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Simulation of Groundwater Contamination Flow and Transport

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Abstract

The purpose of this study is to predict the migration pathways and concentrations of contaminants in groundwater. By constructing a model to investigate computational flow and transport of contaminants within groundwater that represents the situation at a Canadian Forces Base Borden landfill in Ontario that was used as a refuse/ waste dump from 1940 to 1973 and then as a sanitary landfill. The model will be constructed using the site- specific geology and hydrogeology data collected as part of the site characterization. The Groundwater Vistas program will be used to construct the model to produce flow and transport of the contamination source which is placed in this model. The use of three – dimensional grid and a steady- state flow condition which can be justified and thus adequately forecast plume development. The model will be extensively used to determine the area of influence from a contamination source, optimize the design, and predict the performance when using a pumping system as a remediation. In order to delineate the capture of the plume of contaminated water in this model, it is necessary to have one or more pumping wells, which pump the contaminated water from ground to surface for treatment. The pumping wells are located down hydraulic gradient of the contamination source area at various depths and locations with different pumping rates. Each well will have what is known as a capture zone, which is an area contributing flow to that particular well. Computation of capture zones to determine the optimum number of extraction wells, their locations and rate at which they should be pumped will be undertaken.

Keywords: Contamination, Dispersion, Plume, Capture Zone, Extraction Well.

1. Introduction

Water is one of the basic and fundamental requirements for the survival of human beings on the surface of the earth. Groundwater is a significant source of freshwater used by industry, agriculture and domestic users. In this present world, with the increase in the population, the requirement for safe and good quality water free from all the pollutants is essential. With the development of countries, more and more industries are being created. Industries usually produce a significant amount of waste products, which include many types of chemicals and heavy metals, depending upon the type of industry. Generally these chemicals and heavy metals are thrown into the ponds, streams drains and open fields through which they can reach the groundwater.

Also, increasing use of pesticides and fertilizers as well as atmospheric deposition constitutes threat the quality of groundwater. The use of fertilizers and manure leads to the leaching of nitrates into the groundwater and atmospheric deposition contributes to the acidification of soils that may have an indirect effect on the contamination of water. As a result of all this, the groundwater gets polluted. Nearly 80% of all the diseases arise as a result of using unsafe and contaminated water. Groundwater contamination has long been a deep concern to environmentalists due to its harmful effects on human health. The presence of different effluents in groundwater should be known as accurately as possible so that necessary arrangements can be made to provide treatment to this contaminated water [1].

The objectives

The fundamental objectives of the construction model of groundwater flow and transport are to:

1 - Investigate transport and dispersion of the plume.

2 - Predict the migration pathway of the contaminants in groundwater over time.

3 - Delineate the well capture zone for the contamination in groundwater.

4 - Quantify the effects of different pumping rates on the groundwater flow capture.

Conceptualization of Groundwater Flow Modelling System

The conceptualization of the flow system is essential because it forms the basis for model development. Steps in the development of the conceptual model include:

1) Definition of the aquifers and their properties.

2) Delineation of hydrologic boundaries encompassing the area of interest.

3) 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).

4) Distribution of groundwater recharge, pumping or injection of groundwater, leakage to or from surface-water bodies [1].

The application of existing groundwater models include gaining knowledge about the quantitative aspects of the unsaturated zone, simulating of water flow and chemical migration in the saturated zone, assessing the impact of changes of the groundwater regime on the environment, setting up/optimising monitoring networks, and setting up groundwater protection zones [2].

Groundwater Vistas software description (GV)

GV facilitates the use of complex three dimensional ground-water models through a flexible user interface that allows the modeller to create a model in a variety of ways. There are several important concepts and assumptions built into GV that will affect the way of construct a ground-water model. Groundwater is a unique groundwater modelling environment for Microsoft Windows that couples a powerful model design system with comprehensive graphical analysis tools. GV is a graphical design system for MODFLOW and other similar models, such as MODPATH and MT3D. GV displays the model design in both plan and cross-sectional views using a split window (both views are visible at the same time). Model results are presented using contours, shaded (colour flood) contours, velocity vectors, and detailed mass balance analyses. Another unique aspect of GV is its use of grid independent boundary conditions. Grid independent boundaries do not change position as the grid is modified. This allows the modeller to make major changes to the mesh without wasting time repairing the location of boundaries. GV is designed to be a model-independent system. This means that the modeller only needs to learn one software program in order to use a wide range of groundwater models[9].

Site and Model Construction Description

The landfill site at Canadian Forces Base Borden was used as a refuse/waste dump from 1940 to 1973 and then as a sanitary landfill. The aquifer is a glaciofluvially deposited sand, consisting of a complex distribution of beds and lenses of fine-, medium- and coarse-grained sand. Locally, the aquifer is heterogeneous, but on a larger scale the aquifer is reasonably uniform [3].

The three-dimensional grid represents an area of interest which covers a 328- by 656- ft area that is subdivided into 100 rows; 100 columns; 10201 nodes in each layer. The model height is 262.5 ft and it is divided into 30 layers, the thickness of each layer is 8.75 ft. The layers are subdivided into three zones, each zone has 10 layers. The row and column dimension of each cell is uniform throughout the model area. Row space is 6.56 ft and column space is 3.28 ft with an area of cell is measuring 21.52 ft^2. The groundwater flow will be constructed using a gradient that sets using constant head boundaries 260 ft at the west and 255 ft at east end of the study site, and no-flow boundaries at the north and south edges of the aquifers. The hydraulic conductivity (K) of the layers is divided into three zones each zone has its own value of hydraulic conductivity and zone number. In the top ten layers are represented zone 1 which has hydraulic conductivity $7*10^{-5}$ m/day, the middle ten layers are represented zone 2 which has hydraulic conductivity $6*10^{-5}$ m/day, and the last ten layers in the bottom is represented zone 3 with hydraulic conductivity $5*10^{-5}$ m/day. The porosity of the layers is estimated to be 33%. Recharge from precipitation is estimated to be 0.002 ft/day employed everywhere in the top layer. The contaminant source located at row 50 and column 20 as a well with an injection rate of 500 ft^3/day, and a constant concentration 2.5 mg/l applied to the top ten layers.

Methodology of Groundwater Flow Simulation

The model has been constructed and run by Groundwater Vistas software as a steady-state condition. The model application is considered to be in two distinct processes:

1) Steady- state simulation with an injection well.

2) Steady- state simulation with pumping wells.

In order, to assess the area of influence of the contamination source (dispersion), and performance using pumping wells system as a remediate regime.

2. Analysis and Plot of the Results of each Run

The First run creates data for the transport flow system for the base model without any injected flow rate during the process of this run. Fig. 1 shows the plot of contours head of all layers. The head drops gradually in a series of straight lines with a constant interval distance from 260 ft which is the constant head at the west edge to 255 ft which represents the constant head at east edge during the entire process term in this steady-state condition.

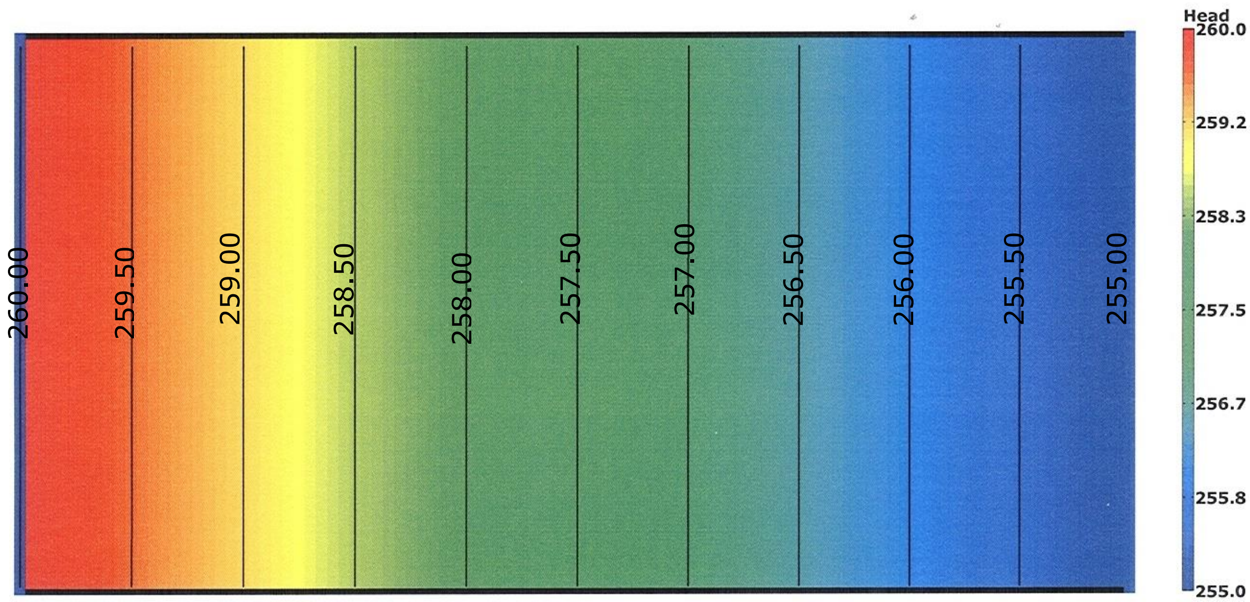

Figure 1. Contours of head through the layers for the base model.

Fig. 2 illustrates that the plot of head along row cross-section within the flow direction. It also displays the water table as a linear line between the constant heads at the west and the east edges, so the direction of groundwater flow in the model is in a western direction as the head dropped from 260 ft in the west edge to 255 ft in east edge.

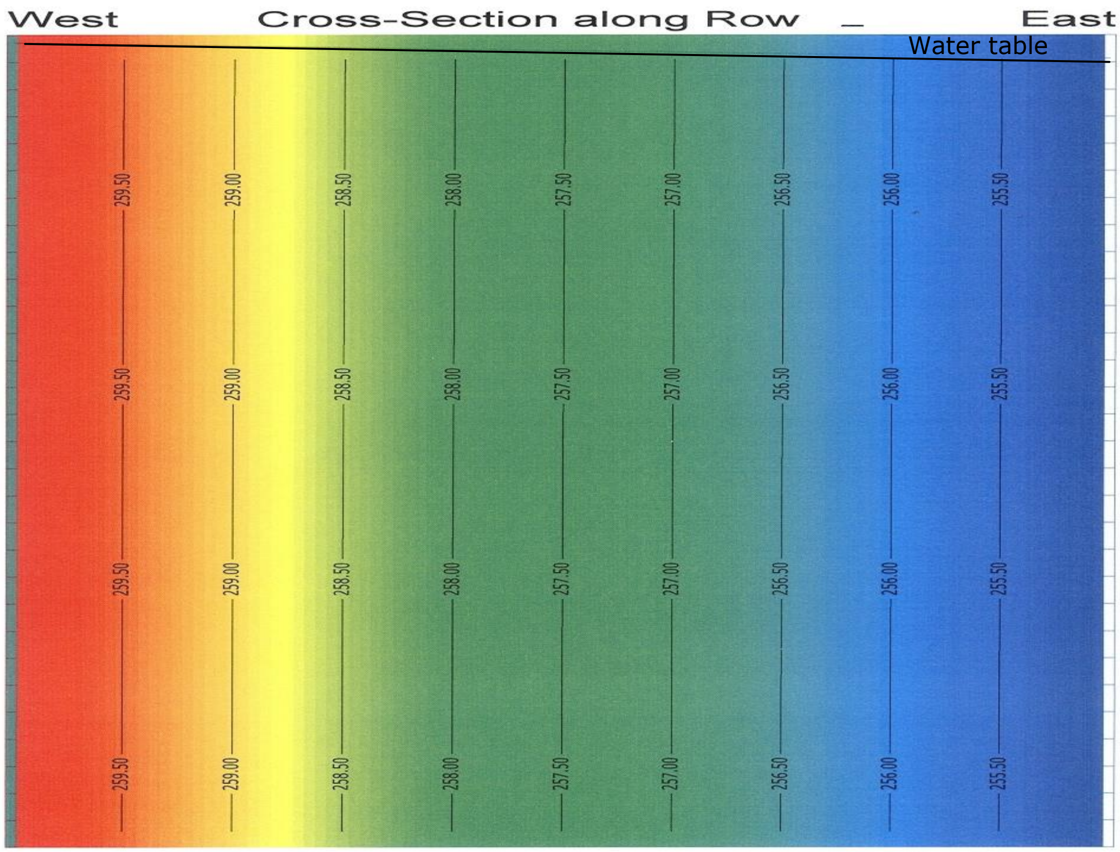

Figure 2. Contours of head along a row for the base model.

The Second run is within the injection well that introduced into the model to investigate a dispersion and concentration of the contamination within the transport of groundwater over hundred day investigation. At the beginning of the investigation period it spreads closely around the source and does not exceed more than layer 10 where is located the end of the injection well, then the process of the dispersion is developing gradually surrounding the source and extending much deeper. The final dispersion shape is expressed at the end of the hundred day investigation period where it reached the maximum at layer 20 then it declines slowly until it disappeared totally in layer 25. Fig. 3.

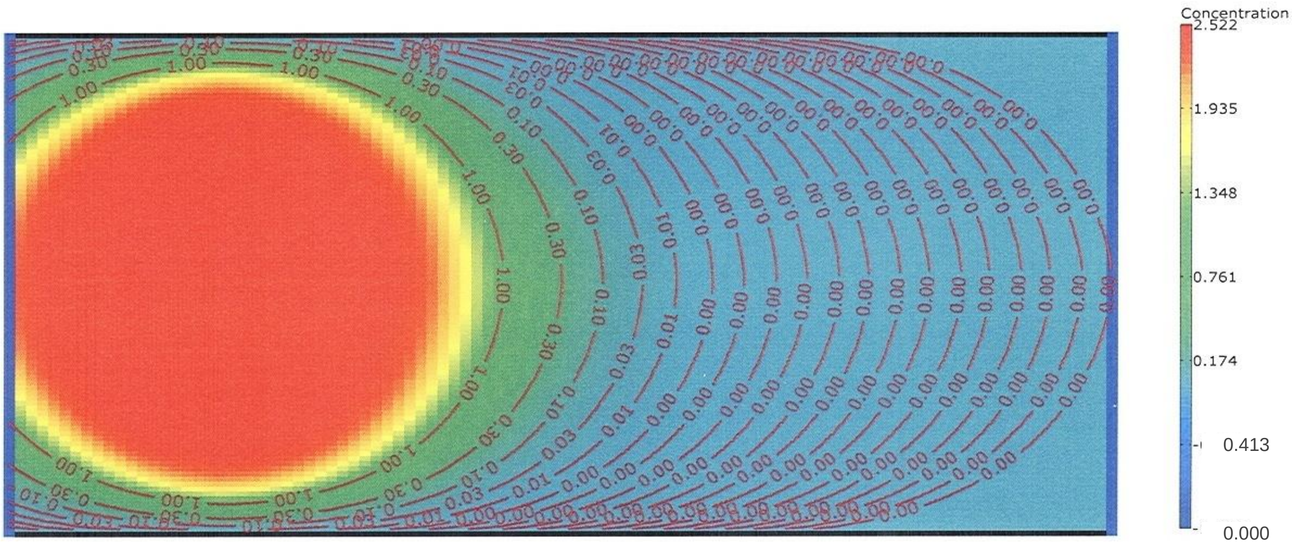

Figure 3. Dispersion & contours concentration in layer 1 at the investigation day 100

The head plot illustrates that the contours shape are converted from lines into curve where the injection well is located as result of rising of the flow rate. Then they are recovery gradually to straight lines as they move further away. Fig. 4. shows the contours head through the injected well to have risen to 261.5 ft until layer 10 then the shape head start recovery until they became as the same before the injection in layer 25. The water table increases to 261.5 ft at the injection well then returns to the normal figure before employing the injection well as it is moving further down gradient with the flow.

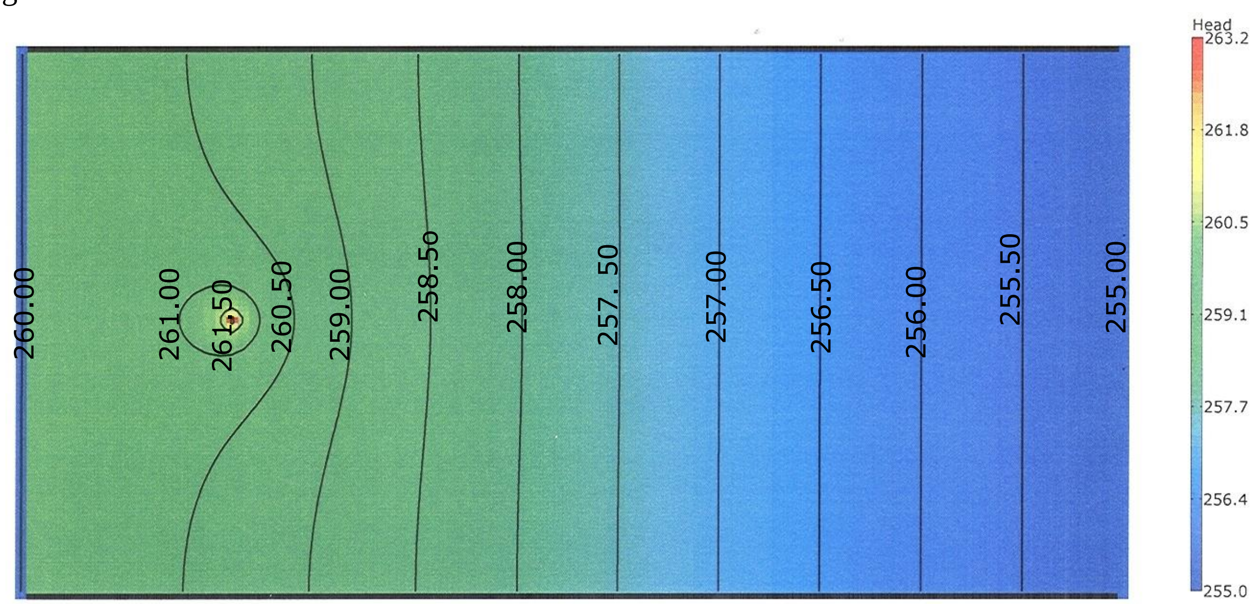

Figure 4. Contours head in layer 1 to 10 at the investigation day 100.

The third run with the extraction wells was to clean up groundwater and this is accomplished by controlling the migration of contaminants. For the design of any treatment system, the nature of the pollution source will affect the choice of system design. Where the pollution is a single point source, a simple porous barrier, single extraction or injection borehole can be justified, but if non-point sources are responsible for pollution, production must be constructed by a surrounding gallery of treatment systems for instance, trench, but this method is only suitable for shallow flow systems. In deeper flow systems, treatment can be created by injection or extraction borehole. A pumping groundwater method is applied to contain contaminations in the plume zone which has been delineated from the previous run, and to prevent groundwater flows within the contaminated plume zone.

3. Methodology of installation extraction wells

Groundwater monitoring wells would need to be installed down gradient with groundwater flow direction in the vicinity of the plume zone to give adequate coverage of plume area. The extraction wells radius is selected to fit with the cells dimensions of the constructed grid. The remediated regime process is started by:

A) A single extraction well is located approximately in the center of contamination plume with various depths and pumping rates to get sufficient control contamination from escaping with the groundwater flow. The extraction well is located at row 50 and column 40, the pumping rate starts from 48,450 ft^3/day with 157 ft depth until layer 20, then the pumping rate has decreased as the well depth increased till layer 25 then layer 30 which is located at the bottom of the model. As result of installing a single well the head dropped to zero at end of the well then it is increasing gradually horizontally and vertically down as it moves away from the well until it reached a maximum figure at the edges of the model. Therefore, the single extraction well does not capture completely the dispersion zone on the sides of well where as the head is increasing as it moves away from the well position.

B) Multi-wells is a second remediated regime to provide a sufficient capture for dispersion zone in both directions. These multi-wells start from double wells then three wells with multi depths and pumping rates. The locations of the multi-wells are distributed in line down gradient of the dispersion zone at row 40 with a distance between wells as double distance between the well and the edge.

The balance between pumping rates and wells depths of installation these multi-wells indicates that the most efficient multi-wells to prevent the dispersion from escaping is installation of the set of three extraction wells with pumping rates (-23,650 ft^3/day -24,900 ft^3/day -23,650 ft^3/day) and depth till layer 25 since the water table decreased to zero at the bottom of these wells then increased to less than 100 ft at the bottom and anywhere else on the sides of these wells, so the flow of groundwater in the gaps between the wells and between wells and edges of model is under the plume zone. This is because the maximum dispersion shape was at layer 20 then declined until it totally disappeared at layer 25 at the end of investigation period. What is more, the combined pumping rates of the set of three wells are considered to be more efficiency because they are much lower than the operating pumping rate of a single well or double wells. Fig. 5 & 6 show that the result of installing the three wells until layer 25.

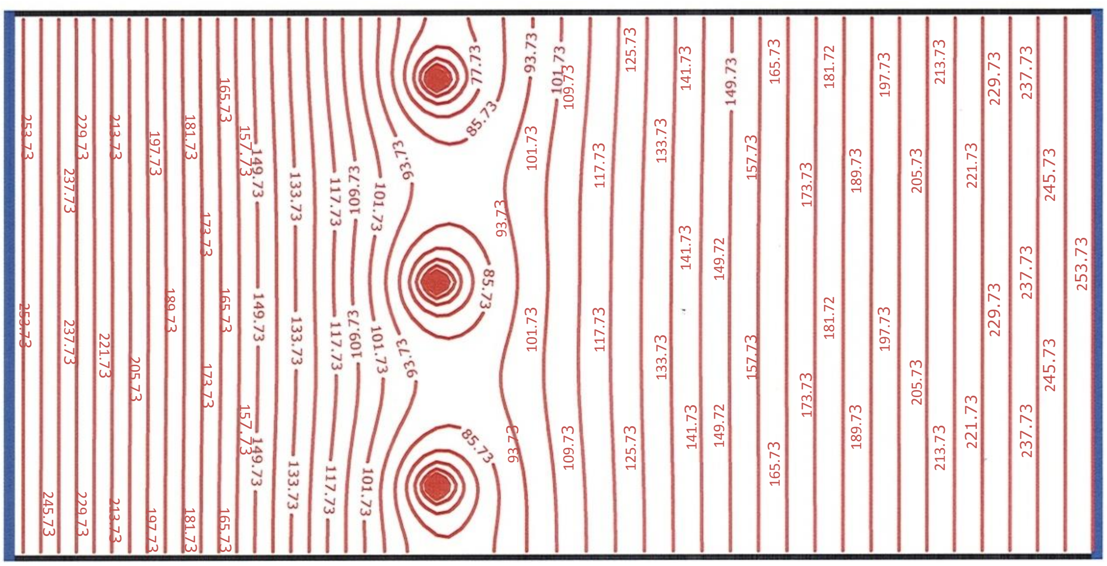

Figure 5.The capture zone through layer1with the three extraction wells till layer 25.

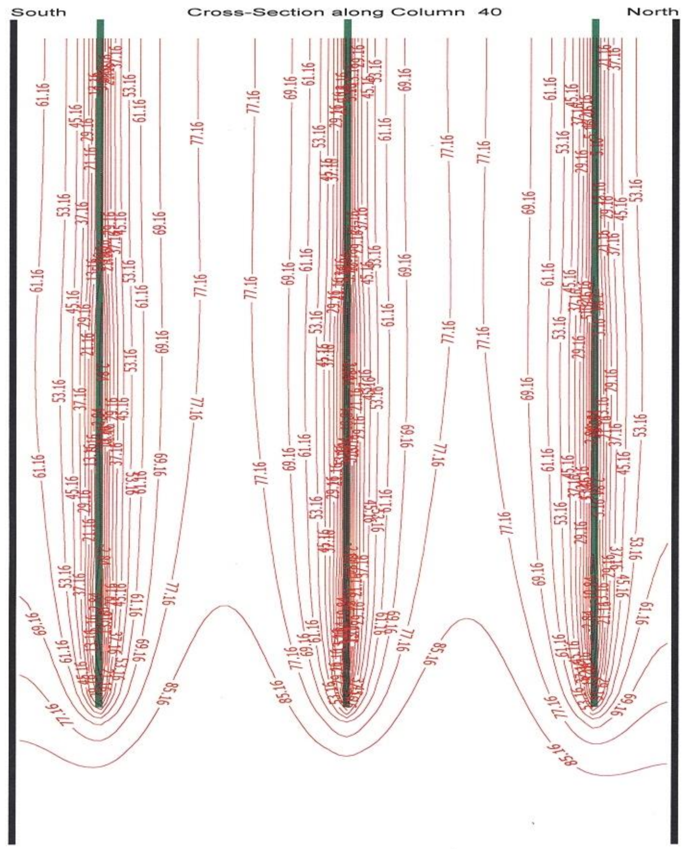

Figure 6.The head contours along the extraction wells a cross the flow direction.

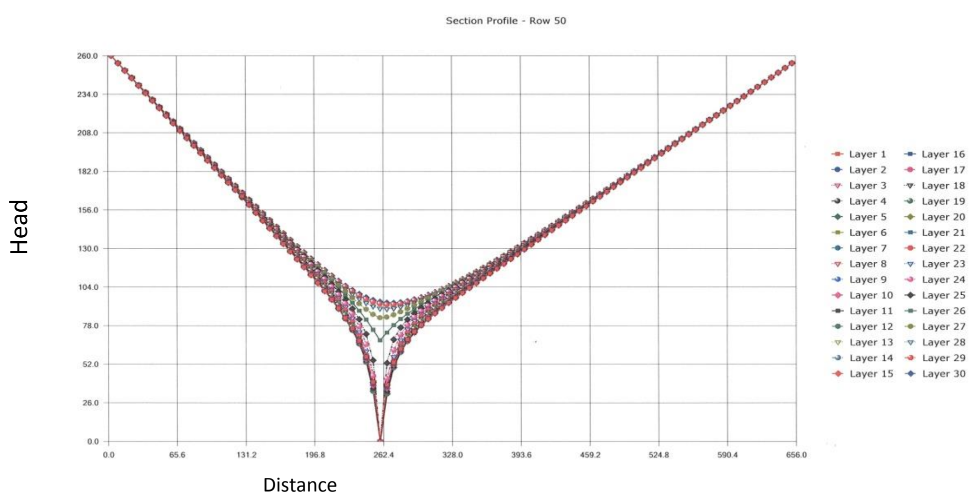

Figure 7. The head profile at the extraction well till layer 25

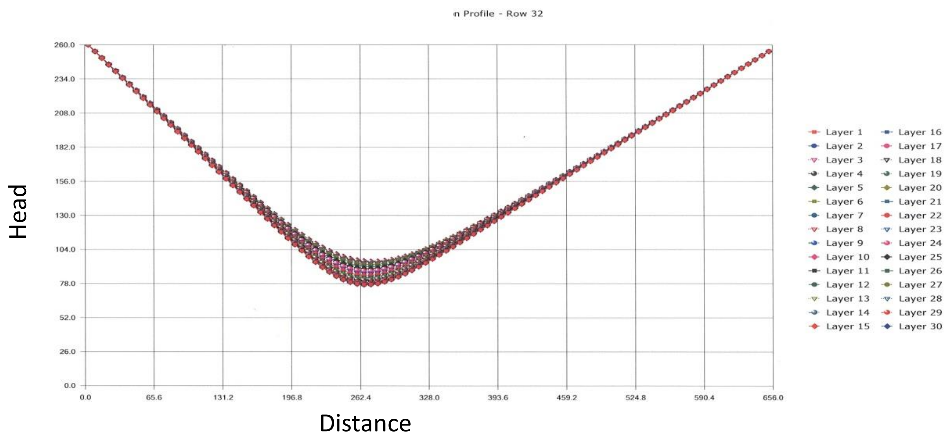

Figure 8.The head profile between the extraction wells till layer 25

4. Conclusion

Using the Groundwater Vistas software it was shown that the groundwater flow and transport model seems to be able to predict an accurate level of concentrations and dispersion plume zone that spread from the contamination source. Particularly, in term of time investigation, it seems very well to address the shape of the plume. The results of running the model clearly demonstrate that the performance of the set of extraction wells and revealed the efficiency of using set of wells in reducing pumping rates and wells depths that were tackling contaminants escape from the plume zone to flow with the groundwater. The analysis has been concluded that the optimum performance was the application of the three wells until layer 25 within the combination of the pumping rate of 24,900 ft^3/day in the middle well and 23,650 ft^3/day in the edges wells where the head dropped to zero at the bottom of these wells and less than 100 ft beneath them and anywhere else between these wells. Therefore, the set of three wells provide a sufficient protection for groundwater flow from combined with the plume zone. What is more, the effectiveness of using multi wells is considered to conduct the pumping rates required for these wells which located much closer and deeper, since the pumping rates are more expensive and may need to be over period of time rely on the quantity and quality of contamination that spread beneath the water table. The pumping contaminated water method has the advantage of using proven techniques and is easy to control. The main disadvantages are that it disturbs the routine way that groundwater flows, and it requires steady energy and other inputs. However, the success of such approach has been questioned, considering the high costs involved. But, the operational costs outweigh the capital costs associated with the construction of the barriers as an alternative, in situ treatment technique [4] . Further work can be constructed from this study as following

- In order to really solve the groundwater contamination issues, more site data needs to be investigated.

- Once the dispersion shape is addressed, the selected remediation needs to be definitely validated upon the quality and quantity of contamination balance between the operating cost and effective capture for contaminants.
- At last, a detailed study of quality of contamination source to determine the effects of multi-chemical plumes emanating from the emplaced source is required (degradation). Moreover, understanding the chemical and biological processes affecting these plumes and their natural attenuation need to be improved.

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