stress period. The CHD package requires the following information for each Constant Head grid cell for each stress period:



Generally we use many cells to define a feature. Here, shaded cells are used to simulate flow to compare to measured flow Q2-Q1. Other cells would be used to define the rest of the river.

3.6.2 River boundary condition

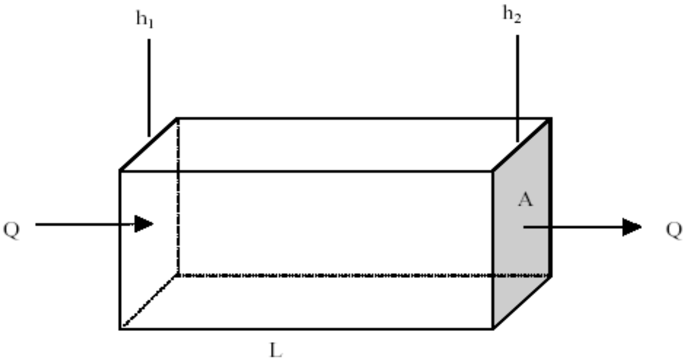
The River boundary condition was used to simulate the influence of a surface water body on the groundwater flow. Surface water bodies such as rivers, streams and lakes may either contribute water to the groundwater system, or act as groundwater discharge zones, depending on the hydraulic gradient between the surface water body and the groundwater system. The MODFLOW River Package simulates the surface water/groundwater interaction via a seepage layer separating the surface water body from the groundwater system. The MODFLOW River Package input file requires the following information for each grid cell containing a River boundary;

1 River Stage: The free water surface elevation of the surface water body. This elevation may change with time.

2 Riverbed Bottom: The elevation of the bottom of the seepage layer (bedding material) of the surface water body.

3 Conductance: A numerical parameter representing the resistance to flow between the surface water body and the groundwater caused by the seepage layer (riverbed).

Conductance is a combination of several parameters used in Darcy's law. Darcy's law defines one-dimensional flow in a prism of porous material (Fig 3.6.) as



$$Q = \frac{-KA(h_2 - h_1)}{L}$$

Fig. 3.6 One-dimensional flow in a prism of porous material

The River bed Conductance value (C) may be calculated from the length of a reach of river (L) through a cell, the width of the river bed (W) in each grid cell, the thickness of the riverbed (M) in each grid cell, and the vertical hydraulic conductivity of the riverbed material (K) using the following formula:

$C = (K \times L \times W) / M$ Therefore, Darcy's law can be written as

$$Q = C(h_1 - h_2)$$

3.6.3 Recharge boundary condition

The Recharge Package is typically used to simulate recharge to the groundwater system. Most commonly, recharge occurs as a result of precipitation percolating into the groundwater system. However, the Recharge Package can potentially be used to simulate recharge from sources other than precipitation, such as irrigation, artificial recharge, or seepage from a pond.

The recharge rate is a parameter that is not often measured at a site, but rather, it is assumed to be a percentage of the precipitation. This percentage typically ranges from 5% to 20% depending on many different factors including:

1 The predominant land use and vegetation type,
2 The surface topography (slope), and
3 The soil cover material

3.6.4 Evapo-transpiration boundary condition

The Evapo-transpiration Package simulates the effects of plant transpiration, direct evaporation, and seepage at the ground surface by removing water from the saturated groundwater regime. The Evapo-transpiration Package requires the following information:

1 **Evapotranspiration rate**: The rate of evapo-transpiration as it occurs when the water table elevation is equal to the top of the grid cell elevation.
2 **Extinction Depth:** The depth below the top of grid cell elevation where the evapotranspiration rate is negligible.

The Evapo-transpiration Package approach is based on the following assumptions:

1 When the water table is at or above the ground surface (top of layer 1), evapo-transpiration loss from the water table occurs at the maximum rate specified by the user.
2 When the elevation of the water table is below the ‘extinction depth’, or is beneath layer 1, evapo-transpiration from the water table is negligible.

3 Between these limits, evapo-transpiration from the water table varies linearly with water table elevation.

Since evapo-transpiration from the groundwater system usually occurs at or near the ground surface, Visual MODFLOW only allows Evapo-transpiration values to be assigned to Layer 1

3.6.5 Zone budget

Zone Budget calculates sub-regional water budgets using results from steady-state or transient MODFLOW simulations. Zone Budget calculates budgets by tabulating the budget data that MODFLOW produces using the cell-by-cell flow option. Flow observations, such as baseflow to a stream, or flux across a boundary, are very useful for calibrating a groundwater flow model against data other than just head measurements. The utilization of flow observations provides a stronger line of evidence to verify the model predictions, and is particularly useful in models where the water table is relatively flat.

3.6.6 Calibration of groundwater flow model

In Priyadarshini watershed Groundwater occurs under semi-confined conditions and extracted by dug wells. WH solver is a method of solving large set of partial differential equations iteratively through an approximate solution. The model (steady state) was calibrated by several parameters with in a narrow range of values until a best fit was obtained between the observed data and simulated results. Such trials are designed to calibrate the model, a process of selecting the suitable set of parameters that produce the best simulation of a known water table contours. Minor adjustments in permeability distribution have not brought appreciable changes. Thus, the simulated permeability seems to represent the actual value. Comparing computed versus observed heads at three observation wells made the calibration. The computed water levels accuracy has been judged by comparing mean error, mean absolute value of the difference between the calculated head and observed heads are summated. Root mean square error is the square root of the sum of the square of the difference between the calculated and observed heads, divided by the number of the observation wells.

The simulation time in visual MODFLOW is divided into several stress periods under transient condition. A stress period is defined as a time period in which all the stresses (Boundary conditions, pumping/ recharge rates etc.) on the system are assumed constant. Visual MODFLOW uses boundary conditions imposed by the user to determine length of each stress period for a transient simulation. Stress periods are, in turn, divided in to time steps. Within each stress period, time step from a geometric progression. Transient run simulation during April 2002 to April 2006 has been divided into 28 stress periods. The pumping for irrigation mostly takes place during September to February. However, the pumping for drinking water supply and domestic consumption continues throughout the year. Stress periods are divided based on the pre monsoon and post monsoon pumping rates and the recharge periods under transient state. First the model has been simulated in steady state for period of 30 days and then simulated in transient state for five year period. All data, such as constant head, recharge, river boundary and evapotranspiration have been provided as input with respect to the time to construct transient state model.

Transient State Simulation: After the successful run in the steady state, model was run for five-year period for 28 stress periods. The model was simulated with pumping wells (only irrigation dug wells) and simulated results were compared. The model acted like as if in field situation i.e. rise of water table in the monsoon period, decrease in water table after the monsoon. This indicates conceptual model and initial parameters were matching closely. Input parameters are further refined i.e. spatial variation of recharge at different macro/micro-landform and soil types (topographic and soil maps used), spatial variation in evapo-transpiration in different land use units (land use map used), hydraulic conductivity on different landform and weathered material (aquifer hydro-geophysical property used). After refinement of the model input, model was finally calibrated for the actual field condition.

3.7 The Impact of Soil and Water Conservation Measures on Groundwater Recharge.

The soil and water conservation measures, namely, the staggered and continuous contour trenches, bench terraces, on-stream water harvesting pond, cement plugs on the nala, loose boulders and vegetative barriers were carried out in the treated watershed area. The major soil and water conservation measures adapted are

1. Bench Terraces (within university boundary) = 2.9 ha.
2. Continuous and Staggered trenches = 2 ha.
3. Loose Boulder structures (main stream) = 13
4. Loose Boulder structures (other streams) = 12
5. Cement Plug (main stream) = 03
6. Vegetative barriers (small streams) = 04
7. On stream ponds = 01
8. Recharge pond = 03

Weekly water levels in these nine wells from April 2002 to April 2006 were recorded for analysis. Total nine observation wells were selected for the groundwater study. Out of these nine wells only three wells were considered for simulation of recharge modeling, which are situated inside the watershed area as shown in Fig.3.4 and other six wells were situated nearer to watershed boundary. These nine wells were used for domestic water supply as well as irrigation water supply. Wells used for domestic water supply were W5, W6, W7 and W8. Wells W1, W2, W3 and W4 were used for irrigation purpose. The depth was measured from fixed reference point above groundwater level of each well. Water level of Priyadarshini pond observed weekly for the study of the impact on groundwater recharge.

IV. RESULTS AND DISCUSSION

Estimation of different component of water balance equation and development of groundwater model for Priyadarshini watershed were the primary objectives of this research study. The results of the work are discussed briefly in this chapter.

4.1 Water Balance by SWIM Model

The major inputs to water balance model were soil hydraulic properties, vegetation, daily rainfall and pan evaporation. The parameters such as recharge, runoff, evaporation, transpiration, and soil moisture of the water balance model were computed by using SWIM computer based model. The inputs to the SWIM model were starting time, finishing time, vegetation type, root depth, root density, maximum fraction of PET, soil conductance value, runoff, hydraulic properties of soil, cumulative evaporation, and cumulative precipitation.

The first step in formation of water balance model applied to the area considering weighted average soil depth and textural class. The textural soil class was sandy loam. The watershed area was divided into five sections on the basis of soil depth class as shown in Fig. 3.2. The average soil depths in different sections of the watershed area are given in Table 4.1.

Table 4.1: Depth wise soil classification of selected watershed

Section	Depth class	Soil depth (cm)
I	D1	Less than 7.5
II	D2	7.5 to 22.5
III	D3	22.5 to 45
IV	D4	45 to 90
V	D5	Greater than 90

The computer programme was used for estimating the different components of water balance equation. The major inputs of the model were daily rainfall and pan evaporation.

The annual groundwater recharge and other components of the water balance model during 1985 to 2006 are presented in Table 4.2. Monthly groundwater recharge and runoff, during 1985 to 2006 have been summarized in Table 4.3 and 4.4. Rainfall and Pan-evaporation data tables are shown in Appendix-C.

Groundwater recharge in the watershed mostly took place during July to September and occasionally in June and October with evidence of groundwater recharge occurring during non-monsoon period. Also the monthly groundwater recharge was varying from 2 mm to 202 mm (Table: 4.3).

The average annual rainfall, estimated Surface runoff and Groundwater recharge from the watershed were 3386.1 mm, 990.02 mm and 336.64 mm, respectively under normal agro climatic condition. The percentage of mean annual groundwater recharge and surface runoff to rainfall was estimated as 10.32 % and 29.33 %.

Recharge to the water table was maximum in the year 1985, 1990 and 2000, which was above 500 mm for good rainfall of greater than 4000 mm. The minimum annual recharge was 220 mm. during 1986 and 1987, for corresponding rainfall of upto 2421 mm.

The estimated recharge was less than annual average in 11 years out of 22 years. It is seen from the Table 4.3 that maximum recharge occurred in the month of July (38%) and August (29%), followed by June (23%) and September (9%). This is clearly showed in Fig.4.1.

The estimated runoff was less than annual average in 11 years out of 22 years. It is seen from the Table 4.4 that maximum runoff occurred in the month of July i.e. 36%, and minimum runoff occurred in the month of October i.e. 3%, which is shown in Fig. 4.2.

Table 4.2 Annual Water balance components for Priyadarshini Watershed

Year	Rainfall (mm)	Runoff (mm)	Actual evapotranspiration (mm)	Recharge (mm)	Soil moisture (mm)
1985	4947.4	1460.61	2934.66	537.78	4.35
1986	2403.9	720.97	1428.61	220.08	34.24
1987	2419.2	719.22	1431.8	223.24	44.94
1988	3445.5	1028.23	2032.72	362.22	22.33
1989	3194.2	930.06	1887.63	317.22	59.29
1990	2907.9	966.1	1599.34	298.75	43.71
1991	3769.9	1106.58	2227.32	366.83	69.17
1992	2992.7	874.32	1765.68	293.76	58.94
1993	3847.4	1154.22	2269.95	340.38	82.85
1994	2919.1	847.9	1721.79	245.81	103.6
1995	3273.4	930.06	1931.29	298.48	113.57
1996	3112.5	917.45	1774.12	414.02	6.41
1997	3788.4	1112.74	2267.42	370.35	45.83
1998	3796.8	1135.74	2259.46	352.05	49.55
1999	4226.2	1017.94	2577.98	446.22	184.05
2000	4619.1	1303.29	2725.26	510.08	80.47
2001	2380.4	696.99	1417.99	244.65	20.77
2002	2730.7	813.71	1616.3	236.25	64.44
2003	3004.6	899.46	1772.71	292.96	39.47
2004	3517.8	1025.37	2085.74	364.67	42.02
2005	3650.8	1095.94	2153.96	339.42	61.42
2006	3511.6	1008.18	2099.81	330.94	72.67

4.1.1 Groundwater recharge

Annual groundwater recharge taken place in the watershed area due to rainfall estimated by water balance equation is presented in Table 4.2 indicated that, it was also proportional to the annual rainfall and runoff values. The average annual recharge was found to be 336.64 mm, which was 10.32 % of the average annual rainfall.

Annual recharge during different year varies from 8 to 11 %. Monthly groundwater recharge occurred during different year is shown in Table 4.3.

Table 4.3 Groundwater recharge (mm) in Priyadarshini watershed during 1985-2006

Year	Rainfall	Monthly Recharge (mm)	Annual	Annual

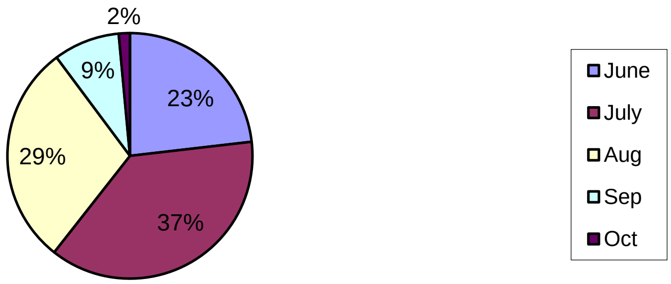


Fig. 4.1 Recharge percentage in different month

	(mm)	June	July	Aug.	Sep.	Oct.	Recharge (mm)	Recharge (%)
1985	4947.4	202.78	163.52	150.53	4.95	16	537.78	10.81
1986	2403.9	77.24	48	92.79	2.05	0	220.08	9.08
1987	2419.2	94.17	67.28	45.16	3.05	13.58	223.24	9.19
1988	3445.5	52.34	145.27	87.64	76.97	0	362.22	10.51
1989	3194.2	65.66	137	92.83	17.33	4.4	317.22	9.91
1990	2907.9	69.67	96	105.61	15.17	12.3	298.75	10.27
1991	3769.9	67.31	197.58	98.14	3.8	0	366.83	9.94
1992	2992.7	25.48	107.33	144.4	12.75	3.8	293.76	9.81
1993	3847.4	54.94	125.44	100.64	59.36	0	340.38	9.08
1994	2919.1	35.76	108.32	67.1	30.63	4	245.81	8.42
1995	3273.4	39.74	115.61	76.21	52.72	14.2	298.48	9.11
1996	3112.5	21.87	158.36	78.14	150.43	5.22	414	13.30
1997	3788.4	99.67	146.52	103.89	20.27	0	370.35	9.77
1998	3796.8	64.31	138.81	115.43	19.77	13.73	352.05	9.27
1999	4226.2	186.46	155.85	64.55	30.87	8.49	446.22	10.55
2000	4619.1	137.33	197.46	167.89	4.2	3.2	510.08	11.04
2001	2380.4	41	99.41	92.55	11.69	0	244.65	10.27
2002	2730.7	68.65	61.12	89.97	13.92	2.59	236.25	8.65
2003	3004.6	86.26	119.65	69.7	17.35	0	292.96	9.75
2004	3517.8	109.76	119.3	108.63	26.98	0	364.67	10.36
2005	3650.8	47.06	138.3	99.93	50.89	3.3	339.48	9.29
2006	3511.6	68.62	126.8	109.1	22.21	4.21	330.94	9.42
Avg.	**3386.1**	**78**	**126.04**	**98.21**	**29.42**	**4.95**	**336.64**	**10.32**

Table 4.4 Runoff (mm) from Priyadarshini watershed during 1985-2006

Year	Rainfall (mm)	Monthly Runoff (mm)					Annual Runoff (mm)	Annual Runoff (%)
		June	July	Aug	Sep.	Oct.		
1985	4947.4	608.34	411.24	351.33	29.7	60	1460.61	29.52
1986	2403.9	331	129.3	248.37	12.3	0	720.97	29.99
1987	2419.2	313.92	183.84	120.48	19.5	81.48	719.22	29.72
1988	3445.5	157	426.81	214.11	230.31	0	1028.23	29.84
1989	3194.2	218.88	411	225.9	74.28	0	930.06	29.11
1990	2907.9	99.1	226	515.3	83.9	41.8	966.1	33.22
1991	3769.9	288.48	592.74	225.36	0	0	1106.58	29.35
1992	2992.7	109.2	321.99	366.63	76.5	0	874.32	29.21
1993	3847.4	135.47	476.32	277.2	254.43	39.54	1154.96	30.01
1994	2919.1	202.56	294.96	166.6	183.78	0	847.9	29.04
1995	3273.4	108.39	334.83	199.68	225.96	61.2	930.06	28.41
1996	3112.5	12.25	460	185.85	100	42.35	917.45	29.95
1997	3788.4	298.53	436.56	256	121.65	0	1112.74	29.37

1998	3796.8	214.38	416.43	303.9	118.65	82.38	1135.74	29.91
1999	4226.2	308.53	389.64	136.38	132.42	50.97	1017.94	24.08
2000	4619.1	357	493.65	394.74	25.2	32.7	1303.29	28.21
2001	2380.4	123	262.95	222.42	70.14	18.48	696.99	29.28
2002	2730.7	294.2	170.43	239.94	83.64	25.5	813.71	29.79
2003	3004.6	287.22	358.95	179.19	74.1	0	899.46	29.93
2004	3517.8	329.28	327.9	271.59	96.6	0	1025.37	29.14
2005	3650.8	201.69	399.9	245.28	215.37	33	1095.24	30
2006	3511.6	205.86	374.4	252.54	133.26	42.12	1008.18	28.70
Average	**3386.1**	**241.46**	**359.08**	**254.53**	**107.34**	**27.79**	**990.02**	**29.33**

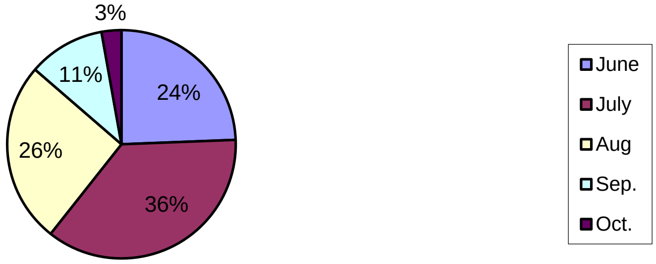


Fig. 4.2 Runoff percentage in different month

4.1.2 Other components of water balance equation

The actual evapotranspiration from watershed area varies from 1428 to 2725.26 mm annually, with an average of 1999.16 mm. This component of water balance equation contributed maximum portion of average annual rainfall i.e. 59%.

The runoff from watershed area varies from 719.22 to 1460 mm annually, with an average of 990.02 mm. This component of water balance equation comes to 29.33 % of the average annual rainfall.

The soil moisture from watershed area varies from 6.41 to 184.05 mm annually, with an average of 59.73 mm. This component of water balance equation comes to 1.76 % of the average annual rainfall.

The above results of water balance equation indicated that the input rainfall and output (Recharge, Runoff, Evapotranspiration) were exactly matching for study period. From the above discussion and results of water balance equation, it can be concluded that Runoff, Recharge and Evapotranspiration components from the watershed area comes to 29.33%, 10.32 %, and 59 %, respectively.

4.2 Aquifer model

Groundwater recharge in the watershed area during rainy season estimated by the water balance equation in previous section was used along with estimated withdrawal of groundwater from the aquifer through the open well (draft) and aquifer parameters estimated through the pumping test, to develop a aquifer model for the Priyadarshini watershed.

4.2.1 Steady state model calibration

The initial water level configuration of the observation during April 2002 was used for steady state level calibration. The groundwater flow solution was obtained through use of visual MODFLOW software. The model was calculated by assuming hydraulic heads during April 2002 under equilibrium condition. The calibration was made by comparing the computed versus observed heads of three observation wells in the selected watershed area under steady state condition.

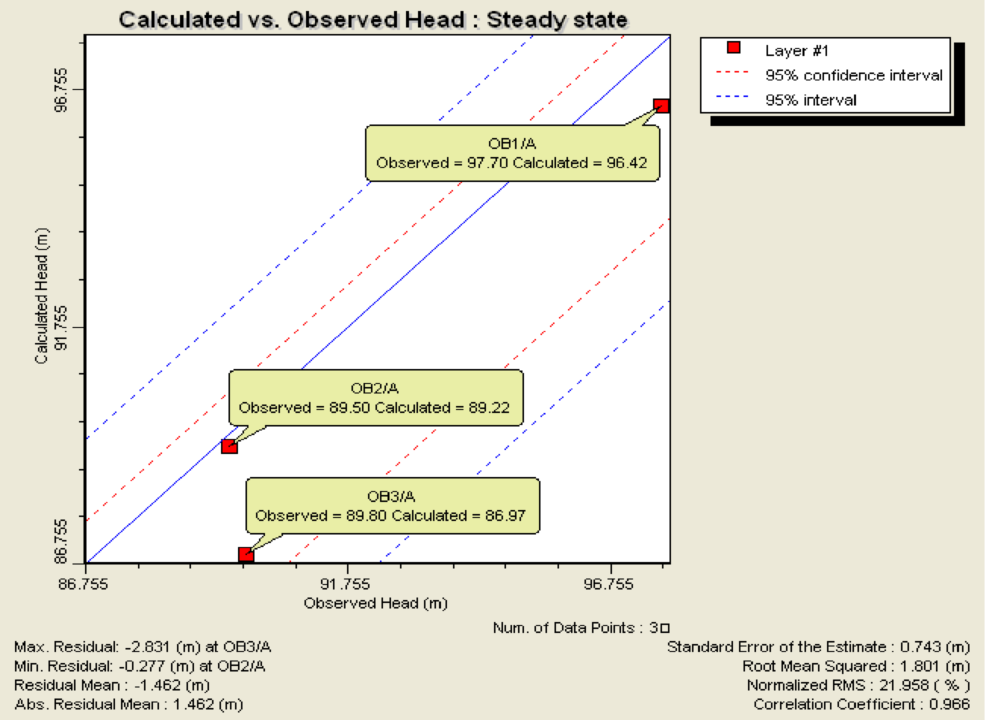


Fig. 4.3 Calculated Vs Observed head in Steady state condition

Several runs were conducted on a simulated watershed area under different conditions and in the calibrated run most of the wells had compatibility with reference to observed heads and calculated heads. The solver performed iterations and showed a convergent solution with maximum residual of – 2.831(m) for observation well No.3. The remaining wells that were slightly deviated from best-fit line were falling approximately distance from the best line. Standard error of estimate of 0.743 (m), root mean square error 1.801(m) and Correlation coefficient of 0.966 were obtained in the final run as shown in Fig.4.3.

4.2.2 Inputs and outputs

For comparison of best match between computed and observed water level, three trial runs were carried preceding the calibrated run. In the calibrated run (final run), recharge and draft values were modified from actual one slightly for close matching. The recharge to the groundwater regime occurs due to monsoon rainfall and forms the main input to the aquifer. The modified recharge values fed to all the meshes as an input were as given in Table 3.2.

The outflow from an aquifer mainly took place through groundwater withdrawal from open wells. Total draft per day from the aquifer of this watershed was estimated by knowing total area under well irrigation in different seasons, cropping pattern, pump horsepower and operating hours. The unit draft was worked as 250 m^3 /day approximately. Most of the groundwater draft occurs during the post monsoon period from October to February whereas draft for drinking water supply remains continuous through out the year. The draft values are assigned to different meshes. In calibrated run the draft values have been modified from 10 to 250 m^3/day and fed to all meshes during rainy and drought seasons respectively.

The aquifer parameters (transmissivity and specific yield) calculated from pumping test (Appendix –A) was uniformly fed to all the meshes as an input. The transmissivity and specific yield were found as 86.25 m^2 /day and 14.89 %, respectively. After feeding of all inputs to different meshes, the visual MODFLOW model was operated by WH solver. The differences between computed and observed water levels in different wells for steady state condition are shown in Table 4.5.

Table 4.5 Comparison of groundwater levels under steady state condition (April, 2002)

Well No.	Observed water levels (amsl)	Computed water levels (amsl)	Difference (m)
1	97.7	96.42	1.28
2	89.5	89.22	0.28
3	89.8	86.97	2.83

4.2.3 Transient state calibration

Under transient state the simulation time in MODFLOW was divided into several stress periods. A stress period is defined as time period in which all the stresses (Boundary conditions, pumping rates, etc…) on the system are assumed constant. Visual MODFLOW uses boundary conditions imposed by the user to determine length of each stress period for a transient simulation. The stress periods are, in turn, divided into time steps. The user defines number of time steps, and time step multiplier or ratio of the length of each time step to that of the preceding time step. Using these terms, visual MODFLOW calculates length of each time step in a stress period. The entire duration of simulation from April 2002 to 2006 has been divided into 28 stress periods.

After obtaining the steady state results, the dynamic run i.e., transient state was run on the model fixing the parameters. Computed water level contours from the model during transient calibration for the years April 2002 in pre-monsoon and post-monsoon with figures is placed in Fig. 4.6. The input and output stresses have been fed into model in monthly time span. The specific yield values estimated through the pump test have also been assigned to all the meshes. The dynamic variations of groundwater with drawals (Table 4.6) as well as the groundwater recharge (Table 3.2) have been fed to the aquifer model in monthly time steps during transient condition. The groundwater flow model was calibrated from April 2002 to April 2006 for transient condition through comparison of computed and observed well hydrographs. The hydrographs of all wells in the basin shows a close match under normal rainfall years.

For the comparison of hydrographs calculated and observed heads are drawn on ordinate while time is drawn on the abscissa. The hydrographs of three observation wells during transient condition from April 2002 to April 2006 on the simulated model were computed.

Since, it is a transient model and considering dynamic recharge, storage coefficient has been reduced in order to increase fluctuations over the 28 stress periods. The hydrographs of observation wells at Well 1 and Well 2 are matching to most extent and shows that the post-monsoon groundwater heads of calculated and observed are matching closely.

Table 4.6 Drafts for Transient Calibration.

Start Time (Days)	End Time (Days)	Draft (m^3/day)
0	1	-250
1	150	-10
150	365	-250
365	515	-10
515	730	-250
730	880	-10
880	1095	-250
1095	1245	-10
1245	1245	-250
1460	1460	-10
1610	1825	-250

4.2.4 Calibration of groundwater flow model

The salient aspects of the simulation well hydrographs obtained from the groundwater flow model during transient calibration for 5 years for different wells are discussed below.

Well 1

Well 1 was in the Northwest part of watershed. The area around the well is under cultivation. Frequent pumping of groundwater from the well was carried out for irrigation. Comparison of computed and observed hydrograph shows that computed water level rises from the month of June to September. The water levels of the observed hydrograph also followed the same trend. The mismatch between observed and computed hydrograph during the post monsoon period was within 1.15 m (Appendix-B). The computed water levels were greater than observed water levels during April 2002 to April 2006 that may be due to continuous draft of groundwater from the well for irrigation to crops. The graph of comparison of observed and computed water levels is shown in Fig. 4.4

Well 2

This observation well was located near the stream bank at the center regime of watershed. Average computed water level fluctuation during pre-monsoon and post-monsoon period was found to be 3.12 m, which was very close to observed water level fluctuation 2.39 m (Appendix-B). Except in the year November 2005 computed water levels were lower than the observed one. This may be due to the fact that the well was not in used for irrigation as well as for drinking purpose. The comparison of observed and computed water levels are shown in Fig. 4.5

The above results of groundwater flow model for Priyadarshini watershed, demonstrates the applicability and validity of the groundwater recharge estimation obtained from the water balance model. Close fitting of the rising limb of hydrographs from pre monsoon to post monsoon in all the years confirms the accuracy of the water balance model.

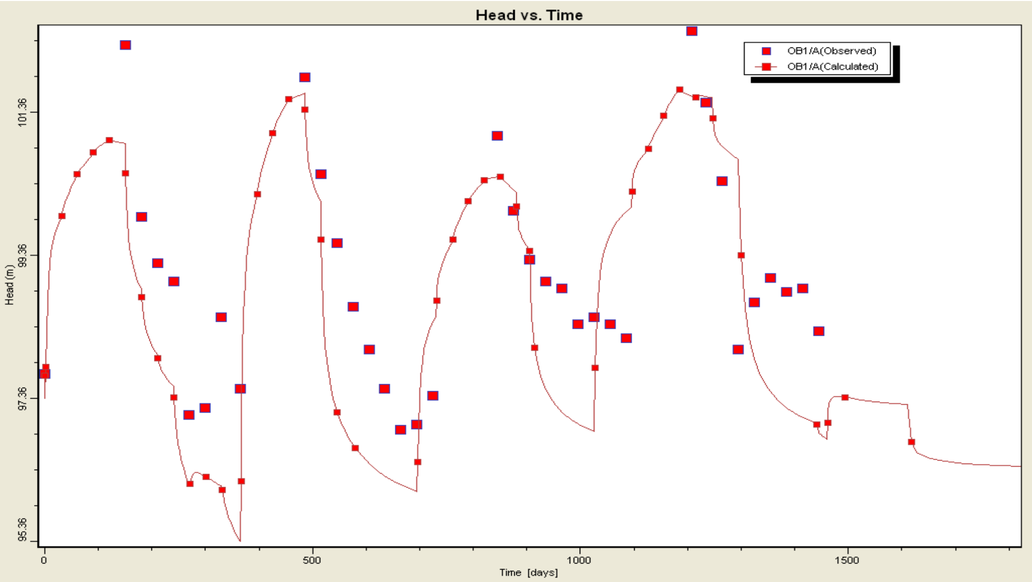


Fig. 4.4 Observed and calculated water table in well-1 during April 2002 to April 2006

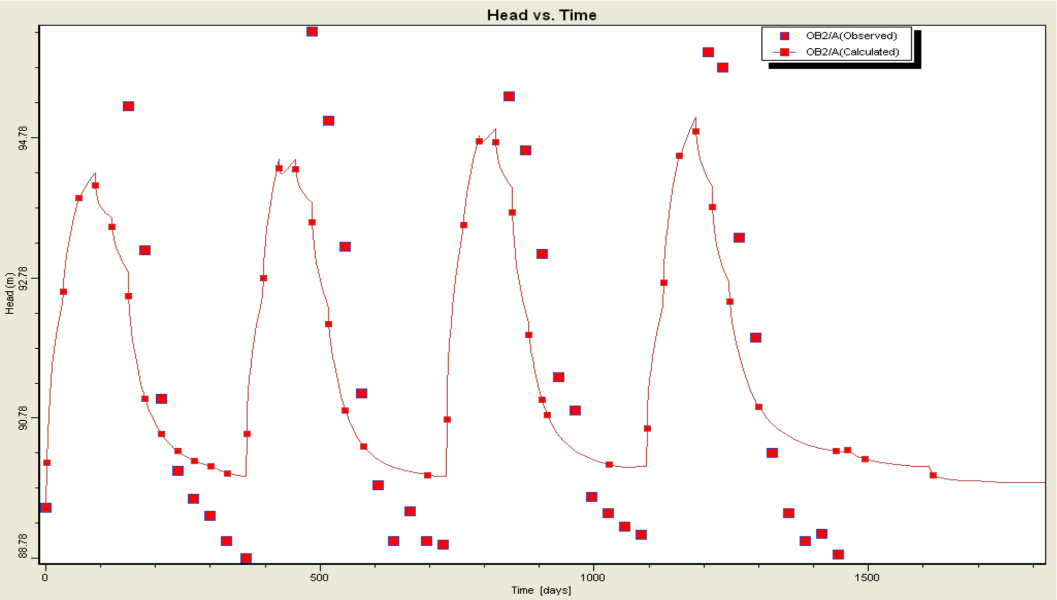


Fig. 4.5 Observed and calculated water table in well-2 during April 2002 to April 2006

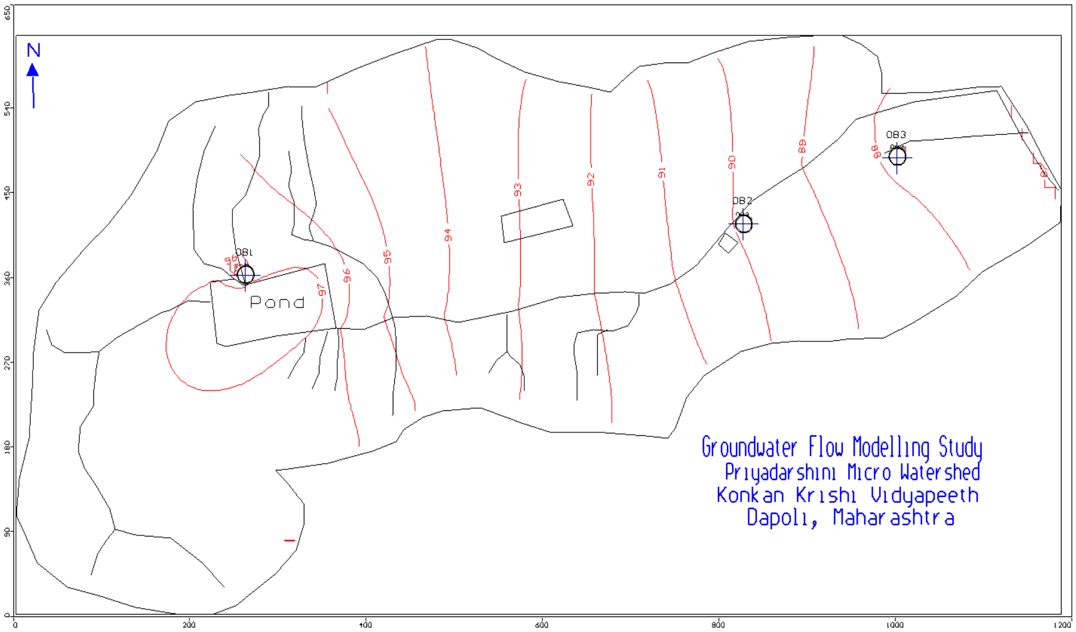


Fig. 4.6 Computed water level contours of Priyadarshini watershed (April-2002)

The modeling has given an understanding of hydrogeological setup and interaction of hydrologic stress on the groundwater regime. It is fairly common for comprehensive and intensive investigation to include the development, application and calibration of simulation models of groundwater flow and to use them to make predictions. Data collection and monitoring in a study area tends to be crucial. This inevitably results in deficiency of future data relating to prediction period. To make the most reliable prediction for a given groundwater problem, all relevant information should be considered and be evaluated in order to arrive at the best estimate of the future behavior of system.

The primary aim of groundwater models in this analysis was understanding of the aquifer system. This knowledge in turn, should allow better management of groundwater resources and their protection regardless of the prediction accuracy of model.

The flow model gives the aquifer properties values i.e. storage coefficient (0.02), hydraulic conductivity (6 m/day), and recharge (10%) of annual rainfall with 10% variation between calculated and observed values.

This study revealed that the soil and water conservation works play an effective role for maintaining and improving the groundwater potential of the area.

4.3 The Impact of Soil and Water Conservation Measures on Groundwater Recharge.

The water conservation measures were found to be effective for rising of water table in observation wells located in a treated area of watershed. The watershed has area of 38.72 ha, out of which the 29.05 ha was under university precinct. The watershed was fern shaped and has average slope of 6.01 % at upstream side of pond while the other is flat part (0.98 % slope) at downstream side of pond. The watershed has hilly topography and shallow lateritic soil. The average soil depth of watershed was 45 cm. The existing soil and water conservation works were the staggered and continuous contour trenches on the top hill slopes and the bench terraces on the non- arable land. The structures found on main nala were the water harvesting pond covering 0.85 ha, a stepped spillway upstream to pond, a cement check dam and loose boulders down streams to pond.

The adjoining streams were found to have some vegetative barriers and loose boulder structures as the control measures against gullying. The remaining area was partially treated with tiny bench terrace along with horticultural cultivation. There were paddy fields at the top of the watershed. All wells exhibit the natural phenomenon of water level variation. Water level in wells starts receding after the monsoon and reached to lowest level just before the monsoon. During the monsoon water level rises due to water recharge. The maximum and minimum depth of water level in wells recorded just before the monsoon and after monsoon. The average groundwater levels in treated and untreated zone were found to be below the ground surface, by 5.38 m and 6.99 m respectively, indicating that there was the avg. water table higher by 1.61 m in treated zone. Water table fall (m) in different wells of study area in five-year period is given in Table 4.7. From the water table data of 2006-2007 also shows that in meteorological week 5 to 16 average water level in the wells of treated area remains flatter than that of wells of untreated area. Water level in wells of untreated area deplete faster than wells of treated area as shown in Fig. 4.7.

Table 4.7 Water table fall (m) in different wells of study area

Sr.No.	Wells	2002-03	2003-04	2004-05	2005-06	2006-07	Average
	Treated area						
1	W1	2.2	3.8	3.45	1.79	3.2	2.78
2	W2	5.79	6.45	6.05	6.26	7.25	6.30
3	W3	5.52	5.8	5.6	5.32	6.95	5.81
4	W4	5.58	7.07	6.8	5	8.89	6.66
Overall Average							**5.38**
	Untreated area wells						
5	W5	5.35	6.25	6	6.37	7.1	6.21
6	W6	4.5	6.25	5.9	5.43	7.25	5.86
7	W7	9.1	7.6	7.7	8.31	7.5	8.04
8	W8	6.5	9.42	8.2	5.94	10.02	8.01
9	W9	7.1	6.25	6.1	7.18	7.55	6.83
Overall Average							**6.99**

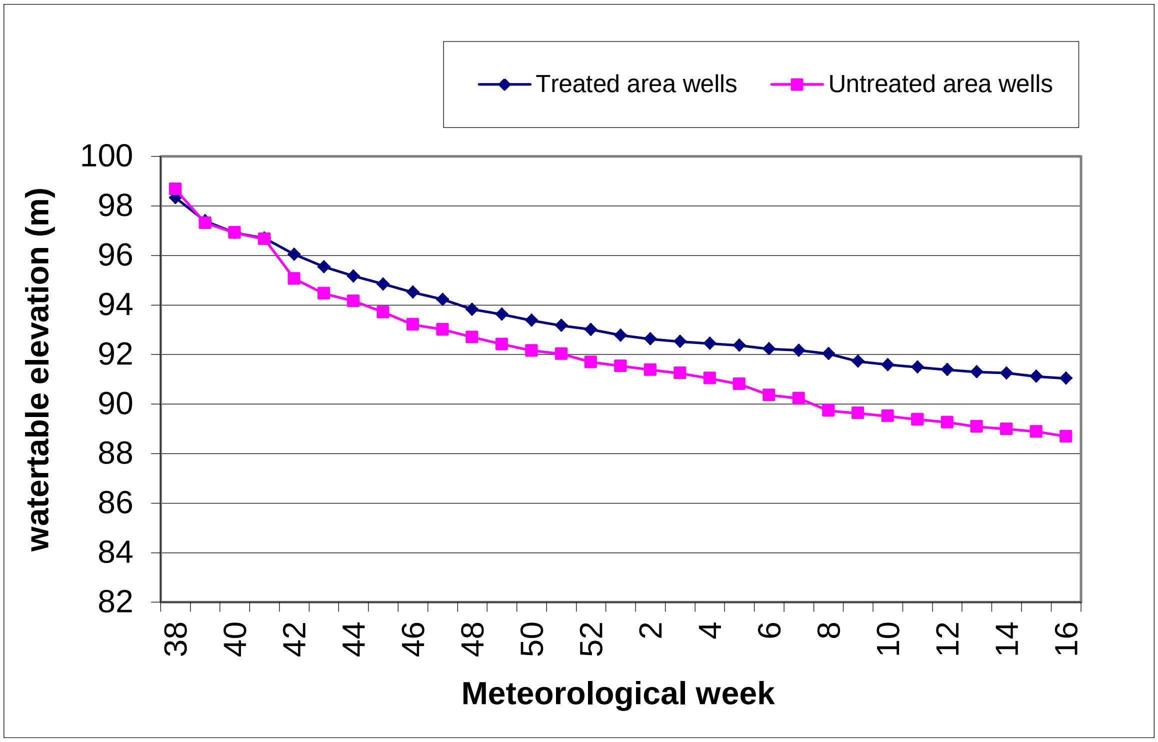


Fig. 4.7 Time Vs Water table elevation of treated and untreated area wells**.**

4.3.1 Ground water recharge impact by priyadarshani pond in treated watershed

It is a clear from Fig 4.8 that the water impounded behind the Priyadarshani pond was maximum in the month of July, August and September. This is due to the heavy rainfall received during the monsoon season. It was observed that there was continuous reduction in the volume of water impounded behind the Priyadarshani pond after September. This is due to evaporation losses, pumping from the pond for domestic as well as irrigation purpose in post monsoon season and percolation. Some part of volume of impounded water behind the structure was resulted into the ground water recharge. It was also observed that the structure became totally dry in the first week of March.

The result of the study clearly indicated that the water harvesting structure such as nala bund, cement plug, improved the groundwater potential of the area which could be utilize for increasing productivity of the land.

4.3.1.2 Seasonal storage of farm pond

Seasonal storage of farm pond was monitored and presented in Fig 4.8. It is observed that farm pond was completely filled on 25/6/2006 and water level start depleting from the 7th October 2006 and storage was available still last week of January 2007.

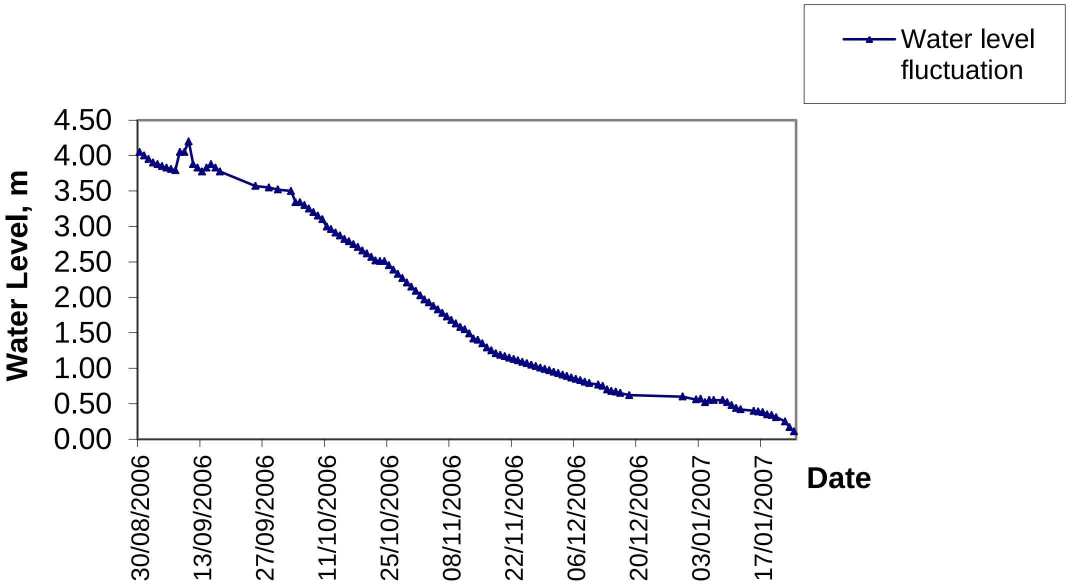


Fig.4.8 Water level fluctuation in Priyadarshini watershed

Though there was no practical storage available from First week of March 2006, water was still available at the bottom of the wall of farm pond. Flow is coming only from the ridge and the general groundwater flow direction towards the catchment outlet in the East direction of watershed and different colours shows different water table contours as shown in Fig. 4.9. The colour codes of the different water table contours are shown in Table 4.8. Isometric view of water table contour map is shown in Fig 4.10. The water table contour map and observation wells location during the year 2006-07 are shown in Fig. 4.11.

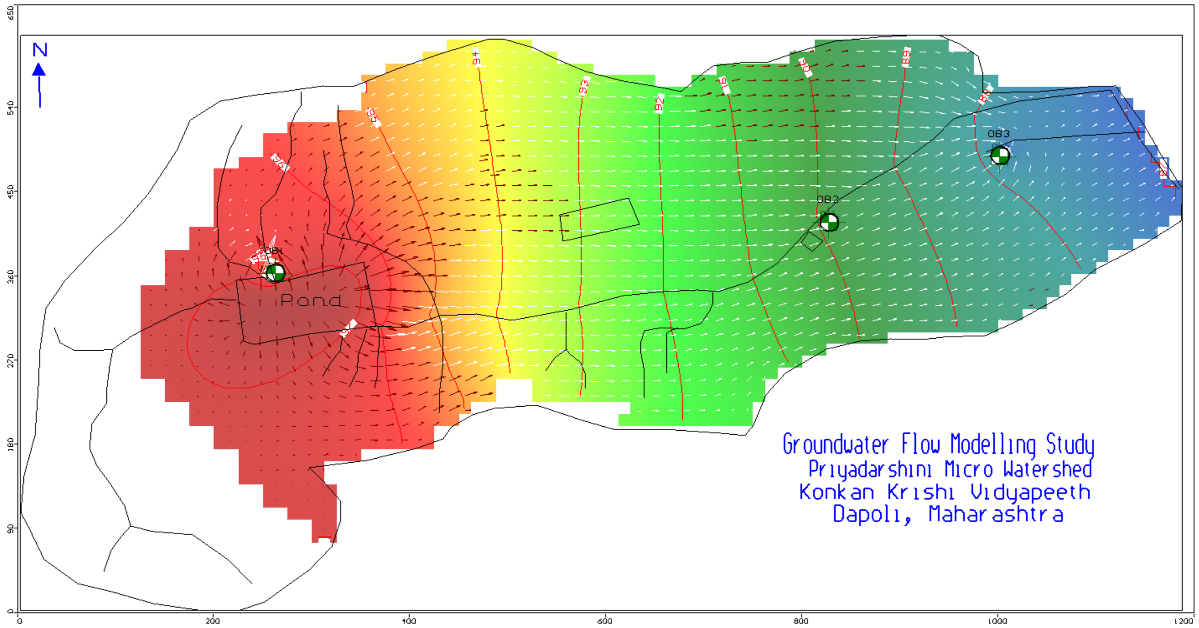


Fig. 4.9 Groundwater flow Direction in Priyadarshini Watershed in April 2002

Table: 4.8 Water table contour map with colour code

Sr.No	Contour Colour Code	Contour levels (m)
1	Dark Red	97
2	Faint Red	96
3	Orange	95
4	Yellow	94
5	Yellowish Green	93
6	Greenish Yellow	92
7	Green	91
8	Dark Green	90
9	Greenish Blue	89
10	Blue	88
11	Dark Blue	87

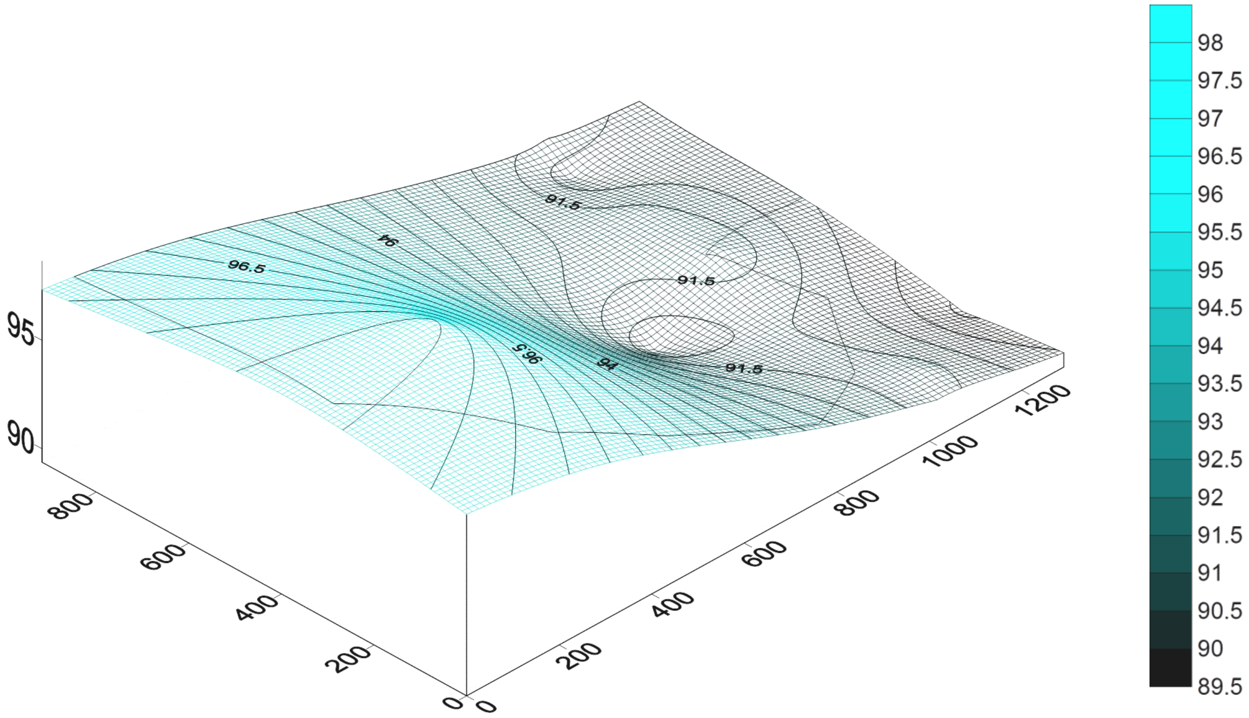


Fig 4.10 Isometric view of water table contour map of priyadarshini watershed, during the year 2006-2007.

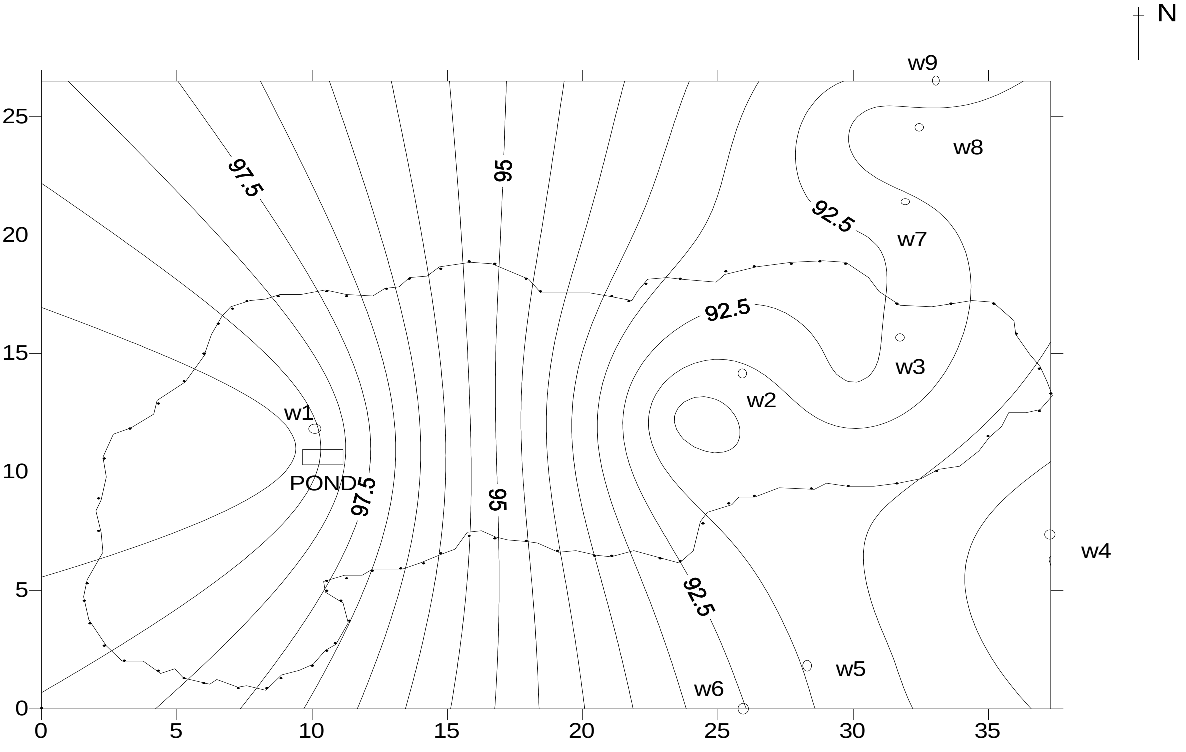


Fig. 4.11 Water table contour map and observation wells location during the year 2006-07

V. SUMMARY AND CONCLUSIONS

5.1 Summary

Research on “Simulation of groundwater recharge in Priyadarshini watershed” was carried out at Priyadarshini watershed, covering 38.78 ha area, which falls in the warm and humid climate.

Groundwater recharge in the watershed was estimated using the SWIM water balance model with daily rainfall and pan evaporation data of the study area during the period from 1985-2006. The textural soil class of the watershed was found as sandy loam. Whereas, from the soil depth variation in the selected area, the weighted average soil depth was 45 cm.

The components of water balance were estimated by SWIM computer model available with National Geophysical Research Institute, Hydrabad. Water balance model study showed that average annual runoff and recharge in the study area was 29.33 % and 10.32 %, respectively.

In the observation period of 22-years, 50% years produced more than average runoff and 50% years produced less than average runoff. The recharge in the observation period of 22-years, 50% years more than average recharge and 50% years less than average recharge. The average annual evapotranspiration component in study area was found to be 59 %.

The result of the water balance study indicated that both input (rainfall) and output (recharge, runoff, evapotranspiration and soil moisure) components of the water balance equation were exactly matching.

Groundwater recharge estimated by the water balance model was used to develop an aquifer model for the Priyadarshini watershed in addition to estimated groundwater withdrawal through open wells (draft) and aquifer parameters estimated through the pumping test.

In order to develop a groundwater flow model, the selected watershed was divided in to 5376 nested square meshes of 12.5 x 12.5 m size incorporating the boundary conditions, stream channel and location of observation wells using computer software. The initial water level configuration of the observation wells during April 2002 was used for steady state calibration. The groundwater flow model was developed using visual MODFLOW software. The model was calibrated by assuming hydraulic heads during April 2002 under equilibrium condition. For getting the best match between computed and observed water level of April 2002, in calibrated run the estimated recharge and draft values were modified and fed to visual MODFLOW software as an input and solved by using WHS. Water level in different observation wells indicated close matching with an overall standard deviation of 1.2 m.

For transient calibration, the input and output stresses were fed into model in monthly time span. The specific yield values estimated through the pump test were assigned to all meshes. The dynamic variations of groundwater withdrawals as well as the groundwater recharge were also fed to the aquifer model. The model was calibrated from April 2002 to April 2006 for transient calibration through comparison of computed and observed well hydrographs. The hydrographs of all the wells in the basin showed a close match under normal rainfall years.

The above results of groundwater flow model developed for the Priyadarshini watershed, demonstrated the applicability and perfectness of the groundwater recharge estimated by the water balance model. The aquifer parameters used in the groundwater flow model were unchanged which indicates the validity of the estimated aquifer parameters through pump test. The transmissivity and specific yield of aquifer determined from the pumping test on large diameter dug well was found to be 86.25 m^2/day and 14.85 % respectively.

The soil and water conservation measures were found to be effective for rising of water table in observation wells located in treated area of watershed. Data collected from 2002 to 2006 was analysed. The maximum and minimum depth of water level in wells recorded just before the monsoon and after monsoon. The average groundwater levels in treated and untreated zone were found to be below the ground surface, by 5.38 m and 6.99

m respectively, indicating that there was the average water table higher by 1.61 m in treated zone.

5.2 Conclusions

Based on the result obtained from this study following conclusion are drawn

1. Water balance study indicated that 29.33% rainfall resulted into runoff.
2. Ground water recharge in the area was found to be 10.32% of rainfall.
3. An evapotranspiration loss was found to be 59% of rainfall.
4. Soil moisture was found to be 1.76% of rainfall.
5. Close matching of computed and observed groundwater levels with standard deviation of 1.2 m in steady state calibration of the developed aquifer model indicated that the hydrological set up and other set of input parameters simulated in ground water flow model were best fitted.
6. A close match of well hydrographs computed by the developed ground water flow model, MODFLOW model and observed indicated the accuracy of estimated recharge by the water balance model.
7. Calibration test of the developed ground water flow model indicates that, it can be further modified and used for management of ground water resource.
8. The soil and water conservation measures were found to be effective for rising of water table by 1.61 m in treated zone.

5.3 Suggestions for future work

Groundwater simulation model is no more than an approximation of a complex field situation. Improvements in the approximation is always possible, thus much should be considered as dynamic representative of nature, subject to further refinement and improvement. As new information becomes available previous forecast could be and should be modified. The primary value of deterministic groundwater models in many analyses is in understanding of the groundwater flow system. This knowledge in turn should allow better management of groundwater resources and their protection regardless of the prediction accuracy of the model.

The present model studies of water balance and groundwater flow modeling can be treated as a preliminary one and can be further refined with additional field data such as crop pattern, rainfall, recharge, transmissivity, specific storage and draft (complete well inventory). Since model is of a dynamic process. Continuous monitoring of water levels and hydro meteorological data is needed.

For increasing accuracy of model predication about groundwater availability, selection of dug well site, selection of bore well, groundwater recharge pattern and groundwater flow pattern, it is necessary to increase the study area i.e. watershed area (minimum 80-100 ha). Select 10-15 dug wells or bore wells are required under boundary of watershed area and 5- 10 years water level readings will provide strong data for recharge modeling.

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APPENDIX –A

Aquifer performance test

The analysis of the pumping test data provides the invaluable information for determining the various hydraulic properties of aquifer or water bearing formation; which directly or indirectly influences the performance of the aquifer and the well yields as for as the ground water movement and its occurrence in different types of aquifer are concerned. Hydraulic properties of the aquifer, such as Hydraulic conductivity (k), Transmissivity (T) and Specific yield (μ).

The pumping test was carried out on well (7). Before pumping test, well inventory form was fill up. During pumping test drawn down and recuperation data was collected after every 5 min from starting of pump. Time vs Drawdown curve was drawn, for calculation of aquifer performance test. Time vs Drawdown curve is shown in Fig. A-1.

Calculation of pumping test for well W 7

1. Test Well: W 7 (This well is situated in Priyadarshini hostel)
2. Average diameter D = 9.7 m.
3. Discharge = 518.4 m^3/d.
4. Pumping duration = 375 min.
5. Observed drawdown s = 1.68 m.
6. Slope of straight lime on time drawdown plot Δs = 1.1.

Calculations

$$1.\ T = \frac{2.3Q}{4\pi\Delta s}$$

$$T = \frac{2.3 \times 518.4}{4 \times \pi \times 1.1}$$

$T = 86.25 \text{ m}^2/\text{d}.$

2. $$\mu = \frac{2.25KHt}{r^2}$$

$$\mu = \frac{2.25 \times 86.28 \times 0..01805}{4.85^2}$$

$$\mu = 14.89\ \%$$

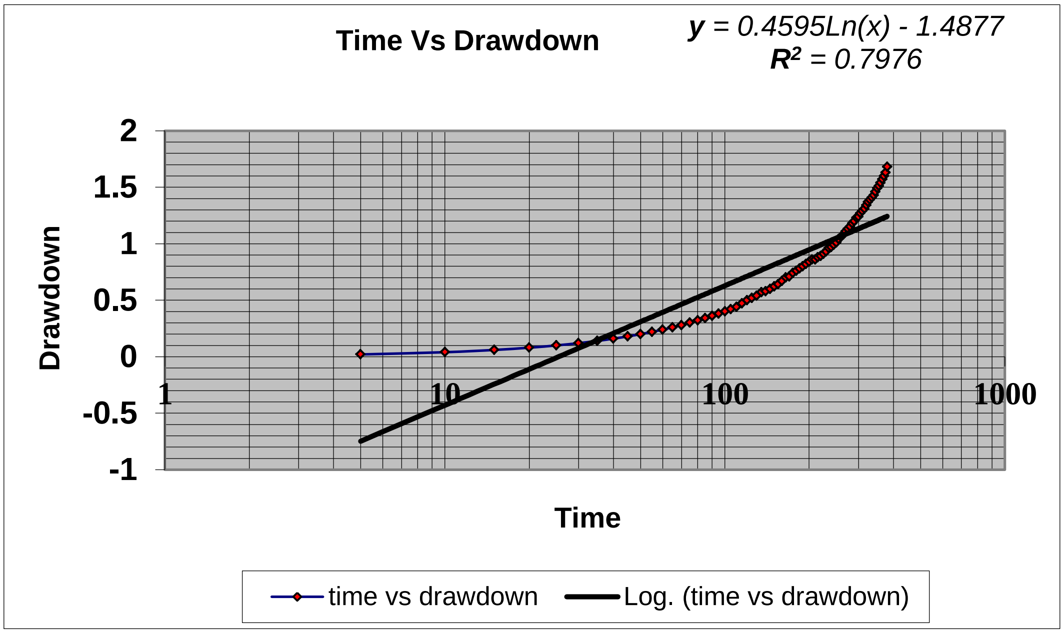

Fig. A-1 Time Vs Drawdown curve of aquifer performance test

Table - A1 Time Drawdown data of Aquifer performance test for well 7

Time, min	Drawdown, m	Time, min	Drawdown, m
5	0.02	190	0.8
10	0.04	195	0.82
15	0.06	200	0.84
20	0.08	205	0.86
25	0.1	210	0.88
30	0.12	215	0.89
35	0.14	220	0.91
40	0.16	225	0.93
45	0.18	230	0.96
50	0.2	235	0.97
55	0.22	240	0.99
60	0.24	245	1.01
65	0.26	250	1.04
70	0.28	255	1.06
75	0.3	260	1.08
80	0.32	265	1.11
85	0.34	270	1.13
90	0.36	275	1.15
95	0.38	280	1.18
100	0.4	285	1.2
105	0.42	290	1.23
110	0.44	295	1.24
115	0.47	300	1.27
120	0.49	305	1.29
125	0.52	310	1.31
130	0.54	315	1.34
135	0.57	320	1.37
140	0.58	325	1.39
145	0.6	330	1.41
150	0.62	335	1.43
155	0.64	340	1.46
160	0.67	345	1.49
165	0.7	350	1.51
170	0.71	355	1.54
175	0.74	360	1.57
180	0.76	365	1.6
185	0.78	370	1.63
		375	1.68

APPENDIX- B

Well No. 1

Table B1: Comparison of observed and calculated water table reading during April 2002 to April 2006 from well hydrograph (well-1)

Month	Observed (W.L.)	Computed (W.L.)
April-2002	97.07	96
Nov.-2002	99.04	98.5
April-2003	97.7	97
Nov.-2003	99.25	97.2
April-2004	97.5	94.25
Nov.-2004	92.64	91.82
April-2005	97.4	96.05
Nov.-2005	99	98.31
April-2006	98.2	95.83

Well No. 2

Table B2: Comparison of observed and calculated water table reading during April 2002 to April 2006 from well hydrograph (well-2)

Month	Observed (W.L.)	Computed (W.L.)
April-2002	88.8	88.45
Nov.-2002	91.73	92
April-2003	89.58	89.23
Nov.-2003	91.05	91
April-2004	88.78	88.49
Nov.-2004	91.13	91.10
April-2005	88.98	88
Nov.-2005	91.37	92.19
April-2006	89.11	88.48

APPENDIX - C

Monthly Rainfall and Evaporation Data

Table C-1 Monthly Rainfall (mm) in Priyadarshani Watershed during 1985 to 2006

Year	May	June	July	August	September	October	November	Total
1985	78.5	2027.8	1370.8	1171.1	99	200.2	0	4947.4
1986	0	1103.5	431	827.9	41	0.5	0	2403.9
1987	9	1046.4	612.8	401.6	65	271.6	12.8	2419.2
1988	1	523.4	1422.7	713.7	769.7	14.8	0.2	3445.5
1989	4.6	729.6	1370.4	753	247.6	88	1	3194.2
1990	192.2	997	900	205.1	613	0.6	0	2907.9
1991	0.6	961.6	1975.8	751.2	76.9	1.4	2.4	3769.9
1992	2.2	364	1073.3	1222.1	255	76.1	0	2992.7
1993	1	784.9	1254.4	824	848.1	131.8	3.2	3847.4
1994	12.8	675.2	983.2	555.5	612.6	79.8	0	2919.1
1995	173.2	361.3	1116.1	665.6	753.2	204	0	3273.4
1996	0	417.5	1533.6	619.5	363.4	174.5	4	3112.5
1997	0	995.3	1455.2	853.6	405.5	10.4	68.4	3788.4
1998	10.6	714.6	1388.1	1013.4	395.5	274.6	0	3796.8
1999	166.4	1695.1	1298.8	454.6	441.4	169.9	0	4226.2
2000	214.5	1250.3	1645.5	1315.8	84	109	0	4619.1
2001	80.1	410	876.5	714.4	233.8	61.6	4	2380.4
2002	18.2	980.8	568.1	799.8	278.8	85	0	2730.7
2003	0	957.4	1196.5	597.3	247	6.4	0	3004.6
2004	79.1	1097.6	1093	905.3	322	20.8	0	3517.8
2005	0	672.3	1333	817.6	717.9	110	0	3650.8
2006	151.4	686.2	1248	841.8	444.2	140	0	3511.6
Average	**54.33**	**884.17**	**1188.49**	**773.81**	**377.93**	**101.40**	**4.36**	**3384.52**

Table C-2 Monthly Pan-Evaporation (mm) in Priyadarshini Watershed during 1985 to 2006

	Months									
Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.
1985	126.2	145.5	175.8	192.8	191	30.8	54.8	47.6	102.1	92.8
1986	131.5	123.7	176.3	193.6	218.2	69.3	20	10	110.2	141.5
1987	138.6	148.7	181.3	189.6	214.3	116.4	43	11	64.6	81.4
1988	121.3	133.2	167	173.6	202	92	52.8	80.2	67.7	129.9
1989	115.6	136	148.3	171.7	182.2	62.8	82.9	96.4	92.4	106
1990	118.8	132	135.5	165.8	155.2	85.3	77.4	75.3	113.4	87.5
1991	109.6	125	148.8	155.1	169.4	92.2	50.5	83	116.9	139.6
1992	112.4	136.6	181.4	185.8	192.7	126.7	85.5	72.1	96.7	114.9
1993	105.4	121.3	160.1	167.7	197.6	106.3	45.1	77.5	58.2	80.9
1994	110	120.5	175.2	150.8	180	20.7	74.6	71.2	65.2	109.2
1995	111	116.5	167.8	168.3	173.2	111	35.6	75.5	61	102.2
1996	105.7	110.2	154.4	160.6	187.7	101.6	35.3	41.3	70.4	95.7
1997	116.6	118.2	154.7	175.5	212.2	92	44.9	47.1	80.7	138.2
1998	123.1	121.5	133.6	164.9	180.6	90.4	52.8	89.6	78.8	106.5
1999	108.9	116.9	157.1	152.8	141.5	65.4	53.3	50.4	103.2	131
2000	141.1	161.6	186.7	181.6	155.9	88.3	76.2	76.6	133.9	125.6
2001	96.7	115.6	149	177.8	178.1	99.5	77.5	66.8	88.7	106.5
2002	102.5	132.9	190.4	222.7	216.8	91.8	113.7	79.5	142	179.3
2003	111.3	158.8	199.3	245.9	207.1	80.7	62.2	89.1	96.6	112.8
2004	112.5	124.3	151.2	181.8	166.3	83	86.8	87.8	98.6	141.4
2005	111.6	121	151.1	189.7	228.3	137.8	75.9	89.7	59.9	139.3
2006	126.8	136	175.9	192.1	162.7	96.3	67.5	68.3	107	108.8

ANNEXURE X

(Pl. see rule No. 29 (ii))
Proposal for submission of M. Tech. Thesis

(To be accompanied with the approved copy of synopsis)

(To be neatly filled in or type written by the student and submitted in duplicate to the chairman, advisory committee)

1.	Name in full	Gattani Anand Radhesham
2.	Registration No.	17/2005
3.	Discipline	Agricultural Engineering
4.	Date of joining	05-10-2005
5.	Proposed date of submission of thesis	19-05-2007
6.	Approved thesis title	Simulation of groundwater recharge in Priyadarshani watershed
7.	Total course work assigned (Including additional course work if any assigned at the qualifying examination)	37 credits
8.	Total course work completed (Up to the last semester)	37 credits
9.	Semester in which course work completed / proposed to be completed.	3 rd semester
10.	Cumulative grade point average	7.26
11.	Qualifying examination passed on --	12-01-2007
12.	a. Major field of passed on b. Minor(s)	Soil and Water Conservation Engineering
	Date:	Anand Radheshyam Gattani
13.	Advisory committee 1. Er. S. B. Nandgude 2. Mrs. S. M. Kulkarni 3. Er. M. R. More 4. Er. K. D. Gharde	

		(dilip MAHALE) Chairman Advisory Committee