GROUNDWATER FLOW MODELING OF THE NAIVASHA BASIN, KENYA

(MODELACIÓN DEL FLUJO DE AGUAS SUBTERRÁNEAS EN LA CUENCA DE NAIVASHA, KENYA)

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ABSTRACT: The Naivasha basin in Kenya has been characterized in recent times by an intense agricultural development, this situation has caused the water consumption to increase. Because the amount of groundwater used for this purpose has increased substantially its level in the basin have been affected together with the flow directions. A groundwater numerical model has been constructed and calibrated in order to estimate the amount of flow in different areas in the whole basin, that is, groundwater balance calculations have been made with the model. A sensitivity analysis of the model has been made and the necessity for better knowledge of parameter spatial distribution has been confirmed. Future situations, which are likely to occur, have been modeled and the results interpreted. Pumping tests have been carried out and their results analyzed using available methods. The results have revealed the great variability of hydraulic parameters in the basin. Finally, the model results have been evaluated from an environmental point of view.

Keywords: Modeling, groundwater, lake Naivasha.

RESUMEN: La cuenca de Naivasha, Kenya, ha estado caracterizada en tiempos recientes por un intenso desarrollo agrícola, esta situación ha provocado que aumente el consumo de agua. Debido a que este consumo con fines agrícolas se ha incrementado substancialmente en los ultimos tiempos los niveles en toda la cuenca se han visto afectados y con ello las direcciones de flujo. Un modelo numérico ha sido construido y calibrado con el propósito de estimar los volúmenes de flujo en diferentes áreas en la cuenca, o sea, los cálculos de balance hidráulico han sido realizados a partir del modelo. Un análisis de sentitividad se realizó y se llegó a la conclusión de que un mejor estudio de los parámetros hidrogeológicos era necesario. Algunas situaciones futuras también han sido modeladas e interpretadas. Los resultados finales han revelado la gran variabilidad de la conductividad hidráulica en la cuenca, además de la posible aplicación del modelo con fines ambientales.

Palabras claves: Modelación, aguas subterráneas, lago Naivasha.

INTRODUCTION

One of the best known lakes in Kenya's Rift Valley is Lake Naivasha, which lies about 90 km northwest from Nairobi, capital of Kenya. Lake Naivasha is one of the world's most famous for bird watching and it is an extremely important source of fresh water for both agriculture and human consumption, moreover, other activities are developed as the fishery and horticultural industry and tourism. This situation explains why Lake Naivasha is better documented than the other lakes in the Rift Valley which are more saline; but the relatively great number of investigations that have been carried out concerning the lake and its environment have been spread among a great number of scientific institutions, that explains why it is difficult to gather and organize the existing information needed for a new research. Modeling studies related to the lake and its catchment are quite recent and little experience has been accumulated in this context for the area. The Naivasha catchment is characterized by complex geological conditions making groundwater studies more difficult compared with surface water studies. The area consists, mainly, of volcanic strata and lake sediments derived from this volcanic material. Layers of diatomeas are also found. The catchment is also affected by two fault systems (Wiberg, 1974), a system that is developed along NNW – SSE trending directions and a more recent N-S system.

LOCATION, CLIMATE AND VEGETATION

Naivasha basin is located between coordinates (18 5000, 990 000) and (240 000, 997 000) according to U.T.M. Zone 37, topographic sheets 133/1, 133/2, 133/3, 133/4, 119/4, scale 1:50 000 Survey of Kenya (1975). The basin forms part of the Gregory Rift Valley, flanked by scarp lines to the east represented by Aberdare Range and Kinangop Plateau and to the west by Mau Escarpment, Figure 1. To the north the catchment is bounded by the Bahati Uplands and to the south by the Olkaria Complex. The basin has a

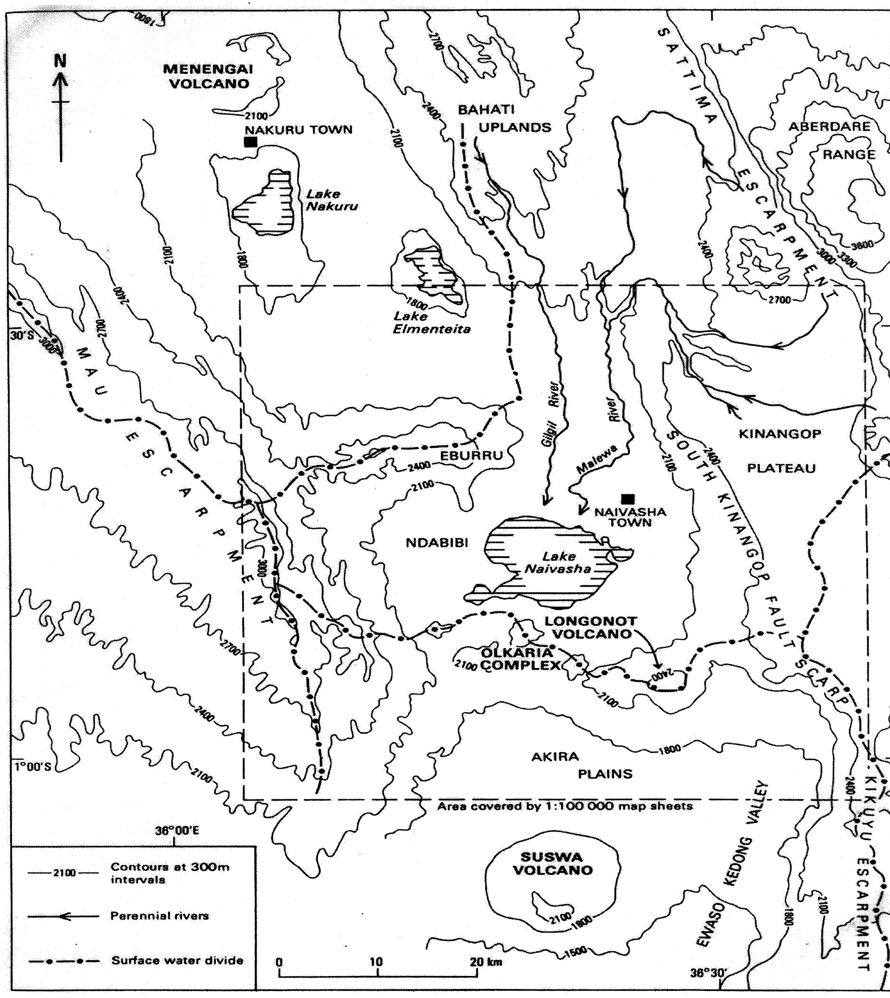

Figure 1. Study area and main physiogeographic features (after Clarke *et al.*, 1990).

total superficial area of 3387 km^2 of which 132 km^2 belong to the lake, and is characterized by moderate temperatures and a semiarid climate in areas surrounding the lake, while the climate is semi-humid to humid in mountainous areas where well developed rain forest is present.

Annual values of precipitation for the hilly zones are high, ranging from 1 250 mm to 1 500 mm with similar or lower rates of evapotranspiration (Clarke *et al.*, 1990). Under these conditions potential evapotranspiration exceeds precipitation, often by several times. The annual rainfall average at Lake Naivasha is 650 mm (Wiberg, 1976). Vegetation in flat areas is represented by bushes and vegetation of savanna mainly, with the exception of areas surrounding the lake, the swamp zone, where Papyrus spp and Eucalyptus spp are the most representative species. The highlands support well-developed tropical rain forest, which partially covers the Aberdare, Mau, Kikuyu, and Kinangop escarpments. Precipitation in the highland areas is significantly higher than within the Rift, where the vegetation has a semi-arid character.

GEOLOGY

One of the most remarkable features of the Earth's crust is the Rift Valley of Africa. The valleys, rather than just a single valley, form a more or less continuous scar from Israel and Jordan in southwestern Asia to Mozambique in southeastern Africa (Ase et al., 1986). One prominent part of the valley system is the so-called "Gregory Rift Valley" in Kenya. Flanked by scarp lines to both eastern side, Aberdare Range, and western side, Mau Escarpment, it reaches relative altitudes of 1000 meters or more. The main part of the Rift Valley faulting took place during the Middle Pleistocene (Wiberg, 1974), possibly along older fault lines and continued into Upper Pleistocene, although some investigations suggest that the development of the fault system continues nowadays (Ase *et al.*, 1986).

STRUCTURAL AND LITHOLOGICAL FEATURES AND THEIR RELATIONS TO WATER CIRCULATION

Structural features such as faults in the rocks often optimize storage, transmissivity and recharge, particularly when they occur adjacent to or within a surface drainage system. In the region a series of parallel faults run in north-northwestern direction along the eastern face of the Mau Escarpment. The same feature can be observed along the western face of the Kinangop Plateau, finalizing in the largest fault of the Plateau called *South Kinangop Fault Scarp*, Figure 1. Faults will have the highest impact on hard and massive rock types, elastic formations such as tuffs and weakly consolidated deposits will bend rather than break. As a result, they tend to suppress the radius of influence and the magnitude of the damage caused by tectonic events. In relatively plastic rocks, the porosity will not increase in the area affected by the fault. Hard layers such as lavas on the other hand, will be broken by fractures and joints, thus giving rise to increased secondary porosity. Faulting in the area is an on-going process. Among the most prominent structural features of the region are volcanoes: Longonot and Suswa to the south of the study area. Also at Olkaria volcanic complex numerous craters and volcanic cones are found. In the area the most common types of rocks are volcanic or are related to volcanic activity, the surrounding of Lake Naivasha is the exception where lacustrine material is predominant.

EFFECT OF FAULTING IN THE MODELED ZONE

Although the faulting process has been intense and of long duration, its effect on the shallow aquifer formation in the modeled zone does not appear to be of great importance with the exception of the boundaries of the model which have been selected according to the existence of fault lines mainly. Inside the modeled area there is a predominance of sedimentary material composed by fluvial and lacustrine deposits and pyroclastic material. As mentioned before the effects of tectonic activity upon these types of formations will be suppressed and the influence of faults can be safely neglected, moreover, during the author's field investigation in the area of interest no evidence was found that could indicate that the fault system plays an important role in the shallow groundwater flow.

HYDROGEOLOGY

The hydrogeology of an area is determined mainly by the nature of the geology, topography and climate, these aspects are related to characteristics such as the parent rock, structural features, weathering and patterns of precipitation and finally the human activity. Highland areas are characterized by deep groundwater tables, steep groundwater gradients, and also by its larger rainfall values as compared with the valley, approximately 1200 mm versus 500 mm a year. Valleys are characterized by a shallow water table, which gently slopes to the lake, low values of precipitation and low values of natural recharge. With a mean rainfall value of 500 mm a year and an estimated groundwater recharge of about 50 mm Lake Naivasha is the most representative of this type of environment in the region. Human activities have influenced groundwater levels in recent years. For example, nearby Lake Naivasha water abstraction for agricultural harvest has caused a drop in the water table, thus changing flow direction. Within volcanic rocks, groundwater primarily occurs within fissure zones, fractures and bedding. Lava flows rarely possess significant pore space, their porosity is purely secondary, such as cracks, joints and fissures. However, pyroclastic and especially sedimentary deposits as opposed to massive volcanics, do have a primary porosity and the cavities between the mineral grains or clasts are usually open and interconnected. Consequently, they can contain and transmit water.

GROUNDWATER OCCURRENCE

Groundwater occurrence is controlled by the geological conditions of the area and the available water for recharge. Fresh volcanic rocks are known to be virtually compact and with no intergranular or primary porosity although secondary porosity may be well developed locally. The permeability of the volcanic rocks underlying de Rift Valley are generally low, although, there is considerable local variation and layers with poor hydraulic characteristics can be followed by layers with good hydraulic properties. Because this volcanic deposition was accompanied with other materials of different origin it is common to find intercalated zones of high and low transmissivities. Areas where alluvial deposits appear are characterized by good hydraulic properties and are favorable for groundwater occurrence. However, in places where volcanism has been a major ingredient of the geological history low values of transmissivities are found quite often and their importance for groundwater occurrence is limited.

RECHARGE AND GROUNDWATER FLOW

The groundwater level in the upper aquifer is governed by the lake level and water abstractions (Wiberg, 1976). Because of the raised lake level since 1950's and the increasing use of groundwater, the gradient and thus the recharge from the lake is likely to have increased. Apart from the groundwater recharge from the lake and highland areas there is evidence of recharge from the rivers (Wiberg, 1976). Despite the fact of the high evapotranspiration rates existing in the Rift floor some of the recharge is believed to come from irrigation of cultivated fields. Large quantities of water, coming from the lake as well as from the aquifer, are being used for this purpose. Important sources of recharge for the shallow aquifer are the rivers in the zone and the lake. Some of the recharge may be due to highland surface runoff discharging into the valley. The existence in mountainous areas of high annual values of precipitation associated with the presence of a forest cover creates favorable conditions for rainfall infiltration and groundwater recharge. Moreover the valley also receives recharge by infiltration of local precipitation.

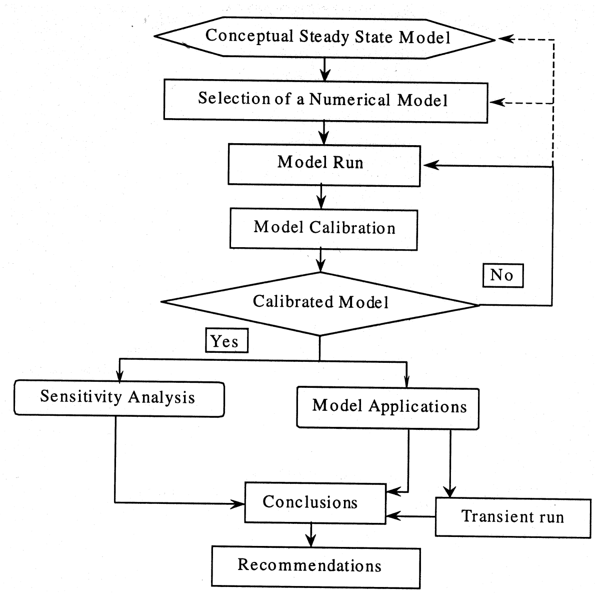

Figure 2. Steps of the modelin process.

MODEL SETUP

A brief description of all characteristics related to the aquifers is presented in this section as well as the point of view utilized to construct the model. The modeling steps are shown in Figure 2.

AQUIFER SYSTEM

The aquifer system in the area is characterized by the presence of interbedded permeable and less permeable layers. It has been seen that near the lake a shallow groundwater table exists with a depth below surface varying from one meter to six or seven meters. This first water-bearing layer is considered an unconfined aquifer. There are two main reasons why this succession of permeable and less permeable layers has been considered as a unique multiple leaky aquifer system. First of all in the area no information exists that could help in separating the aquifers and second these clay and silt layers are of reduced thickness in comparison with layers composed by sand, conglomerates, volcanic and others materials. Alluvial deposits are characterized by high transmissivities, 5 000 m^2/d, however, volcanic ashes and fine-grained volcanic rocks together with fine lacustrine sediments possess transmissivities of the order of 0.01 m^2/d. Also good hydraulic properties can be observed in wells located in fractured volcanic rocks. These wells are characterized by high discharges rates with very little water table depletion. The aquifer system is characterized by the presence of thin and less permeable layers of clay, silt and basalt interbedded with thicker layers of sand and coarser material; the real situation represents a multiple leaky aquifer system with a top aquifer unconfined. To build the conceptual model for this particular case the concept of hydrostratigraphic units has been applied. This concept implies that geologic units of similar hydrogeologic properties may be combined into a single hydrostratigraphic unit or a geologic formation may be subdivided into aquifers and confining units. The concept of hydrostratigraphic units is most useful for simulating geologic system at a regional scale (Anderson *et al.*, 1992).

BOUNDARY CONDITIONS

Boundary conditions are mathematical statements specifying the dependent variable, heads, or the derivative of the dependent variable, fluxes. The boundaries in the model were selected following geological and geomorphological features, structures and hydrogeological evidences. Among the geological features faults, including the rift faults, are the most important. These fault lines are *physical boundaries.* Surface water divides belong to the *hydrological boundary* type. Groundwater EC measurements assisted in the definition of the boundaries. Lakes and rivers were taken as constant head boundaries.

To the East: In the eastern part a long and pronounced fault scarp is present, South Kinangop fault scarp, Figure 1. EC routing studies made by Graham (1998) showed that the differences in EC readings on both sides of the fault were almost comparable, the same observation was made during a recent fieldwork (Behar, 1999). This situation indicates that the groundwater inflow from the eastern part of the fault is almost negligible and as such was considered a *no flow boundary*. Another evidence taken into account to select this fault as a no flow boundary was obtained from digital image processing.

To the West: In the western side of the area another fault line is present. Although no definite evidence exists to consider that alignment as a physical model boundary it is believed, after the inspection of the geological map and a false color composite image, that this feature may behave as a fault which acts as a no flow boundary.

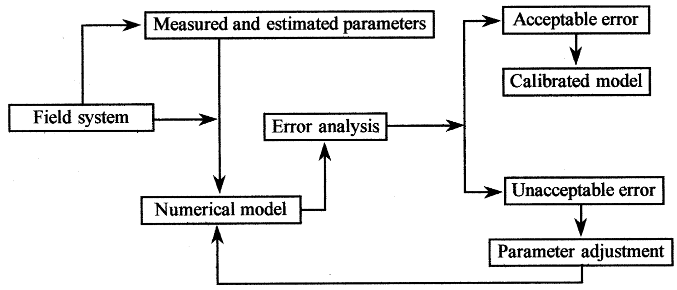

Figure 3. Trial and error calibration procedure (after Anderson *et al.,* 1992.

To the North: This boundary has been selected following a water surface divide. It is assumed that through it no groundwater flow occurs, therefore a no flow boundary has been placed there for the model.

To the South: In the south Longonot volcano and Olkaria complex represent geomorphological features and geological structures that provided evidences to consider this part of the model as a *no flow boundary,* Figure 1. This zone coincides with a surface water divide.

AQUIFER HYDRAULIC CHARACTERISTICS

The hydraulic properties, e.g., transmissivity, of the aquifer used in the model for its first run were obtained from the analysis of pumping test data collected during a fieldwork, furthermore, transmissivity values obtained from a preceding modeling effort were also used. The magnitude and spatial distribution of hydraulic properties of the aquifer are not well known for the zone and had to be calibrated.

SURFACE WATER BODIES

Surface water bodies are represented by Lake Naivasha itself and a by smaller lake to the southeast of Lake Naivasha, this small lake was previously connected to the larger one, Figure 1. At present they are not connected, however, for the effect of modeling there is no difference between considering them as two independent lakes or just as one larger lake. Lake Naivasha acts as an inexhaustible source of recharge to the aquifer in zones where the water table has dropped below the lake's level.

NUMERICAL MODEL

Except for very simple situations analytical solutions are used to solve flow problems. Numerical models are more versatile and with the widespread availability of computers, are now easier to use than some of the more complex analytical solutions. In this particular case the GMS 2.1 software has been chosen to implement, edit and translate the conceptual model into a numerical model. Facilities provided by the software were used to convert the conceptual model from a high-level feature object-based definition to a grid-based MODFLOW numerical model, which was considered to have the necessary capabilities to solve the problem in question. This

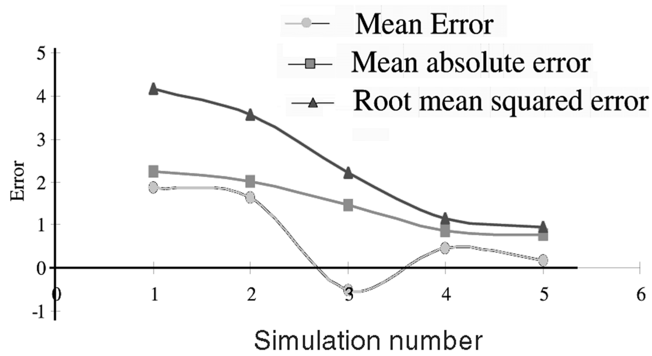

Figure 4. Simulation errors *versus* number of simulation.

package is a three-dimensional finite difference model for steady and non-steady conditions. The grid dimensions were established at 1 km x 1 km. The model consists of 42 rows and 39 columns, making a total of 1 638 cells.

TABLE I. ERROR VARIATION DURING THE SIMULATION TIME

Run number	Mean error	Mean abs. error	Root mean sq. error
1	1.87	2.24	4.18
2	1.65	2.02	3.57
3	-0.5	1.48	2.21
4	0.45	0.87	1.16
5	0.13	0.73	0.87

MODEL CALIBRATION

Calibration is accomplished by finding a set of parameters, boundaries, stresses that produce simulated heads and fluxes matching observed values in the field. A complication in groundwater problems is that the distribution of heads is always incomplete and flux calculations are not always known accurately. Estimates of flux have associated errors that are usually larger than errors associated with head measurements (Anderson *et al.*, 1992). Nevertheless, it is advisable to use estimates of flow as calibration values in addition to heads in order to increase the likelihood of achieving a unique calibration. Most models are initially calibrated against the steady-state heads, the head distribution is usually well known. The complete calibration procedure is shown in Figure 3. Computed head values must match closely those measured at observation points. Improvements during the calibration process by reducing the model result errors are given in Table I. A graphical representation of these error variations is shown in Figure 4. The model was considered calibrated when a good agreement between observed and calculated heads was found, an error summary appears in Table II. A graphical representation of this agreement is shown in Figure 5.

TABLE II. ERROR SUMMARY OF THE CALIBRATED MODEL

Error summary

Calculated parameter	Value (m)
Mean error	0.13
Mean absolute error	0.73
Root mean square error	0.87

SENSITIVITY ANALYSIS

The purpose of sensitivity analysis is to quantify the uncertainty in the calibrated model caused by uncertainties in the estimates of the aquifer parameters, stresses, and boundary conditions. Sensitivity analysis is typically performed by changing one parameter value at a time. The procedure followed here was:

- Start changes in transmissivity values having constant the recharge.
- To keep constant transmissivities and make changes in recharge values.
- Observe the area most affected by the changes.

REMARKS ABOUT SENSITIVITY

In general, the areas more affected by increases in transmissivities were in the east, southeast and west of the modeled area. Those zones are characterized by low transmissivities. The zone with the well field appears to react slowly to these increasing values of transmissivities and only when this increment is of the order of 40 % the levels change substantially. It is seen that the model is more sensitive to a decrease in values of transmissivities than it is to an increase in such values, Figure 6. A decrease of 40 % provokes a strong reaction in the well field. A decrease of 50 % in transmissivity affects the whole model, to the east the water levels went up but in the well field they decreased. To the west water levels were also increasing. A graphical comparison of model reaction to changes in both recharge and transmissivities is shown in Figure 6.

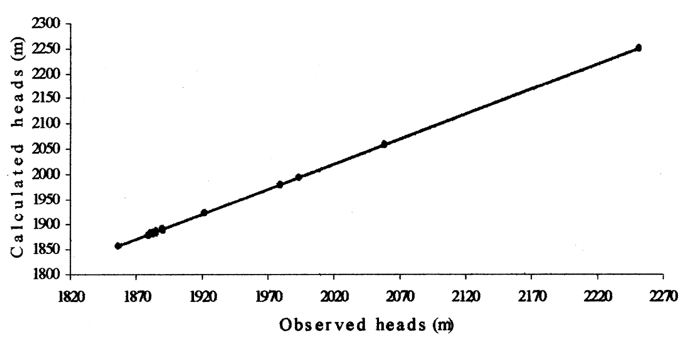

Figure 5. Comparison of observed *versus* calculated heads.

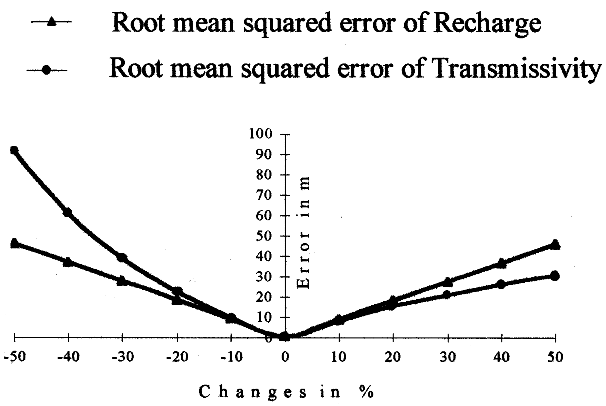

Figure 6. Model response to changes in values of transmissivity and recharge.

ENVIRONMENTAL ASPECTS OF THE MODEL SOLUTION

Present day environmental researches should not only study scientific or technical aspects but also try to integrate environmental aspects. Water in the region is a fragile natural resource, first because of its scarcity and second because of the threats to its quality. Every year the abstraction from the lake increases and so does the use of fertilizer and pesticides in the agricultural areas. A substantial part of these products ends up in the lake waters thus contaminating it. These contaminated waters are used again for irrigation and once more will return to the lake with added contamination. It has been seen from the model solution that lake waters are flowing into the aquifer in some parts of the area. In that situation the groundwater quality may become affected by such products. This has implications not only for agricultural activities in the zone but also for human health because among the numerous water wells in the area, some are used for human consumption. Agricultural development in the area is likely to increase in the coming years and the same holds for water consumption. This situation will inevitably lead to higher water abstraction from both lake and aquifer and therefore a decrease in groundwater levels is to be expected in the aquifer. If this is the case the model results show that more water will flow from the lake into the aquifer. Moreover, due to the variability in climatic conditions of the catchment this scenario might be even worse.

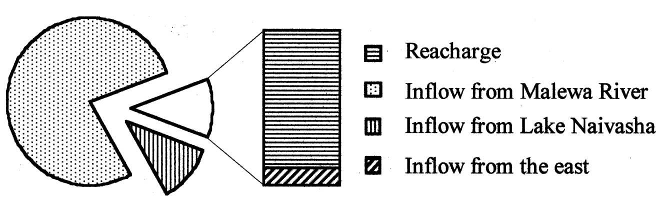

Figure 7. Components of groundwater inflow into the area of interest.

TABLE III. WATER BALANCE CALCULATIONS FOR THE AREA OF INTEREST

Comnponent	Amount [m^3/day]	Amount [m^3/month]
Groundwater abstraction	18 000	540 000
Recharge	1 800	66 000
Inflow from Lake Naivasha	2 000	60 000
Inflow from Malewa River	14 000	420 000
Inflow from the east	200	6 000

Water balance

Q_{in} = 18 000 m^3/day	Q_{out} = 18 000 m^3/day	$\Delta Q = 0$
Q_{in} = 540 000 m^3/month	Q_{in} = 540 000 m^3/month	

GROUNDWATER FLOW CALCULATIONS

It is clear that in areas where an intense agricultural development has taken place the water levels have dropped. In this particular case many water levels measured in wells have been found to be even below the lake level. This situation led groundwater to flow from the rivers and the lake into the aquifer. The difficulty is to quantify these flows. Water balance calculations are mainly affected by uncertainties in precipitation values, evapotranspiration values, groundwater inflow to and outflow from the catchment and stream flows. Different total outflow volumes have been estimated, McCann (1974) estimated an outflow of $34 \cdot 10^6$ m^3/year; Ase (1986) estimated an outflow between 45-$50 \cdot 10^6$ m^3/year; Gaudet and Melak (1981) estimated an amount of $44 \cdot 10^6$ m^3/year; Ojiambo (1992) calculated a value of $38 \cdot 10^6$ m^3/year. An outflow value of approximately $55 \cdot 10^6$ m^3/year has been estimated by Mubui (1999). As can be seen from the presented figures substantial variations exist in the estimated lake outflows. It is understood that any water balance calculations made with the model will be affected by uncertainties derived from the poor knowledge of the outflow rates as well as of the parameters. Flow calculations concentrated not to the south but on an area to the northeast of the lake, because of its importance for agricultural development. Flow calculations in the area were made in order to determine the amount of lake water draining into the aquifer as a consequence of groundwater abstraction.

FLOW FROM THE LAKE INTO THE AQUIFER

Because the water level in the well field, located to the NE of Lake Naivasha, has dropped, groundwater is flowing from the lake into this well field. By using the model an estimate of this amount of flow can be obtained. It is observed that to the northeast of the lake there is an important seepage zone, through which water is flowing into the aquifer. An outflow rate of 2 000 m^3/day equivalent to 60 000 m^3/month was obtained. In other areas this quantity is much less and amounts to approximately 180 m^3/day, 5 400 m^3/month. The amount of flow of 60 000 m^3/month is just a small portion of the total abstraction rate in the area which rises up to 540 000 m^3/month (Calculated amount based on declared abstraction rates by farmers).

FLOW FROM THE RIVER INTO THE AQUIFER

It could be realized that groundwater is also flowing from the Malewa River into the aquifer. Before modeling it was believed that the major component of the groundwater inflow into the well field came from this river. This belief was corroborated by model calculations. The model estimated value amounts to 14 000 m^3/day, which is equivalent to 420 000 m^3/month. Based on the quantities presented an estimate for the water budget balance was made. Results are presented in Table III. Every inflow component for the water balance is shown in Figure 7. The model also gives insight about the order of magnitude of the groundwater inflow into the lake. The value obtained according to the model amounts to 75 000 m^3/day, equivalent to 2.25×10^6 m^3/month (30 days month).

None of the previous works took into account the volumes draining from the lake to the agricultural area. From this paper a more complete result is presented; the total lake outflow, considering Mubui´s work and the water balance made with the model, is around 55.73×10^6 m^3/year.

CONCLUSIONS

- The river level plays an important role in heads distribution, mainly, in areas where the lake influence is absent.
- The river level plays an important role in the amount of flow from it into the aquifer.
- The aquifer transmissivity has a high variability, varying from less than 1 m^2 / day to more than 5 000 m^2 / day.
- The model is more sensitive to high values of recharge than to high transmissivities.
- The model is more sensitive to low transmissivities than to low values of recharge.
- Water balance calculations give approximate results because uncertainties in the variables influence the calculation, even so the results are quite reasonable.
- The model may serve as a tool to predict possible contaminated zones in the future due to inflows of water from the lake.

RECOMMENDATIONS

- To carry out systematic water level recording over longer periods of time in order to perform a calibration under transient conditions.
- To measure the water level in Gil Gil and Malewa rivers more accurately and at so many points as possible, get its exact elevation above datum.
- To measure water levels in the western and southeastern parts of the modeled area.
- To collect more information about existing pumping test data and to conduct more tests in areas where information is not available.
- Determination of storativity values in the catchment for use in transient simulation.
- To determine more accurate recharge values. The location for these measurements must be as homogeneously distributed as possible.

BIBLIOGRAPHY

Anderson, M.P. and W. W. Woessner (1992): *Applied Groundwater Modeling, Simulation of Flow and Advective Transport*. California Academic Press Inc.

Ase, L.E., and K. S. Per Syren (1986): *Studies of the Lake Naivasha, Kenya, and its Drainage Area*. Stockholm: Stockholm Universitet.

Behar, H. A., 1999: “Surface Water–Groundwater Interaction, Lake Naivasha, Kenya”. ITC, The Netherlands, MSc Thesis.

Clarke, M.C.G., D. G. Woodhall, D. Allen and G. Darling (1990): *Geological, Volcanological and Hydrogeological Controls on the Occurrence of Geothermal Activity in the Surrounding Lake Naivasha, Kenya*. Republic of Kenya, Ministry of Energy.

Fetter, C.W. (1994):*Applied Hydrogeology*. New Jersey, Prentice-Hall Inc.

Freeze, R. A. and J. A. Cherry (1979): *Groundwater*. New Jersey: Prentice-Hall Inc.

GMS 2.1. (1998): Reference Manual Groundwater Modeling System, version 2.1. USA: Brigham Young University–Engineering Computer Graphics Laboratory.

Graham, A. (1998): “Groundwater Recharge Estimation of Malewa Catchment, Naivasha, Kenya”. [MSc Thesis], ITC, The Netherlands.

Gressando, J. (1999): “The Application of Geophysical Techniques, Groundwater Investigation Around Lake Naivasha, Nakuru District, Republic of Kenya. [MSc Thesis], ITC, The Netherlands.

Huaccho, L. (1998): Water Availability Assessment Using Multi-Objective Decision Support System, Lake Naivasha, Rift Valley Province, Kenya. [MSc Thesis], ITC, The Netherlands.

Kijabe LTD. (1998): Borehole Site Investigations at Naibor Ajijik, Narok District, Kenya. Republic of Kenya: Report No. 98/547.

Kruseman, G. P. and N. A. De Ridder (1994): Analysis and Evaluation of Pumping Test Data. The Netherlands: ILRI Publication 47.

Lubczynski, M. (1997): Application of Numerical Flow Modeling Combined with Remote Sensing and GIS Techniques for the Quantification of Regional Groundwater Resources in Hard Rock Terrains. The Netherlands: IAHS Publ. No. 241.

McCann, D.L. (1976): Hydrogeologic Investigation of Rift Valley Catchments, United Nations-Kenya. Republic of Kenya: Government Geothermal Exploration Project.

Mc Donald, M. (1988): and Harbaugh, A.W. A Modular Three-Dimensional Finite-Difference Groundwater Flow Model. USA: Scientific Software Group.

Mubui, S.G. (1999): Long Term Water Balance Analysis of Lake Naivasha, Kenya. [MSc Thesis], ITC, The Netherlands.

Ojiambo, B. S. (1992): Hydrogeologic, Hydrochemical and Stable Isotopic Study of Possible Interactions Between Lake Naivasha, Shallow Subsurface and Olkaria Geotherma, USA.

Roehrich, T. AQUITEST for Windows, version 2.54. Ontario: Waterloo Hydrogeology Inc.

Stuttard, M., J. Hayball, G. Narciso, G. Carizi, M. Suppo, R. Catani, L. Isavwa, J. Baraza and A. Oroda (1995): Monitoring Lakes in Kenya: An Environmental Analysis Methodology for Developing Countries. CEC DG XIII STD-3 Programme.

Terlien, M.T.J. (1996): Modelling Saturated Subsurface Flow in Steep Mountainous Catchments. The Netherlands: ITC Journal 3 / 4, pp. 264-271.

Thompson, A.O. and R. G. Dodson (1958): Geology of the Naivasha Area. [MSc Thesis], England.

VIAK Ltd. (1975): Naivasha Water Supply Project. Republic of Kenya: Ministry of Agriculture.

Welldrill & Geotechnics Consultants. (1997): Report on Groundwater Investigations at Naivasha. Republic of Kenya: Welldrill & Geotechnics Consultants.

Wiberg, I. (1976): Naivasha Water Supply Project: Groundwater Investigation. Republic of Kenya: Ministry of Water Development.