

Analysis of Subsurface Contaminant Transport in Akaki Well Field and Surrounding Areas, Central Ethiopia

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Abstract-This study generated a model and recommendations that allows decision makers to establish a framework for regulating contaminants that are likely to pose risks to drinking water in the well-field. The acute need for water calls for a development approach that considers environmental factors. It becomes more pressing as industrialization and development advances. In view of this, the current study aims to identify the pathways of pollutants and travel times of contamination. The well field provides more than 30 % of drinking water supply of Addis Ababa. The study area is a sub basin in the Awash drainage basin, particularly in southeast of the Akaki catchment. A groundwater flow model was constructed to indicate the existing flow condition. The model was then calibrated both under steady state and transient state flows, to prove that the model represents actual conditions. The Modeling tools have been eventually used by introduction of particles at contaminant sources upstream of wells and at the well field, then to identify the path lines, and travel times. The results revealed that the flow lines intersect with the Akaki River in numerous places. Furthermore, the flow lines converge towards Akaki well field, implying contaminated water from the upper part of the aquifer will be pulled into the wells. Therefore, there is a high risk of vulnerability of the well field to pollution. Hence, the following recommendations are helpful in cutting the risks posed. One should conduct contaminant transport analysis taking into account chemical reactions, attenuation and multiple layer aquifer; Manufacturing activities having pollution potential must be limited in special areas far from water wells; Industrial enterprises shall create closed-loop water supply systems involving effluent reuse; Environmental policy with regard to waste disposal and agricultural practices to be allowed in the area must be implemented with particular emphasis for the protection zones around the well field.

Key words: Contaminant Transport: Pathways and Travel times, Groundwater flow model, Akaki well field, Ethiopia

I. INTRODUCTION

Water is the most essential nutrient for human existence. Therefore, the need for the management of water resources is crucial and even more pressing as industrialization and development advances. Monitoring and mapping groundwater movement and contaminant flow is important

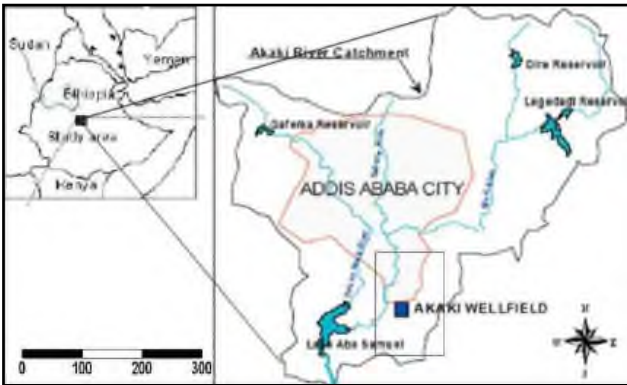
specifically for health care of the communities and generally for sustainable development. The ability to predict the rate and direction of groundwater flow and contaminant transport in the aquifer systems would be of great value in planning and implementing the remediation of contaminated aquifers. The Akaki well field provides 30% of the water supply of Addis Ababa and it requires a delicate aquifer management (Tamiru Alemayehu et al., 2005). This study intends to understand the travel time of contaminants as well as to delineate the path lines of contamination. As surface and groundwater are intimately linked to each other, there might be leakage from the highly polluted Akaki River. The quality of well water in such areas depends on the depth as well as pumping rate of wells. In the area, where large-scale industries have been expanding, pollution due to disposal of untreated industrial waste seems to be forthcoming. In addition, quarrying and agricultural activities that increase the influxes of solutes to water are widespread and locally increasing concentrations from harmless to toxic levels. The area is densely fractured by lineaments. As a consequence, permeability and transmissivity of rock matrix are high, facilitating accidental and/or deliberate introduction of contaminants into aquifer. Environmentally incompatible industries like skin and hide, chemical, metal and textile factories etc are unfavorably located along the Akaki road. In Akaki area, water resources have been investigated in terms of potential, flow models, and vulnerability by a number of investigators [e.g. Alemayehu, 1983; AAWSA and AESI, 1984; Vernier, et al., 1985; Tesfaye, 1988,1993; AAWSA and SEURECA, 1991; AAWSA et al., 1992; AAWSA et al., 1993 a, b; Anteneh, 1994; WWDE, 1996; AAWSA and COMPLANT, 1997; Eccleston, 1997; AAWSA, 1999; Aynalem, 1999; AAWSA et al., 2000; Gebrekidan, 2000; Alemayehu, 2001; Berhanu, 2002]. Although they vary in scope and degree of information, they have stressed that the quality of surface water is affected by waste disposal and these would have also potential impact on the quality of groundwater. Natural concentrations of contaminants are low in waters and soils but the problem aggravates when human activities locally upset the natural cycle. For instance, Sewage, garbage, and toxic pollutants are continually disposed into Akaki River. The contaminants may eventually enter into the aquifer system through porous, permeable media cut by numerous structures or clay materials that lose their filtration capacity. The results of current study can be applied in establishing preventive

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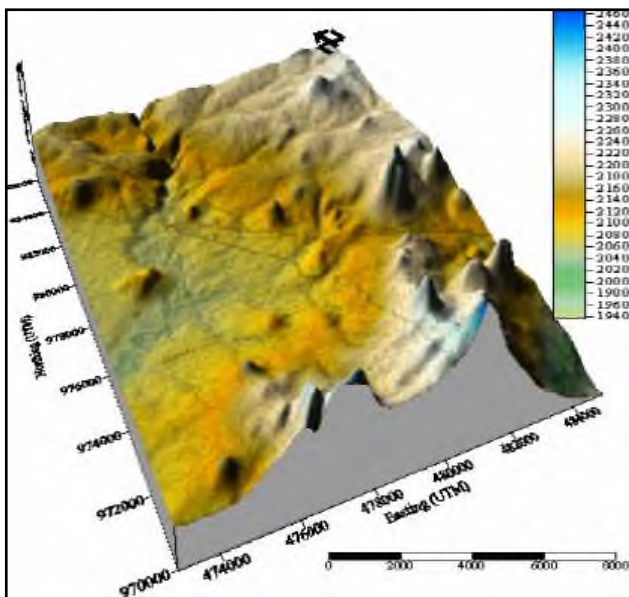
strategies and control further expansion of groundwater contamination, and in preparing a working model for solving similar problems elsewhere in the country. Therefore, analysis of transport of contaminants in a well-field which is clearly under threat by industrial wastes is not only a timely speculation but also a strong instrument in alleviating problems of drinking water.

II. ENVIRONMENTAL SETTINGS OF THE AREA

The project area lies within the Akaki river catchment (fig. 2.1). Fig.2.1. Regional location map of the Akaki catchment with major reservoirs, lakes, and rivers (modified after Shiferaw Lulu et al., 2005). The digital elevation model of the area shows a sharp topographic variation close to the ridge in the south, and east while the area is relatively flat towards center (fig. 2.3). Fig. 2.3 3D Digital Elevation Model of the study area constructed from a topographic map using surfer software.

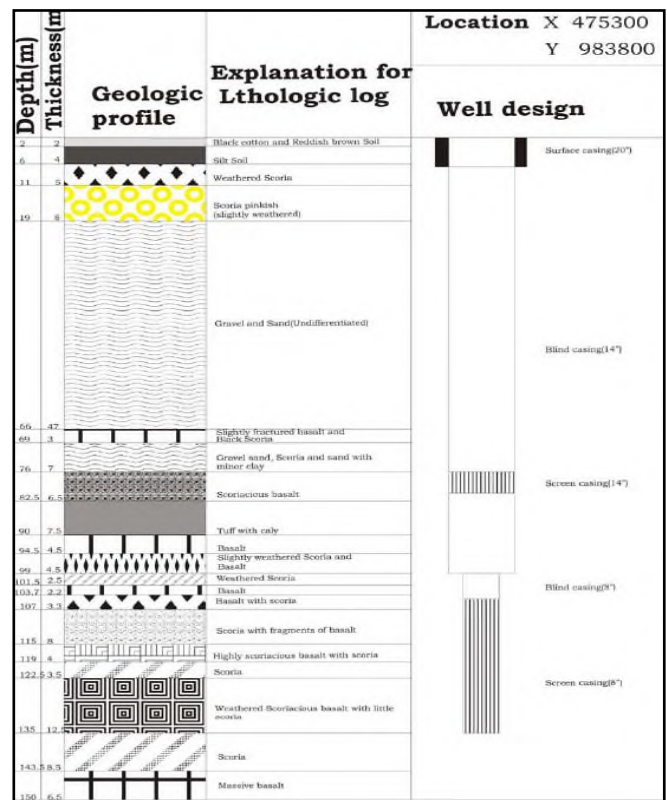
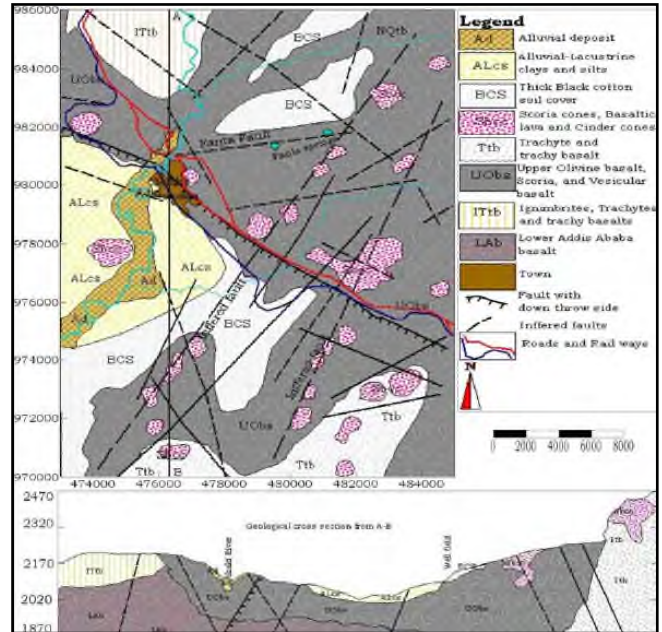


The lithology in the area form trachy basalt, Ignimbrites, tuff and volcanic ash, Akaki basalt, scoria and scoriaceous basalt, and recent alluvial deposits fig 2.5. Fig. 2.5 Geological map of the study area (modified after AG consult, 2004). Vertical exaggeration is 5x horizontal scale.



The rocks are subject to rift tectonics, as manifested in a

number of faults having a general trend of the rift system. Mixture of alluvial and lacustrine materials such as sand, clay, gravel, volcanic ash and tuffs are variably found at certain depths fig 2.6. Fig. 2.6. A Representative geological log of BH 06 in the well field showing the subsurface geology and thickness of the stratum. All soil types in the. (Berhanu Gizaw, 2002) Table 2.2



area have a relatively higher hydraulic conductivity

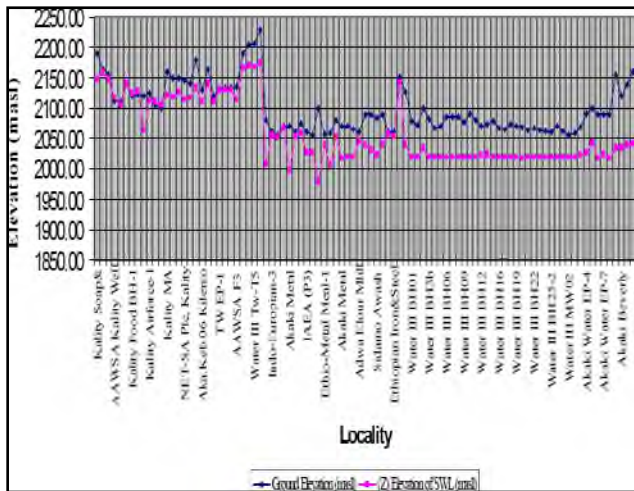
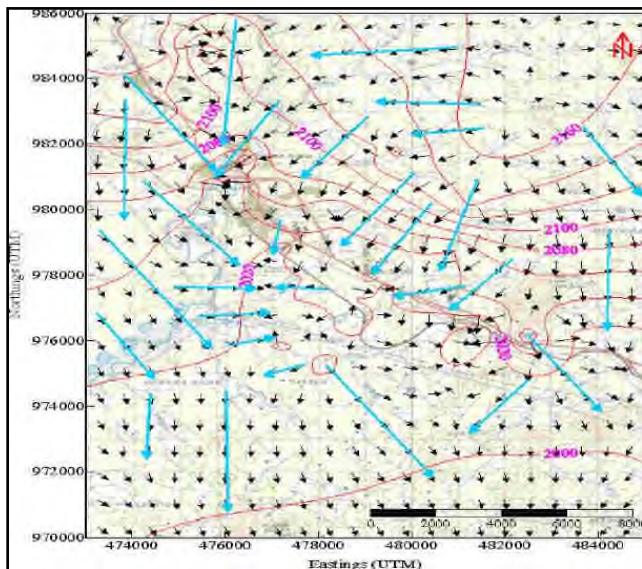


Fig.2.10. Comparison of ground surface elevation and elevation of SWL at respective wells location of the area that have spatial variations. It indicates the groundwater is in connection with the surface water in some localities. Fig.2.11. Map of local groundwater flow directions in the study area. The elevations of water level in boreholes are used to determine the general direction of groundwater flow in the study area. The groundwater movement is sub-parallel to the surface water flow direction and more or less controlled by the topography of the area. Convex contour lines at the northeastern and northwestern corners of the area (fig. 2.11) indicate regions of groundwater recharge, while concave contour lines at centre and along Akaki River are associated with groundwater discharge areas. The flow lines, sketched perpendicular to the contour lines, show the direction of groundwater flow. Land use pattern of the area is diverse but broadly classified into Urban, agricultural and open areas with rock exposures (grazing site). Scattered settlements are also found. Quarries are common near Tulu



Dimtu. Prospecting for new quarry sites and expansion of existing ones is going on.

III. METHODOLOGY

A MODFLOW package represented by matrix blocks, and an advection contaminant transport model known as PM PATH are used as tools. The analysis was conducted by constructing the groundwater model and performing flow simulations; by calibration of the model both under steady state and transient state flow conditions, and Introduction of particles at contaminant sources upstream of wells are conducted and observed for the path lines and how far the contamination moves using PMPATH. Finally, correlation coefficient, water budget analysis and calibrations were conducted to check the accuracy of the result for calculating the path lines and travel times of contamination by particle tracking method using the modeling tools. In pursuit of the overall objectives, the study followed scientifically approved procedures as Desk work that focused on literature review and assessment of previous works, Field work that include site observation and verification of previous geological map including structural features of the area and its hydrogeological setting, Post-field work that encompassed revision of geological and hydrogeological maps; evaluation of all data, borehole geologic logs and geophysical results from previous studies. A zonation approach is adopted where similar hydraulic conductivity, transmissivity and storage coefficient values are assigned to specific regions.

IV. MODELING APPROACH

The current model was to characterize flow in the study area by determining distribution of hydraulic head, flow velocity, and direction. A three-dimensional model grid was used to represent a two-dimensional aerial flow through a single layer. The following assumptions were used in simulation of the model. Fractures and weathered zones are considered as porous medium; Net recharge is not spatially uniform; Variation in geology and anisotropy impact the spatial distribution of hydraulic conductivity and Head dependent boundary condition is assumed on wet land of Akaki River, flux boundary is assumed at north, NE, and NW of the study area. The model simulates flow by the following governing equations thought to represent the physical processes that occur in the system.

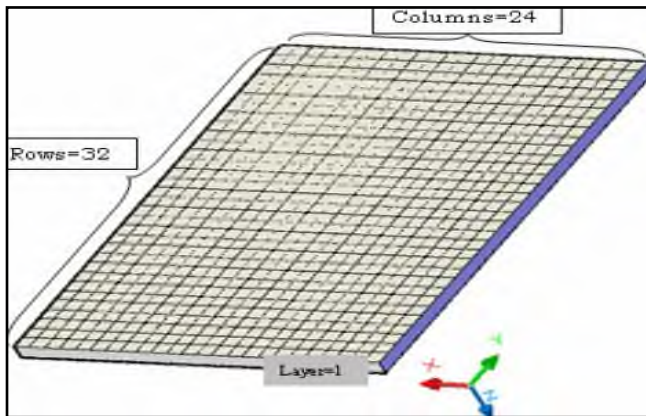
$$\frac{\partial}{\partial x} \left(k_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_{zz} \frac{\partial h}{\partial z} \right) - w = 0$$

.....Steady state condition (Eq.1)

$$\frac{\partial}{\partial x} \left(k_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_{zz} \frac{\partial h}{\partial z} \right) - w = Ss \frac{\partial h}{\partial t}$$

.....Transient condition (Eq.2)

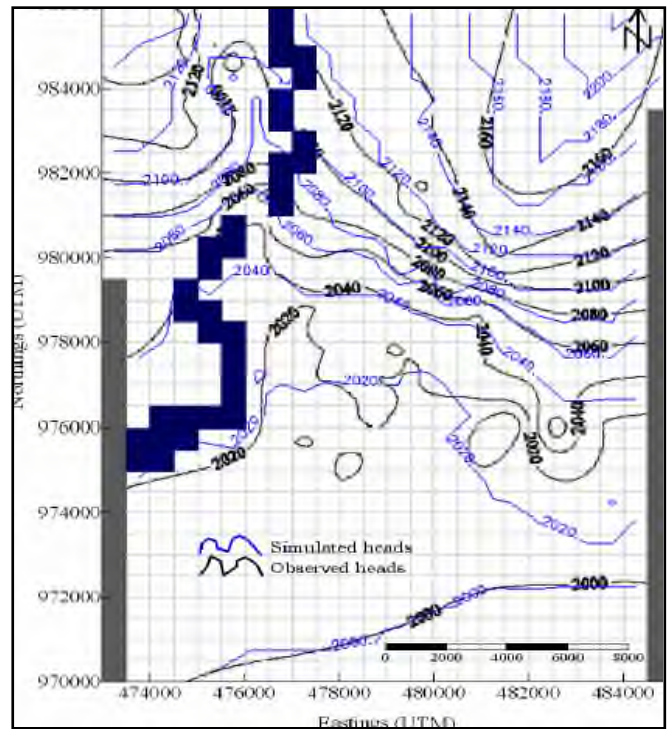
Where K_{xx} , K_{yy} , and K_{zz} are values of hydraulic conductivity along the x, y, and z, (LT^{-1}); h is the



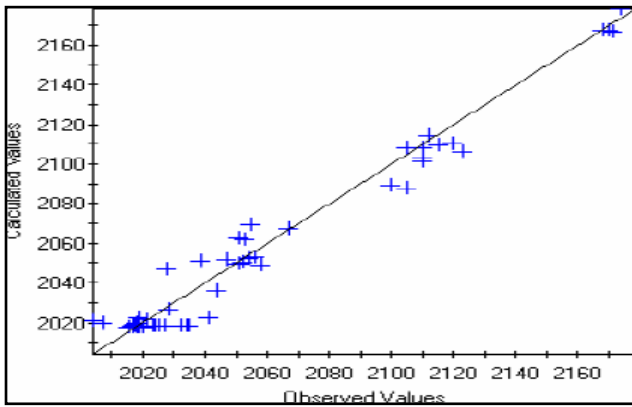
potentiometric head (L); w is a volumetric flux per unit volume (T^{-1}); S_s is the specific storage of the porous material (L^{-1}); t is time (T).

An aquifer system is replaced by a discretized domain consisting of an array of nodes associated in finite difference cells fig. 3.1. Fig.3.1 a 3 dimensional conceptual geospatial model frame work. To use a finite difference approximation, a grid is superimposed over the topographic map of the study area, and aquifer hydraulic parameters are averaged over the area of cell and assigned. Spatial input parameters of the model are initial hydraulic head, horizontal anisotropy, horizontal and vertical hydraulic conductivities, transmissivity, recharge, discharge, storage coefficient, specific storage and effective porosity. They were assigned to each active grid cell. Temporal input parameters are number of stress periods, time steps and transport steps. Since flow can not take place parallel to the actual groundwater contour lines, no flow boundary has been assumed in the eastern and western boundaries of the study area. The boundary condition array contains a code positive 1-for active cell, negative 1-for constant head cell and 0-for inactive cell. Because there are no significant massive rocks that inhibit flow across them, most of the cells in the center of the study area are treated as flux boundaries. There are few cells along Akaki River and in wetlands near Aba Samuel Lake where hydraulic head is kept fixed at a given value all over the entire simulation time. By convention the area outside the model domain is deemed to be a "no flow". Since the area is a volcanic terrain, the scoria and scoriaceous basalt are not continuous laterally as observed from the geological map. Therefore, it is difficult to identify well-defined distinct units and the aquifer parameters are obtained as a cumulative effect of all layers. At this stage it was difficult to justify a multi-layer representation of the aquifer hence; the model layer was treated as a single layer. The aquifer structure had been determined by preparing DEM used to construct the top elevation of the aquifer and loaded to MODFLOW matrix. An average depth to static groundwater level in the study area (40m) obtained from well database is subtracted from each DEMs. The results of this calculation are used as initial prescribed hydraulic heads in each cell. But some of them

are slightly altered later through calibration process particularly at borehole locations. Finally, these results are loaded to MODFLOW matrix and used in the modeling process. Initially a contoured hydraulic conductivity map was produced from the conductivity values of boreholes in the area. Then, the map is overlaid on the model grid, and the respective average values are assigned to each model cells. The recharge input was classified into two zones; a recharge of 74 mm/year in all areas except where black cotton soil is widely present and a recharge of 11.1 mm/year in black cotton soil cover. Mean value of the total porosity for medium gravel is 32 %, and for medium sand is 39 %. Therefore, an average effective porosity of 35 % was used in the model sine the black cotton soil and scoria of the area



constitute higher proportion of medium sand and medium gravel respectively. Calibration of the model developed is a process of changing values of model input parameters within some acceptable criteria to derive a close match between the observed water levels and calculated hydraulic heads. A graphical comparison between actually measured and model computed heads is shown in fig. 3.9. Fig.3.9. Comparison of the actual head contours with that of simulated heads in transient state condition. The observed and calculated head values are well correlated with a correlation coefficient of 0.9699 in fig.3.8. Fig.3.8. a scatter diagram of calculated and observed heads in the study area. Observed heads in the study area. In addition to calibration, to check the accuracy of the simulation results, MODFLOW calculates volumetric water budget for the entire model at the end of each time step. The percent discrepancy of in- and out-flows for the model is calculated and acceptably small (0.11%) table 3.5. Table. 3.5. Water budget of the



FLOW TERM	IN	OUT	IN-OUT
STORAGE	8.2457209E+01	8.1595268E+01	8.7194061E-01
CONSTANT HEAD	1.1303267E+00	1.1670703E+00	-3.6743522E-02
WELLS	0.0000000E+00	1.0639998E+00	-1.0639998E+00
RECHARGE	3.1726831E-01	0.0000000E+00	3.1726831E-01
SUM	8.3914803E+01	8.3826340E+01	8.8462830E-02
DISCREPANCY (%)		0.11	

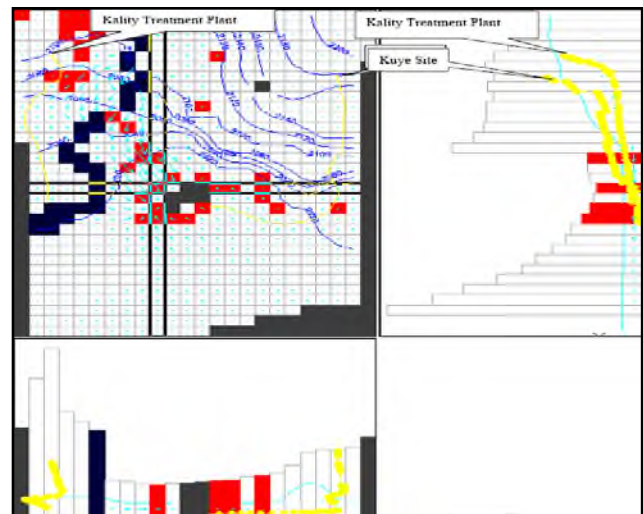
model domain during time step-1 of stress period-1. (Flow terms: M^3/S)

The water budget provides an indication of the overall acceptability of the numerical solution i.e. the model equations have been correctly solved. Sensitivity analyses were used to refine initial estimates of input parameters during model calibration, and to determine which input parameters had the largest effect on simulated head values after model calibration. Sensitivity refers to sticking to the reference mode (to the actual flow pattern) even when key parameters are changed. Therefore the model was found to stick to the actual flow pattern with change in transmissivity and recharge except change in hydraulic conductivity. At the end of this phase it is assumed that the model has simulated the actual hydrogeological condition of the area making possible to simulate the behavior of the aquifer system as well as the contaminant transport.

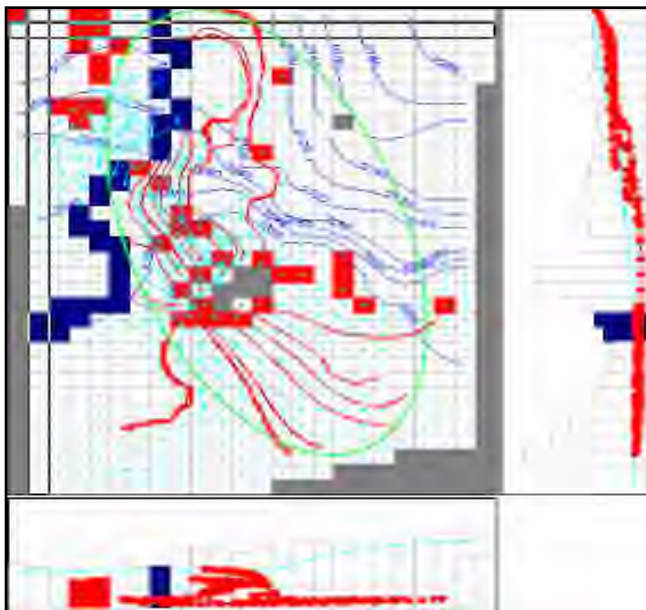
V. CONTAMINANT TRANSPORT ANALYSIS

We have used PMPATH for contaminant transport analysis which is a component of Mudflow Model. It is assumed by PMPATH that fluid properties are homogeneous and concentration changes don't significantly affect fluid density or viscosity and hence fluid velocity. Rate of pollution attenuation depends on the geology, local hydrogeological situations (porosity, permeability and hydraulic conductivity), geochemical processes and the type of pollutants. The weathered rocks of the area and associated structures and their orientation would have facilitating contaminant migration. To identify the pathway and final destination of pollutants, it is necessary to describe

the infiltration capacity of water in the black cotton soils. Contaminants move down with infiltrating water during the rainy season through the cracks formed in the previous dry season. Pollution of surface water can cause degradation of groundwater quality and conversely pollution of groundwater can degrade surface water. The Akaki River may temporarily become a losing stream. When the hydraulic gradient in the aquifer adjacent to the river is reversed due to draw down of water table during the dry seasons of the year and through increasing pumping rates in wells water flows from the river into the groundwater. Groundwater pollution is becoming a major threat particularly where the water table and the surface water coincide, around Kality (Berhanu Gizaw, 2002). Down Stream of Akaki Bridge up to Aba Samuel hydropower plant, the groundwater level is lower than the river bed level. Therefore, there is possibility of leakage through deep cutting fractures (AAWSA et al. (2000)). The pH, EC, TDS, and total coli form concentration in the groundwater also reflect the influence imposed by polluted surface water, implying the strong seepage of surface water into the groundwater system. Though the leakage is attenuated by the black cotton soil in places, the Akaki River could still have impact on the surrounding alluvial aquifer. Slope also determines the extent of runoff and the degree of settling sufficient time for infiltration. Areas with gentle slopes like the well field are highly vulnerable to groundwater contamination. All possible sources of contamination like steel, pulp, paper, pigments, caustic soda paint, pump, brewing, textile, food processing, and meat packing factories; dairy farms, open-air slaughtering, quarries, agricultural plots, grave yards, dense settlements, and open market areas are prevalent in the area. Few specific locations are selected to test for contaminant transport in the current study. These are Tulu Dimtu scoria: a highly fractured, porous and permeable rock sequence, located on elevated topography near the well field, the beds are tilted and; the site is being used as a grave site; Gelan metal industry: located on the way to Debrezeit road adjacent to Dengora stream. It is usually observed to release reddish effluents to the stream; the stream then crosses through the



center of the well field; Kality treatment plant: where highly polluted rivers, most sewerage lines, and sanitation systems are directed into it; and Akaki Mesfin Zelelew dairy farm in order to know the potential leakage of pollutants from the farm (bacteria, animal wastes, etc). The travel time for pollutants in the Akaki well field is calculated by considering lateral separation to be the velocity times travel time (Lawrence et al. (2001) cited in Tamiru Alemayehu et al., 2005). Hydraulic conductivity is considered as velocity in this case. For instance, the time required for bacteria to reach the groundwater level in the fractured scoriaceous basaltic aquifer ranges between 21/2 and 4 hours which could be effective during a single heavy rain period (Tamiru Alemayehu et al., 2005). Therefore, In the Akaki well field bacteria can easily move to a depth of 50 meters where the scoriaceous basalt is exposed on the surface (Tamiru Alemayehu et al., 2005). Particles are introduced at sources upstream in cells (21,18), (15, 20), (5, 3) and (7, 3) and the distance of travel of contaminants through the steady state flow field is observed for 120 days, 180 days, 5 years, and 10 years travel times, respectively (figures 4.8). Fig.4.8. Contamination introduced at cell (7, 3) upstream has arrived the well field after 10 years of travel time. The velocity is relatively higher in areas where there is high gradient as can be seen from the length of velocity vectors. They seem dots in most areas. Moreover, the cross-section in fig. 4.5 shows that the groundwater flows from Akaki River towards the well field. The particle at cell (5, 3) is initially injected



above potentiometric surface; meanwhile moves within the aquifer but later comes on the surface of groundwater. However, contaminant at cell (7, 3) is injected at the potentiometric surface and remains below the water surface entirely. Therefore, remediation may not be easy for contaminants at cell (7, 3). Contaminant sources which can affect the well field are then distinguished and capture zones of the pumping wells over different years have also been examined by running particles backward as observed in fig.4.10. The capture zone agrees with the results of

protection zones delineated by Tamiru Alemayehu, et al. (2005) in groundwater vulnerability assessment. Contaminants from most of the study areas will be captured in 10 years time. Fig.4.10. Capture zone of the pumping wells in the well field in 10 years.

VI. RESULTS AND DISCUSSION

A constant withdrawal of water from the Akaki well field at optimum pumping rate of 30,000 m³/day will causes the highest draw down in the well field followed by Dalota site, and moderately for Upstream Dukem, Fanta and Downstream Dukem. According to AAWSA et al. (2000), discharge of Fanta spring which is situated upstream of the well field will be reduced and will even be dry after 10 years for most of the pumping situations. Even with suitable pumping rate, the drawdown in the well field will reach 20m after 17 years. In the same period, the wells would be affected with a drawdown of about 5m around Kality. Therefore, it is definite that contaminants will be attracted to highly pumped well, and eventually contaminates the well field before the estimated 20 years time. The shape of the iso-values is elliptical, with its long axis oriented along the northeast direction. This shape can be attributed to the fact that the main pumping wells (BH17, BH16, BH12, and BH09) are aligned along the northeast direction as well as the fact that the permeability of the reservoir is anisotropic following major tectonic line aligned in the same direction. Furthermore, the well field area with gentle gradient (wide water table contour spacing,) is characterized by higher hydraulic conductivity or permeability. All these together with the following factors facilitate the easy movement of fluids in the area. Factors like, intercalation of basalt flows separated by baked soils which form weak zones at the contact; the columnar joints of basalt; the inclined bedding of most scoriaceous basalts; intensive network of fractures and their close spacing allow easy groundwater circulation and contaminant migration in the area. In addition, the characteristics of soil influences the amount of recharge infiltrating into the ground, the amount of potential dispersion, and the purifying process of contaminants to move vertically into the vadose zone. In the Akaki well field, particle size distribution analysis done on black cotton soils and scoria indicates that the black cotton soils have relatively lower (10^{-5} to 10^{-4} m/s) hydraulic conductivity values followed by the residual soil (10^{-4} to 10^{-3} m/s) and scoria (assumed to be similar to the main aquifer of the Akaki well field, (10^{-3} to 5×10^{-2} m/s) Berhanu Gizaw, 2002). As indicated in Table 2.2, higher proportion of the grain size distribution of all samples show sand for Akaki black cotton soils and gravel for Tulu Dimitu scoria. Therefore, even the black cotton soils which appear to be impermeable to infiltrations have of course relatively low permeability in the region but they are permeable to fluids. In addition, due to intensive erosional activities, there is poor soil development on most parts of the slope which proves the lack of defense line to hydrogeological system. Therefore, the danger zones are areas of rock exposures with no soil

coverage and faulted zones. Thus, it is important to consider hydraulic conductivity of the scoriaceous basalt, which on average is 340m/day, and is very high if the rocks outcrop on the surface and if the spill occurs on fractures. In that case, there is a possibility of arrival of pollutant to the well field (Tamiru Alemayehu et al., 2005). The Big Akaki River shows wide channel and slow flow velocity that allows enough time for infiltration process near Akaki Bridge. The alluvial sediments of this area are also characterized by high water infiltration capacity. The recharging water is thus available to transport a contaminant vertically to the water table and horizontally within the aquifer. Hence there is higher danger of contamination in shallow wells from the Akaki River. The depth of water table gives an idea of the minimum distance that a pollutant has to travel to reach the saturated zone. The groundwater level in Kality and Fanta areas is shallow and is susceptible to contamination. In the long run, the lowering of the water level due to pumping will change hydraulic conditions at the bottom of the river in these areas increasing the degree of infiltration of polluted water. Groundwater monitoring in the area shall be conducted taking into account their spatial distribution and proximity to the well field and how long the contaminants take to arrive at the centre of the well field from their respective locations. At least half of the length of the travel time shall be assigned as the frequency of analysis. Therefore, one can have at least half to quarter of its full travel time to control the contaminant before it pollutes the whole well field. In addition, if pollution is noticed in the highway area, the nearest wells (Ep-07 and BH-09) should not be stopped because they can be used to control the pollution. Stopping pumping of polluted wells will let contamination of the well field. Instead their discharge should be increased and the water should be disconnected from the system and discharged under a controlled mechanism out of the well field. Therefore, improper abstraction of water along with suitable Environmental setting of the area facilitates contaminant migration. Though the effect of contaminant migration is currently minimal, the model developed in this study clearly shows that contamination of the well field is forthcoming, unless strong environmental protection policy as well as aquifer management strategy is implemented. Groundwater quality monitoring not only help to know the current existing situation but also helps in building models and simulate changes in concentration of contaminants. Table 2.2 Grain size distributions of triplicate soil samples collected from various soil horizons and representative soil types in the area (modified from Berhanu Gizaw, 2002). Note: BCS-Black Cotton Soils, TuluD- Tulu Dimtu, Cl-Clay Si-Silt, Sa-Sand, Gr-Gravel. The soil was classified based on grain sizes: Clay (<0.002mm); Silt (0.002-0.06mm); Sand (0.062mm) and Gravel (2-60mm). The scoria, residual soils and black cotton soils of these types generally expected to have total porosity ranges of 25-50%.

VII. CONCLUSIONS AND RECOMMENDATION

This study indicated that the Akaki well field is highly vulnerable to contamination from surface waters and upstream groundwater. The Akaki River has direct impact on the nearby wells that tap water from alluvial layer as indicated by the intersection of contaminant path lines with the water level. In the study area, the groundwater flow lines converge towards Akaki well field, implying that any contaminants are carried to the well field from all directions. Therefore, the quality of the surface and groundwater up stream will determine the quality of water in the well field. The intensive pumping of groundwater from the Akaki well field will result in rapid decline of groundwater levels, leading to disturbance in the steady state flow system of the groundwater, eventually resulting in increased velocity of groundwater flow towards the depression zone. This process potentially facilitates the rapid flow of contaminated water from upstream sections of the aquifer to the well field. Currently, the degree of contamination of the groundwater is negligible giving certain time to avert the problem. However, the model indicates that water flow path lines with contaminated water injected at contaminant sources upstream will reach in the well field in less than 10 years time. Flow is not linear through out the system; rather it is more rapid where porosity and transmissivity are high depending on the orientation of tectonic fractures. In view of tackling the actual and potential contamination risks of the Akaki well field more effort should be made to: conduct contaminant transport analysis taking into account chemical reactions, attenuation and multiple layer aquifer; effort should be made to create closed-loop water supply systems at industrial enterprises involving effluent reuse; to implement strict environmental policy with regard to industries and agricultural practices that have to be allowed in the area and set standards to discharges and penalties for non-observance of requirements; to limit activities having pollution potential in special areas far from water wells; and to closely monitor the chemical quality of groundwater in the well field.

VIII. ACKNOWLEDGMENT

I wish to acknowledge the professional staffs of different institutions for their co-operation and data needed to

No	Sample	%							
		Cl	Si	Sa	Gr	Total	Cl+Si	Cl+Si+Sa	Cl+Si+Sa+Gr
1	Akaki BCS 1	1.0	8.4	90.6	0.0	100.0	9.4	100.0	100.0
	Akaki BCS 2	1.0	6.9	92.1	0.0	100.0	7.9	100.0	100.0
	Akaki BCS 3	0.9	8.9	90.1	0.0	100.0	9.8	100.0	100.0
	Aver.	1.0	8.1	90.9	0.0	100.0	9.1	100.0	100.0
2	TuluD1	0.0	0.0	21.7	78.3	100.0	0.0	21.7	100.0
	TuluD2	0.0	0.0	26.7	73.3	100.0	0.0	26.7	100.0
	TuluD3	0.0	0.0	22.7	77.3	100.0	0.0	22.7	100.0
	Aver.	0.0	0.0	23.7	76.3	100.0	0.0	23.7	100.0

conduct my research project. The support of Addis Ababa university, especially Asfawossen Asrat (PhD), Addis Ababa Water and Sewerage Authority (AAWSA), Ato Solomon Waltenigus; Ethiopian Institute of Water Technology and Japan International Co-operation Agency (JICA), particularly Ato Shumet Kebede; Water Works Design and Supervision Enterprise, particularly Ato Engida Zemedkun. Finally, I am indebted to AG-Consult Consulting Hydrogeologists and Engineers, Ato Shiferaw Lulu, for Discussion with and experience sharing and Dejene Legesse who has helped me on technical aspects of the MOD FLOW.

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