GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

M.SC. COURSE HYDROGEOLOGY AND ENVIRONMENTAL GEOSCIENCES

GROUNDWATER FLOW AND TRANSPORT MODELING

OPTIMIZATION OF GROUNDWATER ABSTRACTION FROM ALLUVIAL SEDIMENTS AND SIMULATION OF CONTAMINENTS

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1. SUMMARY

In groundwater modeling technique the main application is to study the groundwater flow model and solute transport model. In this report the case study was on the optimization of ground water abstraction from alluvial sediments should be solved. The well location and the pumping rate should be determined in order to avoid the bank infiltration from the nearby contaminated river. Proper planning was done in order to protect the water supply area, the protection zones were determined. The pump and treat technique was determined to remediate the contaminate water caused by the crude oil split into the subsurface.

The model was stimulated using Visual MODFLOW where steady state and transient flow model was run using MODFLOW2000, particle tracking(forward and backward) was run by MODPATH and transport model was run by using MT3DMS.In order to solve this problem, the model was classified into groundwater flow model (which includes steady state and transient flow model) and solute transport model

In the steady- state, hydraulic conductivities (resistivity), the calibration values were Kx=KY=156m/day, Kz = 15.6m/day for channel gravel, where as for the floodplain silt Kx=Ky= 8.5m/day and Kz=0.85m/day, where as in the transient calibration Specific yield (Sy)=0.26 and transport model the calibrated values for effective porosity=0.08 and longitudinal dispersivity (αL) =10m. Sensitivity analysis was also done in order to quantify the uncertainty of calibrated model. Later to this model to optimize the abstraction rate at 6900m3/day, pumping well was located (x: 3750m, y: 950m) to avoid d bank infiltration and drought condition. Protection zones I, II, III were added in order to protect the groundwater from contamination, later to be used to drinking water supply. Using same hydrological setting and boundary condition as steady state flow model the transport model is setup. A leaking pipeline (x: 1950m, y:800-900) releasing unknown amount crude into surface. The remediation techniques such as pump and treat method was used to ascertained respective water quality where contaminated concentration should not exceed 6mg/l. For remediation measure, the best location of pumping well (x: 2000m, y: 950m) and pumping rate 2100m^3/day, in which the contaminant concentration was 4.97mg/l.

2.ABSTRACT

The aim of this modeling report is understand the application of ground water modeling techniques using VISUAL MODFLOW, MODPATH and MT3DMS software tool. In our case study, the model was setup to solve the optimization of groundwater abstraction from alluvial sediment, and later protection zones were added to protect drinking water supply. Furthermore remediation techniques were applied to re-mediate contaminated water affected by burst of crude oil pipeline. Here in this model, we use both groundwater flow model and transport model.

3. INTRODUCTION

The software MODFLOW, is used to find out the numerical groundwater flow, which contains 3-D model. The MODFLOW is initially developed by the U.S Geological Survey. The main objective of this modeling report is to use the visual MODFLOW to stimulate the ground water flow and transport method in the investigated region. The ground water flow model is used mainly for distribution of head, while the solute transport is used for the concentration of solute through advection and dispersion.

In model, the primary case study is to do optimization of groundwater abstraction from alluvial sediments using groundwater flow model and secondary study was to solve contaminant problem of investigated area by using transport model. Taking conceptual model into consideration, with given hydro geological data from the investigated region, groundwater flow model was setup in order stimulate steady state and transient flow using MODFLOW software. The model calibration is done by modifying the hydraulic conductivity for steady state flow and specific yield for transient flow in order to get better fitting with calculated head and observed value so to solve the bank infiltration with maximum abstraction rate and delineation of well head protection area using particle tracking tool and MODPATH.

Solute transport model is setup in order to solve the contamination problem using MODFLOW AND MT3DMS. The model calibration of transport model by adjusting dispersitivity and effective porosity is done to match calculated and observed concentration of observation well. Sensitivity analysis is done on both ground water flow and transport model. Here the model is run by adjusting one parameter by ±10% value and keeping other parameter constant.

4 MODEL SET UP

4.1CONCEPTUAL MODEL

Pictorial representation of the groundwater flow system. Conceptual model has been set before running the numerical model by setting the dimensions of the model and the design of the grid figure 1. The investigated aquifer is situated in an alluvial valley fill. The aquifer consisting of the sediments of sandy silts with low hydraulic conductivity (low resistivity) with formerly active river channel gravel deposits with high hydraulic conductivity (high resistivity). Hydraulic conductivity values in this case were assumed to be Kx= Ky = ten times of Kz. The aquifer is unconfined, anisotropy and heterogenic. The thickness of the aquifer at the contact with the river is 10 meters. The geometry and boundaries of the aquifer investigated is a 4500m×1500m rectangle area and boundary with river flowing was set as constant head boundary where as other three boundaries was set as no flow boundaries. For Steady state, the maximum recharge rate is 365 mm/yr; for unsteady state, a time series of weekly recharge rate for 847days were considered whereas Transport models, the crude oil was considered as constant concentration boundary.

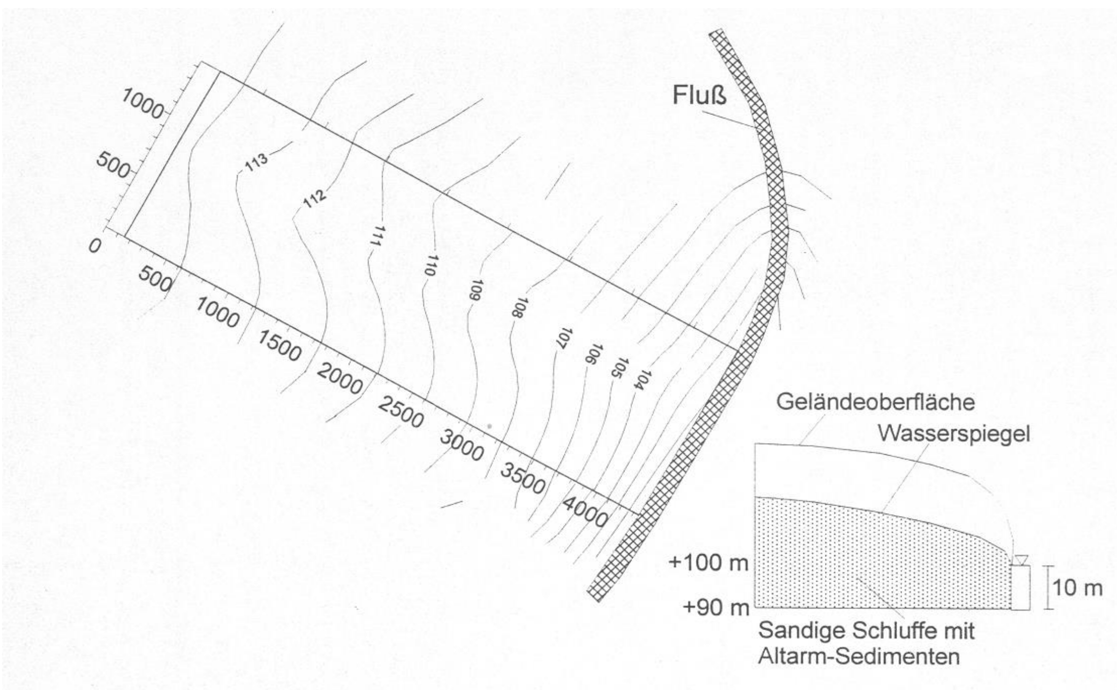

Figure 1: Hydrogeology of the model area.

4.2 MATHEMATICAL MODEL

4.2.1.STEADY STATE MODEL

Steady state flow occurs when the magnitude and direction of flow is constant with time throughout the entire domain. The hydraulic head doesn't change with time in a steady state flow system. This does not mean that in a steady state system there is no movement of groundwater, it simply means that the amount of water within the domain remains the same, and that the amount of water that flows into the system, is the same amount as flows out. According to Darcy law and mass of conversation General governing equation for steady state, heterogeneous, anisotropic conditions, without a source/sink term called as LAPLACE EQUATION

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}+\frac{\partial^2 h}{\partial z^2}=0$$

AND with a source/sink term termed as POISSON EQUATION

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}+\frac{\partial^2 h}{\partial z^2}=-\frac{q}{K}$$

4.2.2.TRANSIENT FLOW MODEL

Transient flow occurs when the magnitude and direction of flow change with time, which means the amount of water that flows entering domain and leaving domain is different. It is used analyze time-dependent problems. For transient conditions, a storage term has to be added to the flow equation. The specific storage coefficient Ss [m^{-1}] is equivalent to the storage coefficient per aquifer thickness (Eqn.1) whereas Eqn. 2 is the general flow equation form to describe hydraulic head for an anisotropic and heterogeneous medium.

$$S_s\frac{\partial h}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K\frac{\partial h}{\partial z}\right)+q$$

Where Specific Storage ,$S_s = V / (\Delta x\ \Delta y\ \Delta z\ \Delta h)$

4.2.3. TRANSPORT MODEL

Transport model includes advection and dispersion solute transport model is essential tool solving the groundwater quality. Main mass transport mechanism is advection. The model is important for groundwater protection and remediation.

a) Advection

The advection term describes the transport of miscible contaminants at the same velocity as the groundwater. For many practical problems concerning contaminant transport in groundwater, the advection term dominates.

$$v = (v_x, v_y, v_z) = \left(\frac{-K_{xx}}{n}\frac{\partial h}{\partial x}, \frac{-K_{yy}}{n}\frac{\partial h}{\partial y}, \frac{-K_{zz}}{n}\frac{\partial h}{\partial z}\right) = -\frac{K}{n}\, gradh$$

b) Interpolation of Linear Velocity

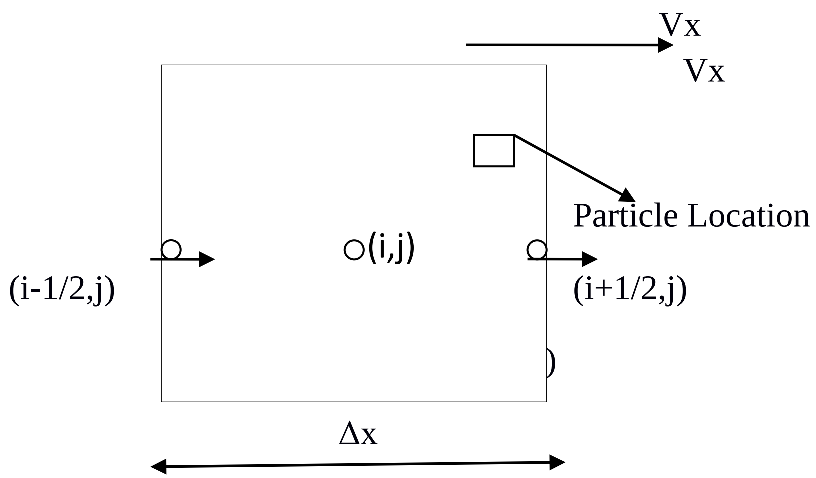

Figure 2: Interpolation of Linear Velocity

According to MODFLOW and MODPATH, linear interpolation to compute velocity V_x in the x direction(figure 2)

$$V_x = (1\text{-}f_x)V_{x(i-1/2)} + f_x V_{x(i+1/2)}$$

Where $f_x = (x_p - x_{(i-1/2)}) / Dx_{i,j}$, x_p is the x coordinate of the particle , i,j are indices in the cell containing particle, therefore similarly is done in y and z direction.

c) Inverse particle tracking

This particle tracking is done using MODPATH in order delineate the protection zones in the catchment for drinking water supply. Using this techniques particle partially placed in the well and adjective velocity is performed by negative linear velocity. It is used evaluate the protection zones (I, II, III) of the pumping well in catchment using particle tracking in MODPATH.

$$\frac{dx_p}{dt}(t) = -v_x\left(x_p(t), y_p(t)\right)$$
$$\frac{dy_p}{dt}(t) = -v_y\left(x_p(t), y_p(t)\right)$$

d) Hydrodynamic dispersion

Hydrodynamic dispersion is total dispersive flux can be combined by mechanical dispersive mass flux and diffusive mass flux as below,

$$J_{dis} = J_{mdis} + J_{dif} = -n(D_{disp} + D_m) = -nD\Delta C$$

According to conceptual model, the mathematical model for the investigated aquifer was set. The lower-left corner of the study area as original point, on x axis the lower boundary perpendicular to river flow direction, on y-axis the left boundary parallel to river flow direction. Unit of coordinate is meter.

5.MODELLING USING MODFLOW SOFTWARE

Visual MODFLOW is a proven standard for professional 3D groundwater flow and contaminant transport modeling using MODFLOW-2000 used for steady state and transient model, MODPATH used to form path lines and MT3DMS AND RT3D used for particle tracking and transport model.

6.PARAMETER FOR SETTING THE MODEL

Geometry

Number of column =15	Xmin=0	Xmax = 4500
Number of rows =15	Ymin=0	Ymax = 1500

Material Properties

Flow Model

Parameter Name	Value	Units
Kx	10	m/d
Ky	10	m/d
Kz	1	m/d
Ss	1E-5	1/m
Sy	0.20	
Eff. Por.	0.15	
Tot. Por.	0.30	
Recharge	0.001	m/d

for steady state flow

Recharge APPENDIX 3 for transient flow

Boundary Conditions

Constant head	101.4 m 100m	boundary along the river from top to bottom
Constant concentration	100mg/L	
Initial conductivity	100m/d	

7.CALIBRATION PROCESS AND SENSITIVITY ANALYSIS

During model calibration, parameter values are adjusted until the simulated head matches the observed value. The simulated head representing the observation well is compared with the measured head at the node. Model calibration solves the inverse problem. these were performed to steady- state, transient and transport data sets. In the steady- state, hydraulic conductivities (resistivity) were the calibration values which were taken from observed water head distribution where as in the transient calibration, Storage coefficient (S) is either storagetivity or specific yield were calibrated by using three hydro-graphs; in the transport model calibration, effective porosity and longitudinal dispersivity were calibrated by using observed and calculated contamination concentration (phenolics) data.

Sensitivity analysis is used as an uncertainty analysis after calibration model. It is the process of changing parameters to see the effects on the model results. The most sensitive parameters need to be checked for accuracy to ensure the best model. During this sensitivity analysis, calibrated values for hydraulic conductivity, storage parameters and dispersion were systematically changed within a plausible range.

8.GROUND WATER FLOW MODEL SETUP

8.1.CALIBRATION OF STEADY STATE MODEL

Calibration of steady state model is helpful in order to determine the spatial representation of the parameter field, that is mainly on hydraulic conductivity of the two sediments (gravel and silts). The equipotential map (Appendix 1) and geoelectrical measurement (Appendix 2) as input data for parameter adjustment. These input data shows the difference between apparent resistivity of channel gravel and floodplain silt. In order to fit the equipotential map, hydraulic conductivity of two sediment was set to get good calibration. According to figure (3), the white region shows hydraulic conductivity of channel gravel where Kx= Ky= 156 m/day, Kz= 15.6 m/day (Kx=Ky= 10 Kz) which means that high hydraulic conductivity (table 1) and blue region shows hydraulic conductivity of the floodplain silt where Kx=Ky=8.5m/day, Kz=0.85m/day which mean low hydraulic conductivity. The red region shows constant head. Figure 4 shows Hydraulic Conductivity after calibration in steady state

Material	Hydraulic Conductivity (m/sec)
Gravel	$3x10^{-4}$ to $3x10^{-2}$
Coarse sand	$9x10^{-7}$ to $6x10^{-3}$
Medium sand	$9x10^{-7}$ to $5x10^{-4}$
Fine sand	$2x10^{-7}$ to $2x10^{-4}$
Silt, loess	$1x10^{-9}$ to $2x10^{-5}$
Till	$1x10^{-12}$ to $2x10^{-6}$
Clay	$1x10^{-11}$ to $4.7x10^{-9}$
Unweathered marine clay	$8x10^{-13}$ to $2x10^{-9}$

Table 1: Hydraulic conductivity of unconsolidated sediment

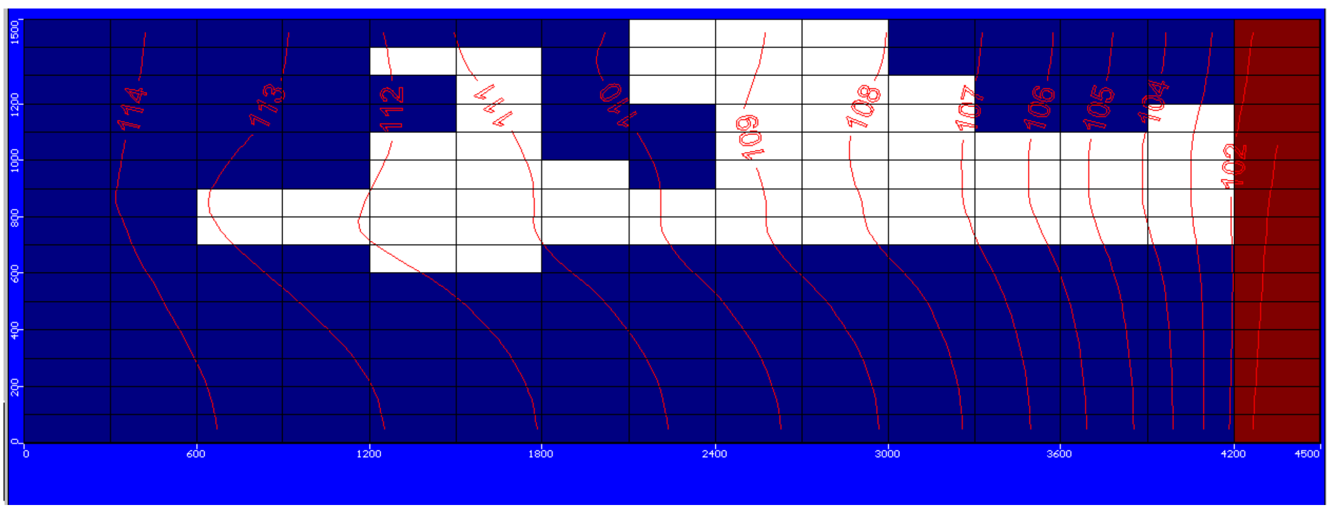

Figure 3 : Equipotential Map and Hydraulic Conductivity

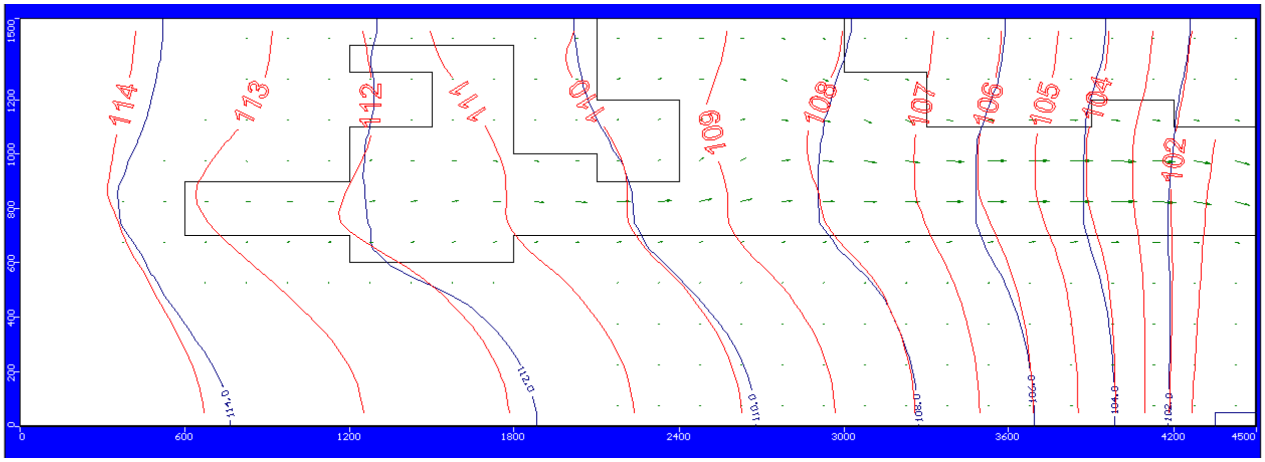

Figure 4: Hydraulic Conductivity after calibration in steady state

Sensitivity Analysis of steady state model was done by the changing the hydraulic conductivity of two sediment by ± 10%. Here the model is run by adjusting one parameter by ±10% value and keeping other parameter constant. If parameter in model has high response then parameter is assumed to be accurate. For high hydraulic conductivity zone, fig5 shows when the hydraulic conductivity increased by 10%, the equipotential line got shifted more (about 800m) towards left side, whereas fig6 shows when the hydraulic conductivity decreased by 10%, the equipotential line got shifted more(about 800m) towards right side. For low hydraulic conductivity zone, in fig 7, shows when the hydraulic conductivity increased by 10%, the equipotential line got shifted less(about 200m) towards left side where as in fig 8, shows when the hydraulic conductivity decreased by 10%, the equipotential line got shifted less(about 200m) towards right side.

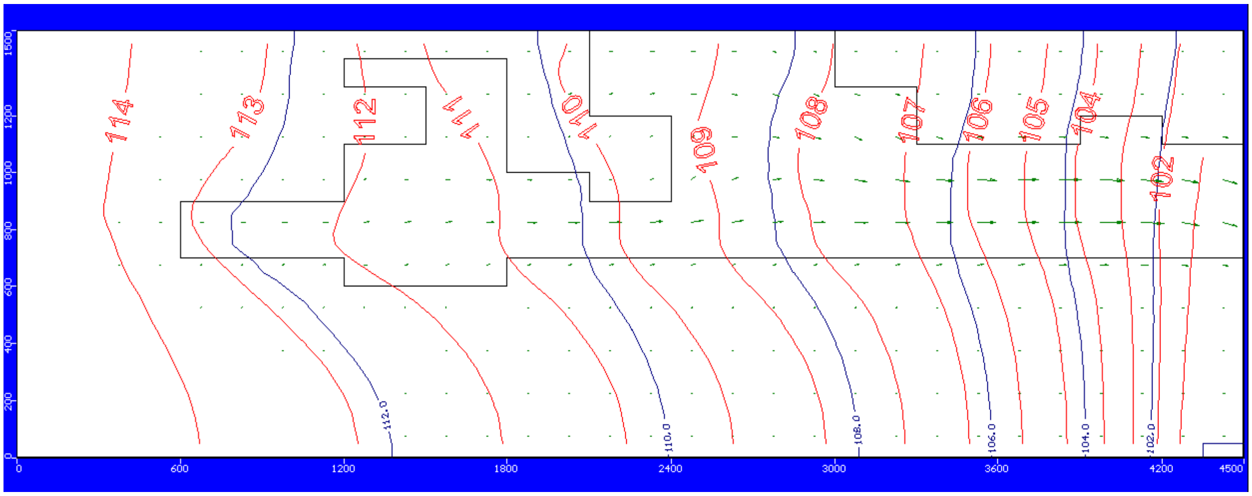

Figure 5: Sensitivity Analysis of the high hydraulic conductivity zone when the hydraulic conductivity increased by 10%.

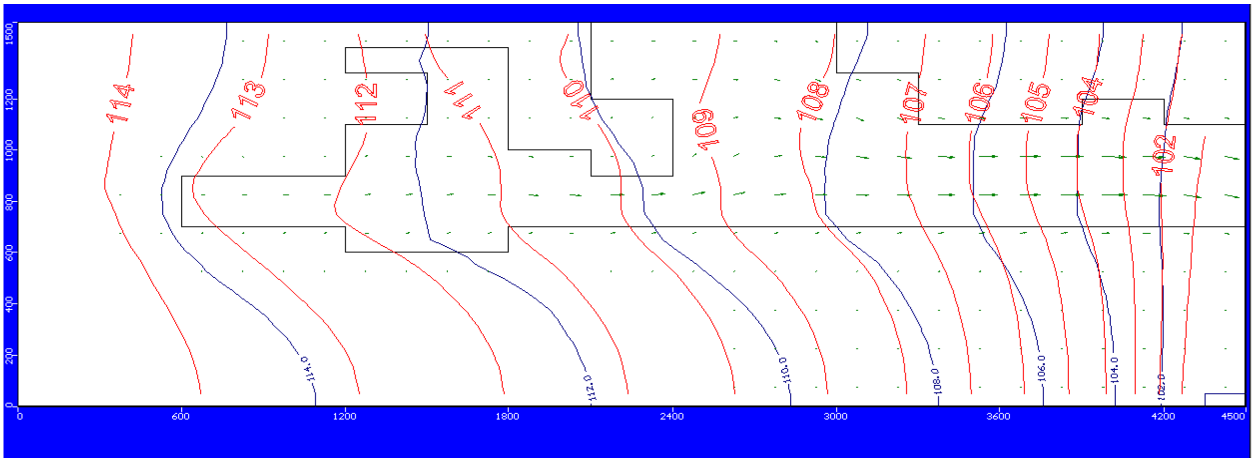

Figure 6: Sensitivity Analysis of the high hydraulic conductivity zone when the hydraulic conductivity decreased by 10%.

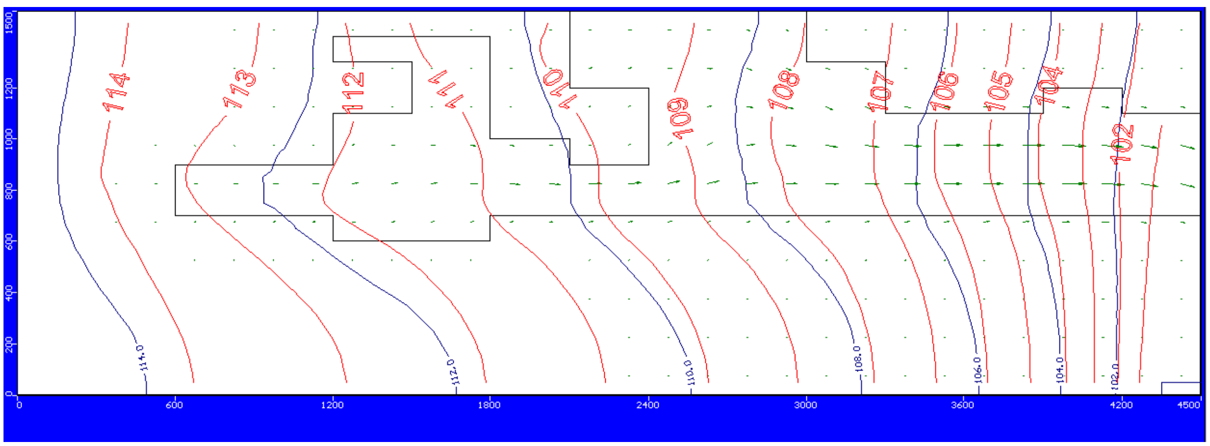

Figure 7: Sensitivity Analysis of the low hydraulic conductivity zone when the hydraulic conductivity increased by 10%.

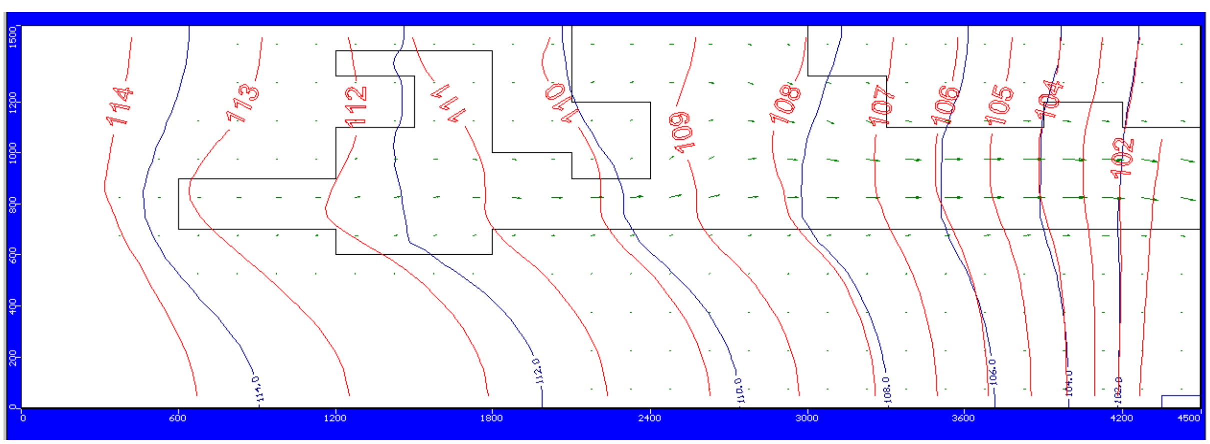

Fig 8: Sensitivity Analysis of the low hydraulic conductivity zone when the hydraulic conductivity decreased by 10%.

8.2.CALIBRATION OF TRANSIENT FLOW MODEL

When groundwater level changes with time, transient flow model was used. Transient model used to determine the specific yields (Sy). For transient model, steady state head distribution was taken as preliminary model. The time series of weekly recharge rates for 2.5 years i.e 847 days (in Appendix 3) and hydrograph of three observation well obs1(x= 1350m,y= 350m); obs2(x=2850m,y= 1050m); obs3(x=3150m,y=850m) was given. These observations well are used for calibration of transient flow model for unconfined aquifer, storagetivity(S) is volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in head, where Sy is specific yield.

$$S = S_y + h\,S_y$$

For calibration of transient flow model, specific yield is taken as key parameter. After calibration, specific yield (Sy=0.26) shows a good fitting(figure 10) .In figure 9 observation well 1 installed in the floodplain silt material whose specific yield is 0.2 and for observation 2 and 3 well is installed in channel gravel as varies with fine to coarse gravel therefore only one value is used (Sy=0.26) (Table 2)

Material	Specific Yield
Gravel, coarse	21
Gravel, medium	24
Gravel, fine	28
Sand, coarse	30
Sand, medium	32
Sand, fine	33
Silt	20
Clay	6
Sandstone, fine grained	21
Sandstone, medium grained	27
Limestone	14
Dune sand	38
Loess	18
Peat	44
Schist	26
Siltstone	12

Table 2: Specific yield of the material

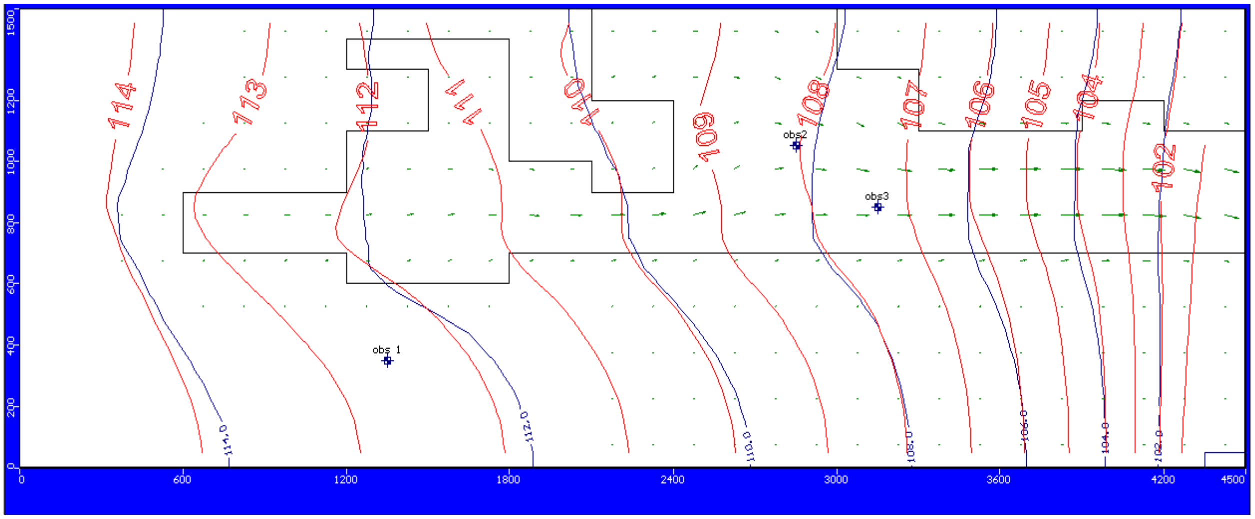

Figure 9: Transient model after calibration

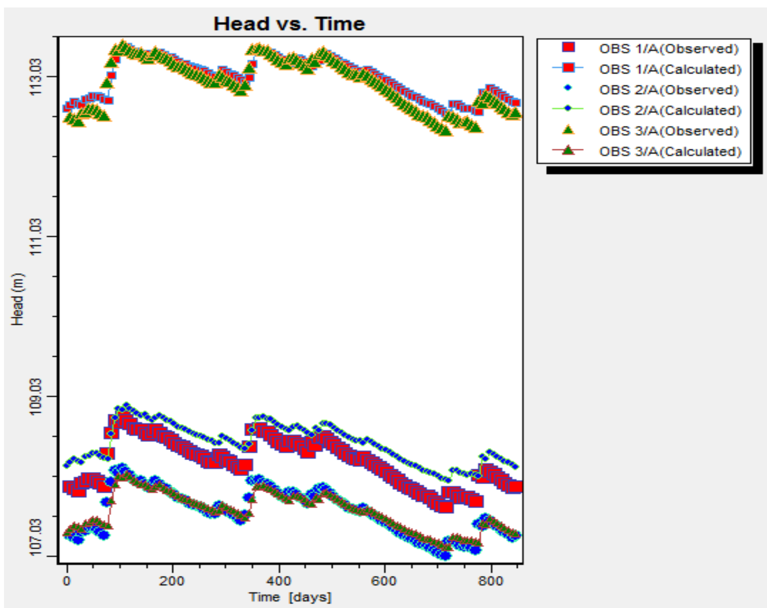

Figure 10: Transient hydrograph of three observation wells Sy=0.26 after calibration

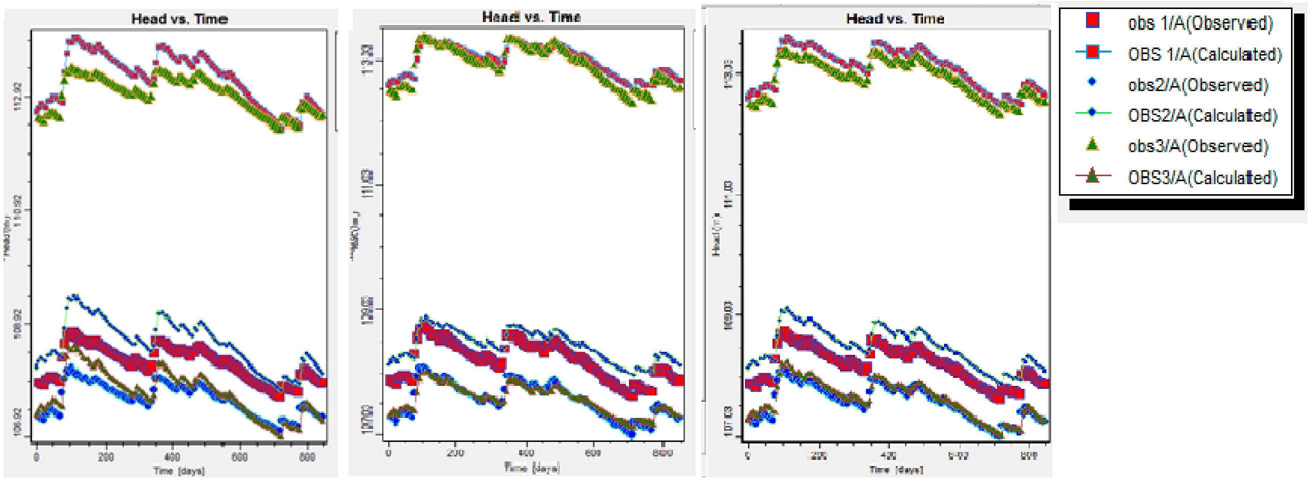

Figure 11: Sensitivity analysis of specific yield Sy=0.12, Sy=0.3, Sy=0.2

Sensitivity Analysis of transient flow model was done by the changing the specific yield (Sy) by ± 10%. Here the model was run by changing Sy values and later graph was observed hydraulic head and time which show calculated and observed values of three observation wells. Here range of value is variable as we considered one value of specific yield in order to have good fitting. Whereas observation 1 good adjusted values since silty sand are located on it whereas as observation 2 and 3 are located at coarse gravel material to fine(Figure11.)

9.TRANSPORT MODELLING

9.1.LOCATION OF PUMPING AND ABSTRACTION RATE OPTIMIZATION

In order to choose appropriate pumping well location and pumping rate, so that it work in drought condition and cannot abstract contaminant water from river. Pumping well (x=3750m, y=950m) was located at high hydraulic conductivity zone near river in order to contamination. In order to see to trace the element visible, particle is released near to river. For particle tracking, model was run using MODPATH, where particle was run in forward direction.

Transient model was run at given recharge rate at 847 days (appendix 3). In figure 12, pumping well location at abstraction rate of 6900m3/day due to which there was a cone of depression and change in flow pattern. The particle was released near to river at time =700days in order to optimize the drought condition of the well and avoid the bank infiltration.

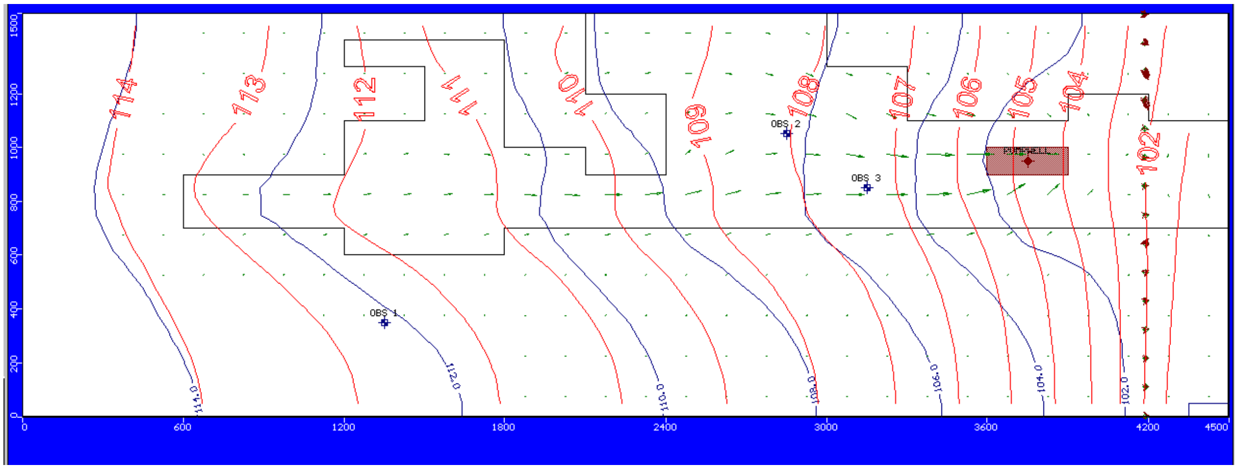

Figure 12: pumping well location and abstraction rate 6900m3/d in transient model

9.2.PROTECTION ZONES

After optimization of the position and pumping rate of the abstraction well, the ground water protection zones were added in order to protect the groundwater from contamination, later to be used to drinking water supply. In this model, three different protection zone were added to catchment area i.e protection zone I, protection zone II, protection zone III. The model is run at steady state and particle was added in form of circle around pumping well. It was run in MODPATH in backward tracking mode. Later its observed using path lines.

Protection zone I were close to surrounding area of the pumping well of radius 5m, in order to prevent contamination of well. Protection Zone II with radius 50m, water need 60 days reach the pumping well (Figure 13) where as in protection zone III with radius 50m was added around pumping well of time 2000days(Figure 14) here the entire catchment area is feeding on well. therefore the protection zone II reference time is 60 day line where as protection zone III its 2000days were chosen for the delineation of well head protection.

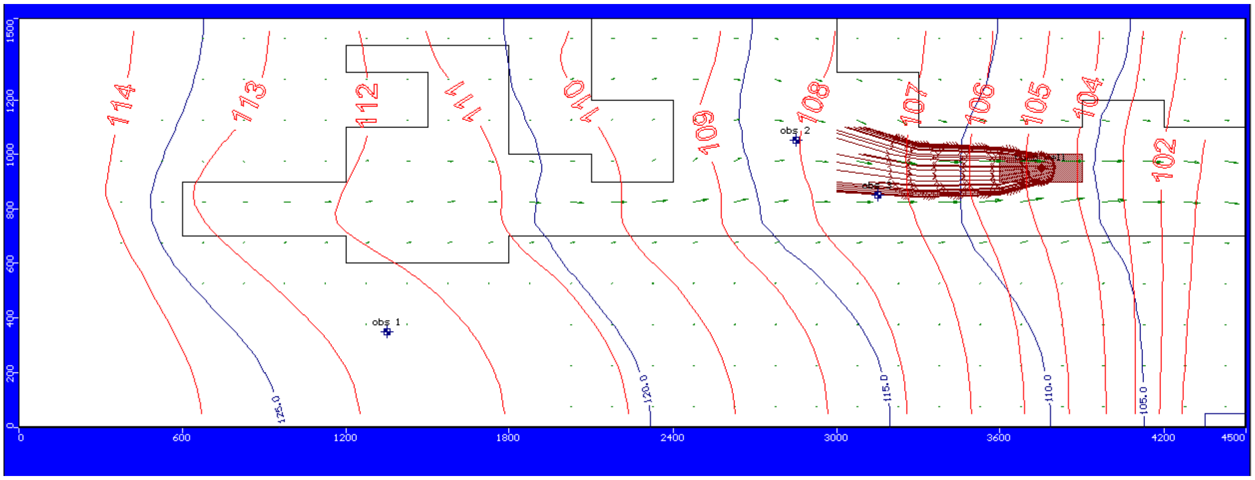

Figure 13: Protection zone II

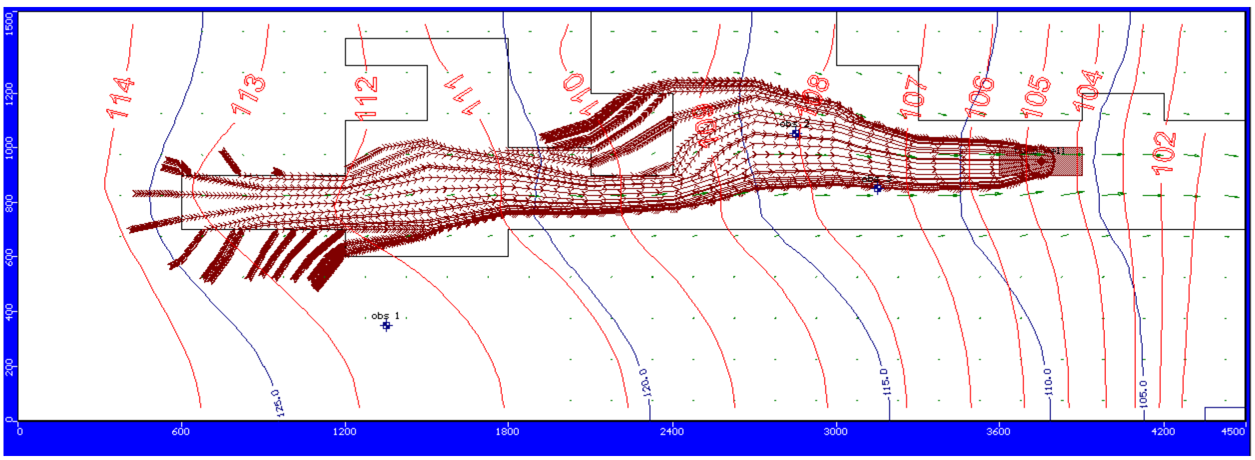

Figure 14: protection zone III

9.3.ASSESSMENT OF THE CONTAIMINATION RISK BY A SOLVENT SPILL

In order to solve the problem of contamination, the solute transport model is build up. Here the unknown quantity of crude oil is being split into the subsurface of 100m length (x: 1950m; y: 800m-900m). The oil components contains BTEX-Aromatics, polycyclic aromatics as well as phenolics of concentration 100mg/l. Ground water well field is situated down gradient of the spill site at (x:3150m; y:950m). The abstraction volume of the drinking water is 7000m^3. In the observation well (c-obs2) (x: 2550m; y: 850m) as well as well close to well field (c-obs1) (x: 3150m; y: 950m), the samples are taken at regular interval and analyzed for contamination specific substances.

The below table 3 shows the values of time series versus concentration of phenolics in the observation well (c-obs2)

Time[days]	Concentration of phenolic(mg/l)
7.0	0.0
10.2	4.9
18.4	10.6
22.5	13.8
26.6	17.0
32.8	21.8
36.9	24.9
51.2	35.0
57.4	38.9

Table 3: Phenolic concentration over 58 days in (c-obs2)

9.4.CALIBRATION OF TRANSPORT MODEL

Calibration of transport model is done using the same boundary condition and hydrogeology setting of steady state flow model. In the transport calibration, effective porosity and longitudinal dispersivity were calibrated by using time series of concentration of phenolics in observation well (c-obs 2) given in table 3. This transport model is run using MODFLOW and MT3DMS tool. After calibration, calculated and observed concentration of phenolic in observation well 2 gives good fitting when effective porosity is 0.08 and dispersivity is 10m as shown in figure (16).

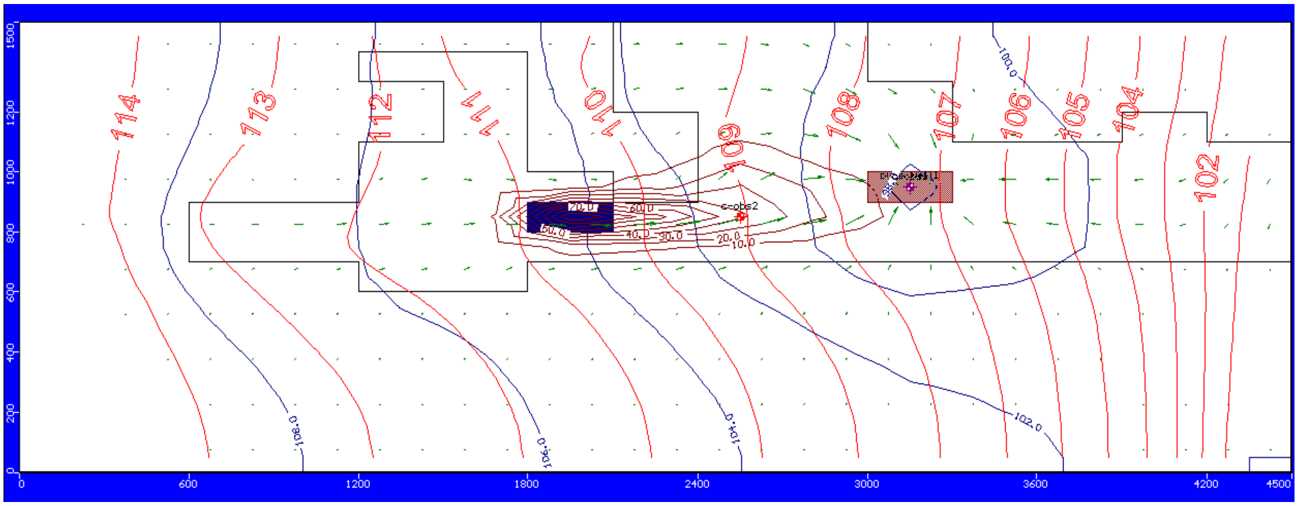

Figure 15: Transport model after calibration

In figure 15,blue color region show crude oil pipeline at (x:1950m,y=between 800m to900m)spill near to observation well (c-obs2) and pink color region shows drinking water well at location (x=3150 m, y= 950m) at abstraction rate 7000m3/day.

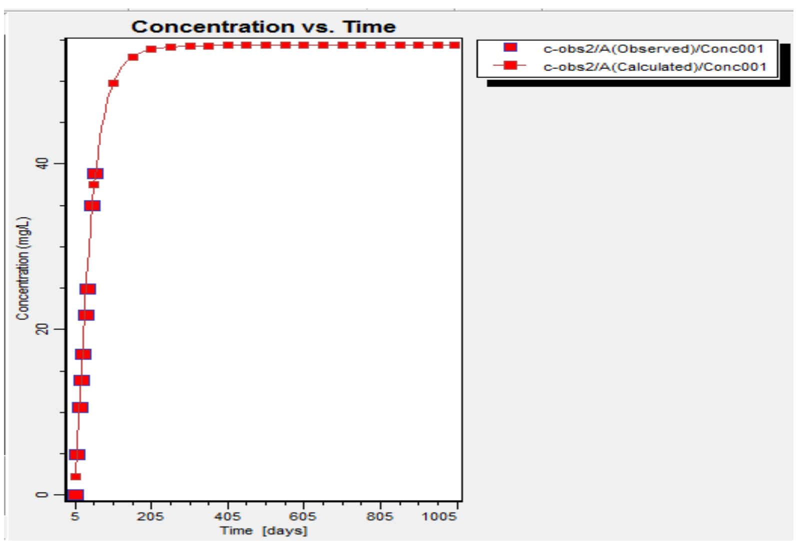

Figure 16: Model calibration of transport model (ne=0.08) and (D=10m)

Sensitivity Analysis of transport model was done by the changing effective porosity and longitudinal dispersivity by ± 10%. Here the model is run by adjusting one parameter by ±10% value and keeping other parameter constant.

The change of(± 10%) in effective porosity (ne) keeping longitudinal dispersivity constant by 10m. In the figure 17, the graph of calculated and observed phenolic concentration in observation well(c-obs2) showed worst fitting where as effective porosity (ne) of 0.08 determined accurate fitting.

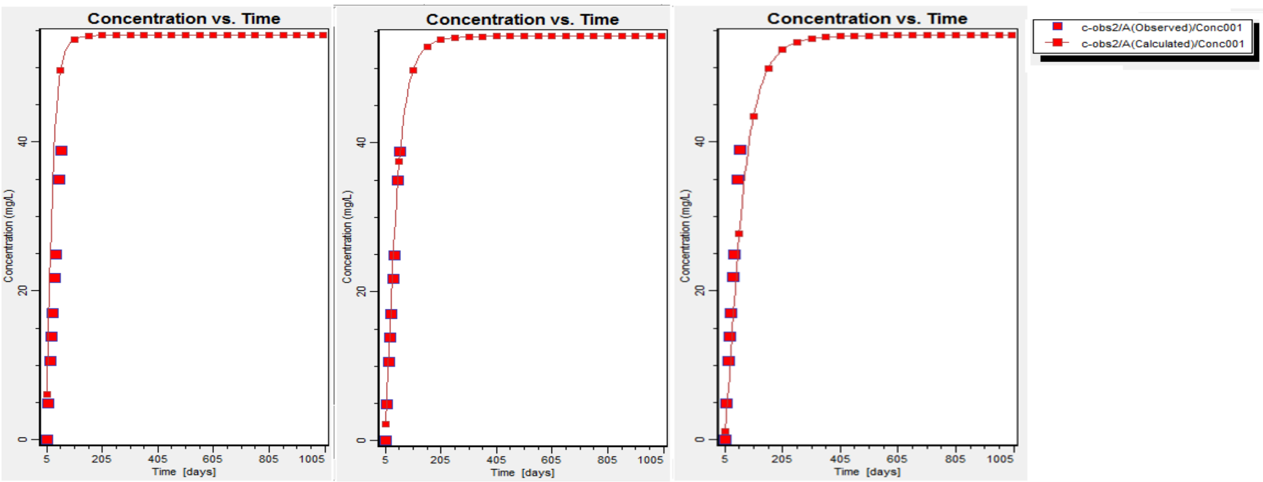

Figure 17.Sensitivity analysis showing the effective porosity ne=0.05, ne=0.08, ne=0.12 with constant longitudinal dispersivity αL =10m

Similarly keeping the porosity constant and changing the longitudinal dispersivity(αL) by (± 10%). In the figure 18, calculated and observed phenolic concentration value of observation well (c-obs2) does not varies within the curve. Therefore the best fitting of curves was seen at longitudinal dispersivity of 10m.

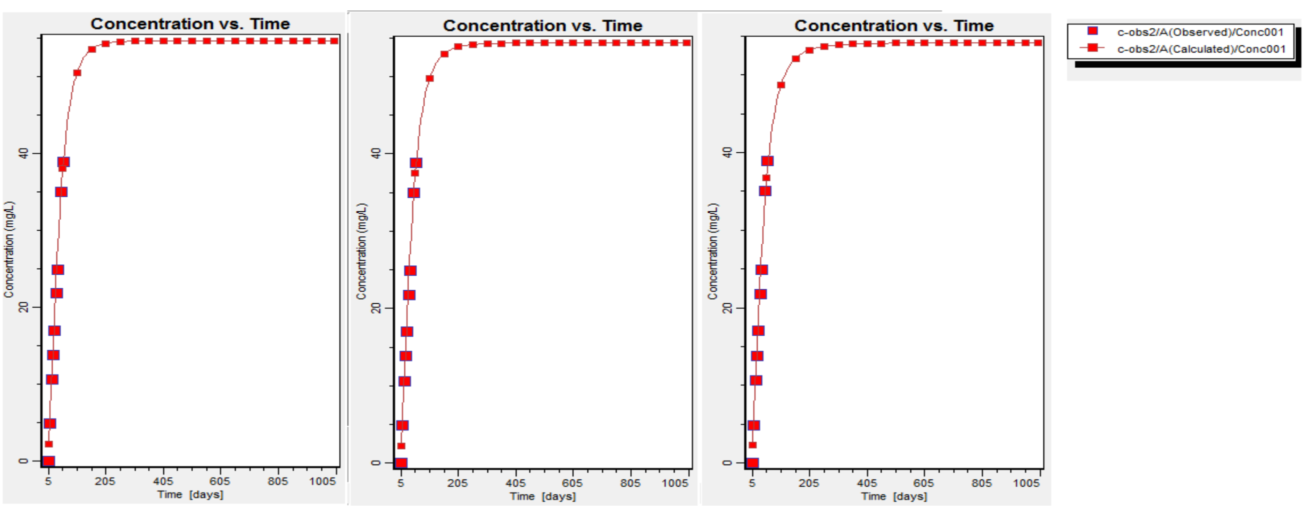

Figure 18.Sensitivity analysis of longitudinal dispersivityαL= 4m, αL =10m, αL =12m with constant effective porosity of 0.08

9.5.PLANNING OF REMEDIATION MEASURES

In the planning of remediation measurement, the pump and treat remediation techniques was employed in order to maintain the concentration of phenols from the pumping well below 6mg/l, so that the water can be used for drinking purpose. The best location of pumping well, (x: 2000m; y: 950m) at abstraction rate 2100m^3/day was placed above the crude oil pipeline. In order to maintain the daily abstraction rate of drinking water from 7000m^3/day, the well pumping rate was reduced to 6000m^3/day, lowers the concentration of phenolics below 6mg/l near to observation well (c-obs1)which is 4.97mg/l where the contaminated water is abstracted and treated outside the aquifer(figure 20)

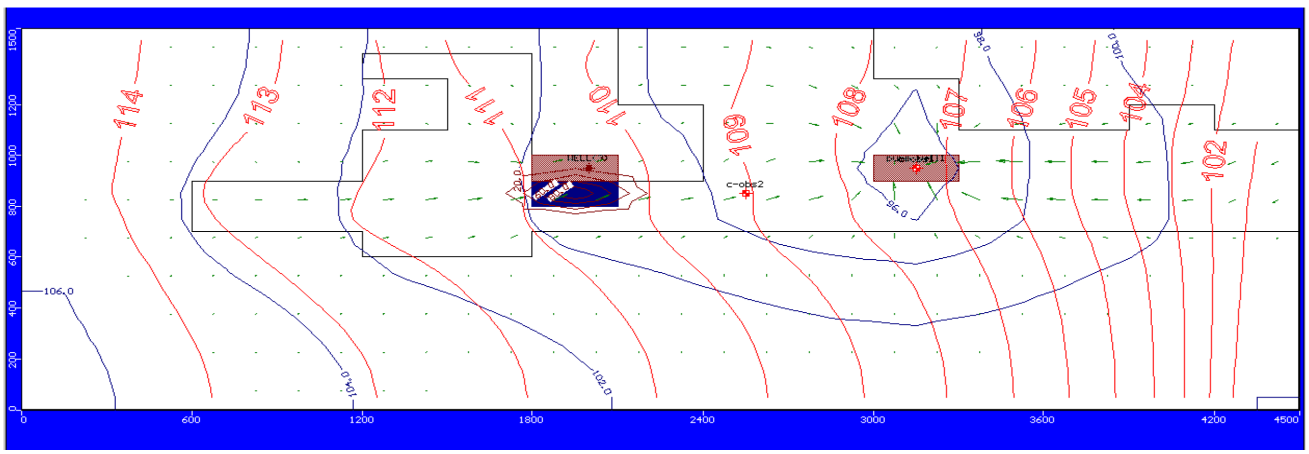

Figure 19. Pink color region represent the location of pumping well(x: 2000m; y: 950m, rate 2100m^3/day) above the crude oil pipe line using pump and treat remediation techniques

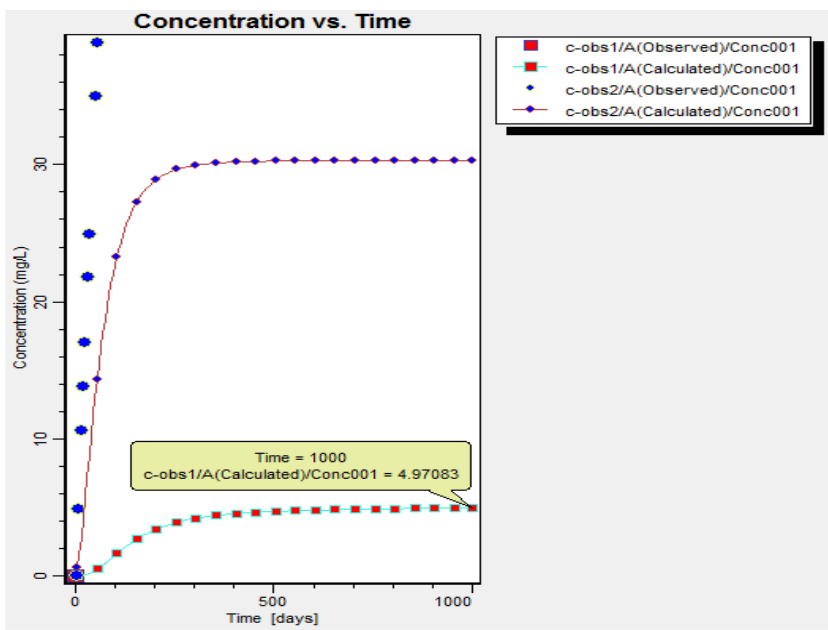

Figure 20. Concentration of phenolics after remediation below 6mg/l.

10.DISCUSSION AND CONCLUSION:

In order to solve the optimization of the ground water flow in the alluvial sediments, the well location and the pumping rate should be determined in order to avoid the bank infiltration from the nearby contaminated river and also in drought condition. Model was first calibrated using steady state flow model in order to determine the hydraullic conductivity of two sediments. Hydraulic conductivity of channel gravel where Kx= Ky= 156 m/day, Kz= 15.6 m/day, which means that high hydraulic conductivity and hydraulic conductivity of the floodplain silt where Kx=Ky=8.5m/day, Kz=0.85m/day which mean low hydraulic conductivity. Continuing with the steady state flow model transient was set up with three observation well. Here the transient flow model was done using recharge distribution over 847days to determine specific yield Sy=0.26. Here the pumping of the abstraction well location was at x:3750m; y:950m at the rate of 6900m^3/day, where there was the cone of depression was seen when the particle was released near to the river in order to optimize the drought condition of the well and avoid the bank infiltration. The partial tracking was done in the forward direction using MODPATH.

After the optimization and pumping of abstraction well, protection zones were added to protect the contamination of water for longer distance. In protection zone II travel time was 60day line, whereas protection zone III was 2000day line was chosen for delineated well head protection. The particle tracking was done in the backward direction using MODPATH.

The transport model was set up using the same boundary condition and hydrogeological setting of steady state flow model. Transport flow model calibration was done by adjusting effective porosity ne=0.08 and longitudinal dispersivity to get proper fitting curve using observed and calculated concentration of phenolics (c-obs2). After calibration with the abstraction rate of drinking water 7000m^3/day was found that the contaminant concentration was more than 6mg/l. In order to reduce the contaminant concentration below 6mg/l, the pump and treat techniques was install at well was located x: 2000m; y: 950m at the rate of 2100m^3/day above the crude oil pipeline fill. Even the abstraction rate of drinking water was reduced to 6000m^3/day in order to secure water supply per day. Therefore the containment concentration was reduced to 4.97mg/l so that contaminated water is abstracted and treated outside the aquifer.

Even sensitive analysis was done for both groundwater flow model and transport model. The sensitive analysis of steady state flow model determines the hydraulic conductivity, whereas the transient flow determines the specific yield. Here the ground water flow model depends strongly on hydraulic conductivity than specific yield. Sensitivity analysis of transport model was done by adjusting the effective porosity and longitudinal dispersivity. Here the effective porosity strong dependence than in longitudinal dispersivity by calculated and observedcontaminant concentration in observation well (c-obs2).

Numerical model such as Visual MODFLOW was theoretically created by hydrogeological process, but it can be used as predictive tool in ground waterflow model and transport model.

The model can be set up with more appropriate information of hydrogeological aspect and with precise data of the investigated area.

11.ACKNOWLEGEMENT

I would like to thank Prof. Dr.- Ing. habil. Thomas PTAK, Prof. Dr. Martin Sauter. Dr. Jannes Kordilla gave me better understanding about ground water modelling.

12.DECLARATION

I (Swathi Mohandas Surekha, matriculation number 21407887) hereby declare that this report is a presentation of my original work. No contributions of others are involved, no parts are copied from other reports or other sources. I am aware that the reports are equivalent to an examination, and that any attempt to defraud will lead to serious consequences such as removal from the registry of students.

Signature: SwathiMS

19.10.2015
Date:

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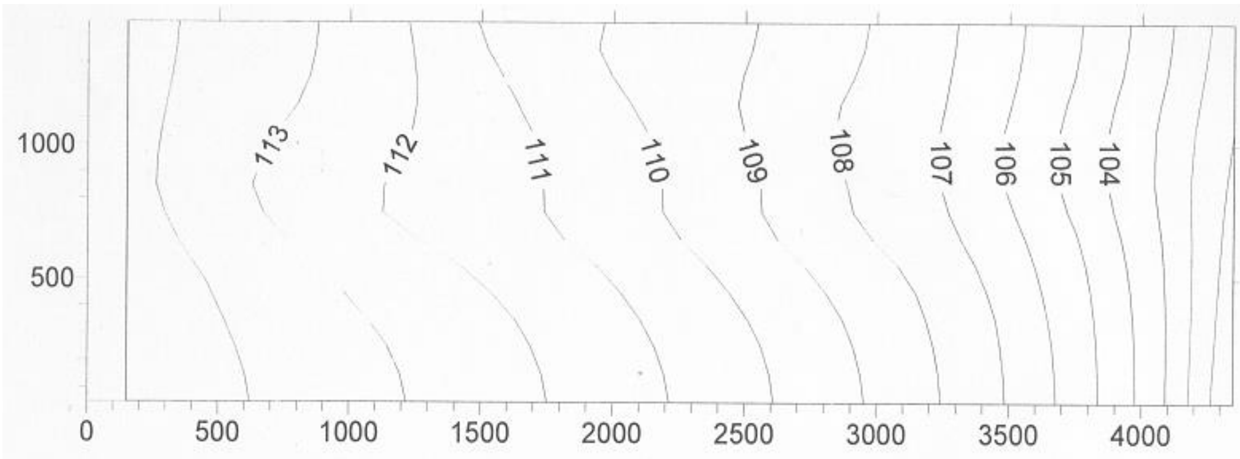
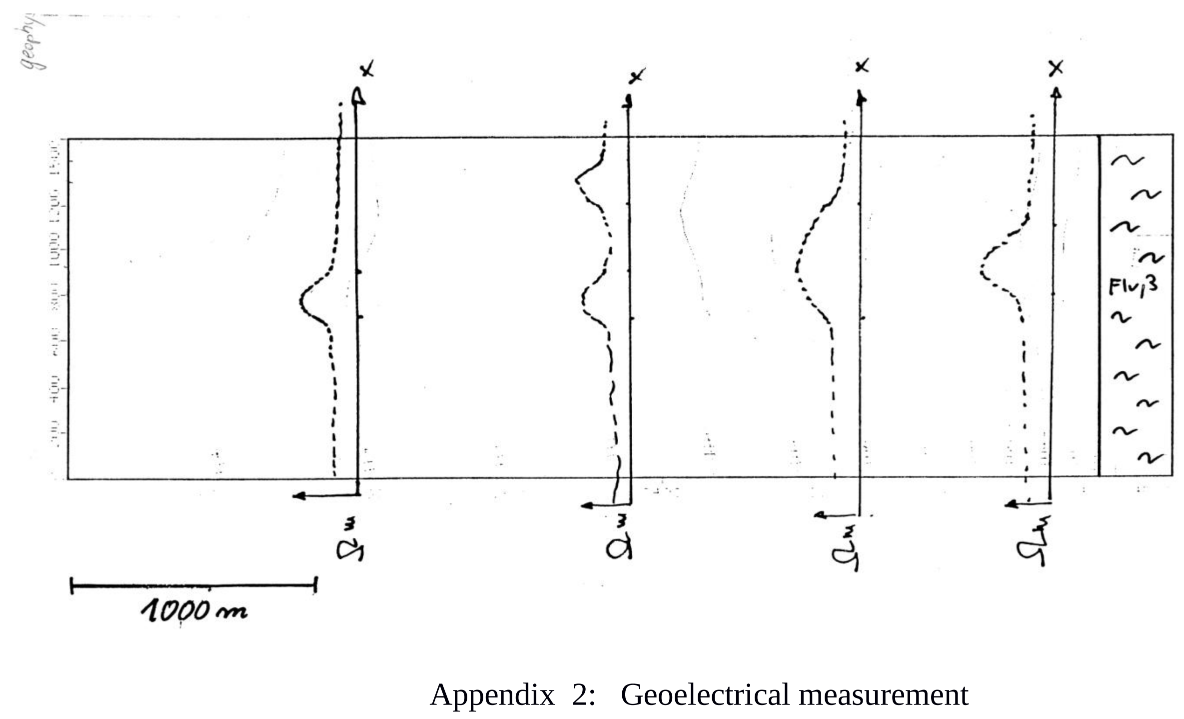
14.APPENDIX



Appendix 1: equipotential map



Appendix 2: Geoelectrical measurement

Start time (d)	Stop time (d)	Recharge (m/d)	Start time (d)	Stop time (d)	Recharge (m/d)	Start time (d)	Stop time (d)	Recharge (m/d)
0	7	0.00274	280	287	0.00396	560	567	0
7	14	0	287	294	0	567	574	0
14	21	0.0003	294	301	0.00011	574	581	0.00031
21	28	0.00369	301	308	0.00033	581	588	0.00006
28	35	0.00136	308	315	0	588	595	0.00013
35	42	0.00239	315	322	0	595	602	0
42	49	0.00099	322	329	0.0001	602	609	0
49	56	0.00026	329	336	0.003	609	616	0
56	63	0	336	343	0.00726	616	623	0
63	70	0	343	350	0.00743	623	630	0
70	77	0.01283	350	357	0.00103	630	637	0
77	84	0.00847	357	364	0.00164	637	644	0
84	91	0.00557	364	371	0	644	651	0.00039
91	98	0.00057	371	378	0.00109	651	658	0
98	105	0.00329	378	385	0.00003	658	665	0
105	112	0	385	392	0	665	672	0.00039
112	119	0	392	399	0	672	679	0.00057
119	126	0	399	406	0	679	686	0
126	133	0.00047	406	413	0.00036	686	693	0
133	140	0.00146	413	420	0.00321	693	700	0
140	147	0.0001	420	427	0.00121	700	707	0
147	154	0	427	434	0.0003	707	714	0.0002
154	161	0.00237	434	441	0	714	721	0.0062
161	168	0.00217	441	448	0	721	728	0.0009

168	175	0	448	455	0	728	735	0
175	182	0	455	462	0.00447	735	742	0
182	189	0.00076	462	469	0.00004	742	749	0.00073
189	196	0.00009	469	476	0.00396	749	756	0.00141
196	203	0	476	483	0.00161	756	763	0.00003
203	210	0.0002	483	490	0.00014	763	770	0
210	217	0.00071	490	497	0	770	777	0.01043
217	224	0.00031	497	504	0	777	784	0.00007
224	231	0.00017	504	511	0	784	791	0.00393
231	238	0.00053	511	518	0.00017	791	798	0.00014
238	245	0.0005	518	525	0	798	805	0
245	252	0.00051	525	532	0	805	812	0
252	259	0.00019	532	539	0.00031	812	819	0
259	266	0.00011	539	546	0.00086	819	826	0
266	273	0.00043	546	553	0.00026	826	833	0.00003
273	280	0.00101	553	560	0.00234	833	840	0
						840	847	0.00166

Appendix 3: weekly recharge rate 847 days