GROUNDWATER MANAGEMENT BY THE APPLICATION OF SUBSURFACE DYKE AND ITS FUTURE SCENARIO IN CHHATTISGARH USING MODFLOW

A

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Submitted By

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented in this report entitled "**GROUNDWATER MANAGEMENT BY THE APPLICATION OF SUBSURFACE DYKE AND ITS FUTURE SCENARIO IN CHHATTISGARH USING MODFLOW"** in partial fulfillment of the curriculum of final semester of Master of Technology in Hydraulics & Water Resources Engineering, submitted in the Department of Civil Engineering, DTU is an authentic record of my own work under the supervision of **T. Vijay Kumar,** Asst. Professor, Department of Civil Engineering.

I have not submitted this matter for the award of any other degree or diploma.

DATE: PRASANNA SONKAR

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

SUPERVISOR:

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CERTIFICATE

This is to certify that the project report entitled, "**GROUNDWATER MANAGEMENT BY THE APPLICATION OF SUBSURFACE DYKE AND ITS FUTURE SCENARIO IN CHHATTISGARH USING MODFLOW**", is being carried out by **PRASANNA SONKAR, ROLL NO. 2K14/HFE/13** in partial fulfillment for the award of degree of Masters of Technology in Hydraulics &Water Resources Engineering (Department of Civil Engineering, DTU) under my supervision during the year 2015-2016.

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ABSTRACT

Groundwater is a finite resource, which is being overexploited due to increase in demand over the years leading to decrease in its potentiality. This drawdown of groundwater results into agricultural drought in various regions and also there is lack of drinking water in summer season. Thus there is a need of sustainable development and management of groundwater resources, for which Subsurface dyke can be one of the good solutions.

In this study Sub surface dyke are briefly described and detailed information about purpose and outcomes of various subsurface dyke constructed in India and other countries. The use and usefulness of the subsurface dyke as a means of sustainable development, and their management of groundwater resources are been analyzed with the help of two case studies. In the first case study subsurface dyke constructed in Bhavaji nagar, plaghat district, Kerala while in the second one, a hypothetical idealized aquifer for Patan region of Durg district of the Chhattisgarh state is selected. For the performance evaluation, and for the analysis of the impact of the Sub surface dyke on the groundwater behaviour, numerical simulation is opted. For this purpose, a well-known computer software, Visual MODFLOW,a Modular Three-Dimensional Finite Difference Groundwater Flow Model of U.S. Geological Survey,(McDonald and Harbaugh.2012) is used. The input such as depth of aquifer, net recharge, aquifer yield, soil type, and hydraulic conductivity are incorporated in the model. The final output of the graph shows that there is increase in groundwater table after the construction of subsurface dyke, around 80% of the area there was more than 1.5 m rise in the ground water table.

This study produces a very valuable alternative source for ground water table as it reveals a very comprehensive indication of increase in groundwater table. This will help to overcome the problems of groundwater depletion, which helps to provide drinking water in summer and improve drought condition in the state.

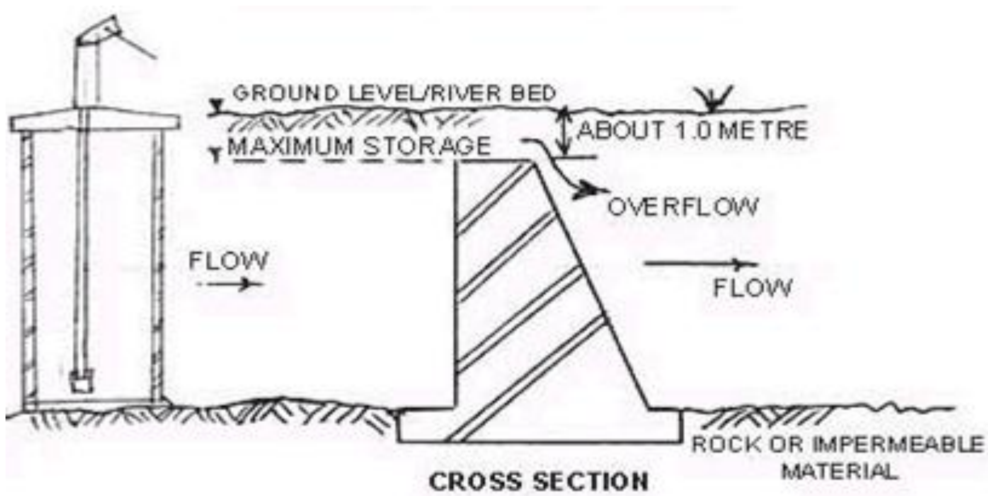
CHAPTER I

INTRODUCTION

1.1 GENERAL

The sustainable development of ground water resources will be one of the key issues in the future. In recent years Chhattisgarh is facing agricultural drought in various parts of the state. There are 117 tehsils declared under drought area in the year 2014-2015. It has been observed that in recent years main focus is on the development of surface water. The need of the thesis is to focus on the sustainable development of both the surface and sub-surface water. There are various techniques for sustainable development and proper management of subsurface water depending upon the geographically and geological area. Subsurface Dyke will be one of the alternative ways of achieving the sustainable development.

In the hydrological cycle groundwater occurs whenever surface water occupies and saturates the pores or interstices of the rocks and soils beneath the earth's surface. The geological formation that are capable of storing and transmitting the subsurface water are known as aquifers.



(Source- Groundwater Dams for Small Scale Water Supply,Nilsson 1988)

Figure 1.1 Typical Sub-Surface Dyke

Subsurface dyke is a structure designed to intercept or obstruct the natural flow of ground water through an aquifer and provide storage for underground water. Subsurface Dyke are intended to be used in regions with arid or tropical climates. Subsurface Dyke is used as small-scale water supply. They cannot be looked upon as universal method for water supply; however they can be treated as alternative solution when conventional methods are not suitable or applicable. By using Subsurface dyke for storing water, instead of conventional methods, the disadvantages of conventional water storage, such as high evaporation rates, pollution, siltation, health hazards may be avoided.

The proper site selection of subsurface dyke necessitates a thorough knowledge of hydrological conditions in the actual area. It is necessary to make generalizations and to use simple geophysical methods. Therefore in a study about Sub Surface dyke it is important to reach simple and useful solutions.

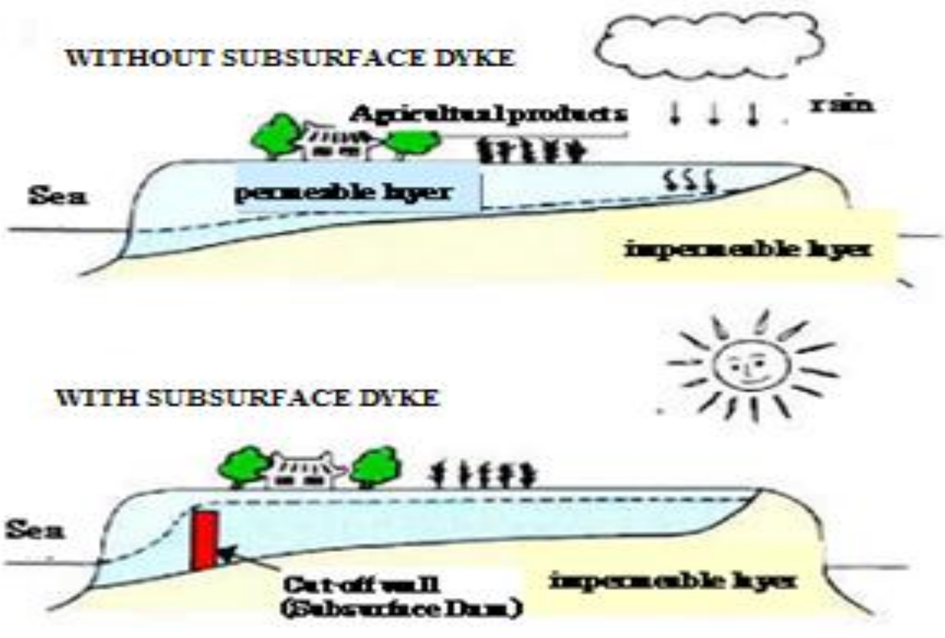


Figure 1.2 Effect Of Subsurface Dam On Groundwater Flow

In this study, since subsurface dyke are not used widespread and there exists few materials about the subjects, information about subsurface dyke especially about how to design and built the dam and other necessary information will be given. After necessary illustration is made about groundwater dams, three cases will be handled using MODFLOW (McDonald and Habaugh,1988). First case will be about a hypothetical idealized aquifer, second case is planned to be a real or almost real aquifer and third case will be proposing a subsurface dyke in patan region of Chhattisgarh. The separate effects of factors such as wells and dam and their combined effects are discussed. The effect of building a subsurface dyke on the variation of water table elevation is to be analyzed using case studies. The actual storage volumes of sub-surface dyke range from a few hundred to several million cubic metres due to difference in design. The effect of subsurface dyke on groundwater flow is given in figure 1.2 .

The design procedure of a sub-surface dyke is that a trench is dug across the suitable part of the valley, which reaches down to bedrock. In the trench an impermeable wall is constructed and the trench is refilled with excavated material. The excavated depths are generally not more than 3-6 m (Nilsson,1988).Sub-surface dyke are generally built at the end of the dry season when there is minimum water in the aquifer. The existing flow has to be pumped out during the construction.

1.2 MATERIAL THAT CAN BE USED FOR CONSTRUCTION OF SUB-SURFACE DYKE

Various construction materials have been used for the impermeable screen such as clay, concrete, stone masonry, reinforced concrete, brick, plastic, tarred-felt, sheets of steel, corrugated iron or PVC (Nilsson, 1988).The subsurface dyke made of clay shown in Figure 1.3(a) is suitable for small schemes in highly permeable aquifers of limited depth, such as sandy riverbeds. The clayey soils are generally available close-by and with low cost can be mined and transported to the site. The clay layers should be compacted. This is usually done by hand using wooden blocks. The risk of erosion damage can be avoided by protecting the dyke with plastic sheets.

A subsurface concrete dyke shown in Figure 1.3(b) is an alternative involving rather more advanced engineering for which skilled labour is needed. It necessitates the use of formwork and the availability of sand and gravel. The stone masonry dyke given in Figure 1.3(c) has the same property with the concrete dyke in labor aspect. The advantage of using reinforced concrete is that very little material, namely steel rods or wire mesh is needed to achieve a very strong wall. But these materials are at reasonable cost and formwork has to be used. The reinforced concrete dyke in Figure 1.3(d) has to be anchored to a solid reservoir bottom. Bricks are generally available or may be manufactured from local clay. It is very simple to build a brick wall and make it watertight. The disadvantages of brick wall are the relatively high cost of bricks and stability problems.

Thin sheets of impermeable materials such as polyethylene is the least expensive choice as far as material cost is concerned. The mounting of sheets to wooden frames and the erection process is rather complicated. A minor rip, that can occur during the erection as well as refilling the trench, will cause leakage losses. If small sheets are joined, to overcome this problem, then the joints may become weak points that may break due to the water pressure. There are also doubts whether plastic material will withstand high groundwater temperatures and the activities of microorganisms in the soil.

Sheets of steel, corrugated iron or PVC can be used to build up an impermeable wall. In construction stages such as the welding of steel sheets skilled labour is needed. However the result is a sturdy and impermeable structure. The crest of a subsurface dam is usually kept at some depth from the surface to avoid water logging in the upstream area and partly to avoid erosion damage to the dam.

The well through which water is extracted may be placed in the reservoir or, for erosion protection reasons, in the riverbank. When aquifers with low permeability are dammed, construction of a series of large-diameter wells or collection chambers may be necessary. By this way a sufficient storage volume for pumping can be created.

It is possible to extract water from the reservoir by gravity if the community to be served by the scheme is located downstream of the dam site. This is managed if the topographical conditions are favourable. By using gravity extraction, problems with pump installation, operation and maintenance are avoided.

Table 1.1 Average Dyke Heights

Dam type	Average height(m)
Brick dyke	6
Concrete dyke	6
Stone masonry dyke	5
Reinforced concrete dyke	4
Clay dyke	3
Plastic sheets dyke	2

Subsurface Dykes

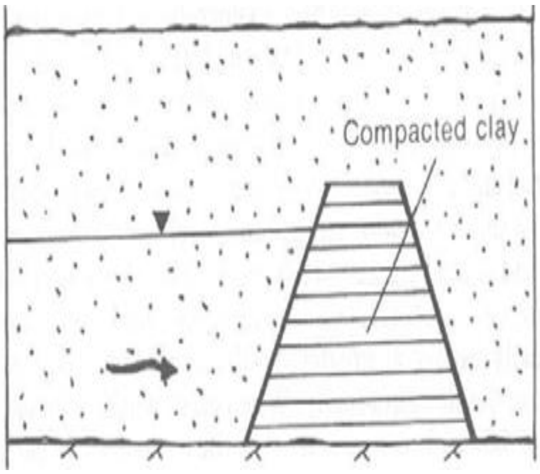


Figure1.3 (a) Clay Dyke

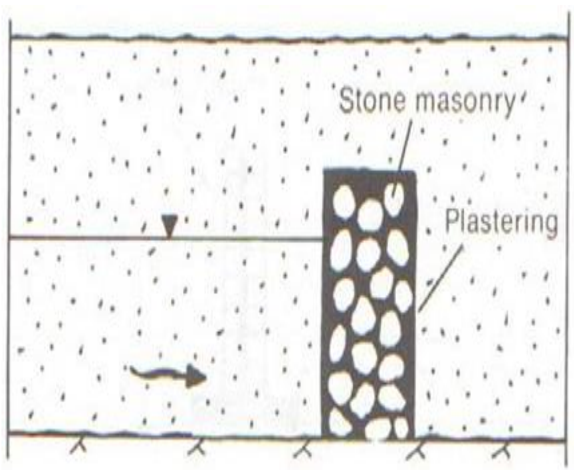


Figure1.3 (c) Stone Masonry Dyke

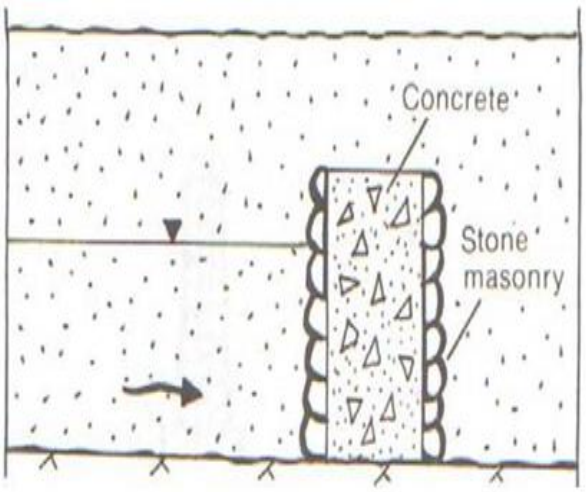


Figure1.3 (b) Concrete Dyke

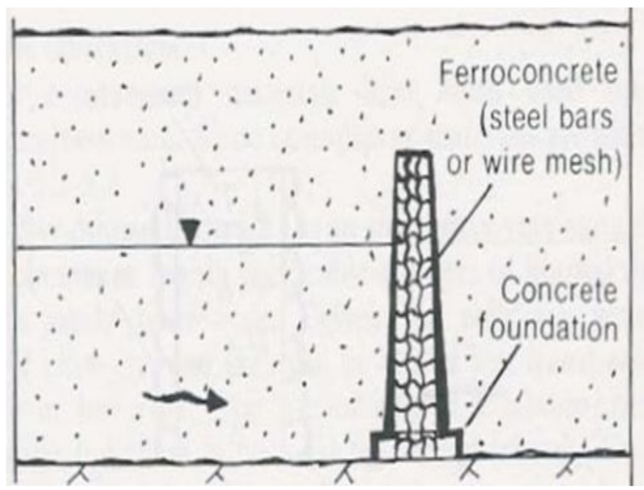


Figure1.3 (d) Reinforced Concrete Dyke

(e)

Figure1.3 (e) Plastic sheets Dyke

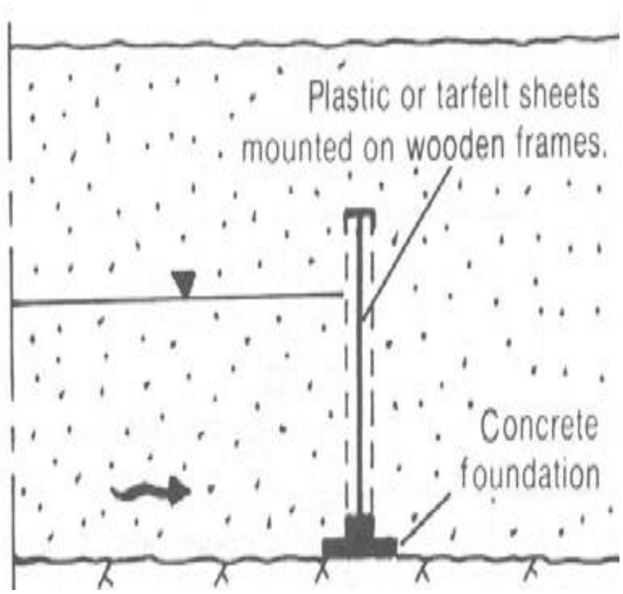


Figure1.3 (e) Plastic sheets Dyke

(Source- Groundwater Dams for Small Scale Water Supply,Nilsson 1988)

1.3 OBJECTIVES

The objectives of this study is as follows :-

1. Literature survey regarding development of subsurface dyke in India and other countries.
2. Application of Visual MODFLOW for computing the water level in already existing sub-surface dyke established at Bhavaji Nagar, Palaghat district Kerala.Validation of water levels with the observed head .
3. Proposal of subsurface dyke at drought prone region of Chhattisgarh State.

1.4 PROLOGUE

This thesis is composed of six chapters.

1. In the second chapter presents Literature Review containing various aspects about subsurface dyke.
2. The third chapter contains the detail description of the study area.

3. In the Fourth chapter tells about the methodology adopted, information for numerical solution and its tool MODFLOW are provided and contains simulations of a real or almost real aquifer and simulation of proposing subsurface dyke in patan region of Chhattisgarh.
4. The different scenarios modeled using MODFLOW in the fourth chapters will give us the opportunity to make comparisons about the results and further discussion about the subsurface dyke in chapters five.
5. In chapter six gives the conclusion on results obtained.

CHAPTER II

REVIEW OF LITERATURE

2.1 GENERAL

This chapter deals with brief review related to various example of Subsurface dyke built all across the world especially in India, necessity of Subsurface Dykefor increase in groundwater table. It gives brief information on the methodology adopted for calculating change in water table.

Various literatures, data were collected and reviewed keeping the prospect and requirement of the study. As the study is mainly focused on design and construction of subsurface dyke, monitoring of ground water level and modeling of aquifer of palghat district(Kerala) and Patan block of Chhattisgarh, information related to observation well locations, various aquifer properties such as conductivity, porosity specific yield and storage of palghat and patan region were used for the calibration and validation in this study.

2.2 SUB-SURFACE DYKE

The first recorded attempt of construction was done in 1907 in Namibia (*Wipplinger,1958*). It was further developed in the Hoanib River and Proposed his 'subsurface dyke'. The economical aspects of subsurface dyke for water conservation have been discussed by *Burger (1970)*. In which it is told that subsurface dyke are built in stages and they are costly in comparison to construction of full height directly. Injected cutoffs have been used to arrest the flow in large and deep-seated aquifer in North Africa and Japan (*Matsuo, 1977)*. In Europe there are several schemes in Germany, France and Italy where sub-surface dyke have been used mostly to raise groundwater levels (*BCEOM, 1978*). A subsurface dyke was constructed to protect fresh water from pollution in Europe (*Ahnfors, 1980*). Sub-surface dyke serving the purpose of containing water in existing aquifers have been constructed in Greece and sub-surface dyke mainly functioning as protection against sea water intrusion into fresh water aquifer have been proposed in Yugoslavia and Greece *(Garagunis, 1981).*Brief information about the design of subsurface dyke using different material and even according to there purpose is explained in *Nissen-Petersen (1982)*.

The book written by *Nilsson (1988)*, called ‘*Groundwater Dams for Small Scale Water Supply*’ presents the results of a literature study combined with studies in Africa and India. Africa is the continent where subsurface dyke are notably used. Several very large sub-surface dyke exist in northwestern Africa, notably in Morocco and Algeria. Subsurface dyke are quite frequently used for water supply in East Africa. There exist sand storage dams in Machakos Regions, Kenya and sub-surface dyke close to Dodoma, Tanzania.

In South America, Brazil is another country where groundwater dams are frequently used. Moreover there is a long tradition of building groundwater dams in the arid southwestern parts of the United States and northern Mexico. Sub-surface dyke called ‘*tapoons*’ have been constructed in sandy riverbeds in Arizona (*Lowdermilk*, *1993*).

The report submitted by *Ministry of theOverseas Environment cooperation Centre(2004)* described about selection of site for sub-surface dyke in already existing fossil valley which was developed in Japan can be applicable to west Africa, in affected regions.

2.3 SUBSURFACE DYKE IN INDIA

First recorded sub-surface dyke have been constructed in kerala, South India; by a private farmer. The private dam was constructed in Ottapalam in 1962-1964,which was successful and inspiring from this result the other dyke was built by the Central Ground Water Board of India. The dyke built by government was completed in 1979. This dyke was constructed across a narrow valley and has a catchment area of about 20 ha. The total length of the dyke is about 160 m and the crest was kept 1 m below the groundwater level to avoid water logging in the upstream area. The main part of the dyke is made up of brick wall but there are sections consisting of tarred felt and plastic sheets. The dyke took three months to complete at a total cost of 3 lakhs.

One third of it was for earthwork and the rest was for equipment and construction materials. The storage volume was estimated at 15000 cubic meters. There are also other sub-surface dyke built in India, namely in Ootacamund in 1981 and by the Minor Irrigation Department in sandy riverbeds in Andhra Pradesh (Hansson and Nilsson, 1986) which was also effectively increased the ground water table area of Ootacamund.

The study of *N. Janardhana Raju(2006)* indicates that consideration of subsurface dams in the Swarnamukhi River basin is feasible and economical by using cheap material like clay and LDPE Film.The water levels increase in the upstream piezometers after construction of the subsurface dams is average 1.44m in the post-monsoon and 1.80m in the pre-monsoon periods. Construction of subsurface dams in the Swarnamukhi River basin increased groundwater storage and thus provided for an increase in land productivity. Watershed management of the basin has improved base flow and improved the storage capacity at subsurface dams and ultimately facilitated the rejuvenation of the river to the extent of becoming a perennial one. The assistance of financial institutions is now very much sought after by the farmers to construct such dams on a co-operative basis.

Routu Balaram(2013) discussed about Somasila reservoir constructed across the Pennar River in YSR District, Andhra Pradesh, India stores over 2 billion cubic metres (BCM) of surface water received from the basin proper and that imported from Krishna River to convey drinking water to Chennai and water for irrigation, drinking and industrial use to downstream stakeholders in Nellore and Chittoor districts. This storage became possible because of constructing a subsurface dam beneath the same reservoir to prevent an equivalent amount of groundwater to remain in the upstream. This incidentally boosted up the groundwater resources of several nearby regions such as the Rajampet area bordered by Cheyyer River in YSR District.

According to *Natarajan (2013)* report a subsurface dyke has been constructed upstream of Vennar at Munar head near Needamangalam for augmentation of groundwater. The dyke, running 140 metres across the river, five metres in width and 4 in depth, is made of nearly 38,000 sand bags arranged in a pyramid like structure and covered by plastic sheet. The dyke will act as a recharge structure. “The imbalance in the demand for water and natural recharge of groundwater in Tiruvarur district.A conservative estimate prepared by TWAD Board officials show net demand for water usage in a particular year is 54.69 tmcft for all purposes, including agriculture in the district. Current natural recharge level is 29.6 tmcft. The imbalance is 25.04 tmcft. Inadequate rainfall, reduction of number of water flow days in rivers, and overexploitation of groundwater for various purposes had caused the depletion of groundwater and intrusion of saline water into first and second aquifers, the In Vennar, there is 4.5 m of sand at the surface level, upon which the surface water flows. Then there is 10 m clay and then comes another thick formation of sand which is the second aquifer. The clay does not allow the surface water flowing in the river to recharge the second aquifer. By constructing the subsurface dyke, we punctured the clay and formed the way for recharging the second aquifer,".Now, the dyke will act as a bed dam at the subsurface level and impound flowing water in the river when water is released and help recharge the second aquifer. Thus, the water will not flow only at the surface level because of the thick clay formation without recharging the second aquifer. The dyke will impound water in an area of about 200 acres of land. In another dimension, it will impound water to a distance of five km upstream of Vennar. It will store 43 million cubic ft of water. The subsurface plastic sheet will not be damaged for 100 years as it is specially prepared and there is no maintenance cost.

*Tamil Naidu Water Supply And Drainage Board (2015)*has given report about the dry Palar riverbed near Palur village now has a new stone structure running across it. It is a dyke built by the Water Resources Department (WRD) to improve the flow of the river.While the river last witnessed floods in 2005 and has not had much flow for many years now, groundwater extraction has grown manifold on the Palar basin. This has meant fast depletion of the water table up to seven metres. Several residents depend on the river for cultivation. The riverbed is between one and 1.5 km wide in Kancheepuram district.The dyke has been laid up to a depth of nine metres beneath the surface level to store nearly 300 million cubic ft of water. The structure, built at a cost of Rs.16.83 crore, will have an impact on several villages, including Reddipalayam, Melachery, Palur, Devanur, Gurumanjeri, Seethanjeri and Arumbuliyur, for a radius of 5 km.

2.4 Visual MOFLOW : A GROUNDWATER MODELLING SOFTWARE

Richard (2002) describes about the importance of groundwater modeling, its use, its feasibility about different types of model, model conceptualization and also it guidance about proper selection of software according to need simulation and has given proper guidance for preparation of modeling report.

Waterloo Hydrogeologic's Visual MODFLOW Manual has provided proper guide through the process of using the software .The manual teaches about designing the model grid and assign properties and boundary conditions, Run the groundwater flow, particle tracking and mass transport simulation, and visualize the result using two- and three- dimensional graphics and animation.

CHAPTER III

STUDY AREA

3.1 INTRODUCTION

As per the literature survey it was found that in India subsurface dyke was built at Palghat district of Kerala State. Palakkad (Palghat) is the land of Palmyrahs and Paddy fields. Palakkad is a major Paddy growing area of the State. It is often called as the "Gateway of Kerala". There is considerable change in the land use and cropping pattern in the district for the last five years. Due to low income from paddy and coconut, farmers are changing the cropping pattern to cash crops like sugarcane, vegetables and flower cultivation. Over dependence on groundwater for domestic, irrigation and industrial purposes in the district has led to the lowering of water table and water scarcity especially along the eastern parts. In most of the areas especially in eastern part of the district decline of water levels necessitates deepening of existing dug wells and putting deep bore wells thereby increasing cost of pumping and quality deterioration. Local enquiry revealed that farmers have taken loan from the banks for putting bore wells and fitting pump sets for irrigation purposes. The district receives on an average 2362 mm of rainfall annually. During 1998 the district recorded a good rainfall of 2407 mm and subsequently the rainfall has been decreased considerably.

3.2 LOCATION

The site that the study is made on is bhavaji nagar, Palghat District Kerala. The investigation area is located between. The study area is located between 10° 32' to 11° 12' latitude north, and between 76° 52' and 76° 06' longitude east. The area is approximately 45 km2. The economy in the region depends upon agriculture, tourism and fishing.

3.3 DRAINAGE AND IRRIGATION

The district is drained mainly by two rivers, viz Bharathapuzha and Bhavani Rivers. Of these Bhavani is east flowing and form a tributary of the Cauvery River. Bharathapuzha basin can be divided into 50 watersheds and 290 mini watersheds. Soil erosion is more in the upstream parts of the basin. Dendritic is the common drainage pattern. 75 % of the population is depending on surface water resources for their irrigation needs, mainly from Bharathapuzha, its tributaries and other water bodies. There are 12 reservoirs in the district associated with two major rivers and its tributaries viz - Parambikulam, Peruvaripallam, Thoonakadavu, Chulliyar, Pothundi, Moolathara, Meenkara, Walayar, Malampuzha, Gayathri, Kanjirapuzha and Mankulam.

There are number of irrigation projects major and minor, existing in the district. The major projects are Malampuzha, Chittoorpuzha, Kuriar Kutty, Karapara, Kanjirapuzha and Attappady Valley Irrigation Project.

The major irrigation schemes are irrigating about 90,000 hectare of land and minor schemes irrigating about 2000 hectares of land. The main crops grown under the irrigation scheme are paddy, coconut, plantain, grams, vegetables etc.

3.4 RAINFALL AND CLIMATE

Based on Thornthwaite's climatic classifications the district experiences humid type of climate. The district receives maximum rainfall during the south west monsoon followed by the north east monsoon. The other months receive considerably less rainfall. The temperature is pleasant from December to February. The annual rainfall varies from 1883 to 3267 mm based on long term normal .The district receives on an average 2362 mm of rainfall annually. Major rainfall is received during June to September in the southwest monsoon (71%). The northeast monsoon contributes about 18%. The western part of the district around Pattambi receives the maximum rainfall whereas in the rain shadow area of Chittur in the eastern part receives the minimum rainfall. The Average monthly rainfall distribution for Palakkad district (2007 to 2011) is given in ANNEXURE.

At Palakkad the maximum temperature ranges from 28.1 to 37.40C whereas the minimum temperature ranges from 22.2 to 25.30C. The average annual maximum temperature is 32.30C and the average annual minimum temperature is 23.40. The wind is predominantly from west and east during morning as well as in the evening hours. The wind speed is high during August (13.6 kmph). The humidity is higher during the monsoon period i.e. from June to September.

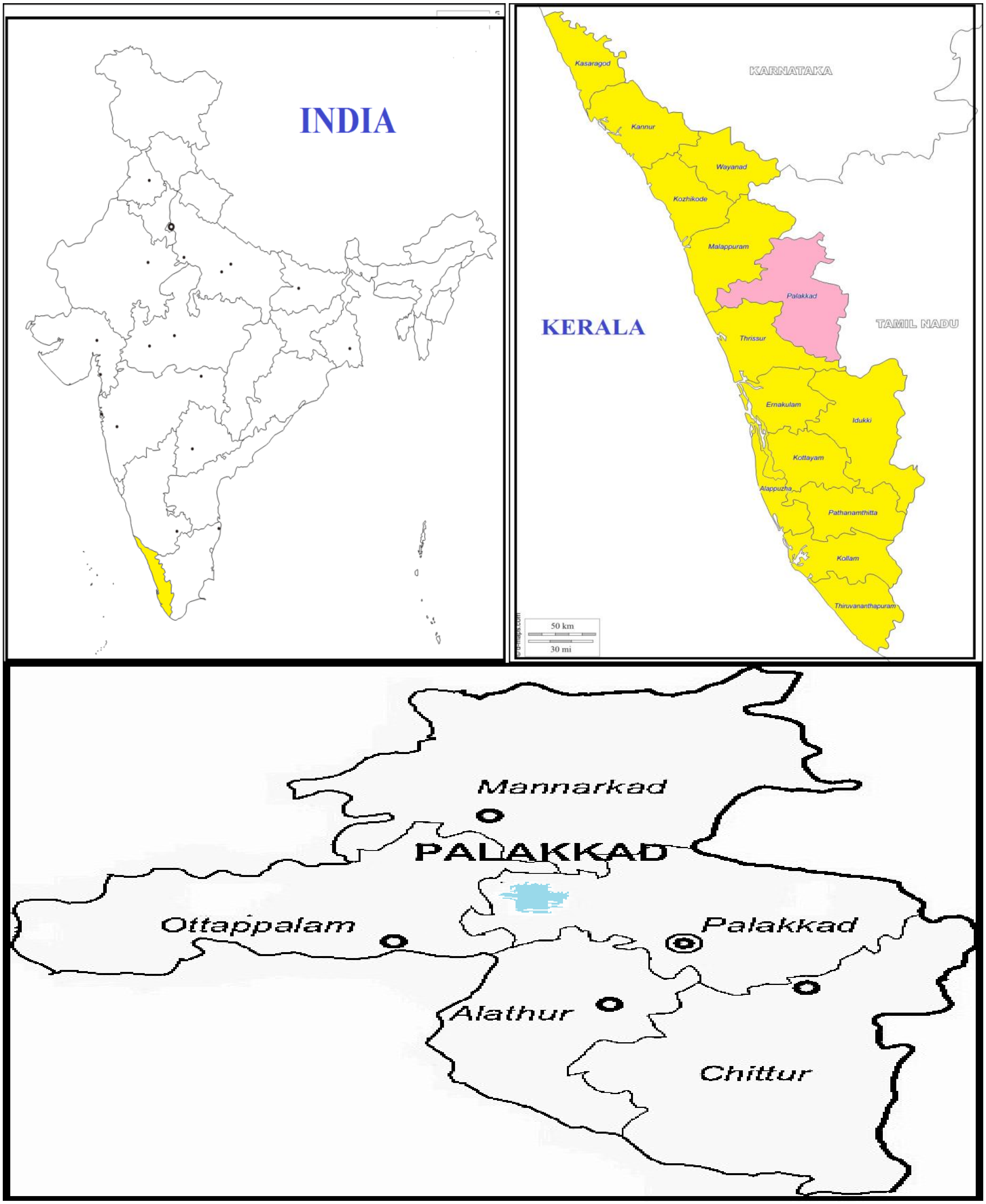


Fig. 3.1 Location map of study area

3.5 GEOMORPHOLOGY AND SOIL

Physiographically the district can be divided into two parts viz, the high land and mid land. Ottapalam taluk lies completely in the mid land region whereas all other taluks lie both in midland and high land regions. The district is not blessed with coastal tract and natural lakes. The elevation of the landforms varies from 20 to 2386 m form msl.

The most important physiographic feature of the district is the Palakkad Gap. The train and road link between Kerala and rest of the country mainly passes through the 32 - 40 km wide gap. The important peaks are Anginda (2386 m), Padagiri (1585 m) and Karimala Gopuram (1440 m). The Terrain units and their areal distribution in % is given in Table 3.1

Table 3.1: Terrain units in Palakkad District Area %

Low lying terrain including flood plain and terrace	27
Moderately undulating mid land terrain with flood plain	26
Highly undulating terrain	12
Hilly area including scrap slope	35

3.6 SOIL TYPES

There are four types of soil

(1) Laterite soil

(2) Virgin forest soil

(3) Black cotton soil

(4) Alluvial soil

(1) Laterite soil - Seen in major part of Ottappalam, Alathur, Chittur and Palakkad taluks. These are most predominant soil type in the midland and gap areas. Laterites on high grounds are more compact when compared to the low lying areas.

(2) Virgin Forest Soil - Seen in Mannarkad taluk and in forest areas. They are rich in humus and organic matter.

(3) Black Cotton Soil - Seen in Chittur and Attapady Valley of the Mannarkad Taluk, which is used for the cultivation of cotton. They exhibit mud cracks and have high water retaining power.

(4) Alluvial soils are found along the banks of Bharathapuzha and its tributaries. In the Valley portion Valley fill deposits composed of talus and scree material are observed.

3.7 GROUNDWATER SCENARIO

Palakkad district is underlain by rocks of Archaean metamorphic complex. They include the granulite group, the gneisses and the schist's above which laterite and alluvium are observed. Intrusive of pegmatite and quartz veins are also common in the northeastern parts of the district.

Groundwater occurs in all the geological formation from Archaean crystallines (hard rock) to Recent alluvium (soft rock). Groundwater occurs in phreatic condition in the laterite, alluvium and weathered crystalline. It is in semi confined to confined condition in the deep fractured rocks. Hydrogeology the entire district can be divided into three units based on hydro geological information.

1) Valley fills/Alluvium 2) Laterite terrain and 3) Crystallines.

Valley fills are noticed along the valley portion and along the river terraces/banks (near Ottapalam, Pattambi area) and are shown in the hydrogeological map. These are mainly seen in Mannarghat, Ottapalam and Pattambi, Trithala blocks. The water level ranges from 2- 11 m bgl (pre monsoon) and 1- 9 m bgl (post monsoon). The fluctuation is generally high up to 4 m. The yield of dug well ranges from 5 to 20 m3/ day.

The laterite province is limited in extent, noticed in Trithala, Ottapalam and Pattambi blocks. The water level ranges from 4 to 11.0 mbgl during pre monsoon and post monsoon water level ranges from 3 to 8 mbgl. The fluctuation between pre and post monsoon varies between 2 to 4 m.

The yield ranges from 5 to 30 m3/ day. In these areas the extraction is less. The specific capacity ranges from 10- 125 l/min/mdd. The hard rock province covers 80 % of the area. This province can be divided into further zones based on weathering characteristics. The blocks covered under crystallines are Chittur, Kollenkode, Nenmara, Palghat, Attapady, Sreekrishnapuram, Alathur, Kuzhalmannam, and Mannarghat. Overall groundwater regime is shown in the hydrogeological map of the district. In the northern part of the area, the high land region (Attapady block), groundwater occurs in semi confined to unconfined condition in the crystalline rocks. The depth of the water level ranges from 5 to10 m bgl. In these areas (Zone A) borewells are feasible along the fractures/lineaments. Exploratory studies of CGWB have revealed that the yield of bore wells ranges from 0.5 to 36 lps (Naduvattom PZ). Restricted development through bore well is possible in this area. The depth of weathering is more in the area and ranges from10 to 23 m bgl. Hence proper casing is required for bore wells. Dug wells are feasible along the valley portions and adjoining rivers/ river lets. The yield varies from 5 to 25 m3/ day. In this zone the fractures are encountered within 170m. Hence the depth of bore wells can be restricted to 20.

Along the middle portion (Zone B) of the district which includes the Palakkad gap (Malampuzha, Palghat, Kuzhalmannom blocks etc), the thickness of weathering is more than 10 m The major hard rock aquifer is hornblende biotite gneiss. The yield ranges from 2 to 30 lps. The water level in bore wells of the region is going down considerably. For example the Bore well constructed at Velamthavalam during 1990 recorded a static water level of 3.89 m bgl and the water level in the bore well drilled close by during 2002 is 64.40 m bgl. The yield of bore well in this zone is site specific. Along the E-W and NW-SE fractures, the bore wells are better yielding. Scientific site location is required in the region before constructing bore wells. Common abstraction structures feasible in the area are dug well, dug cum bore well and bore well. The yielding fracture zones, in general, are encountered generally within 125m and in exceptional cases up to 175m. Now the farmers are constructing bore wells having a depth of more than 300m. In general high yielding fractures are rare beyond a depth of 200m. Hence farmers need not go beyond 200 m depth for their bore wells. The dug well yield ranges from 5 to 30 m3/ day. But most of the dug wells are getting dry during summer season.

In the eastern parts of the district, ie Chittur and Kollenkode blocks, the weathered thickness is less than 10 m (Zone C), and the topsoil thickness is also less. The exploration of CGWB has revealed that the bore wells can yield up to 24 lps. The well drilled at Nellipallam yielded 24 lps and the fracture encountered at 108 m bgl. The major fracture in the E-W direction is highly yielding. The high yielding fractures are getting recharged from a distant source. The piezometers constructed in Chittur block yielded more than 16 lps and the fractures were encountered at depth of 80 to 100 m. In general high yielding fractures are encountered between 80 and 130 m bgl. The yield varies from place to place. Hence detailed geophysical investigation is required in this area for site selection of bore wells. Here also farmers are drilling deep bore wells having depth of more than 200m. The maximum recommended depth of bore well is 200m. The main feature noticed in the area is overdraft of groundwater. This area is a rain shadow region compared to the rest of the region due to which groundwater recharge is comparatively less. This is a potential zone for bore wells. The industrial draft and irrigation draft through borewells is more. Most of the borewells are in the private sector. In this zone the quality of the groundwater is also poor in some pockets. Areas like Nedupeni, Kuduvayoor and Kozhinjampara, Gopalapuram inland salinity is observed within the phreatic zone. Fluoride content is more in groundwater samples of both bore wells and dug wells in Chittoor and Attapadi blocks. The highest fluoride content up to 5.74 ppm is reported from Kopanur area. The other places affected are Kozhinjampara, Eruthenpathi, Chinnammolathara, RVP Pudur and Chittur town. Taking into account of all these factors, further groundwater development is not recommended in the zone.

The pre to post monsoon (April – Nov 2011) fluctuation in the district varies from place to place. The fluctuation varies from 2 to 4 m bgl and the maximum fluctuation is noticed in the eastern part of the district. In the central and western part the fluctuation ranges from 2- 3 m. Long term trend of premonsoon and post monsoon water level, between 2002 and 2011 is analysed. In the eastern side of the district around Chittur area (Chittur block), the water levels for the Premonsoon Period is showing a significant declining trend. Rest of the areas, the water level decline is less. The depth to water level maps (pre and post monsoons) are shown in Figures 3.2, 3.3 respectively.

3.8 STATUS OF GROUNDWATER DEVELOPMENT AND MANAGEMENT

The stage of groundwater development in the district during 2009 is 60.88 % leaving scope for future development. But there is a spurt in the development over the last 5 years (i.e the development was 43.67 % during 2004). The groundwater development in the Chittur block is found to be more and the ground water levels are showing a significant decline.

During 2002-2004 this block was declared as drought affected. Hence future development may be restricted in this block. Groundwater based multinational companies are operating in this district compared to other districts of the State. Proper care should be taken before sanctioning any schemes in the district as a whole and especially in Chittur and Thrithala blocks large scale development shall be restricted. Since number of abstraction structures including private bore wells is on the increasing trend without any proper record, proper census of the abstraction structures is necessary for recommending new structures for future development.

There are about four urban water supply schemes and 154 rural water supply schemes available in the district. In addition about 1250 bore wells are operating which were drilled under Technology Mission. Majority of the water supply schemes are maintained by Kerala Water Authority and local bodies. About 52% of the population is getting water from these water supply schemes. But water supply schemes are not equally distributed on all parts of district and all are not need based. Most of the rural water supply schemes use groundwater as the source whereas the urban schemes depend on surface water or both. Rest of the population (48%) is depending on groundwater by their own dug wells and bore wells. In this district 10971 public taps and 37276 domestic connections are supplying water to people as per the 1998 statistics.

Groundwater is used for irrigation through dug wells, dug-cum bore wells and bore wells. The dug wells located along the valleys of midland and hilly area and the bore wells located along the fractures and lineaments are yielding more water during summer months. Coconut, banana, sugarcane and vegetables are being irrigated using groundwater during summer months. About 40 companies are operating in Kanjikode and Chittur area, which are extracting groundwater heavily for industrial needs. Hence this district records highest industrial and irrigation draft in the State.

Recently there is a tendency for the farmers to go in for bore wells in place of dug wells. Due to this the thickness of the unsaturated zone has increased

Based on the studies the following areas are identified as water scarce areas and these areas need special attention. Groundwater in the district is mostly developed through dug wells and bore wells for domestic, agricultural and for industrial needs. A good percentage of the households in the district have their own drinking water wells. Recently the bore well culture has picked up and gained momentum in the district. In the crystalline terrain the groundwater is developed through dug wells, dug cum bore wells and bore wells. Along the valley fills and laterite terrain groundwater is developed through dug wells.

Groundwater development and management should be coupled with rainwater and surface water. More stress should be given for watershed management which will help in conserving the groundwater and supplementing the recharge.

The existing water resources and dug wells, ponds, streams, should be cleaned, protected and conserved. Rainwater harvesting and artificial recharge schemes should be practiced in the district. Conjunctive use of surface and groundwater shall be practiced effectivelyMass awareness programmes should be organised in Panchayat level to make awareness among people about the importance of conservation of this precious resource, especially in Pattambi, Attapady, Palakkad, Thrithala and Kollenkode blocks. Stress should be given for integrated water shed management and conjunctive use in the district. A comprehensive artificial recharge report has to be prepared for this district for a better water management.

The number of groundwater abstraction structures that can be constructed for 70% development of the resource is expected to be around 26,700 and for 90% development about 34300 structures can be constructed. However, no abstraction structures are recommended in the district without a feasibility study, as most of the blocks are water scarse areas. The census figures presently available about the abstraction structures are not matching with the ground reality. In Chittur block the wells are getting dry during summer season. Any sort of abstraction structures should be constructed with proper site selection and technical support from CGWB and GWD or reputed agencies.

More stress should be given for watershed development through which better groundwater management can be achieved. The existing water resources and dug wells, ponds, streams, should be cleaned, protected and conserved. Rainwater harvesting and artificial recharge schemes should be practiced in the district.

It has also been observed that the existing surface water structures like ponds, tanks and cultivable land, irrigated canal are being encroached for settlement purposes which reduce natural recharge. And also roof top rain water harvesting is to be implemented wherever fluoride is higher than the permissible limit in two panchayats.

In Kollenkode block, 5 panchayats need AR schemes separately. 5 sub surface dykes and 10 ponds from each panchayats have to be cleaned and 6 roof top harvesting with recharge facilities are suggested. 4 Bore well recharge scheme is required.

In Palghat block 6 numbers of gully plug and 3 sub surface dykes are required. In Trithala Block, two sub surface dyke and 4 rain water harvesting schemes required. Sand mining and water level decline has to be checked. Roof top Rain water harvesting with recharges facility is required in all blocks. No additional structures are recommended in the district. Though majority of the block are safe, a declining trend in water level trend is noticed. Most of the ground water is going as base flow.

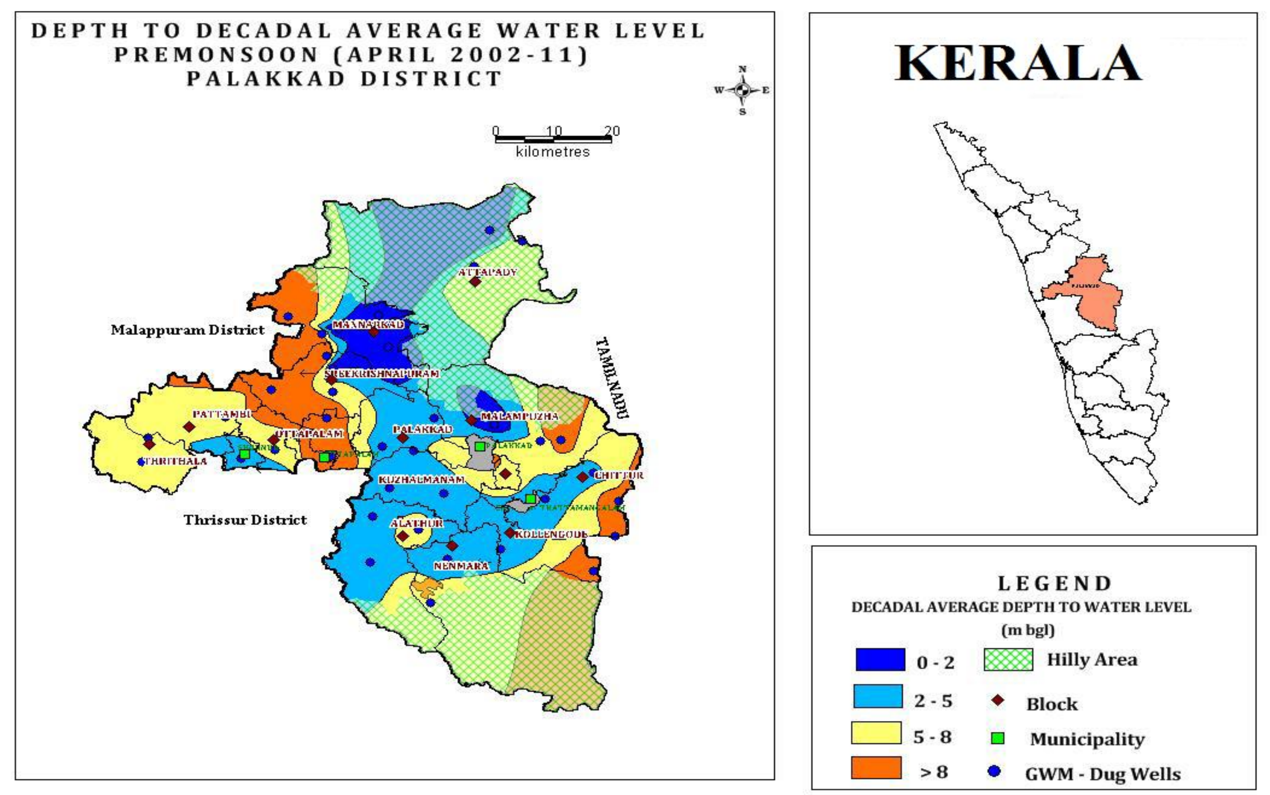


Figure. 3.2 Depth to Decadal Average Water Level (Premonsoon April 2002-11)

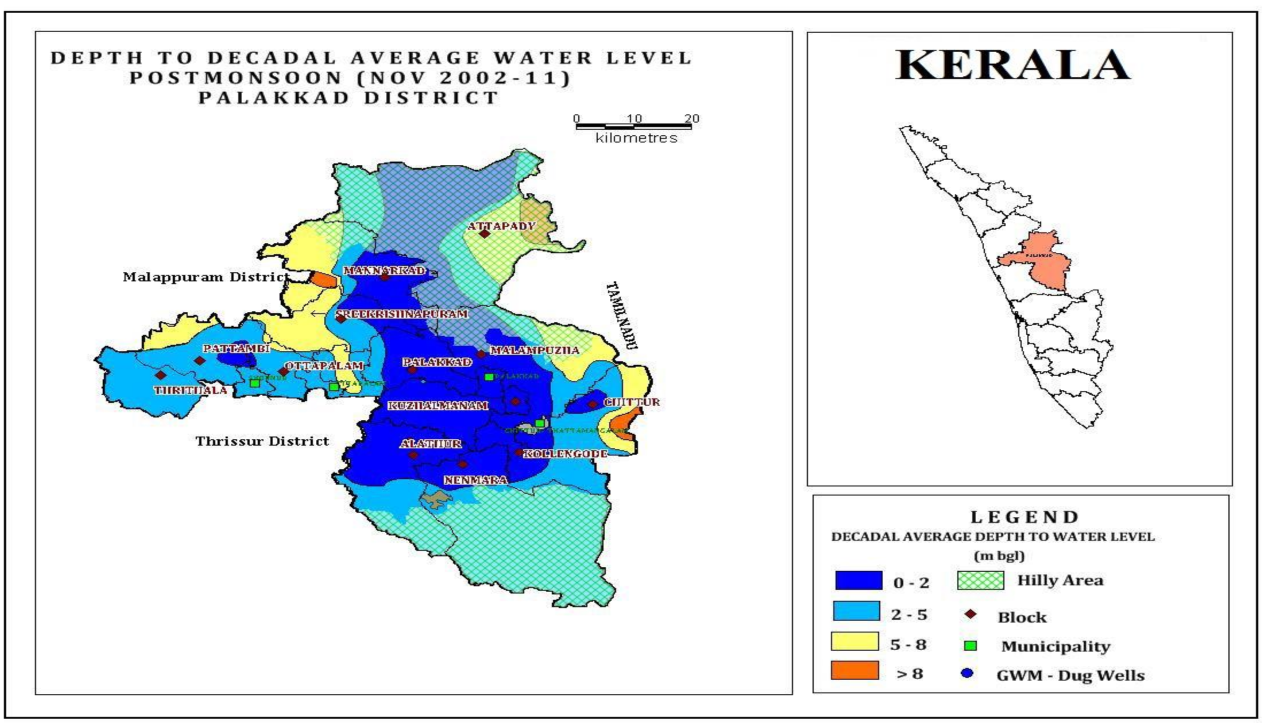


Figure. 3.3 Depth to Decadal Average Water Level (Postmonsoon April 2002-11)

CHAPTER IV

METHODOLOGY

4.1 GENERAL

Methodology adopted for the study is explained in this chapter. The use of groundwater flow models is prevalent in the field of environmental hydrogeology. Models have been applied to investigate a wide variety of hydro geological conditions. More recently, groundwater models have been applied to predict the groundwater flow and level of water for risk evaluation purposes.

This study is intended to assist staff in the evaluation of work plans that propose to use groundwater models, and to assist staff in the evaluation of models that have been developed for remedial design, feasibility studies, development of performance monitoring networks, or for risk assessment. Groundwater flow models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface. Transport models require the development of a calibrated groundwater flow model or, at a minimum, an accurate determination of the velocity and direction of groundwater flow that has been based on field data. An overview of brief description of Visual MODFLOW Flex-2012, important features, application of MODFLOW in preparing model of aquifer using input as well data and other properties of the aquifer.

4.2 GROUNDWATER MODELS

In general, models are conceptual descriptions or approximations that describe physical systems using mathematical equations—they are not exact descriptions of physical systems or processes. The applicability or usefulness of a model depends on how closely the mathematical equations approximate the physical system being modelled. In order to evaluate the applicability or usefulness of a model, it is necessary to have a thorough understanding of the physical system and of the assumptions embedded in the derivation of the mathematical equations. A detailed discussion of the assumptions and derivations of the equations that are the basis of different groundwater models is beyond the objective of this thesis.

Groundwater models describe groundwater flow and transport processes using mathematical equations that are based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer. Because of the simplifying assumptions embedded in the mathematical equations and the many uncertainties in the values of data required by the model, a model must be viewed as an approximation and not an exact duplication of field conditions. Groundwater models, however, even as approximations are a useful investigation tool that groundwater hydrologists may use for a number of applications. Among these are:

1. Prediction of the possible fate and migration of contaminants for risk evaluation.
2. Tracking the possible migration pathway of groundwater contamination.
3. Evaluation of design of hydraulic containment and pump-and-treat systems.
4. Design of groundwater monitoring networks.
5. Wellhead protection area delineation.
6. Evaluation of regional groundwater resources.
7. Prediction of the effect of future groundwater withdrawals on groundwater levels.

It is important to understand general aspects of both groundwater flow and transport models to ensure that application or evaluation of these models may be performed correctly.

The equations that describe the groundwater flow and transport processes may be solved using different types of models. Some models may be exact solutions to equations that describe very simple flow or transport conditions (**analytical model**) and others may be approximations of equations that describe very complex conditions **(numerical model)**. Each model may also simulate one or more of the processes that govern groundwater flow or contaminant migration rather than all of the flow and transport processes. As an example, particle-tracking models, such as MODPATH, simulate the advective transport of contaminants but do not account for other fate and transport processes. In selecting a model for use at a site, it is necessary to determine whether the model equations account for the key processes occurring at the site. Each model,whether it is a simple analytical model or a complex numerical model, may have applicability and usefulness in hydro geological and remedial investigations.

4.2.1 ANALYTICAL MODELS

Analytical models are an exact solution of a specific, often greatly simplified, groundwater flow or transport equation. The equation is a simplification of more complex three-dimensional groundwater flow or solute transport equations. Prior to the development and widespread use of computers, there was a need to simplify the three-dimensional equations because it was not possible to easily solve these equation.

Specifically, these simplifications resulted in reducing the groundwater flow to one dimension and the solute transport equation to one or two dimensions. This resulted in changes to the model equations that include one-dimensional uniform groundwater flow, simple uniform aquifer geometry, **homogeneous** and isotropic aquifers, uniform hydraulic and chemical reaction properties, and simple flow or chemical reaction boundaries. Analytical models are typically steady-state and one-dimensional, although selected groundwater flow models are two dimensional (e.g. analytical element models), and some **contaminanttransport model**s assume one-dimensional groundwater flow conditions and one-, two- or three dimensional
transport conditions.

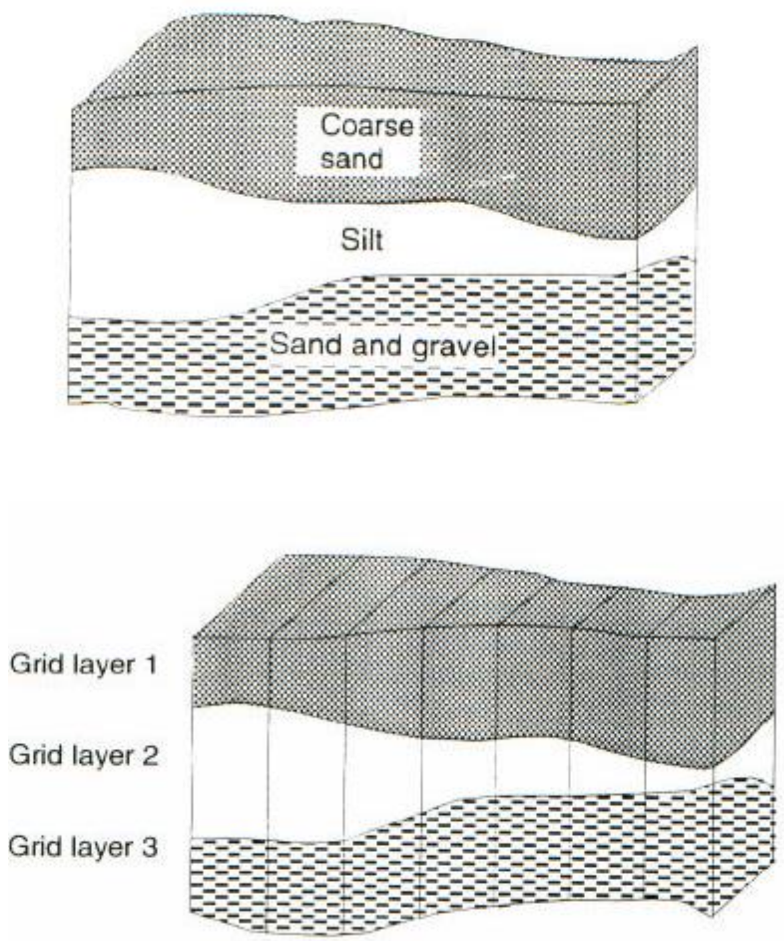
Because of the simplifications inherent with analytical models, it is not possible to account for field conditions that change with time or space. This includes variations in groundwater flow rate or direction, variations in hydraulic or chemical reaction properties, changing hydraulic stresses, or complex hydro geological or chemical boundary conditions.

Analytical models are best used for:

1. Initial site assessments where a high degree of accuracy is not needed,
2. Designing data collection plans prior to beginning field activities,
   An independent check of numerical model simulation results, or
3. Sites where field conditions support the simplifying assumptions embedded in the analytical models.

4.2.2 NUMERICAL MODELS

Numerical models are capable of solving the more complex equations that describe groundwater flow and solute transport. These equations generally describe multi-dimensional groundwater flow, solute transport and chemical reactions, although there are one-dimensional numerical models. Numerical models use approximations (e.g. **finite differences**, **or finite elements**) to solve the differential equations describing groundwater flow or solute transport. The approximations require that the model domain and time be digitized. In this **digitization** process, the model domain is represented by a network of grid **cells** or elements, and the time of the simulation is represented by time steps.An example of representing a multi-layered aquifer system in a numerical model is shown in Figure 4.1.



(Source:- Groundwater Modelling Program, Richard J. Mandle,2002)

Figure 4.1 Digitization Of Complex Hydro Geological Condition By A Numerical Model

The accuracy of numerical models depends upon the accuracy of the model input data, the size of the space and time digitization (the greater the size of the digitization steps, the greater the possible error), and the numerical method used to solve the model equations.

Unlike analytical models, numerical models have the capability of representing a complex multi-layered hydro geological framework. This is accomplished by dividing the framework into discrete cells or elements

In addition to complex three-dimensional groundwater flow and solute transport problems, numerical models may be used to simulate very simple flow and transport conditions, which may just as easily be simulated using an analytical model. However, numerical models are generally used to simulate problems which cannot be accurately described using analytical models.

4.3 GROUNDWATER FLOW MODELS

Groundwater flow models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface. These calculations are referred to as simulations. The simulation of groundwater flow requires a thorough understanding of the hydro geological characteristics of the site. The hydro geological investigation should include a complete characterization of the following:

1. Subsurface extent and thickness of aquifers and confining units (hydro geological framework).
2. Hydrologic boundaries (also referred to as boundary conditions), which control the rate and direction of movement of groundwater.
3. Hydraulic properties of the aquifers and confining units.
4. A description of the horizontal and vertical distribution of hydraulic head throughout the modelled area for beginning (initial conditions), equilibrium (steady-state conditions) and transitional conditions when hydraulic head may vary with time (transient conditions).

5. Distribution and magnitude of groundwater recharge, pumping or injection of groundwater, leakage to or from surface-water bodies, etc. (sources or sinks, also referred to as stresses). These stresses may be constant (unvarying with time) or may change with time (transient).

The outputs from the model simulations are the hydraulic heads and groundwater flow rates which are in equilibrium with the hydro geological conditions (hydro geological framework, hydrologic boundaries, initial and transient conditions, hydraulic properties, and sources or sinks) defined for the modeled area. **Figure 4.2** shows the simulated flow field for a hypothetical site at which pumping from a well creates changes in the groundwater flow field.

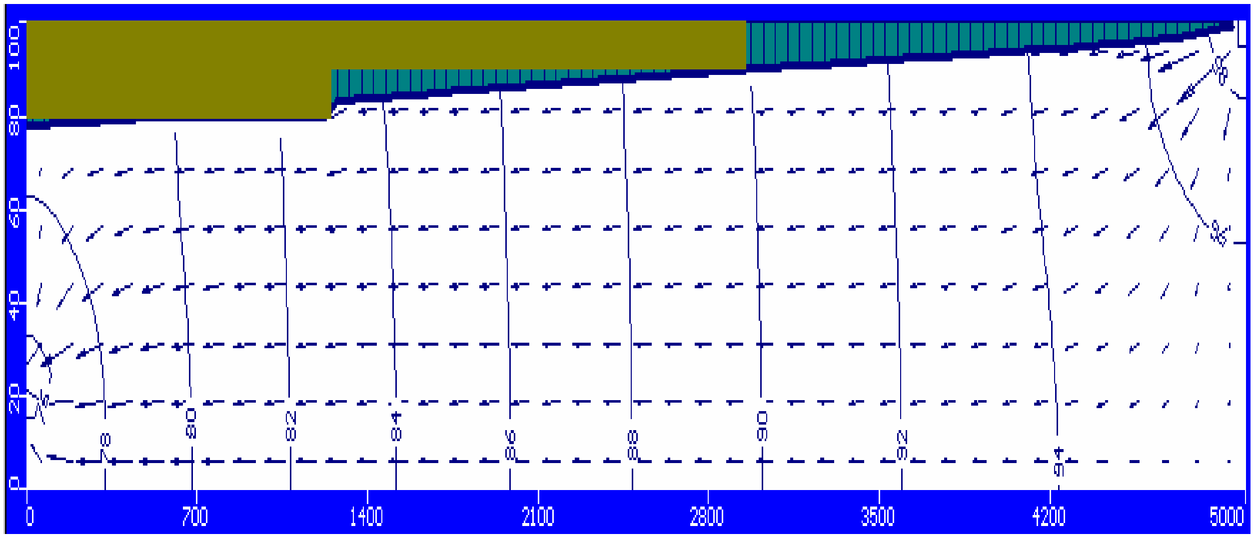


Figure 4.2 Simulated Flow Field For A Hypothetical Site

Through the process of model calibration and verification, which is discussed in later sections of this chapter, the values of the different hydro geological conditions are varied to reduce any disparity between the model simulations and field data, and to improve the accuracy of the model. The model can also be used to simulate possible future changes to hydraulic head or groundwater flow rates as a result of future changes in stresses on the aquifer system.

4.4 GROUNDWATER MODEL DEVELOPMENT PROCESS

4.4.1 Hydro Geological Characterization

Proper characterization of the hydro geological conditions at a site is necessary in order to understand the importance of relevant flow processes. With the increase in the attempted application of natural attenuation as a remedial action, it is imperative that a thorough site characterization be completed. This level of characterization requires more site-specific fieldwork than just an initial assessment, including more monitoring wells, groundwater samples, and an increase in the number of laboratory analyses and field parameters. Without proper site characterization, it is not possible to select an appropriate model or develop a reliably calibrated model. At a minimum, the following hydro geological information must be available for this characterization:

1. Regional geologic data depicting subsurface geology.
2. Topographic data (including surface-water elevations)
3. Presence of surface-water bodies and measured stream-discharge (base flow) data
4. Geologic cross sections drawn from soil borings and well logs.
5. Well construction diagrams and soil boring logs.
6. Measured hydraulic-head data.
7. Estimates of hydraulic conductivity derived from aquifer and/or slug test data.
8. Location and estimated flow rate of groundwater sources and sinks.

4.4.2 Model Conceptualization

Model conceptualization is the process in which data describing field conditions are assembled in a systematic way to describe groundwater flow and contaminant transport processes at a site. The model conceptualization aids in determining the modeling approach and which model software to use.

Process to be followed in developing a **conceptual model** include,

1. Defining of adequate data to describe the hydro geological conditions at the site.
2. Checking many directions is groundwater moving defining the groundwater flow to be characterized as one-, two- or three dimensional.

3. Study of aquifer system composed of more than one aquifer, and is vertical flow between aquifers important.
4. Value of recharge to the aquifer by precipitation or leakage from a river, drain, lake, or infiltration pond.
5. Check for groundwater leaving the aquifer by seepage to a river or lake, flow to a drain, or extraction by a well
6. Defining the aquifer's hydrogeological characteristics remain relatively uniform.
7. Defining the boundary conditions been defined around the perimeter of the model domain.
8. Checking groundwater-flow conditions remain constant, or do they change with time.

4.4.3 Model Calibration

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. This requires that field conditions at a site be properly characterized. Lack of proper site characterization may result in a model that is calibrated to a set of conditions which are not representative of actual field conditions. The calibration process typically involves calibrating to steady-state and transient conditions. With steady-state simulations, there are no observed changes in hydraulic head or contaminant concentration with time for the field conditions being modeled. Transient simulations involve the change in hydraulic head or contaminant concentration withtime (e.g. aquifer test, an aquifer stressed by a well-field). These simulations are needed to narrow the range of variability in model input data since there are numerous choices of model input data values which may result in similar steady-state simulations. Models may be calibrated without simulating steady-state flow conditions, but not without some difficulty.

At a minimum, model calibration should include comparisons between model-simulated conditions and field conditions for the following data:

1. Hydraulic head data,
2. Groundwater-flow direction,
3. Hydraulic-head gradient,
4. Water mass balance.

These comparisons should be presented in maps, tables, or graphs. In an example, the closer the heads fall on the straight line, the better the “goodness-of-fit”. Each modeler and model reviewer will need to use their professional judgment in evaluating the calibration results. There are no universally accepted “goodness-of-fit” criteria that apply in all cases. However, it is important that the modular make every attempt to minimize the difference between model simulations and measured field conditions. Typically, the difference between simulated and actual field conditions (residual) should be less than 10 percent of the variability in the field data across the model domain. A plot showing residuals at monitoring wells (calibration targets) is shown in Figure 4.3. A plot in this format is useful to show the “goodness-of-fit” at individual wells.

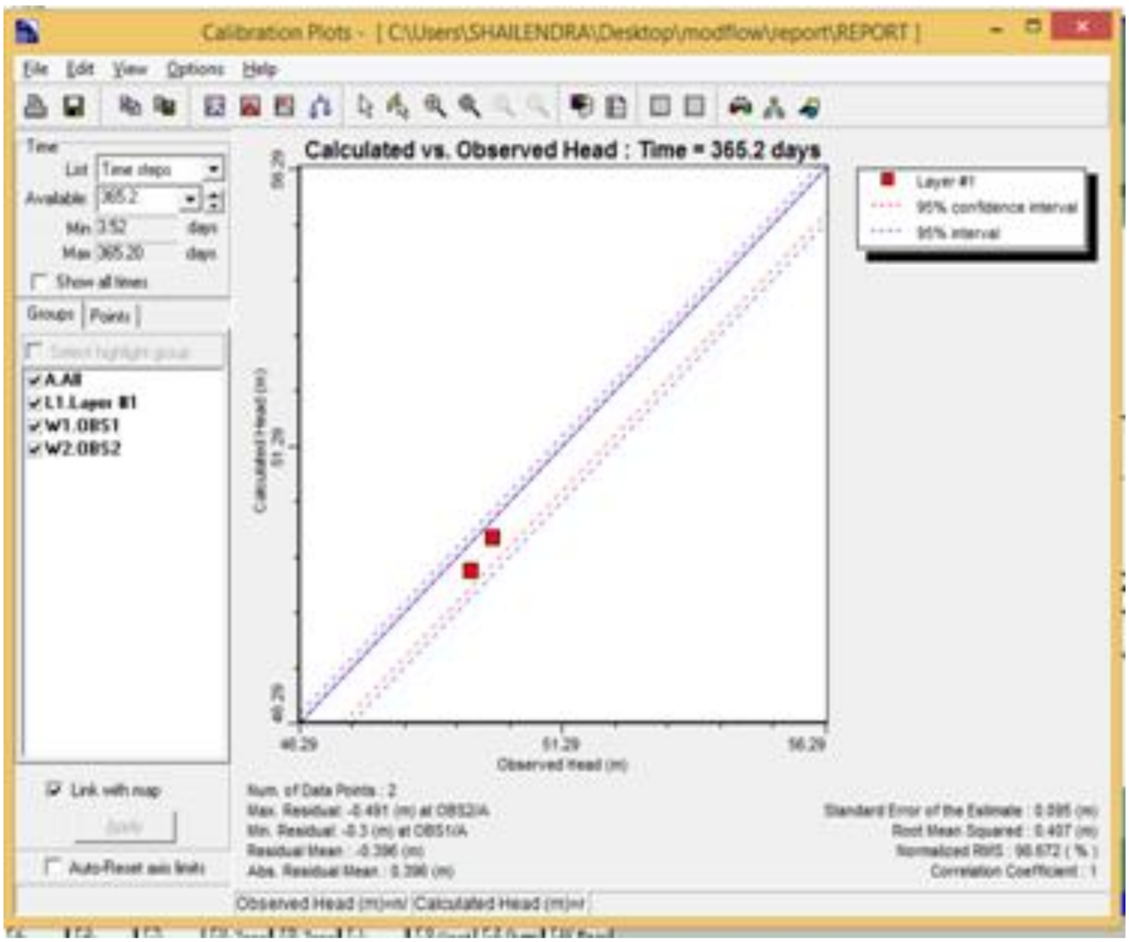


Figure 4.3 Residual From Comparison Of Measured And Computed Heads At Calibration Target

The modeller should also avoid the temptation of adjusting model input data on a scale which is smaller than the distribution of field data. This process, referred to as "over calibration", results in a model that appears to be calibrated but has been based on a dataset that is not supported by field data.

For initial assessments, it is possible to obtain useful results from models that are not calibrated. The application of un calibrated models can be very useful in guiding data collection activities for hydro geological investigations or as a screening tool in evaluating the relative effectiveness of remedial action alternatives.

4.4.4 Model Validation

A calibrated model uses selected values of hydro geological parameters, sources and sinks and boundary conditions to match field conditions for selected calibration time periods (either steady-state or transient). However, the choice of the parameter values and boundary conditions used in the calibrated model is not unique, and other combinations of parameter values and boundary conditions may give very similar model results. This process has been referred to by others as "**modelverification**" or "**modelvalidation**" .

The most common history matching scenario consists of reproducing an observed change in the hydraulic head over a different time period, typically one that follows the calibration time period . The best scenarios for model verification are ones that use the calibrated model to simulate the aquifer under stressed conditions. The process of model verification may result in the need for further calibration refinement of the model. After the model has successfully reproduced measured changes in field conditions for both the calibration and history matching time periods, it is ready for predictive simulations.

4.4.5 Predictive Simulations Or Evaluation Of Remediation Alternatives

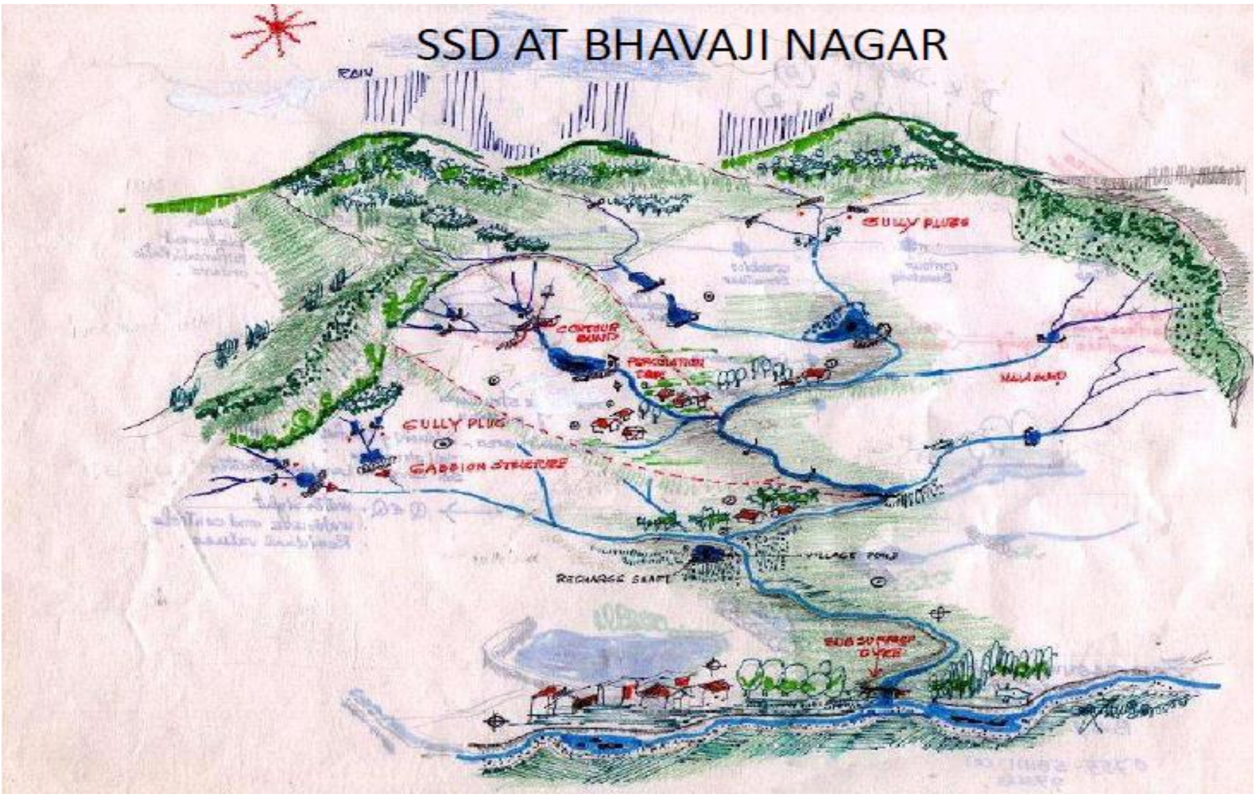
A model may be used to predict some future groundwater flow or contaminant transport condition. The model may also be used to evaluate different remediation alternatives, such as pump-and-treat or natural attenuation, and to assist with risk evaluation. In order to perform these tasks, the model, whether it is a groundwater flow model, must be reasonably accurate, as demonstrated during the model calibration process. However, because even a well-calibrated model is based on insufficient data or oversimplifications, there are errors and uncertainties in a groundwater-flow analysis or solute transport analysis that make any model prediction no better than an approximation. For this reason, all model predictions should be expressed as a range of possible outcomes which reflect the uncertainty in model parameter values. The range of uncertainty should be similar to that used for the sensitivity analysis.

The model predictions may be presented to illustrate the range of possible outcomes resulting in model input data uncertainty. If the purpose of the predictive simulations is to determine the future hydraulic head distribution in an aquifer, the upper and lower estimate of head should be presented so that appropriate decisions may be made.

4.5CASE 1 : CASE STUDY OF BHAVAJI NAGAR PALGHAT DISTRICT

4.5.1 Introduction

The most important river in the region is Bhavani that the study is made on. The discharge values around Bhavani is estimated ss 3.26 m3/s. The sources at around the area of study flow seasonally and diminish by summer.Study area comprises an alluvial valley region. The area is an unconfined aquifer system, having three zones or regions of different conductivity and storage values. High conductivity layer is sandwiched between two zones of lesser conductivity and storage values.The hydraulic conductivity (K) value of the aquifer was found as 0.000523 m/s. The thickness of alluvium is taken as 28 m in this study. The boundaries of the flow domain have to be represented on grid system to get a solution in MODFLOW.Model used for the calibration is MODFLOW, which uses finite difference method to solve the partial differential equations of groundwater flow.



(Source:- Central Ground Water Board Report On Subsurface Dyke.)

Figure 4.5 Subsurface Dyke Constructed At Bhavaji Nagar, Palghat District, Kerala

4.5.2 CREATING AND DEFINING A FLOW MODEL

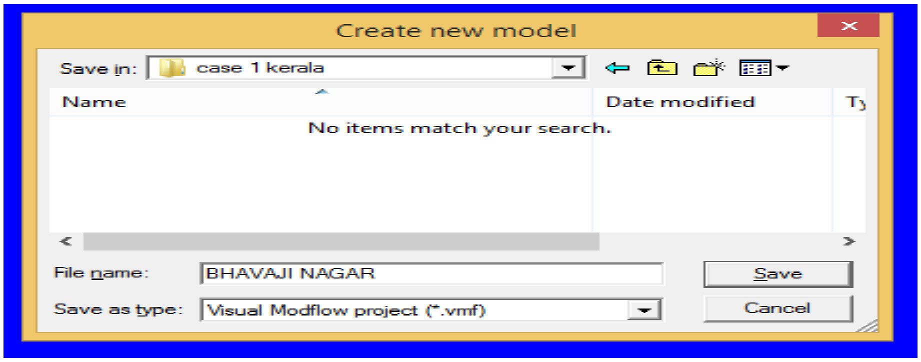
4.5.2.1 Generating a new Model

The step necessary to generate a new model data set using the Visual MODFLOW modeling environment.

- **File** from top menu bar
- **New**

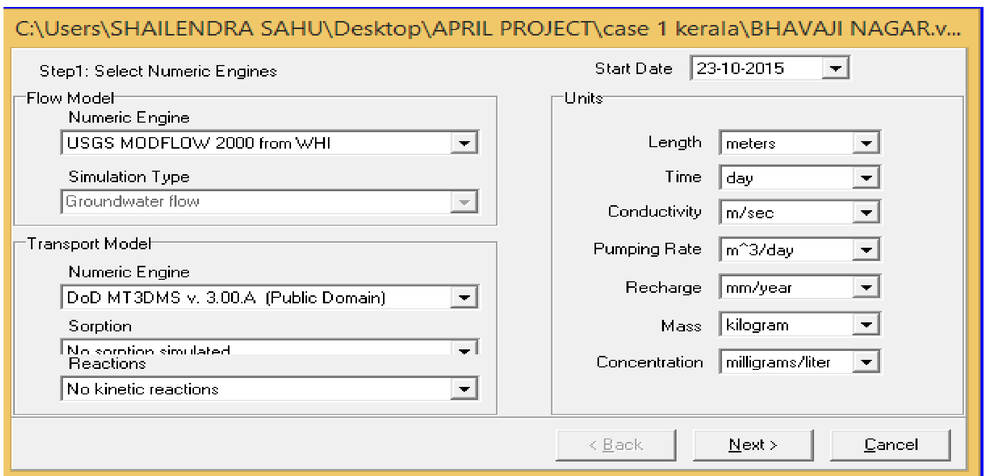
  A Create new model dialog box will appear create a new data set by typing **BHAVAJINAGAR** in the File name fieldname then save.

  Visual MODFLOW automatically adds a .VMF extension onto the end of the filename.



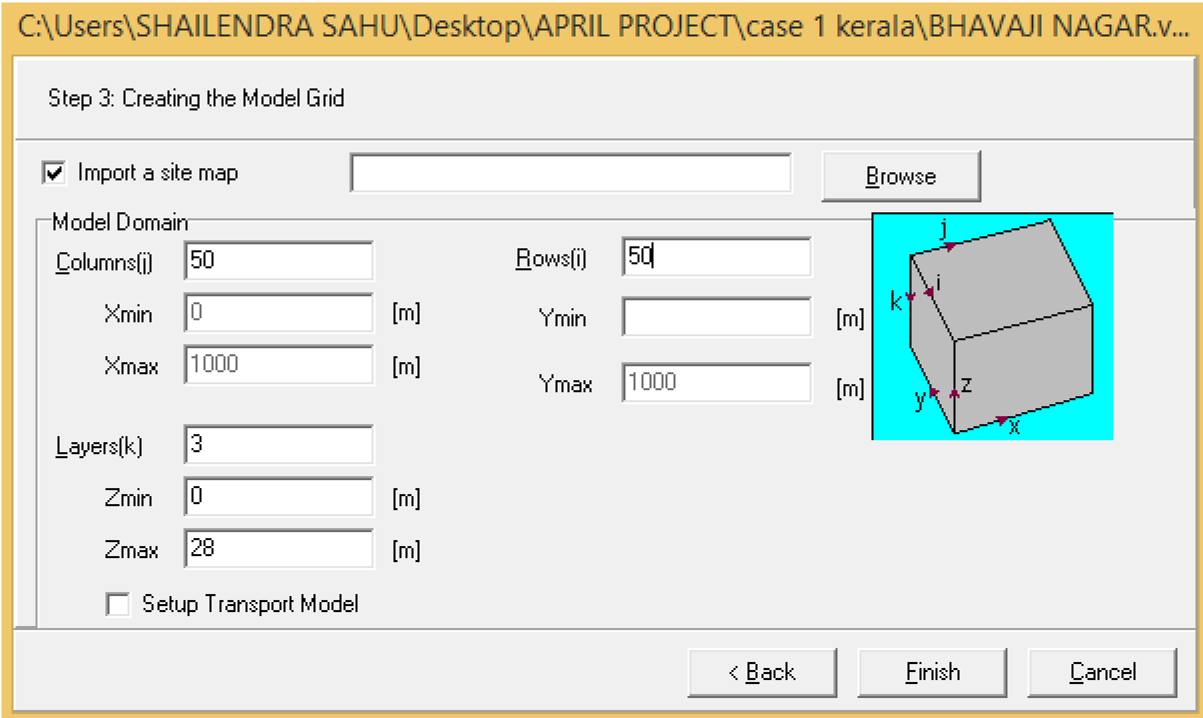
The following window is used to select

1. the desired **NumericEngines** for the Flow and Transport simulation
2. **Units** associated with various flow and transport parameters
3. **StartDate** of the model.



The **Start Date** of the model is the date corresponding to the beginning of the simulation time period. Currently, this date is relevant only for transient flow simulations where recorded field data may be imported for defining time schedules for selected boundary conditions(Constant Head, River, General Head and Drain).

The next step is **Creating the Model Grid(**see figure below**).**



The above window is used to import a site map.specify the dimensions of the Model Domain, and define the number of rows, columns, and layers for the finite difference grid.

Specify the following number of rows,columns and layers to be used in the model.Enter the following into the Model Domain section,

Number of Columns - 50

Number of Rows - 50

Number of Layers - 3

Zmin - 0

Zmax - 28

Next,you must specify the location and the file name of the **.DXF** background map.

A Select Model Region window will appear prompting you to define the extent of the model area. Visual MODFLOW will read the minimum and maximum co-ordinate from the site map and suggest a default location that is centered in the model domain. Visual MODFLOW now allows you to rotate and align the model grid over the site map, use local co-ordinates, and set the extents of the DXF map. If a bitmap was used as background map, the image can be geo-referenced and the grid can be aligned on the bitmap as well.

A file attributes windows will appear to indicate that the "Sitemap" is being saved inside the Visual MODFLOW Project with the name "Bhavaji Nagar.Sitemap".

A uniform spaced 50x50x3 finite- difference grid will automatically be generated within the model domain and a site base map appear on the screen as shown in the following figure.

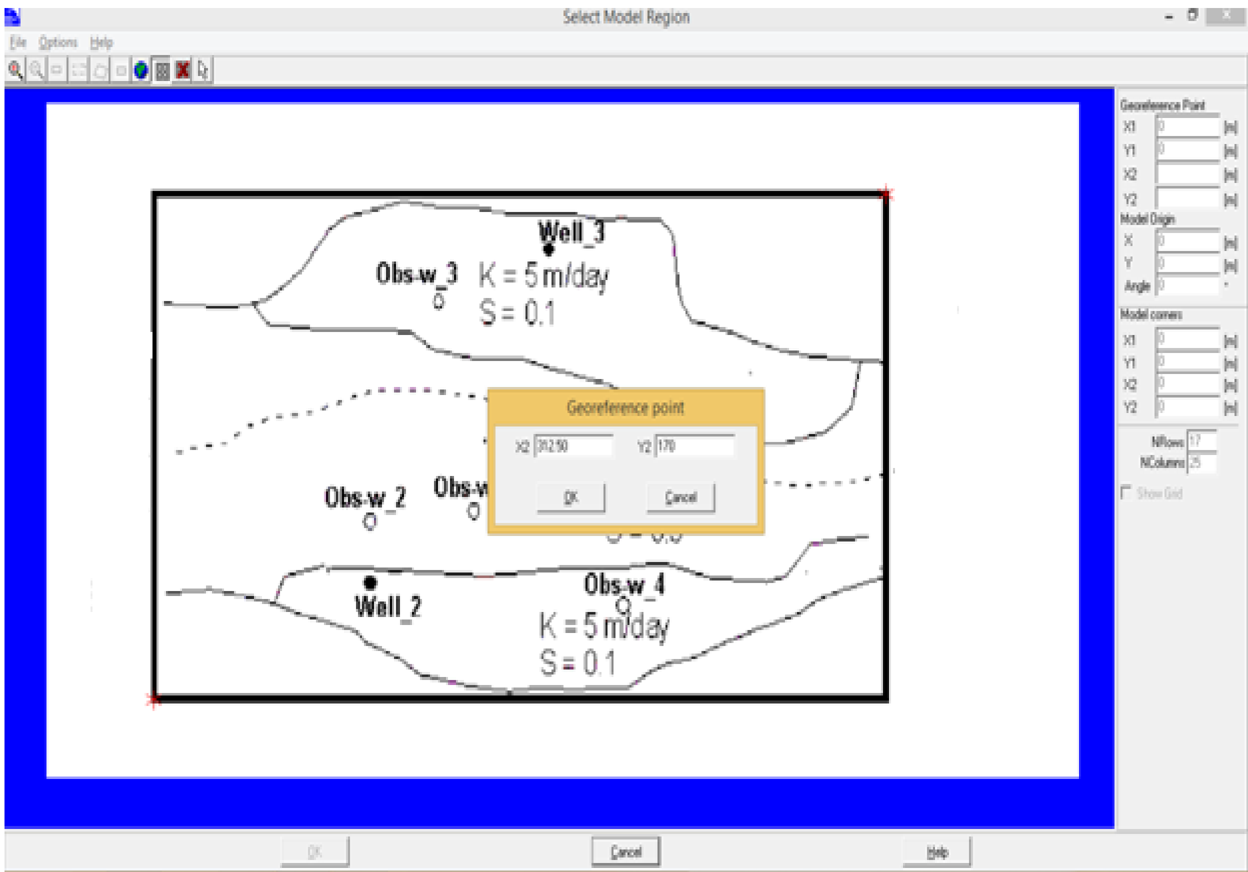


Figure 4.6: An Overview Of Georeferencing Process

This is the Visual MODFLOW **Input** module. The top menu bar of the Input module is divided into the primary building blocks for any groundwater flow and contaminants transport model.

1. **Grid** (for designing the finite difference model grid)
2. **Wells** (for assigning pumping wells, injection wells, and monitoring wells)

3. **Properties**(for assigning property values to each model grid cell)
4. **Boundaries** (for assigning model boundary conditions)
5. **Particles** (for assigning particle tracking locations)

Each of these menu items provides access to an associated Input screen for assigning the various model parameters.These buttons allow you to change the model display from plan view to cross-section at any time. The remaining buttons on left-hand toolbar are the graphical tools associated with the selected Input screen.

The Navigator Cube on the lower left-hand side of the screen shows the location of the current row, layers, and column in the model, and the X,Y,Z and I,J,K location of the mouse pointer. The remaining toolbar buttons describe the various functions that can be performed to modify the model grid.

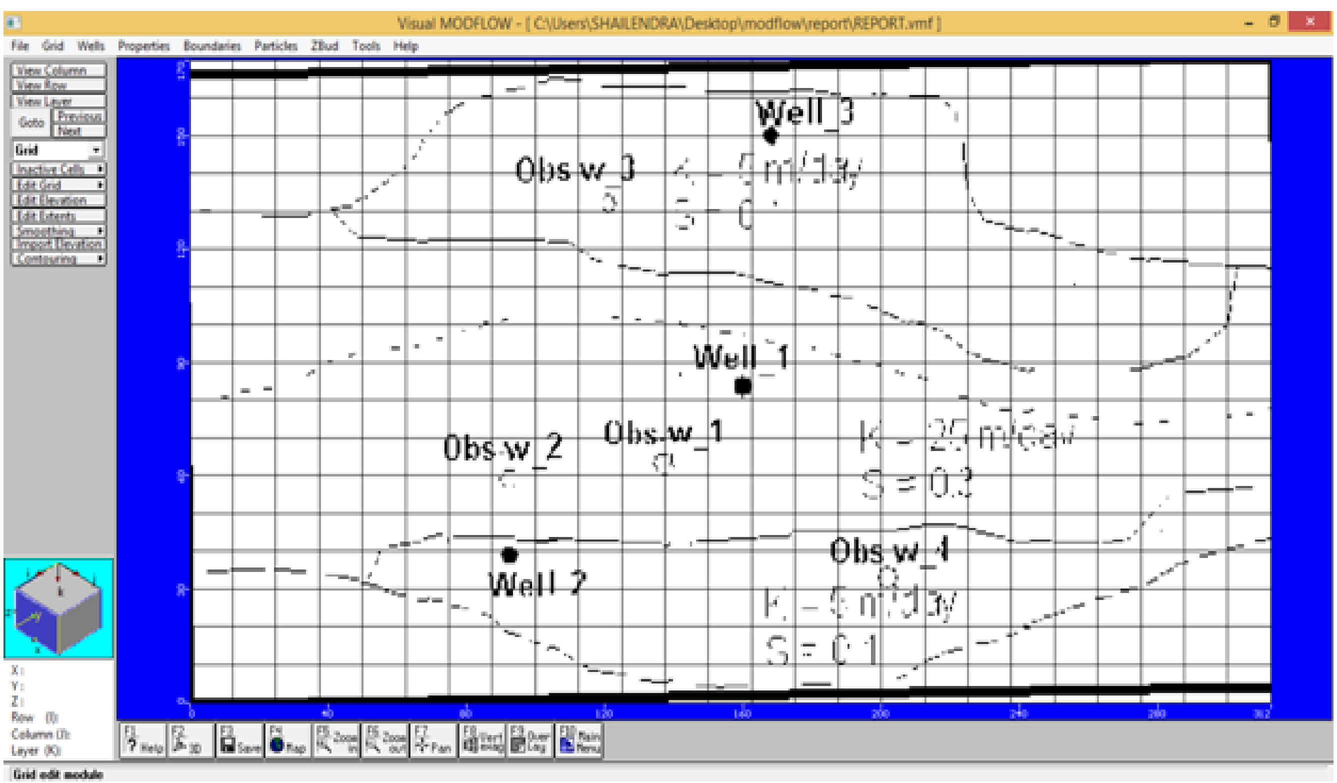


Figure 4.7 Model Created In MODFLOW For Bhavaji Nagar

4.5.2.2 REFINING THE MODEL GRID

The Grid screen provides a complete assortment of graphical tools for refining the model grid, importing layer surface elevations, optimizing (smoothing) the grid spacing, contouring the layer surface elevations, and delineating inactive grid zones.

This section describes the steps necessary to refine the model grid in the areas of interest, such as around the water supply wells and around the sub surface dyke. The reason for refining the grid is to get more detailed simulation results in areas of interest, or where you anticipate steep hydraulic gradients. If drawdown is occurring around the well, the water table will have a smoother surface when you use a finer grid spacing.

The three layers of the model will then be displayed on the screen as shown below. From the figure you can see that each layers has a uniform thickness across the entire cross-section. However, nature rarely provides us with geology that conforms to flat horizontal layering with uniform.

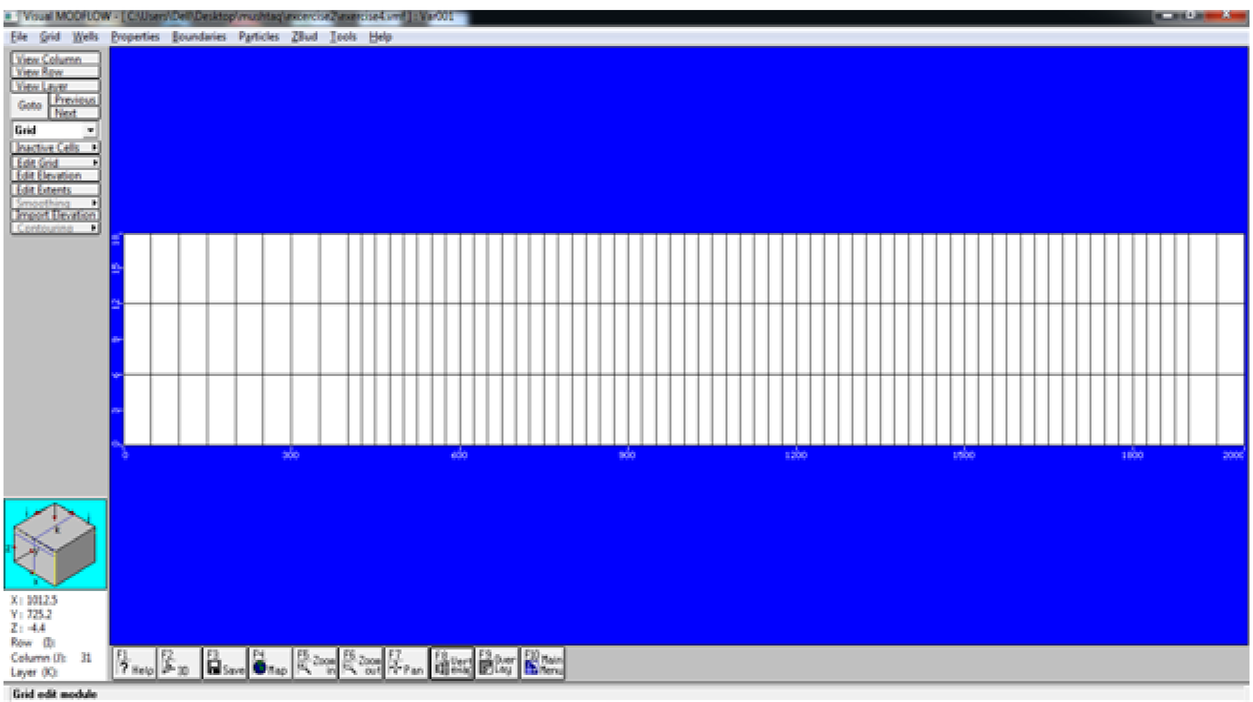
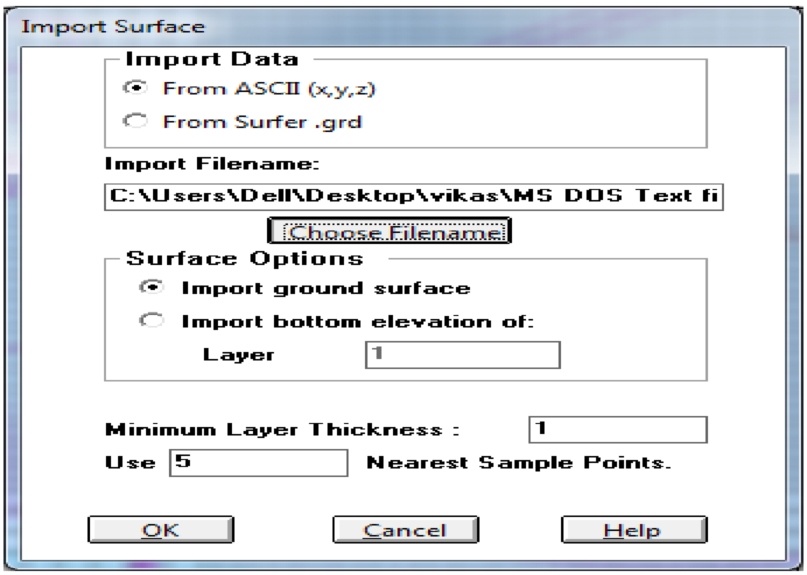


Figure 4.8 Aquifer Layer With Uniform Thickness

Fortunately, Visual MODFLOW allows you to import variable layer elevations from either X,Y,Z text files ,or from Surfer.GRD files, In this example, we will import text files containing elevation data for selected X and Y coordinates within the model domain.
When this data is imported it will create a sloping ground surface topography and layers with variable thickness.

The following Import Surface window will appear.



An **ImportSurfaceFile** windows will appear listing the available *.ASC, *.TXT, and *.XYZ files. The file you will import for the ground surface elevations is **surface.asc**.

This will import a variable surface generally sloping from 28 meters at the northern boundary to 17 meters at the southern boundary. Visual MODFLOW reads the x, y, z data from the file and uses an inverse-distance squared interpolation routine to assign block centre elevations for the top of each cell in Layers 1 using the five nearest sample data points.

To obtain a finer vertical digitization of the model grid, you can also sub divide each of the layers. A deforming layer division will be added at vertical mid-point of layer 1.Repeating the same step to sub-divide the middle confining layers of the model and the lower aquifer layer 3.

The model cross-section should now consist of six layers and should appear similar to the following figure.

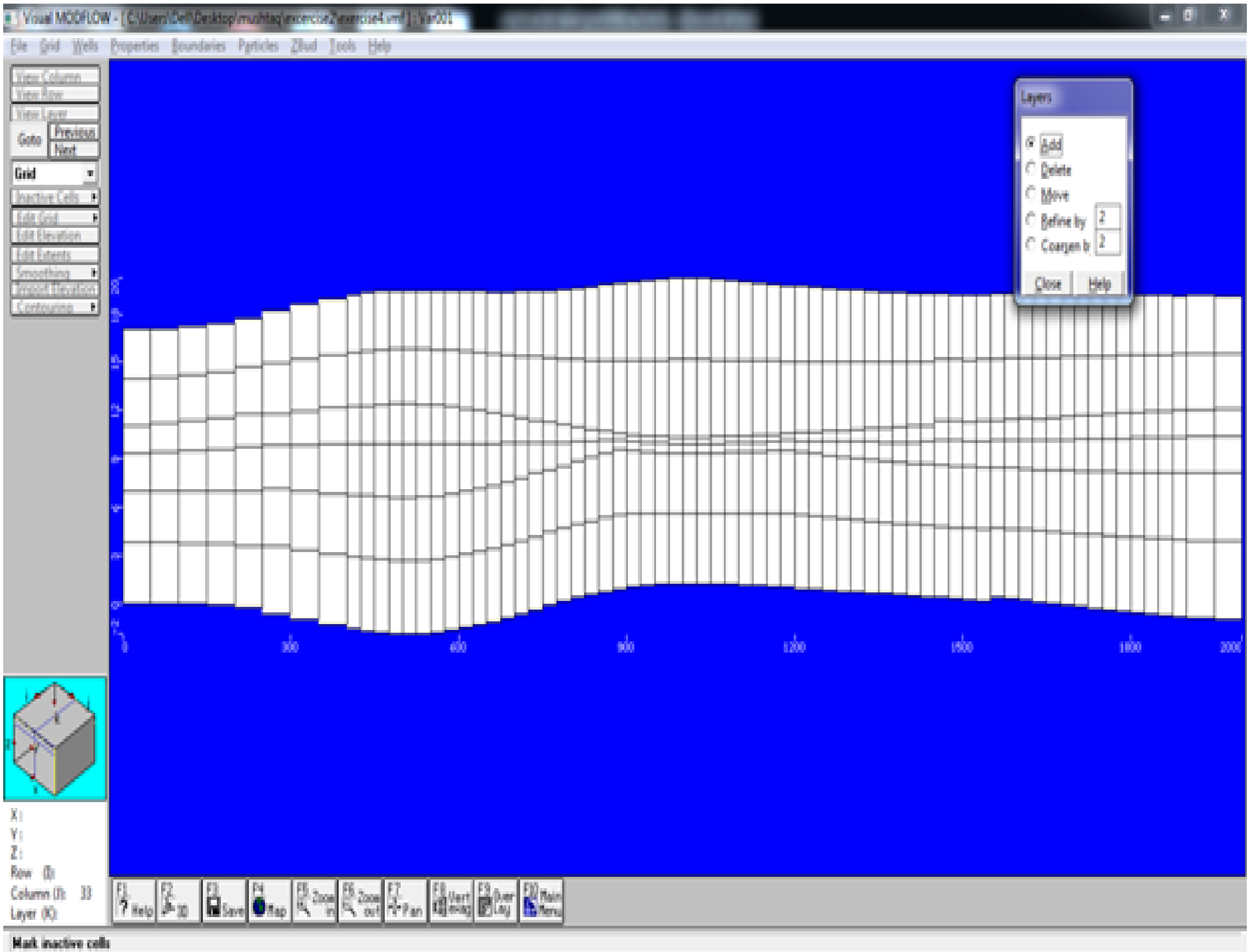


Figure 4.9 Vertical Distribution Of The Study Area

4.5.3 ADDING PUMPING WELLS

Once the model has been saved , Now adding the pumping wells for this model, zoom in on the area and begin adding pumping wells by defining the co-ordinates, pumping rate, duration of pumping, screen size.

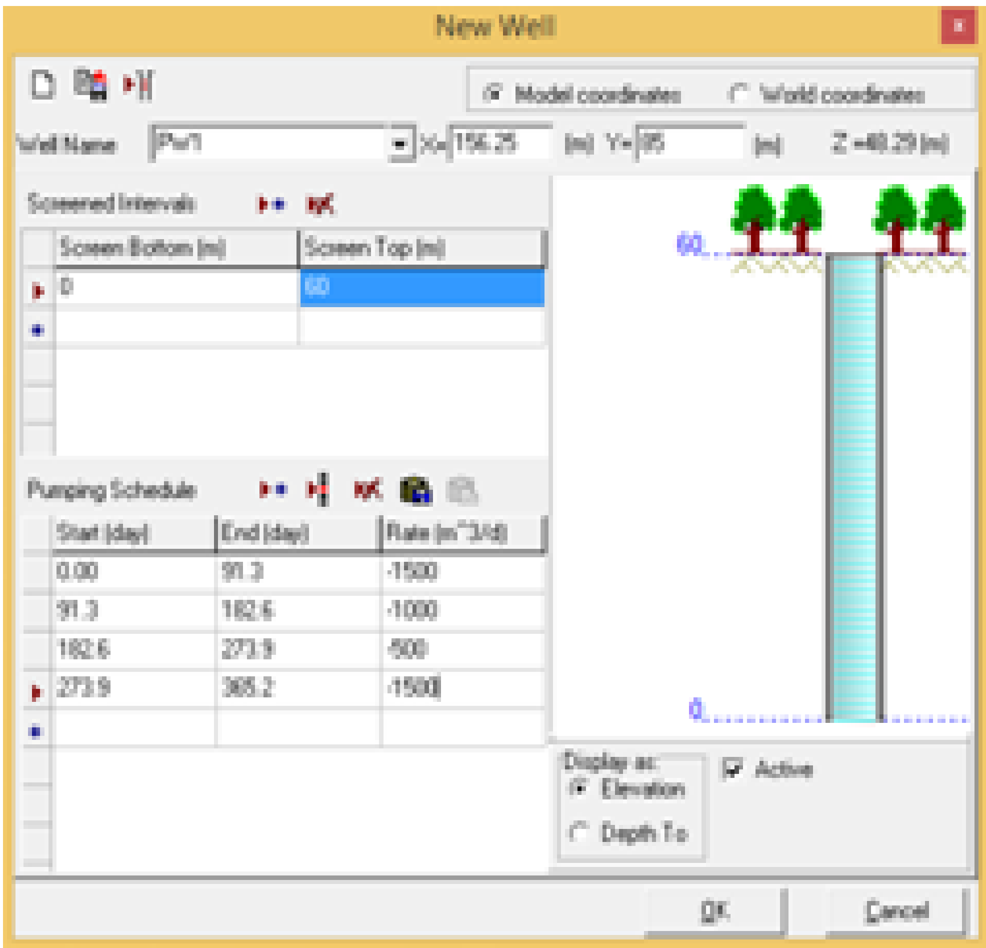


Fig.4.10 Adding Pumping Wells

4.5.4 ASSIGNING FLOW PROPERTIES

Now we have to assign highly contrasting hydraulic conductivities and storage to the different layer of the model .

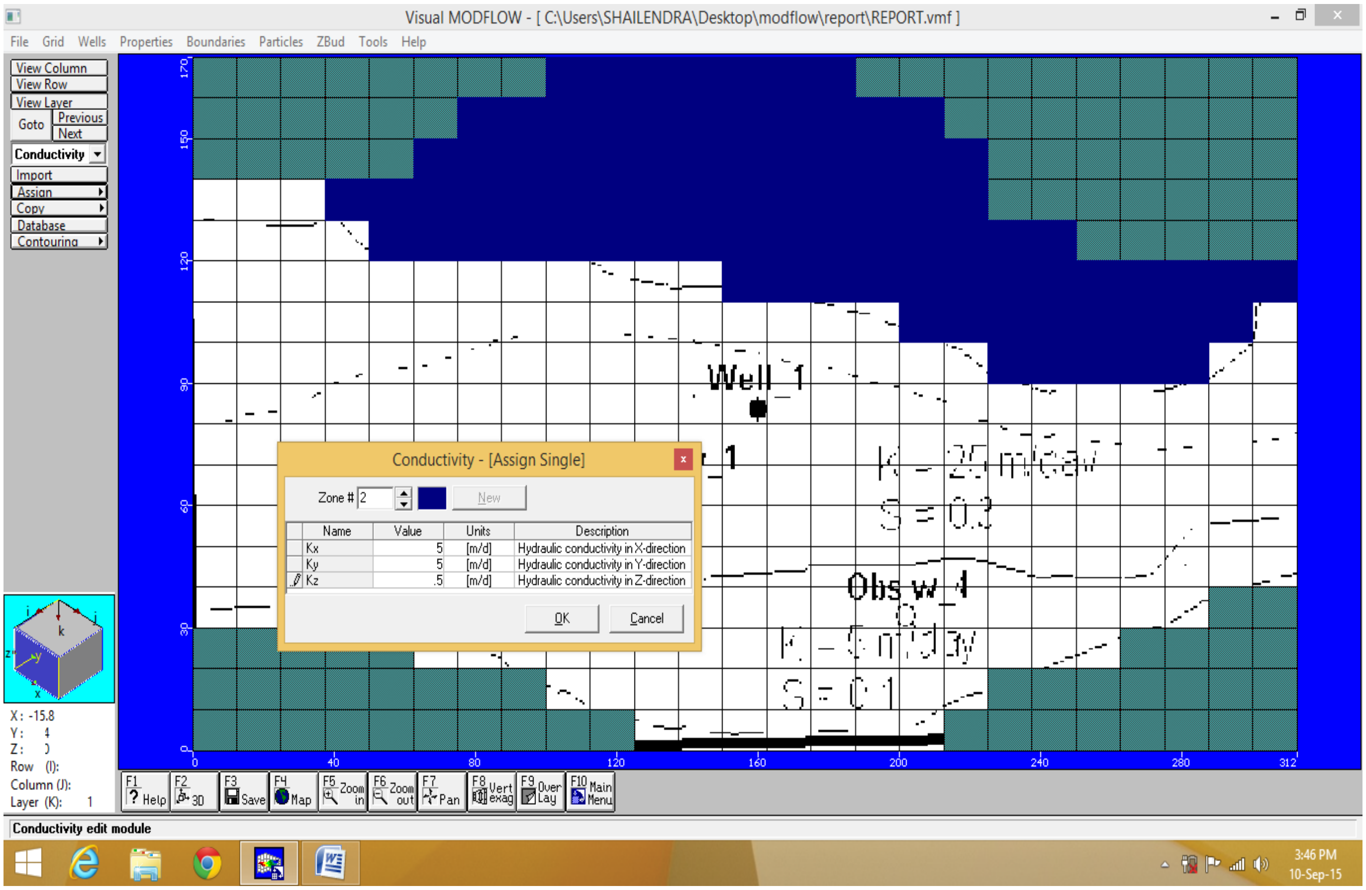
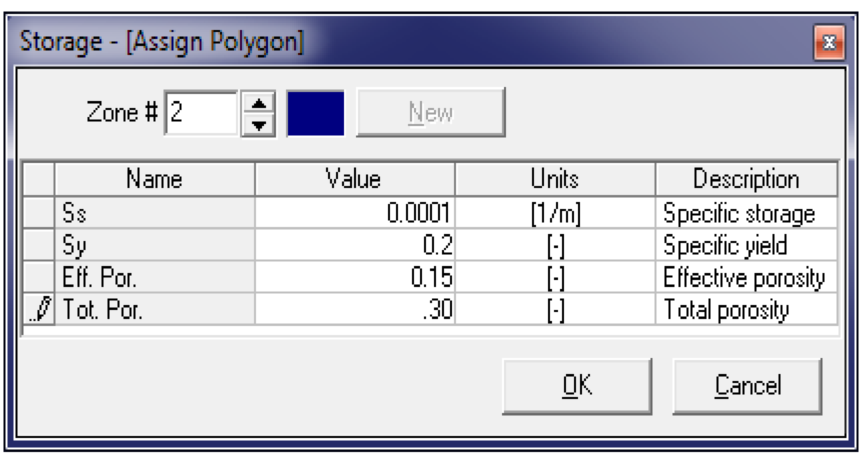


Fig.4.11 Assigning Flow Parameters

Defining specific storage , defining specific yield ,effective porosity as shown in the figure below.



4.5.5 ASSIGNING FLOW BOUNDARY CONDITIONS

Firstly we have assigning of aquifer recharge to the model.In most situations, aquifer are recharged by infiltration surface water. Therefore, in order to assign recharge in Visual MODFLOW ,we must be viewing the top layer of the model. The first boundary condition to assign is the recharge flux to the aquifer.

Then we have assigning of the Constant head boundary conditions to the confined and unconfined aquifer at the north and south boundaries of the model.The first constant head boundary condition head boundary condition to assign will be for the upper unconfined aquifer along the northern boundary of the model domain.

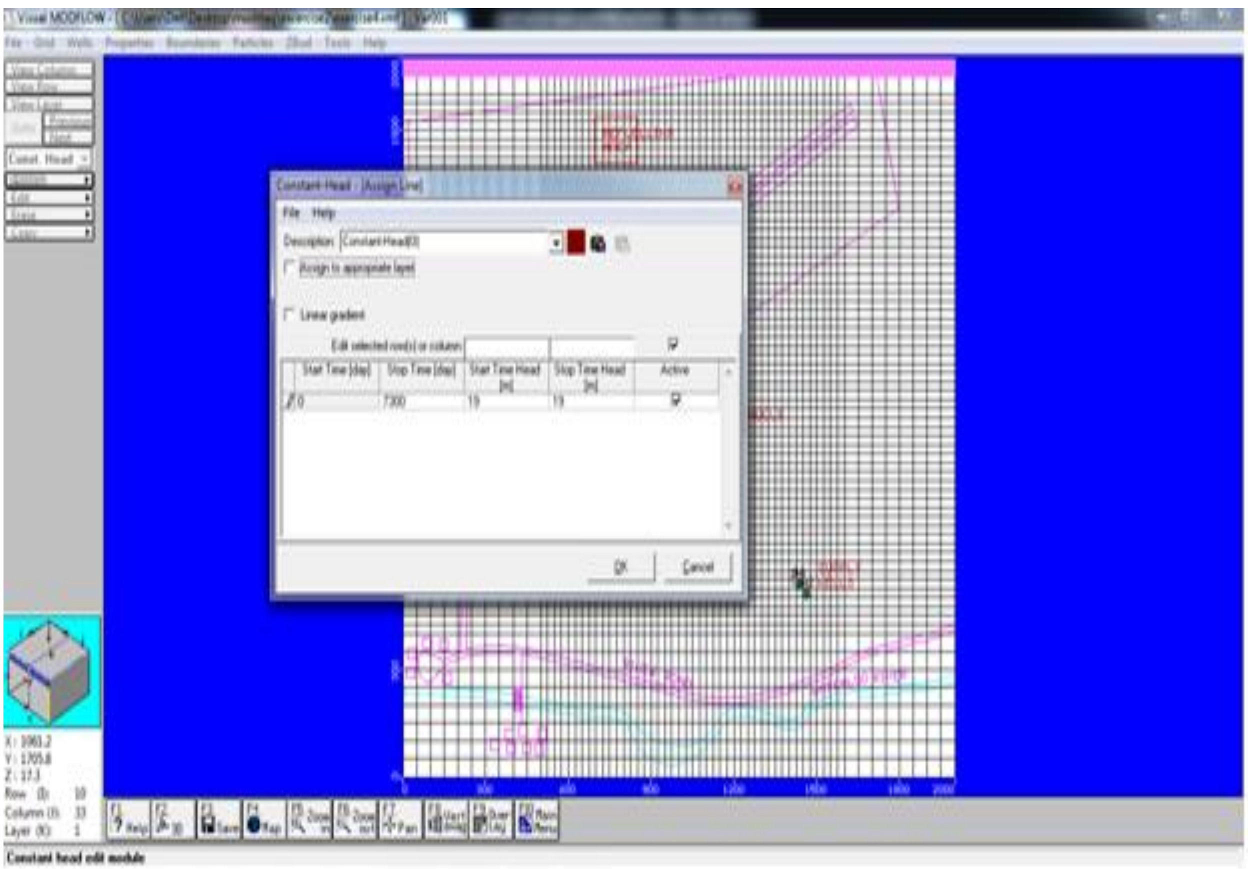


Figure 4.12 Adding Constant Head Boundary Condition To The Model

4.5.6 ASSIGNING RIVER BOUNDARY CONDITIONS

If you look closely at the sitemap of bhavaji nagar , you will see the Waterloo River flowing along southern portion of the model domain.Beginning on the south-west side of the grid and using the sitemap as a guide, digitize a line of grid cells along the river .

Traditionally, the River boundary condition has required a value for the conductance of the riverbed.However the conductance value for each grid cell depends on the length and width of the river as it passed through each grid cell.Therfore, in a model such as this ,with different sizes of grid cells,the conductance value will change depending on the size of the grid cell.

In order to accommodate this type of scenario,Visual MODFLOW allows you to enter the actual physical dimension of the river at the Start point and End point of the line and then calculates the appropriate Conductance value for each grid cell according to the formula.

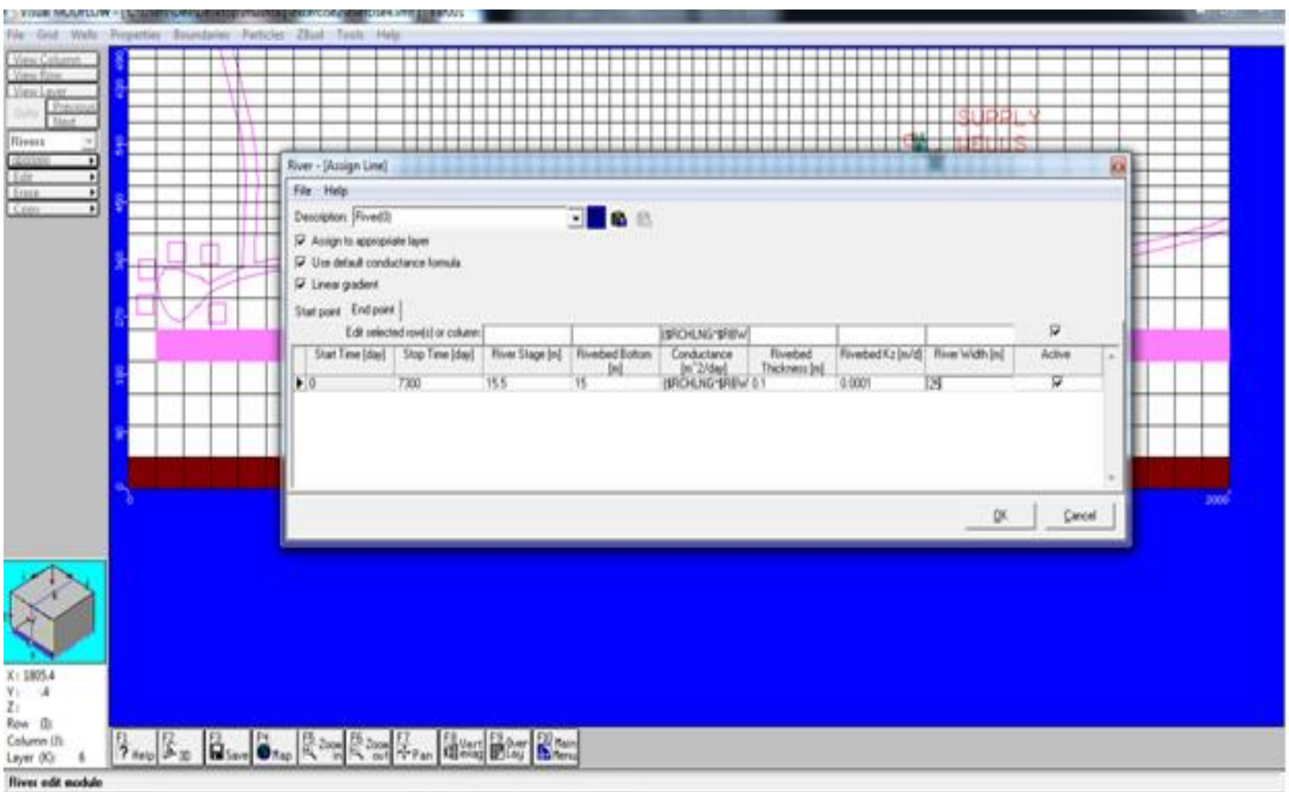


Figure 4.12 Adding River Boundary Condition To The Model

4.5.7 ADDING OBSERVATION WELLS

In the final step, before running the simulation you will add three concentration observation wells to the model to monitor the drawdown. Adding the concentration Observation wells Individually using the toolbar options and importing well data from a variety from a variety of file formats including ASCII(.TXT) file, EXCEL(.XLS) file, ESRI (.SHP) file, or MS Access(.MDB) file.

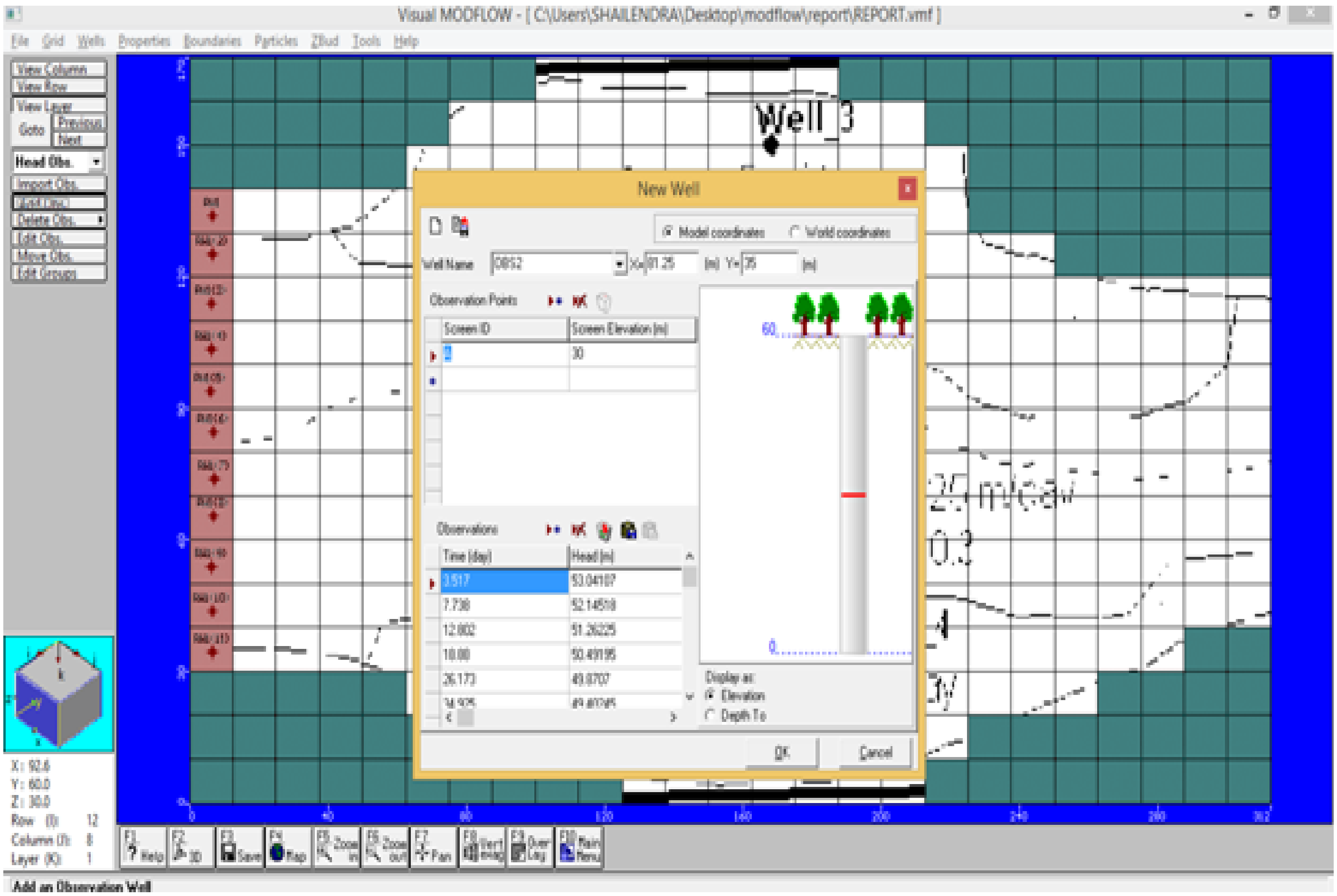


Figure 4.13(a) Adding Observation Well To The Model And Importing There Well Data Respectively

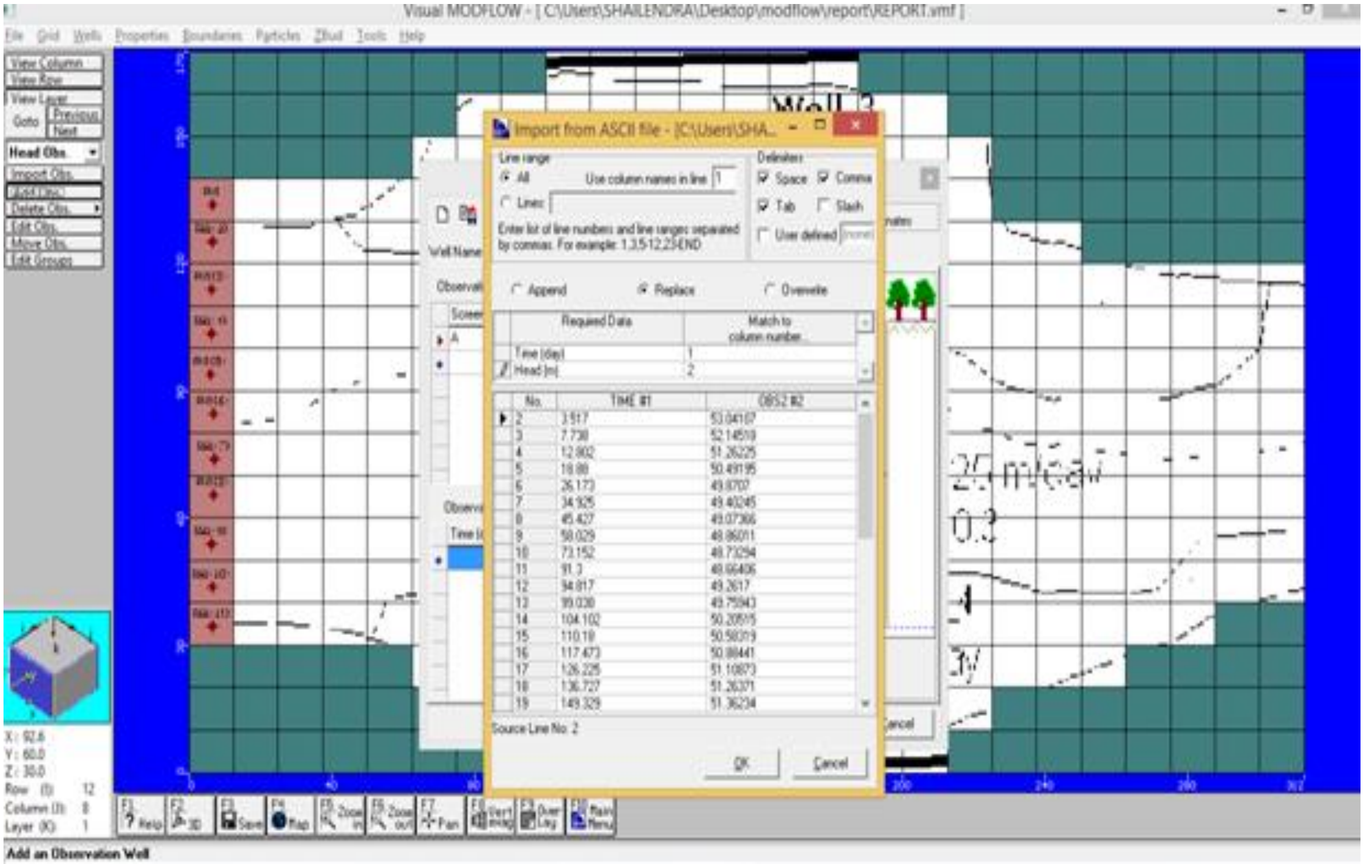


Figure 4.13(b) Adding Observation Well To The Model And Importing There Well Data Respectively

4.5.8 RUNNING VISUAL MODFLOW

Prior to running the simulation you may customize the default run-time setting for MODFLOW,MODPATH and MT3D.The Run section also allows to setup the parameter estimation (PEST) simulation.

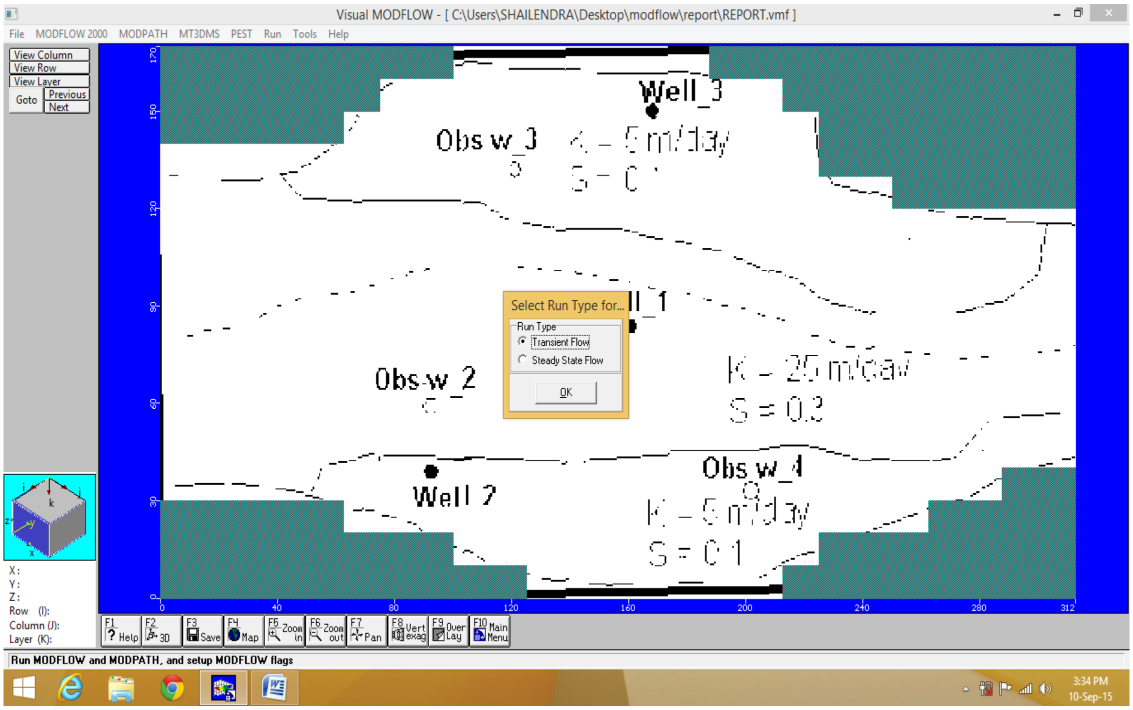


Figure 4.14 Running Visual MODFLOW Under Steady State Conditon

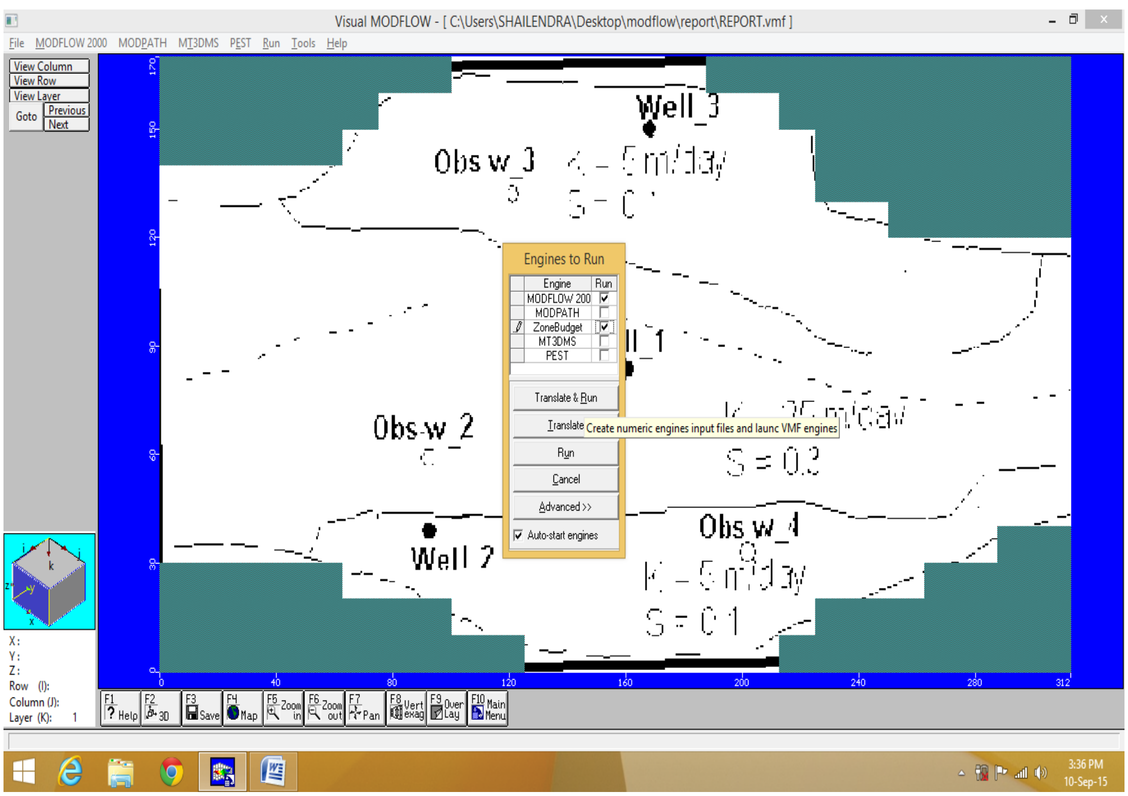


Figure 4.15Translating And Running The Model

4.6 CASE 2 – HYPOTHETICAL STUDY OF PATAN REGION OF CHHATTISGARH

In this part, as Case 1-a hypothetical rectangular ideal aquifer will be considered aiming to analyze the effects of subsurface dam on mainly water storage. The case will be handled step by step. In the first step the hypothetical aquifer will be simulated in natural conditions, without dam, without wells. This situation will be called as Case 1-a. In the next case, Case 1-b, wells will be added to the scenario. The next case, Case 1-c, will be with dam wall and without wells, and Case 1-d will be both with wells and with dam wall. The content of Cases 1-a, 1-b, 1-c, and 1-d are shown in Table 4.1 for simplicity.

Table 4.1 Content Of Cases

Case	**Conditions**
Case 1-a	Without wells without dam
Case 1-b	With wells without dam
Case 1-c	Without wells with dam
Case 1-d	With wells with dam

Figure 4.14 shows the plan view of idealized rectangular aquifer and the location of the wells and underground dam.

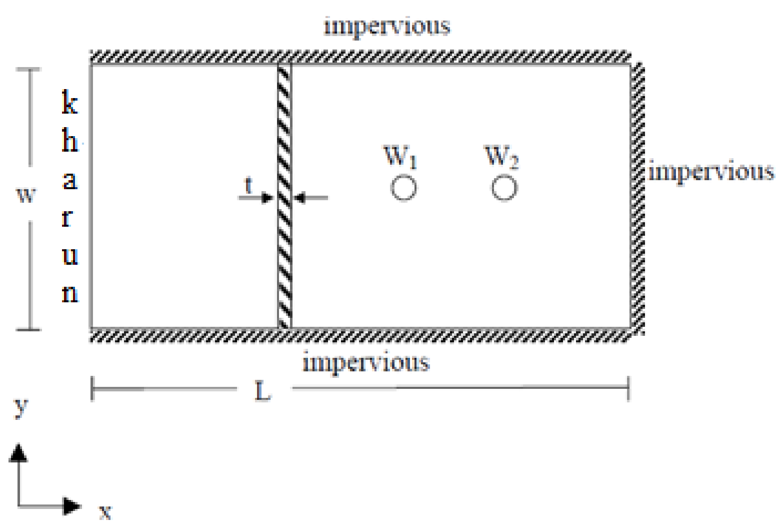


Figure 4.16 Plan View Of Idealized Rectangular Aquifer With Dam Wall And Wells

4.6.1 CASE 1-a :Without Wells Without Dam.

In Case 1-a, natural conditions of the hypothetical ideal aquifer is considered. The groundwater flow in this aquifer is simulated using MODFLOW. The values of L is the length of aquifer along the flow direction namely x direction in MODFLOW, w is the width of the aquifer in y direction and also used as the length of the dam wall in this hypothetical case, b is the thickness of the soil in z direction, Ks is the hydraulic conductivity of the soil, Kw is the hydraulic conductivity of the dam wall, t is the thickness of the dam wall, hsea presents the sea level above impervious bottom, hgw presents groundwater level above impervious bottom, R is the recharge value, Q1 and Q2 are the discharges from the wells W1 and W2, nef and nt are the effective and total porosity values, Ss and Sy are the specific storage and specific yield values. These are all used as inputs in MODFLOW. This is done to form a basis to make comparison between different scenarios. The inputs of Case 1-a, which is analyzed in steady state as other cases, are given as in the Table 4.

The effective porosity can be thought of as the volume of pore space that will drain in a reasonable period of time under the influence of gravity. Sometimes the effective porosity is much less than total porosity, but since this case is hypothetical they are taken equal. When the inputs given in Table 4.2 are used in MODFLOW.

The minus values are just because the water is extracted through the discharging wells and it is in accordance with the convention used in MODFLOW. Some of the inputs that should be used in MODFLOW were lacking in the report. Therefore values consistent with the site area are selected. The boundaries other than constant head boundary are assumed as impermeable. The annual average recharge cannot be accepted as net recharge because of the effects of evaporation, capillarity and other losses. Net recharge value is estimated as 25% of annual average recharge. The variation of water table elevation obtained from the output file of MODFLOW is shown in Figure 5.5 from top view and in Figure 5.6 in cross-section. The units used on the axes are in meters as it is also valid for the remaining figures.

Table 4.2 Inputs Of Case 1-a (Withvut Wells Without Dam)

Parameters	Symbol	Unit
Aquifer length	L	5000 m
Aquifer width	W	1000 m
Aquifer thickness	B	20 m
Dam wall thickness	T	no dam
Groundwater level	h_{gw}	66 m
Mean sea level	h_{sea}	60.5 m
Conductivity of soil	K_s	0.00424 m/s
Conductivity of dam	K_w	no dam
Recharge	R	0.0008 m/day
Discharge from W_1	Q_1	no well
Discharge from W_2	Q_2	no well
Specific storage	S_s	0.001 (1/m)
Specific yield	S_y	0.02 (-)
Effective porosity	n_{ef}	0.02 (-)
Total porosity	n_t	0.02 (-)

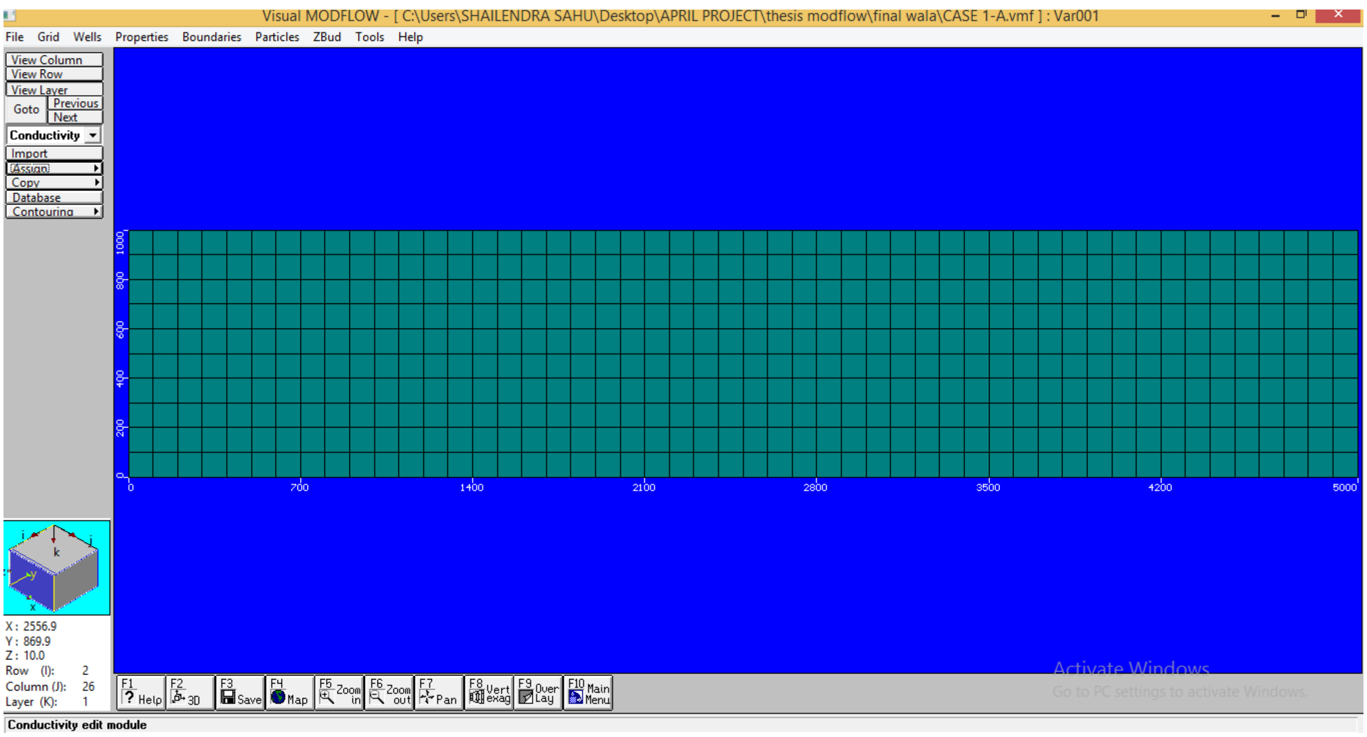


Figure 4.17 Hypothetical model created in MODFLOW for case-:Without Wells Without Dam (1-a)

4.6.2 Case 1-b :With Wells Without Dam

When wells are added to Case 1-a Case 1-b can be established. In MODFLOW the discharge values Q_1 and Q_2 for wells W_1 and W_2 are added. The inputs are as given in Table 4.3.

Table 4.3 Inputs of Case 1-b (With Wells Without Dam)

Parameters	**Symbol**	**Unit**
Aquifer length	L	5000 m
Aquifer width	W	1000 m
Aquifer thickness	B	20 m
Dam wall thickness	T	no dam
Groundwater level	h_{gw}	66 m
Mean sea level	h_{sea}	60.5 m
Conductivity of soil	K_s	0.00424 m/s
Conductivity of dam	K_w	no dam
Recharge	R	0.0008 m/day
Discharge from W_1	Q_1	–7000 m^3/day
Discharge from W_2	Q_2	–7000 m^3/day
Specific storage	S_s	0,001 (1/m)
Specific yield	S_y	0.02 (-)
Effective porosity	n_{ef}	0.02 (-)
Total porosity	n_t	0.02 (-)

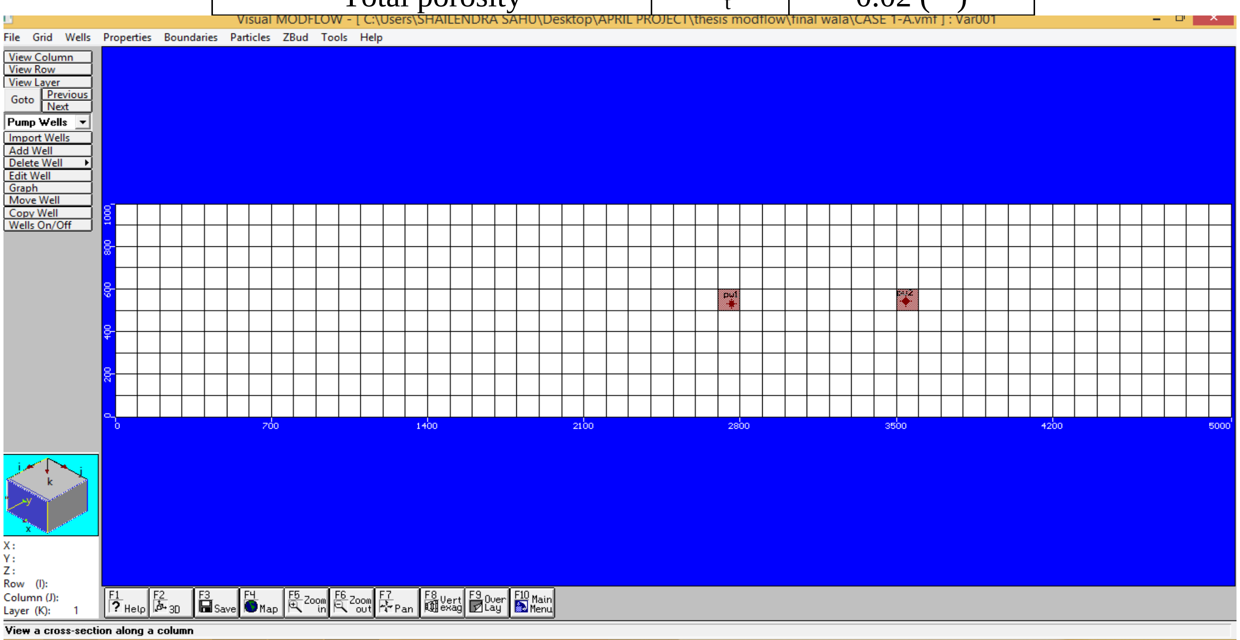


Figure 4.18 Hypothetical model created in MODFLOW for case :WithWells Without Dam (1-b)

4.6.3 Case 1-c : Without Wells With Dam

When wells are removed from Case 1-b and dam wall is added to Case 1-b then Case 1-c is established. The thickness of the dam wall, b and the conductivity value of the wall, Kw that is much less than Ks are additional inputs used in MODFLOW and all other data are same.

Table 4.4 Inputs of Case :Without Wells With Dam (1-b)

Parameters	**Symbol**	**Unit**
Aquifer length	L	5000 m
Aquifer width	W	1000 m
Aquifer thickness	B	20 m
Dam wall thickness	T	8 m
Groundwater level	h_{gw}	66 m
Mean sea level	h_{sea}	60.5 m
Conductivity of soil	K_s	0.00424 m/s
Conductivity of dam	K_w	0.001 m/s
Recharge	R	0.0008 m/day
Discharge from W_1	Q_1	no well
Discharge from W_2	Q_2	no well
Specific storage	S_s	0.001 (1/m)

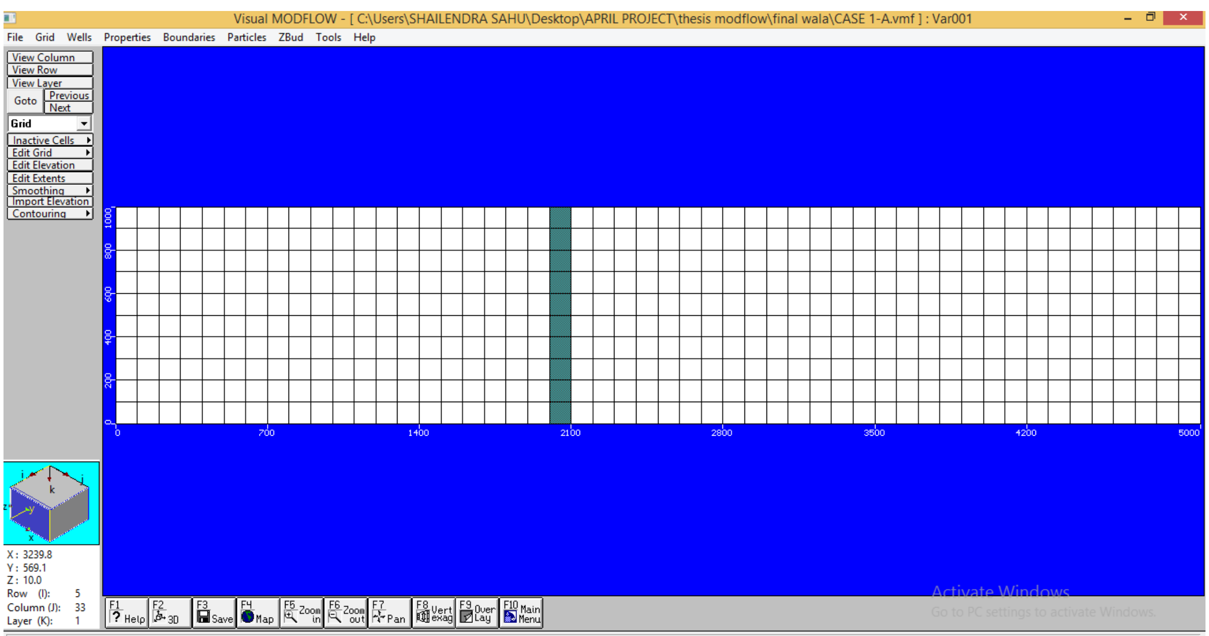


Figure 4.19 Hypothetical model created in MODFLOW for case :Without Wells With Dam (1-c)

4.6.4 Case 1-d: With Wells With Dam

Case 1-d is the hypothetical ideal case with wells and with dam. This case gives us to see the combined effect of cases 1-b and 1-c in MODFLOW.

Table 4.5 Inputs of Case: With Wells With Dam (1-d)

Parameters	Symbol	Unit
Aquifer length	L	5000 m
Aquifer width	W	1000 m
Aquifer thickness	B	20 m
Dam wall thickness	T	8 m
Groundwater level	h_{gw}	66 m
Mean sea level	h_{sea}	60.5 m
Conductivity of soil	K_s	0,00424 m/s
Conductivity of dam	K_w	0.008 m/s
Recharge	R	0,008 m/day
Discharge from W_1	Q_1	–5000 m^3/day
Discharge from W_2	Q_2	–5000 m^3/day
Specific storage	S_s	0.001 (1/m)
Specific yield	S_y	0.02 (-)
Effective porosity	n_{ef}	0.02 (-)
Total porosity	n_t	0.02 (-)

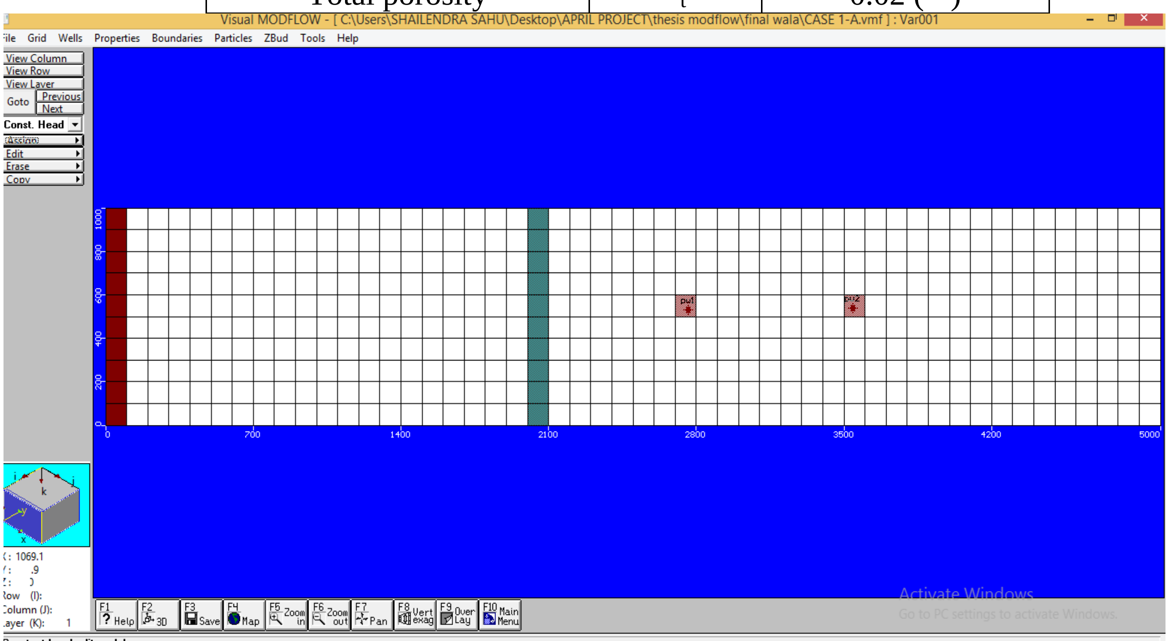


Figure 4.20 Hypothetical Model Created In MODFLOW For Case-1 d (With Wells With Dam)

CHAPTER V

RESULT & DISCUSSION

5.1 VISUAL MODFLOW MODEL RESULT

The final result is developed obtained from simulation of model in Visual MODFLOW gives result of groundwater table vs. time of observation well on both side of sub surface dyke i.e on downstream and upstream side of the sub surface dyke. The change in ground water table before and after construction of the subsurface dyke is shown in result obtained in the output graph. The result obtained from Visual MODFLOW are also compared the actual field data by which the model result has been calibrated numerous number of time. This result will also be helpful for future prediction of groundwater table in the area. From the figure below result we can see that we have been calibration the model upto 92 % between the groundwater elevation given by the model and the actual value given by the observation well installed by Water Resource Department.

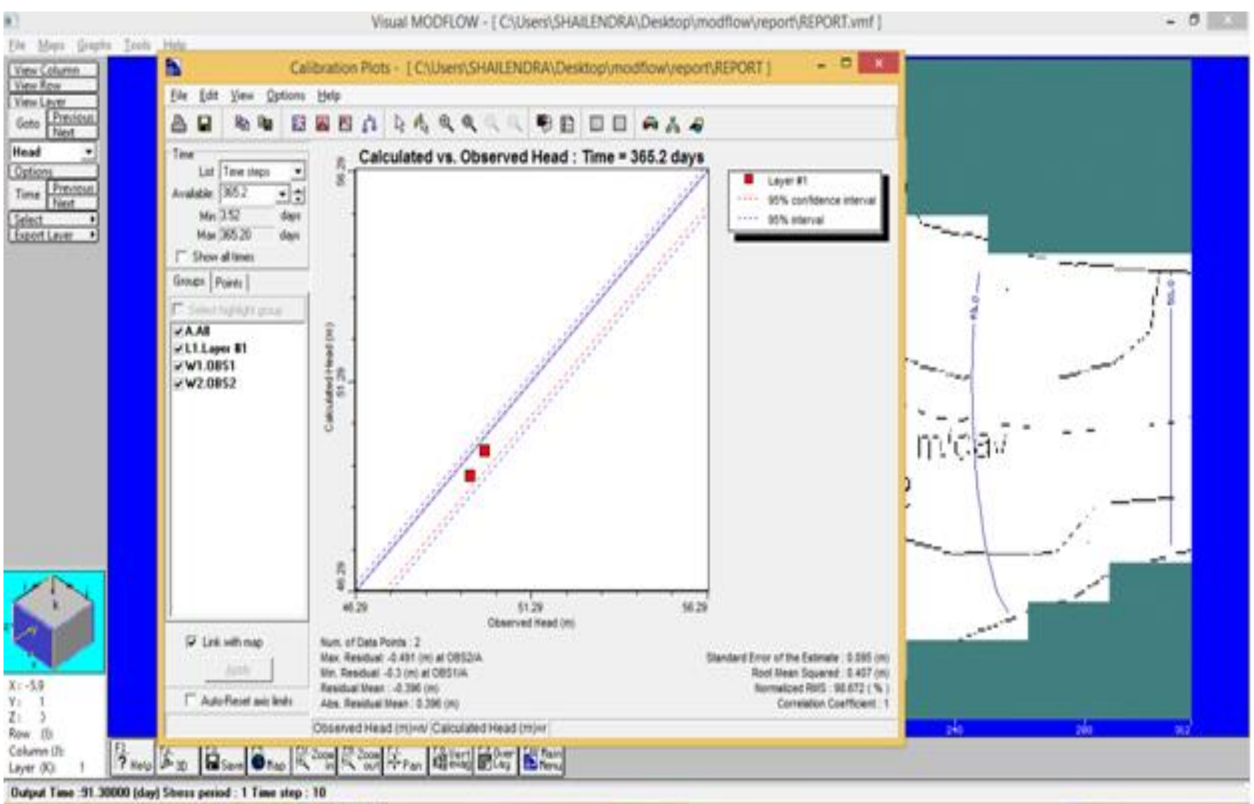


Figure 5.1 Result showing calibration of the model

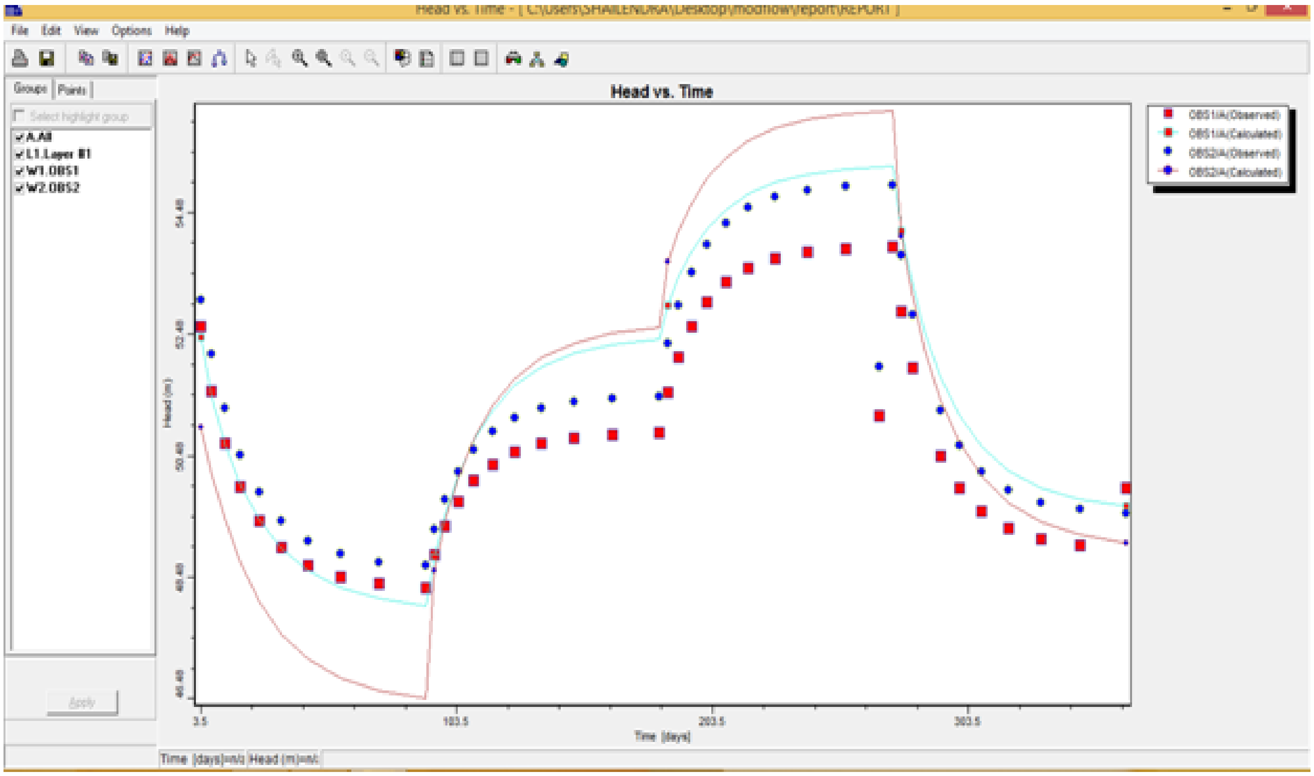


Figure 5.2 Graph Between Groundwater Head And Time Of Both Calculated And Observed Value Of Upstream Side

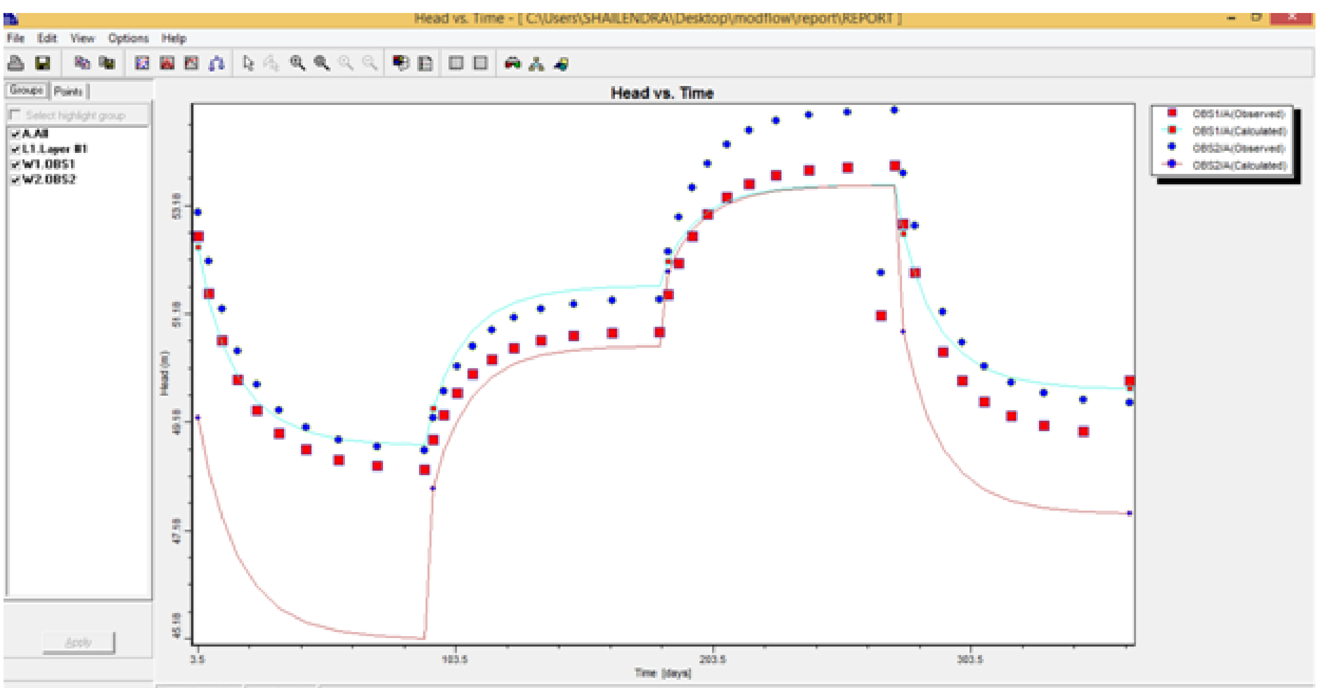


Figure 5.3 Graph Between Groundwater Head And Time Of Both Calculated And Observed Value Of Downstream Side

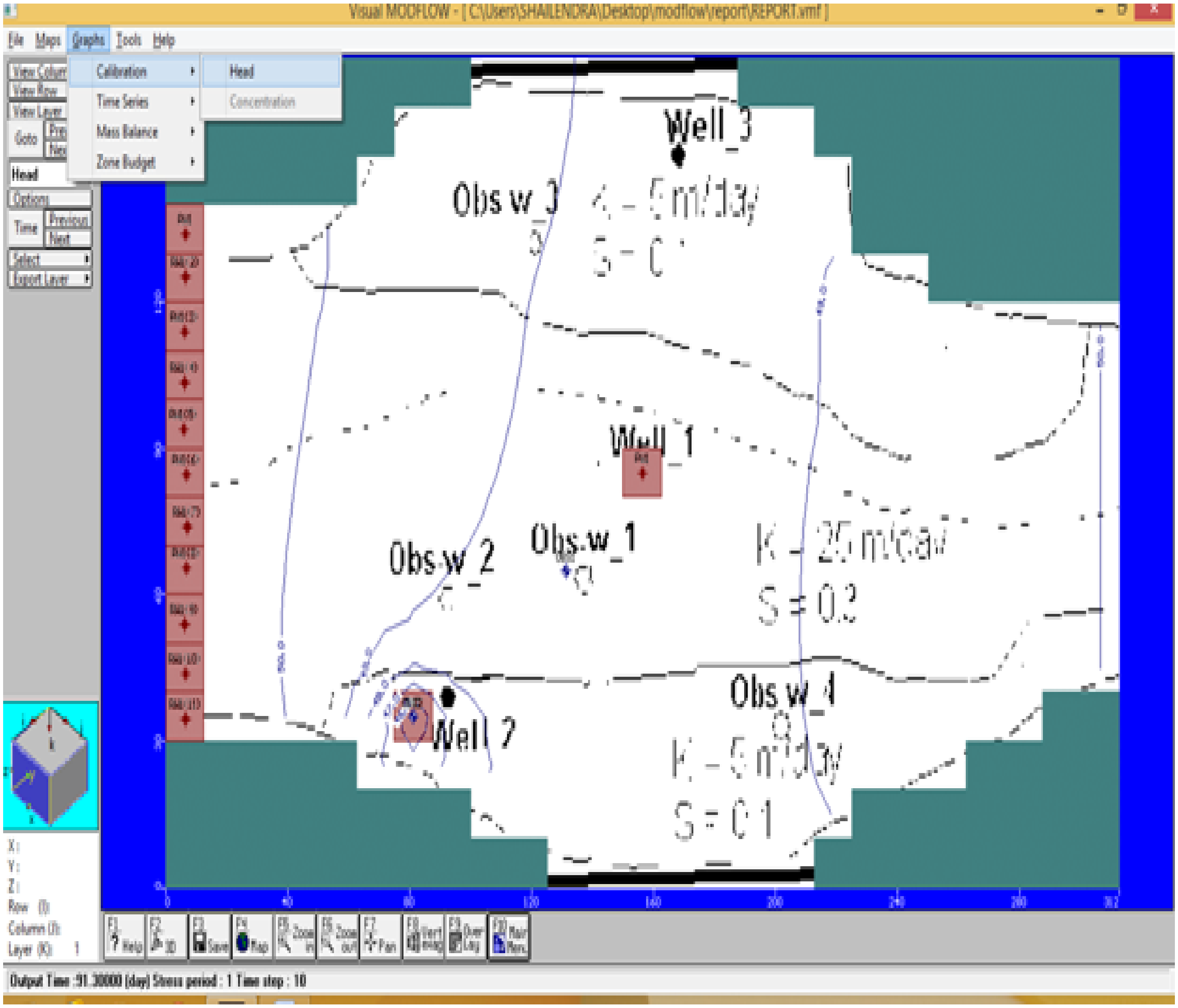


Figure 5.4 Velocity Contour Line Before Construction Of Subsurface Dyke

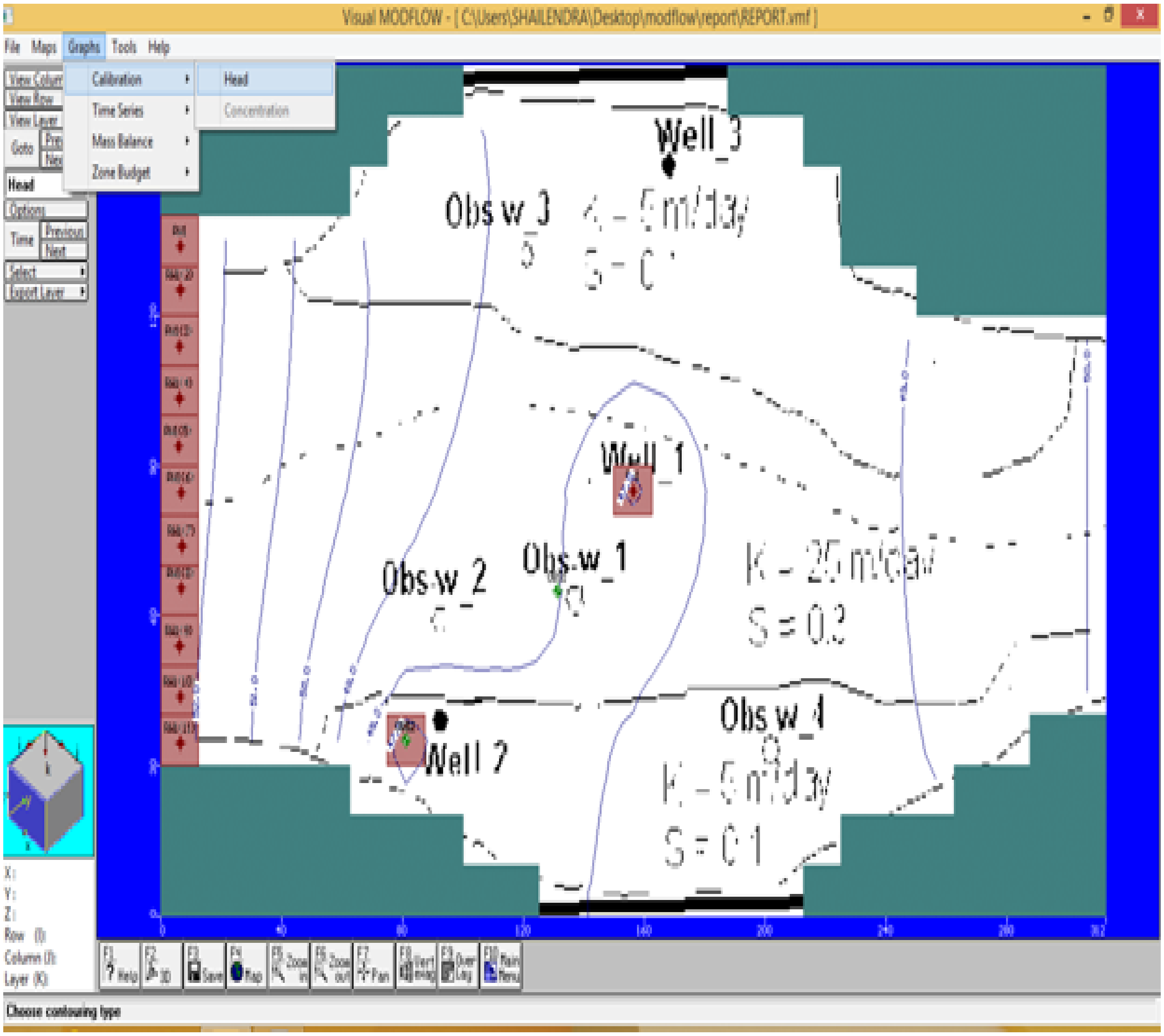


Figure 5.5 Velocity Contour Line After Construction Of Subsurface Dyke

5.2 DISCUSSION

In the hypothetical case of patan region of Chhattisgarh state we can see in the case 2-a that the head values increase from constant head boundary to the impermeable boundary with the effect of recharge.In the second case 2-b we can see that the head drawdown is similar to first case expect there is sudden drawdown can be seen near the pumping well. In the third case 2-cIncrease in head values in the reservoir behind dam wall is seen. After reaching Case 2-d by increasing the Q values the diminishing of the water head levels from upstream to the dyke is observed. The upper limit value of Q1 and Q2 are found by trial and error in MODFLOW. If this value is exceeded than the region around the wells will be dried. By making trial and error solution; by changing the Q values, the maximum discharge extracted without drying the aquifer for this case is found as 7005 m3/day. If this value is exceeded for this case the wells will be dried.

CHAPTER – VI

CONCLUSION

6.1 CONCLUSION

In this study, utilization of subsurface dyke in the management of groundwater resources is analyzed using the computer code, MODFLOW. Two different case studies are provided in the study. In the first case, the map of the potential subsurface dyke construction site in Bavaji Nagar, Palghat district, Kerala is analyzed.`In the second case the proposal for construction of sub surface dyke in patan region of Chhattisgarh is analyzed. In the later case, some of the input data necessary for modelling were lacking, In order to overcome this shortage, a set of assumptions and appropriately estimated values are used. The approach and the conclusions are summarized as follows;

If the groundwater dam were not built, the recharged water would flow towards the constant head boundary, which is the sea or river. By preventing this riverward flow, additional water supply is provided. This is a contribution to the sustainable development.

The discharge values, which may be considered as the potential yield of the aquifer, found in Case 1 and Case 2 are small in amount compared to conventional methods, such as yield of surface reservoirs. Consequently, subsurface are to be considered as alternative or complementary solution to development of water resources. Maximum discharge that can be extracted through the wells without causing drying in the vicinity of the wells can be found using MODFLOW. In addition to that, as it is applied in Case 2, MODFLOW can be used as a tool to find the increase in fresh water storage, with the given assumptions, by building the dam wall.

All of these approaches, which are applied in Case 1 and Case 2 for steady and unsteady solutions, are useful for the planning and design of subsurface dyke.

Though Subsurface dyke can be used as an alternative method for water conservation but it has to be analyzed for economical feasibility. A proper comparison should be done between the subsurface dykes and conventional methods.

As the effectiveness of Subsurface dyke depends upon a lot of factors such as topography, Rainfall pattern, It's effectiveness vary from place to place

CHAPTER 6

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