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Groundwater Contamination Modelling Underneath Regina Landfill

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ABSTRACT: A three-dimensional finite difference regional groundwater model for the aquifers underlying the Regina area is developed. The conceptual model consists of four hydrogeological layers. Specifying zones of constant properties defined aquifer heterogeneities. The initial groundwater flow model conditions were based on hydraulic heads during the period 1977–1987. The model was calibrated by transient calibration for the period of 1987–1999 and generally produced water levels in the continuously monitored wells. Calibration of the transient flow model using trial and error resulted in 10 hydraulic conductivity zones.

Contaminant transport studies from the landfill entailed construction of a local model for the areas surrounding the landfill. The Modflow output was used along with MT3D for contaminant transport studies for contaminants starting from the landfill to the sand zone of the Condie aquifer and the transport of contaminants from the PCC sewage reservoir through the gravel core of the condie moraine. The modeling study was initiated with the migration and transport of chloride representing advective dispersive transport of contaminants without any added reactive effects. Pertinent data and transport modeling reveal that the impact from the landfill towards chloride contamination of the aquifer is in the form of a series of intermittent slugs originating from discrete points in the landfill. The slugs will cease to form once the landfill has been fully covered. Bulk of the chloride from the east of the landfill has been seen to be moving through the continuous gravel core existent through the central part of the Condie moraine. The impact has been seen to have reduced in the past decade with reduced concentration values recorded in monitoring wells reaching the gravel core of the condie moraine as the source have stopped their practice of disposing their sewage into the clay aquitard. Flow and transport parameters are arrived at by a separate sensitivity analysis of the model results with respect to chloride concentrations recorded in monitoring wells showing the impact of the landfill for the period 1990–2000 rather than using plume configurations as there aren't enough monitoring wells in the landfill to reveal an exact shape. The effect is not modeled as there is no identifiable source upstream of the landfill other than the PCC.

INTRODUCTION

The Fleet Street Landfill and the adjoining expansion cells are located outside of the City limits, on Fleet Street approximately 0.5 km north of the 9th Avenue N in Regina, SK, Canada. The Landfill along with its adjoining expansion cells is shown in Figure 1.

The landfill site was established in 1961 with the purchase of 97 ha of land. The present operation utilizes approximately 48 ha (±16 ha added since 1982) of land, of which approximately 24 ha had been land filled as of 1982, and an approximately 38 ha as of 1987. The City of Regina has now commenced closing up of the existing Landfill at Fleet Street as the landfill has reached capacity and have started to pursue construction of an expansion cell adjacent the existing facility within the next six to eight years. The Fleet Street Landfill and the proposed expansion areas overlie a regional aquifer system consisting of the upper Condie aquifer (A-Zone) and the lower Regina aquifer (B-Zone). Both the aquifers are separated by 26 m to 30 m thick till aquitard in and around the landfill. The Regina Aquifer is the primary source of water for approximately about 19 wells in the vicinity of the landfill, which are for municipal and industrial use of water.

From previous studies, it is conclusive that two aquifers are underlying the landfill namely the Condie and the Regina aquifers. Overlain by a layer of Regina clay, the Condie aquifer is primarily unconfined. Due to its proximity to the surface, the Condie aquifer is more susceptible to contamination. Pollution from industrial, agricultural, and other activities was reported to have impacted the water quality in the Condie aquifer (Maathuis *et al.*, 1992). Major potential contaminant sources have been identified, but limited to, the City landfill site, the Provincial Correctional Centre (PCC), the Co-op Refinery and the steel mill of the Inter-Provincial Steel and pipe Corporation (IPSCO). Due to the gross contamination effect currently, the Condie has been discarded for pumping water.

[1]Conference speaker

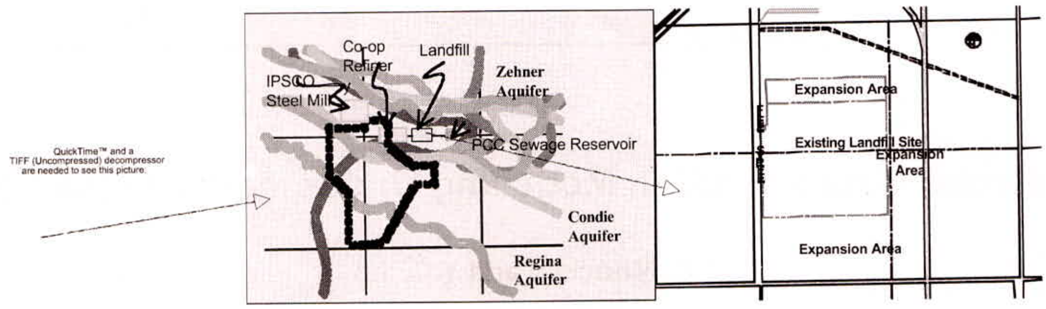

Fig. 1: Location of and Description of study Area

The major water producing aquifer in the area surrounding the landfill is the Regina aquifer. The Regina aquifer is separated from the Condie by a 2 to 32 m thick till aquitard. A major well that has been impacting the groundwater flow in the vicinity of the landfill has been defined as that of the Co-op refinery (Maathuis *et al.*, 1988). The Regina aquifer has been defined as the eventual interceptor of the contaminants moving in the surficial Condie aquifer.

Past sewage disposal practice by the PCC had resulted in a long and narrow plume of about 7.7 km in the central core of the Condie moraine. As a part of the study to identify the plume five transverse cross sections were identified through the central axis of the Condie moraine covering either partly or the whole width of the aquifer (Figure 2), 500 m up stream of the landfill which exhibit the same pattern for virtually all the cross-sections depicts the Condie moraine as a core of sand and gravel flanked on both sides by an apron of sand and silt. The longitudinal cross-section through the axis of the Condie moraine reveals a long and continuous gravel core close to 7.7 km long through the axis of the Condie moraine. The continuous gravel core has been described as bordering the landfill but not necessarily underlying it. The gravel core upstream of the landfill is about 500 m wide. Away from the landfill the gravel core narrows to a width of 300 meters west of the landfill. Not much information is available with regard to the Regina aquifer system other than separate borehole and monitoring well records. Conclusions can only be made from the lithologic logs of boreholes and monitoring wells. Lithologic log of MW 80 indicates sand interbeded with clay and silt and the Lithologic log of MW 82 show a layer of medium to coarse-grained sand for the Regina aquifer.

The monitoring well installation program at the site was started in the year 1979 with four wells being installed. Details of these monitoring wells, test hole drilling and well completion programs leading to the installation of these wells are presented by Beckie hydrogeologists (Beckie, 1980). An analysis of water samples collected from the four monitoring wells 1 to 4 installed showed that leachate was present in the upper aquifer but in the water samples collected all of the water met Saskatchewan standards for drinking water. In continuance with the leachate study it was recommended that additional monitoring wells be installed at the landfill to confirm leachate presence and distribution.

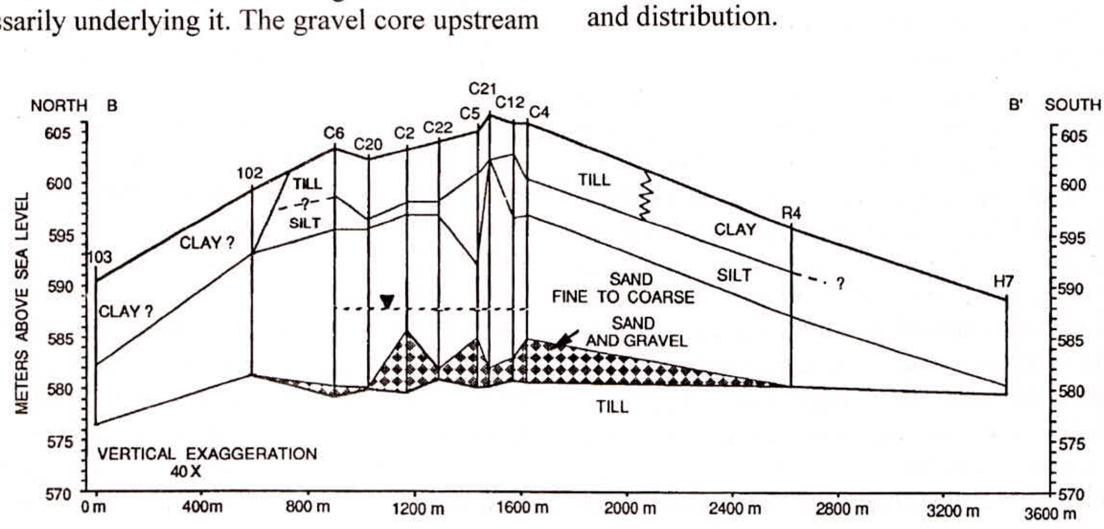

Fig. 2: Condie sand and gravel cross section upstream of the landfill (Maathuis *et al.*, 1992)

A separate study was undertaken to determine the extent of the plume present at the landfill site. As sampling were done from monitoring wells installed within the plume, the extent of the plume was not certain. For this reason additional monitoring wells were installed along the western margin and northeastern corner of the landfill site to solve the anomalous contamination in this area. Also, test drilling of a stretch of area that was a probable location of a buried oil waste pit was done. The shape of the plume along the western margin of the landfill conformed to the general direction of flow. The sampling done on the monitoring wells newly installed along the northeast corner of the landfill indicated high chlorides and phenols. Again the mechanism by which the lechate in the area has moved against the groundwater flow direction were supposed as either lateral flow in the unsaturated zone or rapid dispersion in the saturated zone or a combination of the two.

Further construction of monitoring wells were done in the Fleet Street Landfill and the surrounding proposed expansion areas as a part of the waste management study (Dillon 1989). Only water level measurements were taken at the installed monitoring wells MW 66 to MW 71 along the proposed North expansion area. The general direction of natural groundwater flow through the A-Zone beneath the site was to the west. Not much detail regarding the direction of contaminant migration could be derived. Similarly water level and in addition water quality measurements were taken at the installed monitoring wells MW 75 to MW 79 along the proposed South and East expansion areas. Not much leachate was detected in the sampling of the water done at the site. For both the expansion areas the surficial material in the area is highly fractured, unsaturated, lacustrine clay, which is less than 2.4 m thick in places. As these clays become saturated the clay minerals tend to expand, closing the fractures making this material almost impermeable. Therefore the potential extent of leachate migration under these conditions could not be known at that time.

Several monitoring wells were installed after 1982 in and around the Fleet Street landfill area by MLM ground water Engineering Ltd and Beckie Hydrogeologists Ltd (the monitoring wells are number and their location is given in Figure 3), for the city of Regina to expand the groundwater-monitoring network of which MW 60 to MW 65 (Beckie, 1980) are good examples of monitoring wells installed for this purpose. Some of these wells were installed to monitor the water quality of areas surrounding the landfill or anywhere along the landfill site either of the A-Zone or B-Zone. Until 1986 monitoring of water levels and water chemistry in the various monitor wells has not been systematic. So it was decided that a monitoring study consisting of a monthly measuring and sampling program be conducted on 24 to 47 wells and a quarterly measuring and sampling program be conducted on 10 to 16 wells. For both programs the water level, pH and conductivity of each sample were measured in the field at the time of sampling. For the monthly program, each sample was analyzed in the lab for 6 indicator parameters. These were pH, conductivity, chloride, sodium, ammonia nitrogen and total organic carbon. For the quarterly program, each sample was analyzed in the lab for 9 general parameters, 3 nutrient parameters, 2 organic parameters and 13 trace metals.

The strongest evidence for the temporal variation in one of the indicator parameters is shown in the A-Zone chloride distribution maps for 1979, 1982 and 1987 (Dillon, 1989). A comparison of chloride concentrations in MW 26, MW 30, MW 32, and MW 33 between 1982 and 1987 shows the movement of a high chloride contaminant slug to the west-southwest of the landfill. The 1987 chloride, conductivity, sodium, pH (field), total organic carbon and total organic halogen distribution maps for the A-Zone also substantiate the existence of separate contaminant plumes around the landfill area. It was concluded that the major A-Zone contaminant sources related to the landfill itself appear to be liquid disposal pits, waste oil pits and abandoned box cuts. The effect of precipitation and percolation through dry refuse as an A-Zone contaminant source appeared to be negligible or at least masked out by the effects of liquid and oil waste. Up gradient offsite contamination of the A-Zone had occurred east of the landfill site's proposed east expansion area and up gradient offsite contamination of the B-Zone had occurred to the north of the landfill site's north expansion area. It was also seen that the sampling reports of the water qualities of the A-zone aquifer beneath some of the thickest part of the landfill were nearest background levels.

CONCEPTUAL MODEL OF GROUND WATER SYSTEM

As described earlier the sand and gravel of the Condie moraine form the surficial water table aquifer in the area. In general, groundwater is derived principally from recharge through outcropped sands and gravel west of Rg18 and through surface depression in the Zehner aquifer system and Boggy Creek. The groundwater contour map derived for the Condie, Regina and Zehner aquifer system is shown in Figure 4.

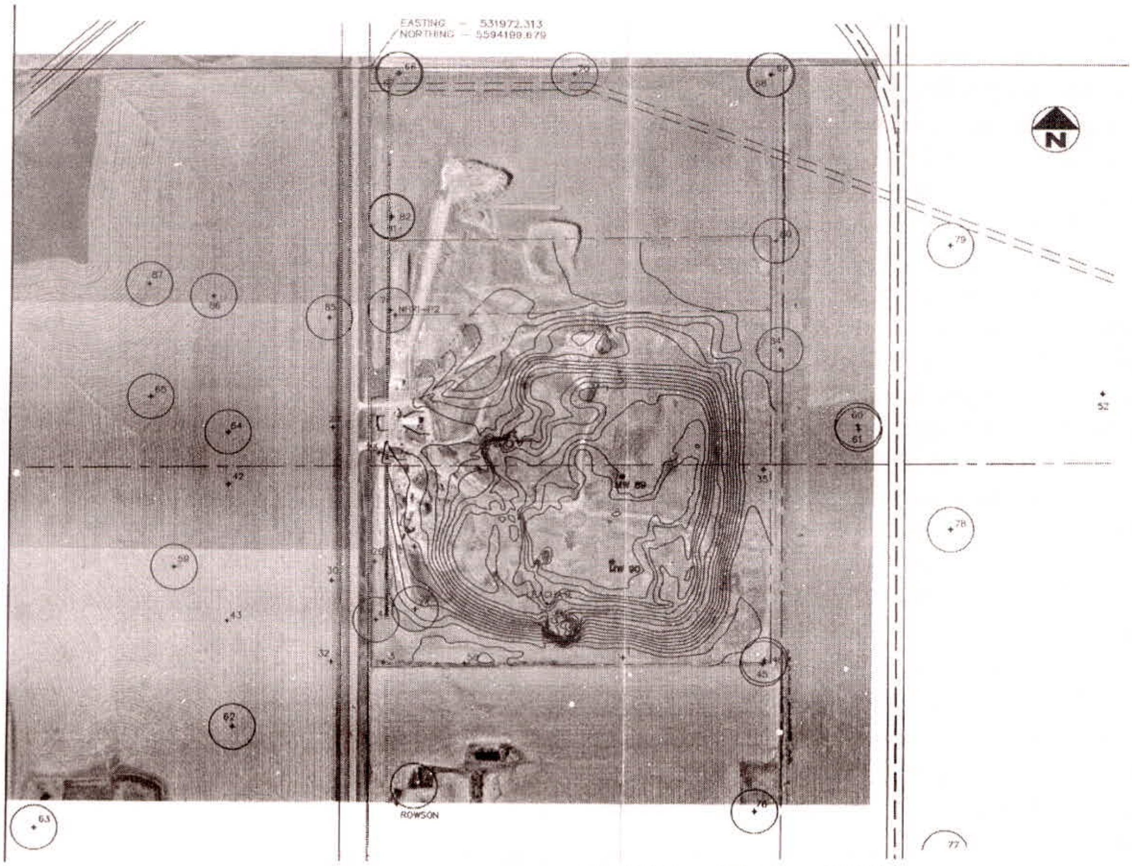

Fig. 3: Location of Monitoring Well (City of Regina, 2000)

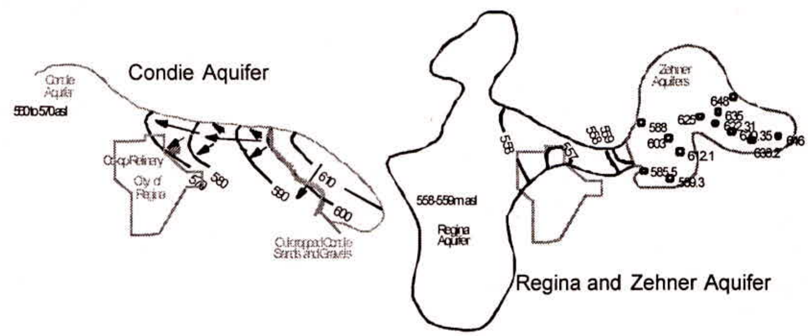

Fig. 4: Hydraulic head and groundwater flow direction in Aquifer system between 1977 and 1987 (Maathuis and van der Kamp, 1988)

Important tools used to characterize aquifer are hydrogeological profiles. Evidence of less permeable material in the southern flanks of the condie aquifer was found in seven geological transverse cross-sections made within the central portion of the condie aquifer by Maathuis *et al.*, (1992). One of the cross-sections covering the condie aquifer east of the landfill has been shown earlier in Figure 2. From the available cross-sections and from the fact that the southern ends of 570, 580 and 590 m contour tend to bend to the south west the Condie aquifer can be classified into four zones by the characteristics of typical geological setting and are depicted in Figure 4. These zones are considered as the upper unconfined aquifer. Next hydrogeological unit present below the Condie aquifer is the till aquitard. Observations from geological cross-sections reveal that the till aquitard as continuously developed within the extension of three major aquifers and for this modeling study the zone defining the till aquitard is applied accordingly. Below the till aquitard are the main water producing aquifers in the region namely the Regina and Zehner aquifer systems.

Groundwater flow in the main aquifer layers is governed by conditions at the boundaries of the regional system. In this aquifer study, three types of boundary conditions are defined; the specified head boundary, specified flux boundary and the head dependent flux boundary. For present study the multi-layered aquifer system has, for practical purposes, been modeled as a two layered aquifer system: an upper unconfined aquifer and a lower confined aquifer separated from the upper layer by a continuous till aquitard.

NUMERICAL MODELING OF GROUNDWATER FLOW

From the preceding discussions it is imperative that the groundwater flow processes are relatively complex and multiple aquifers are present. Hence a 3D numerical model MODFLOW is used for the modeling of groundwater flow. The Preconditioned Conjugate Gradient – 2 (PCG2) procedures was used as the solver to provide stable solution to the flow equations. MODFLOW uses particle-tracking code MODPATH to compute flow paths using outputs from transient groundwater flow simulation. MODPATH uses a semi-analytical particle-tracking scheme that allows an analytical expression of the particle's flow path to be obtained within each finite difference grid cell. Particle paths are computed by tracking particle from one cell to the next until the particle reaches a boundary, an internal sink/source, or satisfies some other termination criterion. Furthermore, MODFLOW has full implementation of the three kinds of boundary conditions including specified head or Dirichlet type of boundary, specified flux or Neumann type of boundary, and mixed or Cauchy type of boundary condition both constant and varying with time. GMS (Groundwater Modeling system) is used as a graphical user interface for pre-processing and post-processing the MODFLOW input and output.

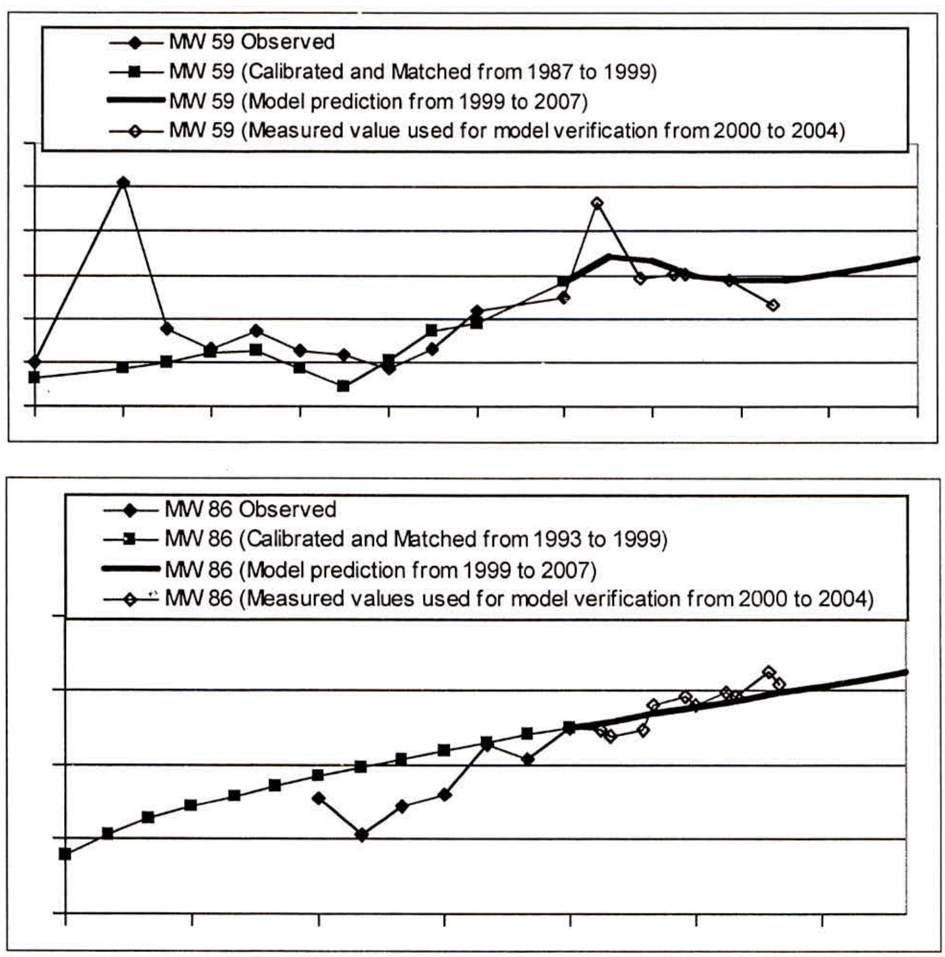

Fig. 5: Calibrated versus historical groundwater levels and model predictions (MW 86 screened in the Condie aquifer located north west of the landfill and MW59 screened in the Regina aquifer located south west of the landfill)

The model is first be calibrated before it can be used to generate water head forecasts; that is, model parameters are adjusted until the simulation is consistent with the analyst's understanding of the groundwater system and all available data. Computed values of head should closely match these measured at selected points (observation wells) in the aquifer. This means a set of historical data is used to compare with the generated heads derived from simulation. Analysis of the difference between measured and computed heads gives an indication as to where adjustment of output parameters may be necessary in order to minimize this difference. In the present study 1987–2000 is chosen as the calibration period, during which fluctuation in water level occur. Most of the calibration fits were reasonable given the only marginally adequate data for this modeling study. For all the observation Figure 5 shows calibrated vs. historical groundwater level and model predictions for selected monitoring wells in the landfill area, the differences between calibrated and measured values were within the 2 m difference as shown in Figure 5.

LOCAL CONTAMINANT TRANSPORT MODEL THROUGH THE CONDIE AQUIFER UNDERLYING THE CITY OF REGINA LANDFILL

A Modular three–dimensional transport model (MT3D), (Zheng, 1990) is used to simulate lateral contaminant transport in the Condie aquifer. MT3D is a comprehensive three- dimensional solute transport model for simulation of advection, dispersion and chemical reaction of contaminants in a groundwater system (Chandwani and Sloan 1998). MT3D interfaces directly with the US Geological Survey finite difference groundwater flow model, MODFLOW, for the head solution and supports all the hydrologic and discretization features of MODFLOW. The MT3D code has a comprehensive set of solution options, including the method of characteristics (MOC), the modified method of characteristics (MMOC), a hybrid of the two methods (HMOC), the standard finite difference method (FDM) and the third order total-variation-diminishing (TVD) method with a wide range of solution option. The model provides a numerically stable solution in a wide range of field options.

The calibrated flow solution was transferred from MODFLOW to MT3D and standard finite difference method with upstream weighing is employed for the simulation of contaminant transport. The fine grid spacing in and around the landfill area for the model helps in removing the numerical dispersion associated with these types of transport schemes. The contaminants dealt with in the modeling exercise is chloride. Chloride is a conservative solute, which undergoes minimal adsorption and no biodegradation and so is modeled.

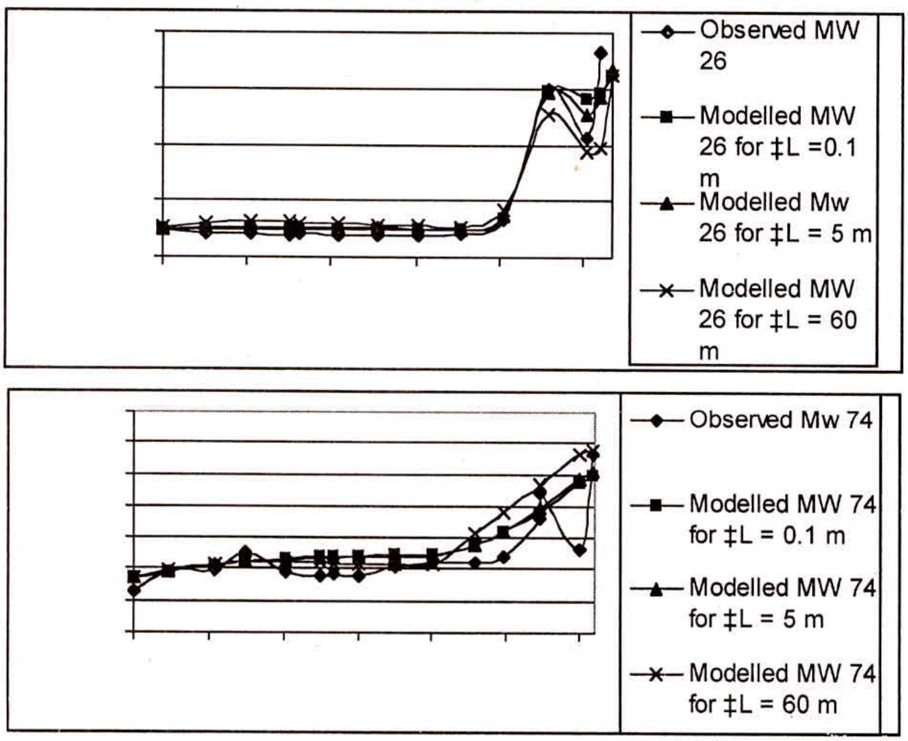

Fig. 6: Sensitivity with respect to horizontal hydraulic conductivity

The water table was approximated as Cauchy boundary corresponding to the recharge function applied to finite sections in and around the landfill. Earlier modeling studies (Maathuis *et al.*, 1992) have tracked a chloride plume 7700 m long through the gravel zone of Regina aquifer. The eastern boundary corresponding to the gravel core of layer 2 was approximated as Dirichlet boundary condition for the release of contaminants from PCC sewage reservoir. However, for this study the plume is tracked only to the spatial extent of the model domain. The calibration of the transport model is done from 1990 to 1999 with respect to monitoring wells. The lack of sufficient monitoring wells to cover the area prevents proper configuration of the plume shape. In addition to this vertical configuration of the plume is not possible, as multiple level piezometers are not installed in the landfill area to record the plume configuration. Before a close fit simulation is attempted, the sensitivity of the simulated plume with respect to horizontal hydraulic conductivity and dispersivity is examined. The sensitivity of longitudinal dispersivity coefficient is carried out so as to match the observed and modeled chloride concentration at key observation wells for the period taken into consideration. The observation wells at the west of the landfill with a longitudinal dispersivity of 5 m to 0.1 m (Figure 6) seem to give a close fit to the observed chloride concentration in the well. The monitoring wells in the Condie sand zone a longitudinal dispersivity of 30 m is seen to be ideal. For mean contaminant distances less than the maximum asymptotic dispersivity, longitudinal dispersivity in uniform aquifers is usually estimated with the following equation.

CONCLUSIONS

A three-dimensional finite difference regional groundwater model for the aquifers underlying the Regina area is developed. The conceptual model consists of four hydrogeological layers. Specifying zones of constant properties defined aquifer heterogeneities. The initial groundwater flow model conditions were based on hydraulic heads during the period 1977–1987. The model was calibrated by transient calibration for the period of 1987–1999 and generally produced water levels in the continuously monitored wells.

The simulation results shows increased sensitivity of water levels in the Condie aquifer to changes in flux in the major zones contributing recharge and the horizontal hydraulic conductivity of the condie sand and gravel zone.

Contaminant transport studies from the landfill entailed construction of a local model for the areas surrounding the landfill. As a preliminary phase in the transport analysis of contaminants, steady state finite difference MODFLOW solutions was calibrated with favorable comparison between field measured water levels and model produced groundwater contours for 1990.

Particle tracking code MODPATH is used to delineate capture zone or wellhead protection area of the Co-op refinery wells reaching the Regina aquifer. The capture zone after 40 years since the pumping was initiated seem to reveal contaminants originating from the landfill travel toward the well.

The Modflow output was used along with MT3D for contaminant transport studies for contaminants starting from the landfill to the sand zone of the Condie aquifer and the transport of contaminants from the PCC sewage reservoir through the gravel core of the condie moraine. The two are separated to delineate landfill and external effects of the PCC the bulk of the contaminants of which are believed to be moving through the gravel zone. The standard finite difference method is used as the option for simulating advective dispersive transport. Even though landfilling operations at the site dates back to early 1960's, extensive monitoring well data are available only from 1993 onwards. The contaminant transport is thus initiated from 1990 to 2010 and the model is calibrated for the period 1990 to 2000. Calibration of the contaminant transport is done with respect to a selected group of wells rather than the entire network of available monitoring wells since many wells have not shown the impact of the landfill within the time taken into consideration for the modeling exercise. The modeling study was initiated with the migration and transport of chloride representing advective dispersive transport of contaminants without any added reactive effects. Pertinent data and transport modeling reveal that the impact from the landfill towards chloride contamination of the aquifer is in the form of a series of intermittent slugs originating from discrete points in the landfill.

The slugs will cease to form once the landfill has been fully covered. Bulk of the chloride from PCC east of the landfill has been seen to be moving through the continuous gravel core existent through the central part of the Condie moraine. The impact has been seen to have reduced in the past decade with reduced concentration values recorded in monitoring wells reaching the gravel core of the condie moraine as the PCC have stopped their practice of disposing their sewage into the Clay aquitard. Flow and transport parameters are arrived at by a separate sensitivity analysis of the model results with respect to chloride concentrations recorded in monitoring wells showing the impact of the landfill for the period 1990–2000 rather than using plume configurations as there aren't enough monitoring wells in the landfill to reveal an exact shape.

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