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Numerical groundwater flow modeling of the northern river catchment of the Lake Tana, Upper Blue Basin, Ethiopia

Nigussie Ayehu Asrie[1*], Mesenbet Yibeltal Sebhat[2]

[1] Water Well Drilling Enterprise, Bahir Dar, Ethiopia.
[2] Faculty of Civil and Water Resources Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia.

**Corresponding author: mesyibseb@yahoo.com*

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Abstract: The study area is found North Western plateau in the North Gondar zone, Amhara regional state, Ethiopia. Its total surface coverage is 1887 km^2. Its boundary was delineated from 90 m Shutter Radar Terrain Mapping (SRTM) digital elevation model (DEM) using Global Mapper 8 software. Based on geologic information, unconfined subsurface flow condition was considered and simulated using MODFLOW 2000. The model calibration accounts the matching of the 58 observation point with simulated head with a permissible residual head of ±10 m. 75% of the difference between the observed and measured water level head is 5 m. The model was calibrated with mean error 0.506, absolute mean error 4.431 m and standard deviation 6.083 m. Based on the calibration process, the model is very sensitive in decreasing order change in recharge, hydraulic conductivity, and stream bed conductance.
The simulated out flow of the model is 205.7 Mm^3/year which is nearly equal to simulated inflow with difference 2,887.45 m^3/yr. The base flow simulated discharge Megech River holds 35.8% of the out flow. The river contributed as recharge in to the aquifer that accounts to 15.3% of the inflow. Steady state withdrawal rates were increased by 15%, 35%, 55%, 75% and 100% to study the response of the system in this scenario. From the simulation results, one can observe that the development of a new groundwater sources would not pose appreciable impact in case of 15% and 35% withdrawal the head declines in this case is insignificant relative to the steady state withdrawal rate and the natural discharges were not altered highly. The simulation result indicated that the stream leakage decreased by 7.9% relative to the whole steady state value, but showed 14.9% decrease for Angereb, Keha, and Shinta river segments near the well field area. The water tables decline by 3.6 m to18.8 m in head observation in the well field area.
The steady state simulated recharge was decreased by 32% and the simulation results showed on average head decrease of 8.06 m over the whole area; with the highest fall 32 m in wells to north and a minimum of about 1m in wells to

the south of the catchment. In addition, the stream leakage, compared to the simulated steady state value and it was decreased by 75.36%.
The simulated value showed an average 2.74 m increased head over the whole area. High difference values were observed at Tseda (7.83 m) and Koladiba (7.3 m). The minimum difference 1.08m was recorded at Angereb well field (observation 94). In addition, the stream leakage compared with the steady state value the change was about 87.43%.

Keywords: MODFLOW 2000, groundwater, modelling, sensitivity analysis, simulation, recharge.

Introduction

Groundwater is an invisible resource, both the dynamic of the resource base and the services it produces are not well known. It is poorly understood resource, yet one that is critical to a wide variety of social, economic and environmental services. Pollution and declining water levels represents direct threat to the sustainability of the environment, domestic, agricultural, and industrial, uses dependent on groundwater flow. In addition, as demands grow and the limits of sustainable extraction become evident, competition between agricultural and other users is increasing rapidly (Abyou, 2008). Each user extracts as much groundwater as possible in order to capture benefits for themselves before the resource is exhausted. The net result can be a spiral of growing demands and decreasing availability (Getachew, 2004). Competition is, thus, a critical social issue that must be addressed in order to manage groundwater on a sustainable basis.

A critical challenge in interpreting both quantity and quality problems are related to understanding of the resource base and its dynamics. Many individuals, ground water professionals included, conceptualize ground water as flowing smoothly through the earth with rapid recharge from rainfall and relatively uniform water quality. In reality, however, complex rock formation and differential recharge rates results in far more complicated dynamics (SMEC, 2008). It is important to recognize that overdraft and water level declines typically affects the sustainability of uses that are dependent on groundwater long before the resource base itself is threatened with physical exhaustion (Tesfaye, 1993). One of the primary objectives of most groundwater resource studies is the determination of the maximum possible pumping rates that are compatible with the hydrogeologic environment from which the water will be taken. Beyond overdraft and water level declines lie the questions of water quality and pollution (Freeze and Cherry, 1979).

Groundwater modeling is being used more frequently as a tool to help answer optimum water management questions because it can lead to a better understanding of how the real system behaves and it can be used to make predictions about the systems future behavior (Zerihun, 2009). This in turn helps to develop operational and regulation strategies that will secure the sustainable development of strategically important water resource (Andarge, 2002). Numerical modeling is being used increasingly to quantify the water resource availability of our complex, dynamic groundwater /surface water systems and to take account of the environment impact of abstraction (Anderson and Woessner, 1992). However, to be credible, modeling tools must be technically valid and agreed representation of the real system. Therefore, one of the key objectives of any resource study is the process of developing a shared understand (conceptual model) of the essential flow mechanisms. Only then can the numerical model be used as a predictive tool to investigate different future conditions (Abyou, 2008).

Because of climatic change, deforestation and construction activity, recharge to groundwater has been decreasing, and because of increasing population size water demand is increasing at alarming rate. The other most important reason to develop the flow modeling of the catchment is to evaluate the impact of irrigation on groundwater. Generally this study gives insight about the response of the catchment groundwater flow system to different possible occurring stresses. Specifically this work has focused on identifying the most sensitive parameter of the hydrogeologic system; effects of increased groundwater withdrawals, altered Recharge, dried Angereb reservoir, development of Megech reservoir and effect of irrigation on groundwater on the study area.

Materials and methods

Materials used

To accomplish the objectives mentioned above, the following materials and equipment were used 1:50,000 scale topographical map, Land satellite images, Geological and hydrogeological maps, various computer software (MODFLOW 2000, ArcGIS 9.2, Global Mapper 8, and Surfer 8), deep meter and Current meter.

Area description

The study area is found in the North Gondar Zone of the Amhara region. It locates between coordinates of 13’53”-14’10”N latitude and 30’50”E-35’70”E longitude inside Ethiopia with an approximation altitude range 1785-2920 masl. The area covers a total surface of 1887 km^2. The Northern, Eastern and Western part of the catchment has characteristics of raged topography and with a chain of ridges bordering sub catchments with in the area and the southern part of the catchment is characterized by gently sloping and plain surface which is an outlet of Megech River to Lake Tana

(Tesfaye, 1993). The climate of the area can be categorized in to two broad seasons; the dry season (winter) which covers the period from October to May and wet season (summer) extends from Jun to September, with slightly rainfall during autumn and spring. The annually mean maximum, mean, and mean minimum temperatures are 25, 19, and 13 °C respectively. The major landform of the watershed comprises chains of hills with mountainous ridge, which include most of what is designated in north central massif (BCEOM, 1999).

It is almost semi oval in shape with dendrite drainage pattern, steps ridges at boundary, numerous convex hills inside the catchment and steep gorges. The rugged landform of the area is due to volcano-tectonic activities that formed the plateau and followed by later erosion and river dissection. The slope classes in the watershed encompasses very steep to gentle topography. The northern and eastern part of the catchment has very rugged topography and steep slopes (FDRE, ANRSBA, RD, 2005). Elevations range from 1785 m (at south tip of study area, Lake Tana) to 2920 m (North Extreme of the catchment). The main tributaries of Megech River; Angereb, Keha, Shinta, Dimaza, Gilgel Megech, and Wizaba, have cut deep trenches that divide the watershed in to sub catchments fig. 2. There are also other two intermittent river catchments that have been included in the study area; Gumero and Derma (SMEC 2008).

The study area is characterized by well developed denderitic drainage pattern. Most of the streams originate from the surrounding volcanic chained hills, which are surface

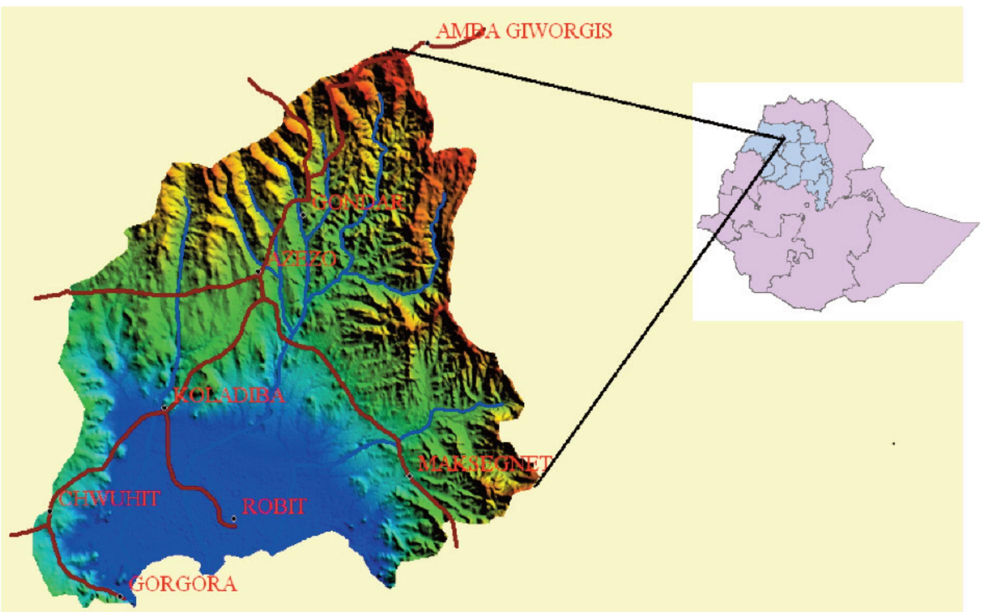

Fig. 1 - Location of the study area, Amhara region, North Western Ethiopia.

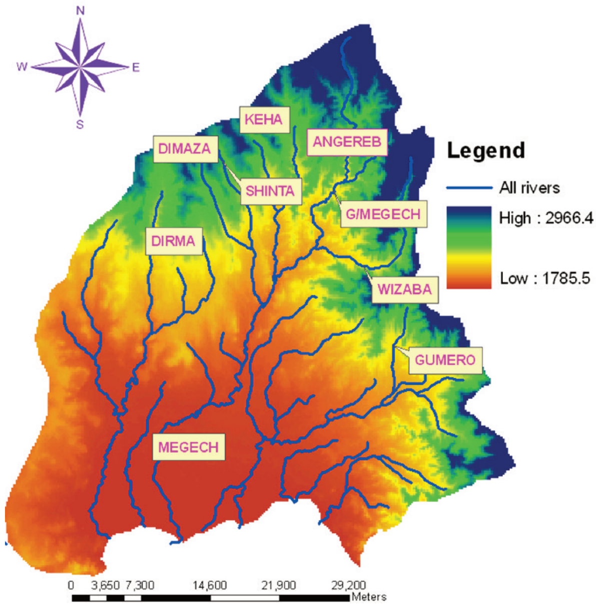

Fig. 2 - Physiographic and drainage pattern map.

as well as believed to be groundwater divides (Beyene, 2007). In the northern part of the catchment the drainage forms relatively steep narrow gorges that can attributed to high rainfall, small depth soil and high topographic elevation. It is known that area with high permeability have lower drainage density that intern may decrease the surface runoff. The Megech river, which is about 75 km long, has a drainage area of about 850 km^2 and an average annual discharge of 11.1 m^3/s (Abyou, 2008). The gauged part of the Megech sub basin is only the upper part of the catchment enclosing an area of 462 km^2 and the mean annual discharge 6.67 m^3/sec.

Most of the inhabitants live on the hill and mountainsides, and the houses are moderately scattered all over the watershed. The domain land uses are cultivated, moderately cultivated with bushes, moderately cultivated with trees, wood land with sparse plots and urban. In most of the northern part of the catchment, the soils are shallow leptosols underline by unconsolidated medium sized gravels with loose joints, which in turn underline by watertight rocky layers (Tesfaye, 1988). The dominant textures identified in this area are silt clay loam and silt clay. Soil depth refers the depth of the soil above a layer of hard rocks, stones or other materials, which hinder root. In this watershed, all the soil depth classes are found but the dominant soil depths are penetration between 25 cm to 200 cm (Engda *et al.*, 2007).

The physiographic position, parent materials, drainage characteristics and soil depth are the key to classify the soils in the study area.

The study area is characterized by unimodal rain fall pattern with peak rainfall season starts at the mid of May and ends at the end of the September. The mean annual rainfall ranges from 863.9 mm/yr recorded at Gorgora to 1225.8 mm/yr at nearby station. The maximum relative humidity corresponds to the rainy seasons and the minimum to the dry months (Yirgalem and Assefa, 2008). The wind speed reaches its maximum in the dry season and minimum in the rainy season.

Geological structures

The geological frame work of lake tana basin as out lined on the 1:2,000,000 Geological Map of the Ethiopia (2nd Ed.,1996) comprises a basement of Precambrian bed rock, over line by Mesozoic Sediments, Tertiary Volcanic and minor sediment, Quaternary Volcanic and recent Alluvial sediments. Ongoing tectonic activities has controlled the distribution of the rock formation and controlled the current configuration of the basin (Samson, 2010). Around eastern boundary boundary of

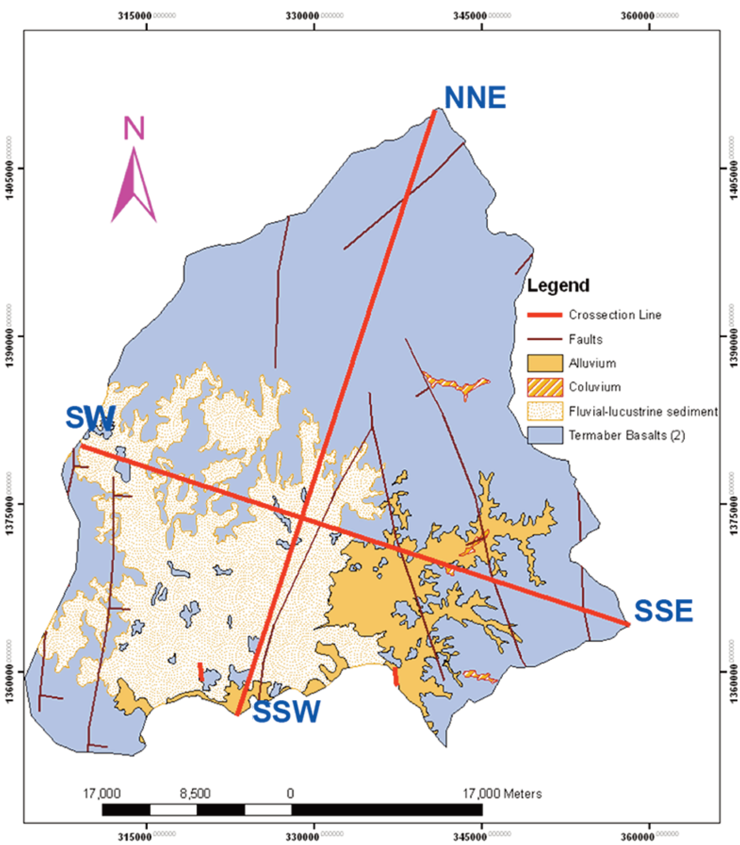

Fig. 3 - Geological map of the study area with NNE-SSW and SW-SSE cross sectional line.

the Gilgel Abay basin the base of the basalt is inferred Mgnetotellic investigation (Bayisa, 2003) to be at depth of around 250 m. It appears that within the basin, the geological structures suggests inward tilting fault blocks and an essentially flat base of the basalt dips away from the Tana basin in the area surrounding the basin (SMEC, 2008).

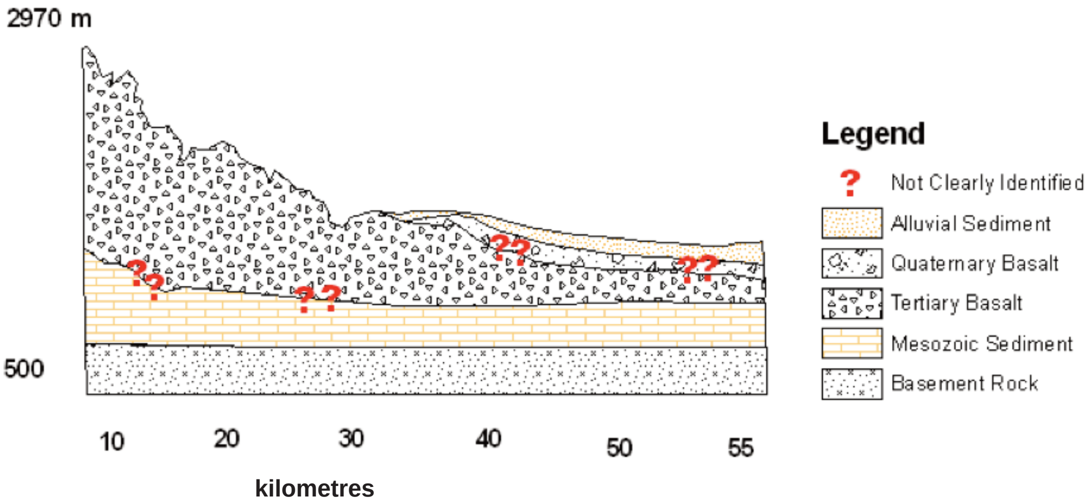

Fig. 4 - Schematic geologic cross section of the study area NNE_SSW profile.

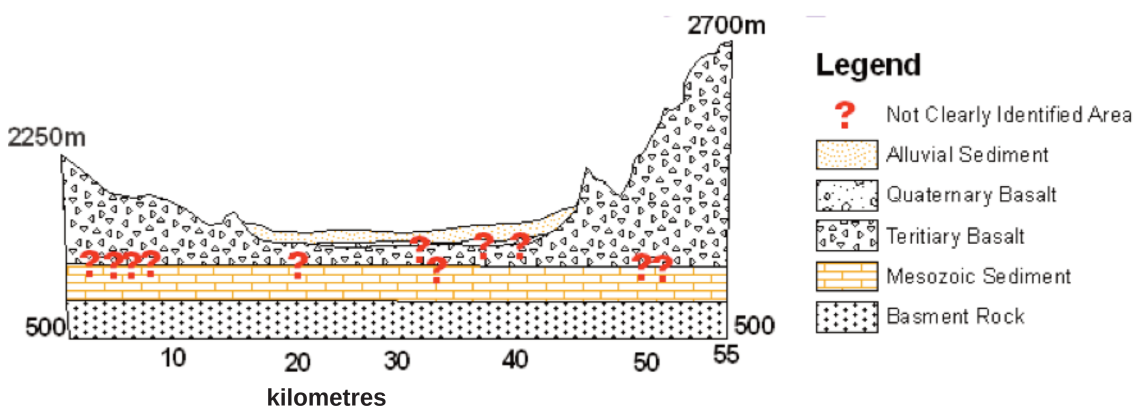

Fig. 5 - Schematic geologic cross section of the study area SW_SSE profile.

Conceptual model development

Conceptual model is a pictorial representation of the groundwater flow system, frequently in the form of a block diagram or a cross section (Anderson and Woessner, 1992). The nature of conceptual model will determine the dimensions of the numerical model and the design of the model. The development of conceptual model is the most important stage in groundwater flow modeling as it simplify the field problems and organize the field as result the system can be analyzed readily. Hydrologic information on precipitation, evaporation and surface water runoff, as well as head data and geochemical information are used in this analysis. Water level measurement are used to estimate the general direction of groundwater flow, the location of recharge and discharge areas, and the connection between the aquifers and surface water systems (Anderson and Woessner, 1992).

System boundary conceptualization

In Northern River Catchment of Lake Tana, the system boundary has carefully delineated based on the DEM data, field visit and existing works. The Northern, Eastern and Western boundary of the catchment of the model coincide with surface water divide line of the study area which is considered as no flow boundary. It should be remembered that groundwater divide is not a really a boundary in nature, but as groundwater on either side of the divide flows away from the divide and not across it, the divide itself acts as a no flow boundary. The southern part of the study area is coinciding with Lake Tana so it considered as specified head boundary. Hydro stratigraphic units defined from geologic information and hydrogeologic properties. The bases to determine the bottom layer of this unconfined aquifer is transmissivity, yield, lithology, fracture of rock, consists of alluvial and lacustrine sediment. In this study, the aquifer thickness lies within the range 210 m to 300 m in most parts of the catchment except along the boundaries where ridges with high elevation are found. The lithology is dominantly highly weathered and fractured tertiary basalt in elevated areas and alluvial sediments in low lands around the Lake.

Numerical groundwater flow modeling

Groundwater flow in the Northern river catchment of Lake Tana aquifer system has been simulated using a modular three dimensional finite difference groundwater flow model of the U.S. Geology Survey which describe and predict the behavior of the flow system. The algebraic equation which can be written in matrix equation is solved with a numerical approach through the iterative process. These numerical approaches, in finite difference approximation involve applying Taylor's expansions

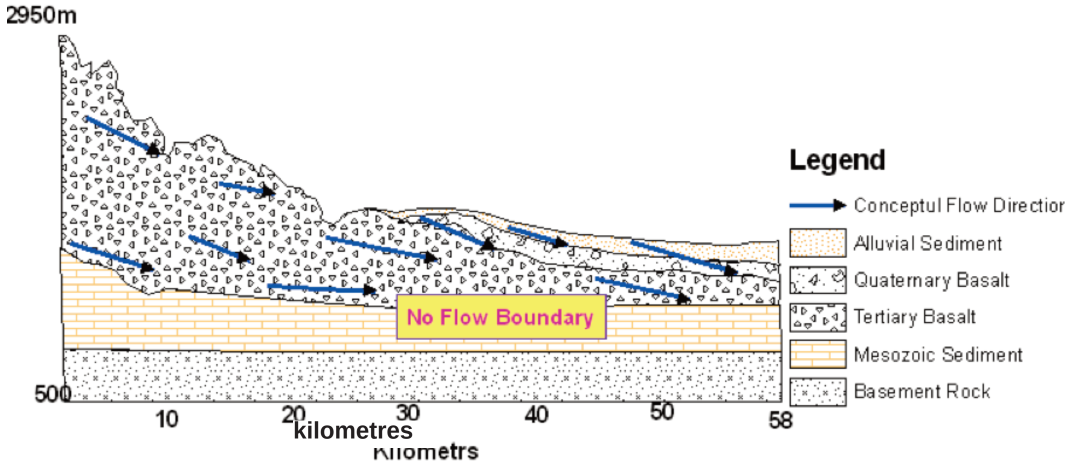

Fig. 6 - Conceptual hydrostratigraphic and groundwater flow of the study area N-S Profile.

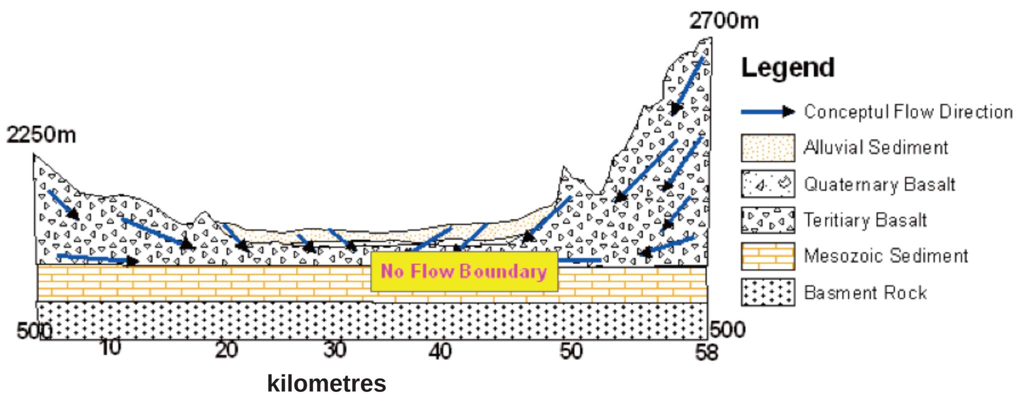

Fig. 7 - Conceptual hydrostratigraphic and groundwater flow of the study area E-W Profile.

the flow equations and approximating derivatives in the equation. It is the representation of physical law that controls the groundwater flow, which is based on Darcy's law and the law of mass conservation. It is used in computer model to describe groundwater flow is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t} \qquad (1)$$

Where:
Kx, Ky and Kz : are the hydraulic conductivity along x, y and z coordinate axes; (LT^{-1}); h: is hydraulic head, in meters; W: is a volumetric flux per unit volume and represents sources or sinks or both of water, such as well discharge, recharge and water removal from the aquifer by drains, per day; (LT^{-1}) Ss: is the specific storage of the porous materials, per meter; (L^{-1}) t: is time, in days.

To model the study area, Northern river catchment of Lake Tana, aquifer system the above governing equation has been adjusted according to the prevailing field condition. This equation assumes flow system view point that allows both vertical and horizontal component of flow throughout the system and there by allows treatment of flow in two dimensional profiles (Anderson & Weossener, 1992).

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)-W=Sy\frac{\partial h}{\partial t} \qquad (2)$$

S_y is specific yield the equivalent of the Specific storage and the steady state is characterized with no storage or change of head through the hydrological year.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)=+(-)R \qquad (3)$$

Where: R is a general sink or source intrinsically positive for to represent recharge and negative for withdrawal of groundwater from aquifer system.

Boundary condition

Boundary conditions are mathematical statements specifying the dependent variable (head) or the derivative of the dependent variable (flux) at the boundaries of the problem domain (Anderson and Weossener, 1992). In this model two boundary conditions were applied; specified head and specified flow/ no flow.

Model layer

Top layer is the top elevation of the aquifer under considerations. The top layer of unconfined aquifer is the water table and not the land surface (topography). The nodal values of ground surface elevation were interpolated from DEM data. The

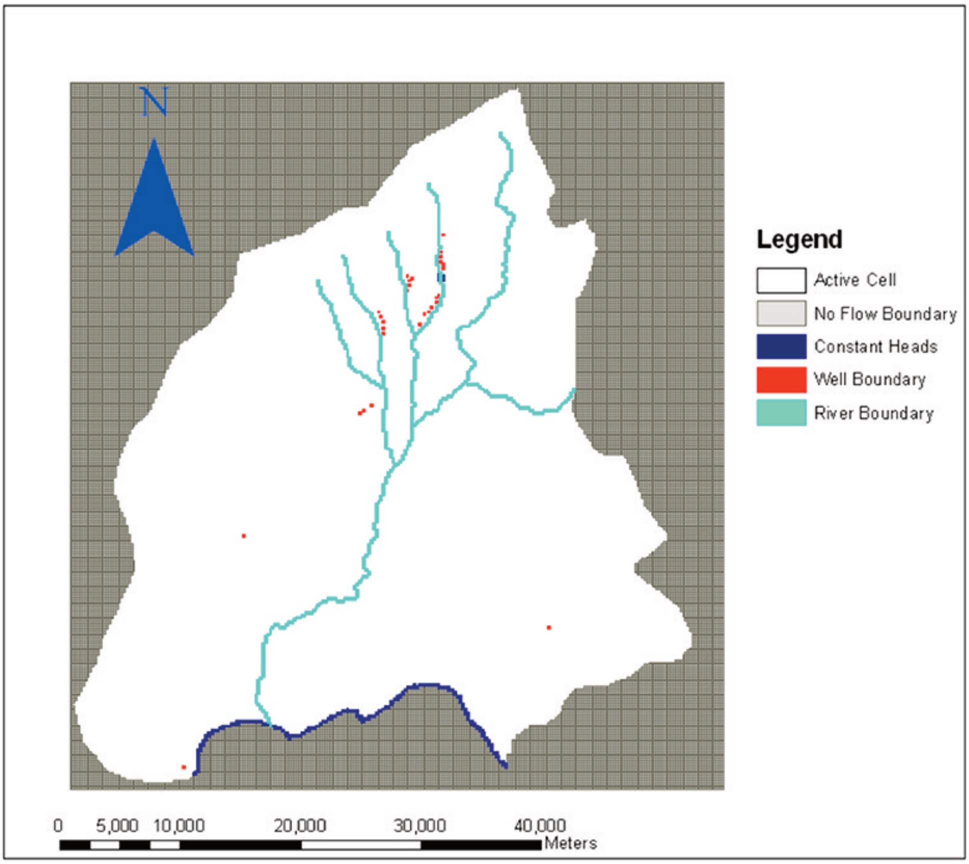

Fig. 8 - Boundary condition of the study area.

interpolation was done at the resolution of 200 m x 200 m and then loaded in to the MODFLOW top elevation array by subtracting surface elevations above from the interpolated water table. Bottom layer is the bottom elevation of the aquifer layer being modeled.

Hydraulic conductivity

The permeability of rock materials in porous media is a function of; their effective porosity, structure, texture, geological history. Hydraulic conductivity distribution map is developed from pumping test results (transmissivity and storativity of the aquifer), geology and hydrogeological map. Since the model is conceptualized as isotropic and single layer unconfined aquifer, no vertical flow (Z) and the same hydraulic conductivity in X and Y direction.

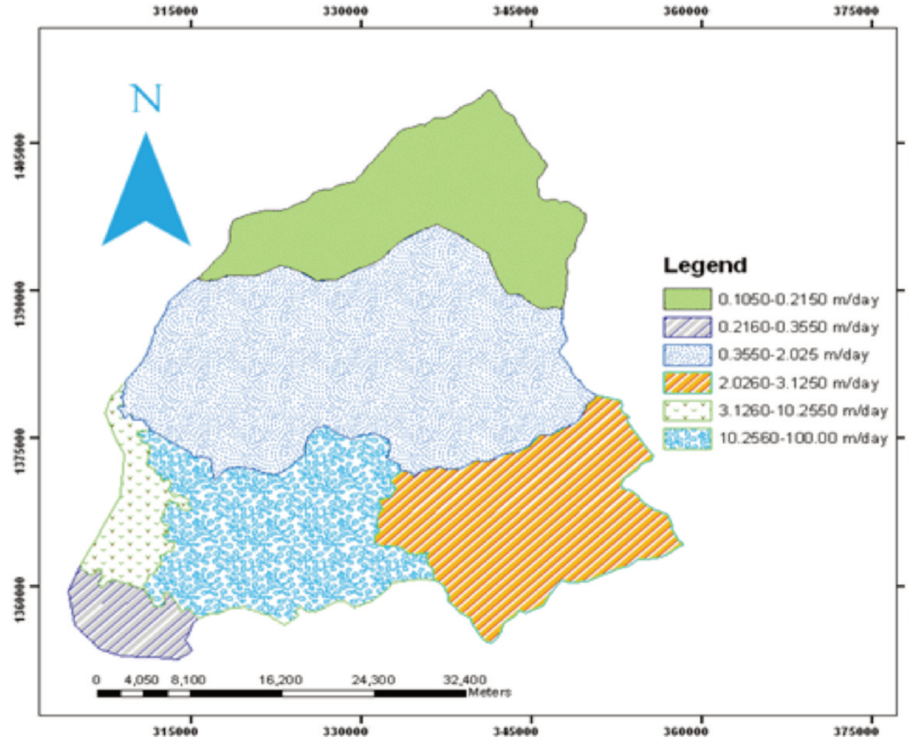

Fig. 9 - Hydraulic conductivity map.

Recharge and spatial distribution

Recharge is most important parameter required in the successful development of groundwater resource that can safely be abstracted as safe yield from aquifers. It is estimated with precipitation fractionation (Geologic character, soil type, topography, land use etc.). The average mean is 105 mm/y from river base flow which is 10% of RF. Generally recharge rate is vary from 5-20% of RF in the Tana Basin (Getachew, 2008, TAHAL, 2009).

Ground water discharge

Groundwater is discharged from the Aquifer as spring, Well discharge for water supply (4681.8 m^3/day), and base flow from the catchment to Tana Lake (90 mm/year, BCEOM, 2006).

Calibration and sensitivity analysis

The model calibration accounts the matching of the 45 observation point with

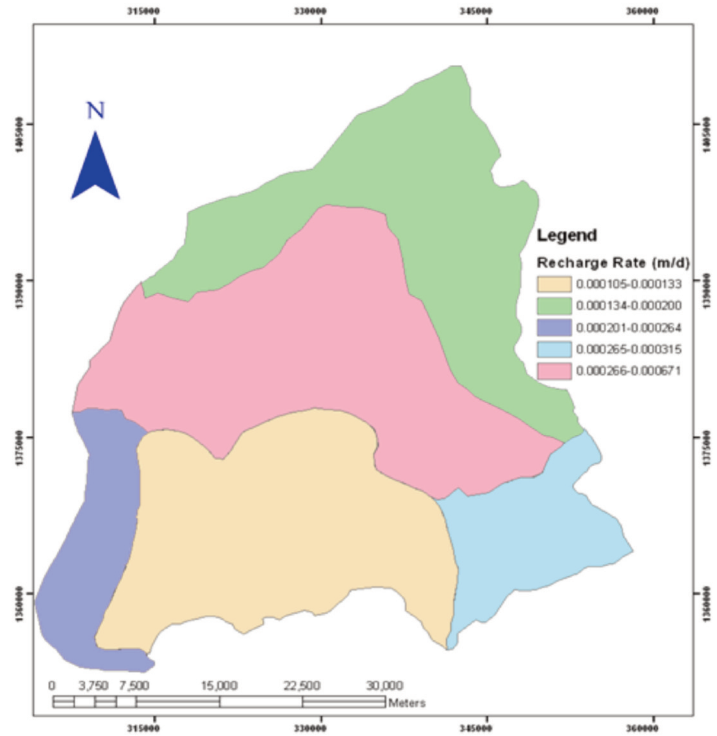

Fig. 10 - Recharge and spatial distribution map.

simulated head with a permissible residual head of ±10 m. The criteria set is almost 75% of the difference the maximum and minimum measurement water level head in the study area which is about 5 m. It is almost with tolerable difference with respect to the gradient, the objective to understand the groundwater flow pattern and the diversity of hydraulic nature of volcanic aquifer. The model was assumed calibrated when the fit between observed and calibrated heads was within this criteria and calibration evaluated based on final spatial distribution of the difference.

Sensitivity analysis

The results of sensitivity analysis are reported as the effect of the parameter change on the average measure of errors or residual selected as calibration criteri (calibration statistics). The effect on the spatial distribution of head residual is also examined. The sensitivity of the major parameters of the model was identified during calibration process. The calibration value of recharge, hydraulic conductivity, and stream bed conductance were varied by 5%, 15%, 30%, and 50% increase and decrease at different times to test the sensitivity of the model to the parameters. The following tables show the result of sensitivity of the model to changes in recharge, hydraulic conductivity, and stream bed conductance on the hydraulic heads and river leakage.

Result and analysis

The final result of the model is a calibrated steady state groundwater flow model with simulated head of groundwater surface. The simulated water budget has been

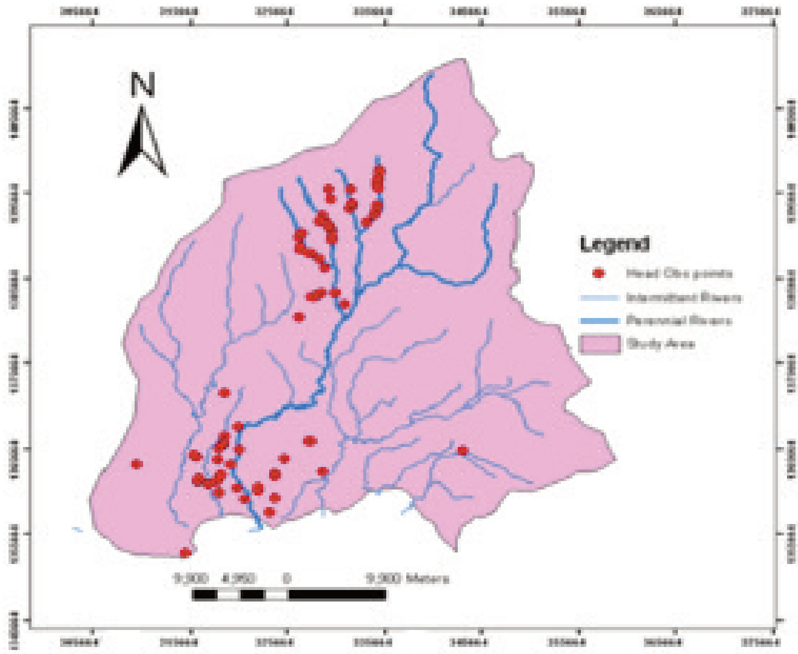

Fig. 11 - Location of observation points used for head calibration.

Table 1 - Result of sensitivity analysis test on hydraulic heads.

Multiplier Factor	Hydraulic conductivity (%)	Recharge (%)	Stream Conductance (%)
0.5	107.76	253.37	81.07
0.7	65.39	84.15	22.52
0.85	12.91	23.1	5.84
0.95	0.92	3.41	0.71
1	0	0	0
1.05	1.10	0.41	0.62
1.15	7.45	6.02	0.87
1.3	22.42	31.31	7.50
1.5	53.82	75.73	15.53

Table 2 - Result of sensitivity analysis test on stream leakage.

Multiplier Factor	Hydraulic conductivity (%)	Recharge (%)	Stream Conductance (%)
0.5	69.04	-76.72	11.99
0.7	30.80	-74.97	6.64
0.85	14.02	-37.79	3.47
0.95	4.46	-12.65	1.21
1	0	0	0
1.05	-4.31	12.73	-2.02
1.15	-12.68	38.48	-4.18
1.3	-24.64	77.72	-8.95
1.5	-39.47	131.29	-15.64

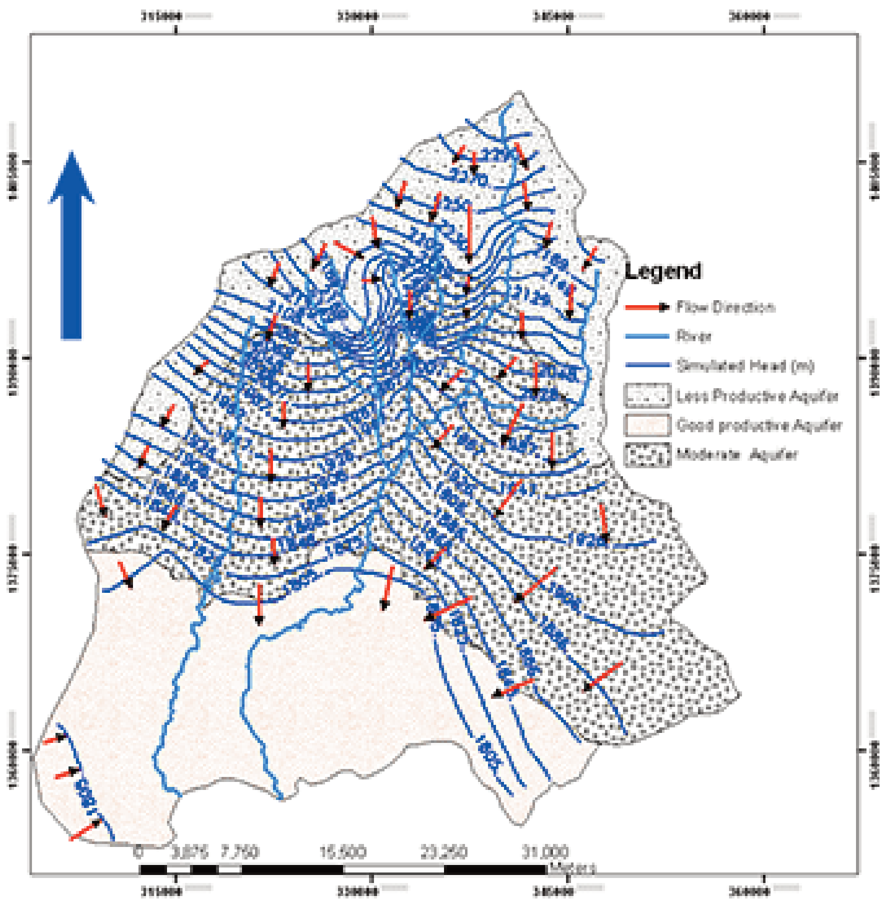

Fig. 12 - Groundwater head contour and flow direction.

computed for the study area. The simulated out flow of the model is 205.7 Mm^3/yr which is nearly equal to simulated inflow with difference 7.9 m^3/yr and 0% of error. The base flow simulated discharge holds 35.8% of the out flow. It also contributed as recharge in to the aquifer that accounts to 15.3% of the inflow. This share of base flow implies the discharge of the groundwater to the dominantly gaining streams and high interaction of surface and aquifer systems. The head distribution shows the groundwater surface follows the topographic contour and it coincides with surface water flow.

Scenario analysis

Changes in water levels and fluxes caused by increased groundwater withdrawl in the whole catchment and effective of local increase groundwater local withdrawal of Gondar-Azezo town and its peripheries were simulated by the model. The effect of changes in water levels and fluxes caused by decreased recharge due to less than normal precipitation that may result from weather modification and deforestation was also simulated. The increasing of the recharge due to irrigation project area has also been simulated using the model. In addition, the response of the system in the absence and development of reservoirs with groundwater has also been tested using the numerical model.

Effects of increased groundwater withdrawals

Gondar-Azezo town expanding, industries flourishing and population are increasing in the study area, it is reasonable to assume that the water demand will increase too. In addition the main water supply source of Gondar, Angereb dam yield is decreasing due to sedimentation of the reservoir site. To meet increasing demand and decline of exciting water supply scheme yield, it is must that the existing boreholes should be pumped a greater rate or with new boreholes with higher capacity should be drilled in the future. The current withdrawal rate estimated under steady state simulation was 4,681.8 m^3/day.

Table 3 - System response to increased groundwater withdrawal.

Multiplier	Decreasing groundwater (m)			Decreasing stream leakage (%)
	Mean	Min	Max	
1.15	0.11	0	0.57	0.37
1.35	0.78	0.002	1.85	0.84
1.55	1.35	0.004	2.50	1.50
1.75	1.85	0.074	3.23	2.00
2.00	2.46	0.102	3.98	2.67

The current estimated groundwater withdrawal rate from the catchment can be considered as the minimum reasonable amount. In addition, it also can induce recharge from surface water bodies such as streams or reservoirs. The steady state withdrawal rates were increased by 15%, 35%, 75% and 100% to study the response of the system in this scenario. These increased are equivalent to withdrawing 5384.1, 6320.4, 7256.8, 8193.15, and 8336.6 m^3/day over the whole catchment respectively and the increased withdrawal rate distributed among the exciting wells. Model simulated results of stream base flow and water table elevations in the scenarios were compared with the model calculated steady state results and the difference showed the response of the system to the assumed scenarios.

Water level changes in individual wells can be exaggerated or dimensioned relative to the regional representation value. From the above simulation results, one can observe that the development of a new groundwater sources would not pose appreciable impact in case of 15% and 35% withdrawal the head declines in this case is insignificant relative to the steady state withdrawal rate and the natural discharges were not altered highly.

In the second scenario, increased groundwater withdrawal in Gondar-Azezo town and its periphery well fields were simulated to see the effects on groundwater level changes and stream reaches. In this case the current withdrawal of the well field from active wells was increased to 23,409 m^3/day for scenario test, which is about five fold increases. The simulation result indicated that the stream leakage decreased by 7.9% relative to the whole steady state value, but showed 14.9% decrease for Angereb, Keha, and Shinta river segments near the well field area. The water tables decline by 3.6 m to18.8 m in head observation in the well field area. The lower Angereb well field head decline is significant when compare with other near well fields.

Generally, if future water demand conditions force groundwater to be withdrawn at rates simulated in these scenarios, other parameters not changed, these will be hydrologic imbalance between groundwater inflow and outflow conditions that may cause pollutants to enter the groundwater system from polluted surface water sources. The effects of withdrawal on four well fields in decreasing order are as follows; Lower Angereb well field, Shinta well field, Upper Angereb well field and Keha well field.

Effects of altered recharge

This scenario simulates a case of decreasing recharge to aquifers that may result from lower than normal precipitation (environmental changes), expansion of agriculture, deforestation and town expansion. It is a real that changes in climatic condition from time to time are affecting precipitation amounts in the country adversely and are reducing recharge to groundwater as the main source of recharge is precipitation. Although difficult to quantify other factors assumed unchanged, the future decrease in recharge amount will be inevitable and rough estimates made above can be used to study system response. The steady state simulated recharge was decreased by 32% and the simulation results showed on average head decrease of 8.06 m over the whole area; with the highest fall 32 m in wells to north and a minimum of about 1m in wells to the south. In addition, the stream leakage, compared to the simulated steady state value and the changes was about 75.36%.

As it has been seen the decreasing of recharge has adverse effect on the groundwater table and stream leakage. So, solutions should be forwarded to tackle such environmental unfriendly problem. On this catchment there is one proposed dam that has been on going to be constructed. To provide ample amount of water to the dam, different remedial measures should be developed to increase the recharge of the catchment that flourishes water to the river. The most important measures that should be taken are decreasing the expansion of agriculture, afforestation, constructing soil and water conservation structures etc.

Effect of dried Angereb reservoir

The source water stored in Angereb reservoir is either from run off during precipitation or leakage from groundwater systems. In this numerical model simulation, the reservoir was considered as constant heads. Angereb reservoir is artificial surface water bodies constructed for domestic water supply purposes for Gondar town. The maximum water demand of the town was estimated to be 346.8 l/sec. the analysis on the adequacy of the current source, if used throughout the year, could only satisfy the water demand of the town up to 2014. And this holds true if and only if sediment flourishing is done as per the design and the watershed is treated with different conservation measures. These two important reasons indicate that the reservoir will dried if the people use excessively to satisfy the demand.

The reservoir has direct or indirect influences on groundwater of the area. Hence, this scenario in intended to test the response of the system in the absence of interaction of groundwater system with this surface water bodies. The simulation results showed an average reservoir peripheries area rise in ground water level by 0.901 m compared to the steady state simulated water level, with maximum value of 4.75 m in wells near the reservoir (observation well3, 800 m from the reservoir). Leakage to rivers increased by 1.85% compared to the steady state simulated amount, which might be due to elevated groundwater relative to stream bottom elevation.

Effect of development of Megech reservoir

Ethiopian minister of water resource has proposed to construct a dam on Megech River. The designed dam is 76.5 m high and 864 m long. The total amount of water that will be stored in the reservoir is 182 Mm^3. The elevation of the dam is 1952 m and the designed live storage elevation is 1947.1 m. The total areal coverage of the reservoir is 2.55 Mm^2. This reservoir is artificial surface water bodies constructed for the purpose of irrigation water and Gondar Water Supply and have direct and indirect influences on the groundwater of the area. Hence the Scenario is intended to test the response of the system in the presence of interaction of groundwater system with these surface water bodies. The simulation results showed an average rise in groundwater level by 0.38 m compared to the steady state simulated water level, with maximum value of 5.042 m in well near the Megech reservoir (observation well 24, 1.8 km from the reservoir). The influence of the reservoir with radius 2.6 km is greater than 1.25 m from simulated water level.

Leakage to streams increased by 45% compared to the steady state simulated amounts, which might be due to elevated groundwater level relative to the stream bottom elevation, dominantly at the reservoir and its periphery area. The leakage to Lake Tana decreases by 11.8% compared to the steady state simulated amounts that may be due to the increased leakage to the streams.

Effect of irrigation water on Megech command area

This scenario simulates in case of increasing recharges to the aquifer that result from irrigation water to the command area. The proposed Megech irrigation project will develop more than 14,600 ha of irrigable land. The irrigation demand of the command area is 116M m3. The return flow from irrigation water is approximately 30 % of the irrigated water (Tahal, 2009). That means the total amount of return flow is 34.8 Mm^3 or 0.238 m/yr. Therefore in this scenario the simulated response of the system to the increasing recharge was compared with the steady state simulated water levels and stream leakages, and the difference showed changes induced due to the increasing recharge. The simulated recharges on the command area was increased by 0.238 m/yr and the simulated recharge showed an average head increase of 2.47 m over the whole area with highest rise 7.28 m in Koladiba well and minimum of 1.07 m in the north at Angereb well field. Besides the stream leakage compared with the steady state value the change was about 47.78%.

In the second scenario, increased recharge (return flow of irrigated water) and development of Megech reservoir were simulated simultaneously to see the effects on groundwater level changes and stream leakage. In the simulation the response of the system was compared with the steady state simulated water levels and stream leakages. The differences showed the effect of development of Megech reservoir and irrigation on the groundwater. The simulated value showed an average 2.74 m increased head over the whole area. High difference values were observed at Tseda (7.83 m) and Koladiba (7.3 m). The minimum difference 1.08 m was recorded at Angereb well field (observation 94). In addition, the stream leakage compared with the steady state value the change was about 87.43%.

Conclusions

The simulated out flow of the model is 205.7 Mm^3/yr which is nearly equal to simulated inflow with difference 7.9 m^3/year and 0% of error. The base flow simulated discharge holds 35.75% of the out flow. It also contributed as recharge in to the aquifer that accounts to 15.30 % of the inflow. The current withdrawal rate estimated under steady state simulation was 4,681.8 m^3/day. Steady state withdrawal rates were increased by 15%, 35%, 75% and 100% to study the response of the system in this scenario. These increased are equivalent to withdrawing 5,384.1, 6,320.4, 7,256.8, 8,193.15, and 8,336.6 m^3/day over the whole catchment respectively. From the simulation results, one can observe that the development of a new groundwater sources would not pose appreciable impact in case of 15% and 35% withdrawal the head declines in this case is insignificant relative to the steady state withdrawal rate and the natural discharges were not altered highly.

In the second scenario, increased groundwater withdrawal in Gondar-Azezo town and its periphery well fields were simulated to see the effects on groundwater level changes and stream reaches. In this case the current withdrawal of the well field from active wells was increased to 23,409 m^3/day for scenario test, which is about five fold increases. Here the additional withdrawal was assigned as a new hypothetical with various discharges in the Angereb, Keha, and Shinta well fields. The simulation result indicated that the stream leakage decreased by 7.9% relative to the whole steady state value, but showed 14.9% decrease for Angereb, Keha, and Shinta river segments near the well field area. The water tables decline by 3.6m to18.8m in head observation in the well field area. The lower Angereb well field head decline is significant when compare with other near well fields.

The simulated recharges on the command area was increased by 0.238 m/yr and the simulated recharge showed an average head increase of 2.47 m over the whole area with highest rise 7.28 m in Koladiba well and minimum of 1.07 m in the north at Angereb well field. Besides the stream leakage compared with the steady state value the change was about 47.78%. In the second scenario, increased recharge (return flow of irrigated water) and development of Megech reservoir were simulated simultaneously to see the effects on groundwater level changes and stream leakage. The simulated value showed an average 2.74 m increased head over the whole area. High difference values were observed at Tseda (7.83 m) and Koladiba (7.3 m). The minimum difference 1.08m was recorded at Angereb well field (observation 94). In addition, the stream leakage compared with the steady state value the change was about 87.43%.

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