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Methodology creation numerical model of alluvial deposit aquifer for inplement heat pump system of Kutaisi international airport

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Abstract

In order to implement heat pump system of Kopitnary International Airport (Kutaisi), had been organized the hydrogelogical testing of two existing and six new drilled drinking water boreholes on the territory of in order to determine the boreholes' properties and to create a model of aquifer. The digital modelling represents the main steps of calibration and simulation process, which gives the possibility to estimate and study the different scenarios of exploatation and development of precesses.

Introduction

Study area is located close to Kopitnary airport, between Rioni and Gubis-tskali rivers and represents the wide flat area. The territory is 340 m^2 and it is flat and is tilted from the North-East to the south-west direction with 0.004^0. The most elevated place of the area is 120-130 m from sea level (to the north) and the lowest place is 20 m to the south-west.

River Rioni, which bounds the territory by two sides, is the biggest river of the west Georgia. The second river Gubis-Tskali bounds the area from the west.

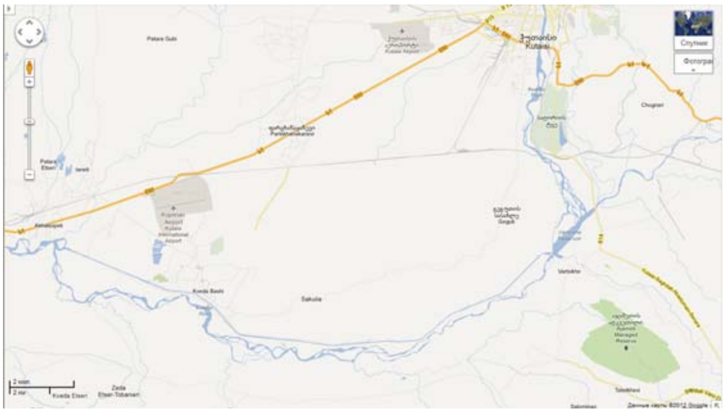


Fig.1 Map of study area

The climate of the area is the type of subtropical, with high temperature regime. The mean annual temperature is 15-16 ^{0}C. The annual precipitation is 1800-2000 mm or 18-20 thousand tones / hectare.

Due to nigh population there functions few water-pumping stations on the above mentioned territory (Phartskhanakanebi, Kopitnari, Mukhiani and etc) for Kutaisi, Tskaltubo and other populated places water supply. There are also passing the main highway and the railway nearby.

Hydrogeological conditions

Study area belongs to the east part of Tskaltubo artesian basin. (1). There are located deep and less deep circulation waters here. Less deep circulation waters are from quaternary and modern alluvial period and the deep (with pressure) circulation waters are cretaceous karstic waters that are located under the above mentioned Quaternary waters. The karstic waters come out on the surface only on the northernmost part of territory, where they are fresh and without pressure. Deeping to the south the temperature and pressure as well as the mineralization is increasing. But this water bearing horizon still is not opened with boreholes.

Thus, only alluvial and quaternary period horizons are subject of our interest. (2)

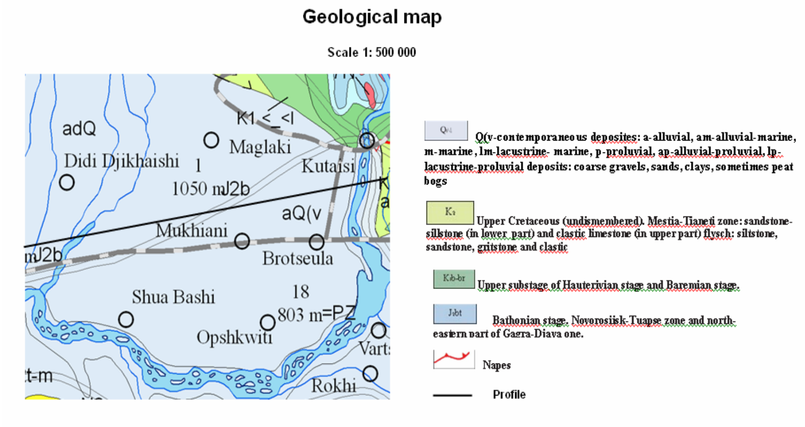


Fig.2 Geological map of the area

Modern alluvial aquifer

Modern alluvial water aquifer strata is developed between the valleys and terraces of rivers Rioni and Gubis-tskali and in the breadth of it at some places reaches 2.5-3 km. the widest part we observe at the end of river valleys. The lithology of sedimentary rocks is conditioned by the diversity of the main rocks: among the volcanic and intrusive rocks we meet sandstones and limestones. The water abundant in water bearing horizons depends on the granule composition of the rocks. The water content of sands, sandstones and gravel is 10 l/sec, the specific debit of boreholes varies from 5 till 30 l/sec, the coefficient of filtration is 100-300 l/day and for sands it increase till 30-50 l/day and sometimes till 100 l/day. The mineralization of water bearing horizon is low 0.3 g/l. As to chemical composition it is hydrocarbonate-calcium and hydrocarbonate-calcium-sodium, with moderate rigidity. Underground water level at river valleys is 05-1 m, in some cases 2-2.5 m. which decreases along the flowing direction. The water bearing horizon is fed mainly by rivers, less by the precipitation. Those underground waters have the close hydrodynamic connection with underlying Quaternary water bearing horizon – aquifer.

Previous Studies

Few years ago, in order to organize water supply system for Kopitnari airport two boreholes (we could not determine the drilling company) were drilled: # 1 (located closer to the Kutaisi-Samtredia highway) and # 2 (located further from Kutaisi-Samtredia highway). The coordinates you can see below:

Table 1. Coordinates of excicting boreholes

#	X coordinate	Y coordinate	Altitude
Borehole #1	4673204	290854	42.85
Borehole #2	4673186	290861	42.52

Table 2. Borehole parameters

Bor.#	Deepness	Diameter (mm)	Borehole spacing (m)	Interval of a flters spacing in boreholes (m)	Stoical level (m)	Dynamic level (m)	Debit (l/sec)
1	40	300	0-40	12-40	-2	-3	15
2	40	300	0-40	12-40	-2	-3	15

According to the done chemical analysis water is of moderate mineralization and rigidity and possible exploitation debit was 130 m^3/hour.

Hydrodynamic Research Methods

In order to determine the hydrodynamical parameters (coefficient of filtration, permeability, conductivity, debit, temperature, static and dynamic pressure and etc) of main quaternary water bearing horizon should be done field pump tests of the boreholes that have been done according to the standard method (Domenico and Schwartz, 1998; Middlemis, 2000) using licensed softwares.

There were already existed two ## 1 and 2 boreholes on the territory of airport from which water was pumped out. For those boreholes was selected the slag testing "pump out" method. In order to reinject water into the aquifer has been drilled six ## 3, 4, 5, 6, 7, and 8 boreholes of different depth. And for their hydrodynamic testing we decided to use "pump in" – reinjection method.

Between the slug-testing methods ("pump in" and "pump out") we used "pump out" method. Before testing the head of boreholes were constructed. On the both boreholes were installed registration equipments. Recorded data gave us possibility to study the background processes.

Data were recorded daily and processed at the laboratory by the specific Exel programme, which formats hex file into text, sorts out data column according to sensors quantity and etc.

The next step was to make time series of microtemperature and hydrodynamical data and analyzing.

Based on recived material we determined the hydrodynamical parameters (coefficient of filtration, permeability , conductivity, debit, temperature, static and dynamic pressure and etc).

Determination of hydrodynamic parameters

One day before starting the pump test, in order to find out the background condition, the pump testing on #1 borehole had been stopped. After we continued pumping process on # 1 borehole using the pump with capacity of 50 m^3/hour. Water level variations had been monitored in both (#1 and #2) boreholes using the "Diver", survey frequency 1 min. (Fig 3, 4)

Hydrodynamic parameters had been calculated based on data from #2 borehole.

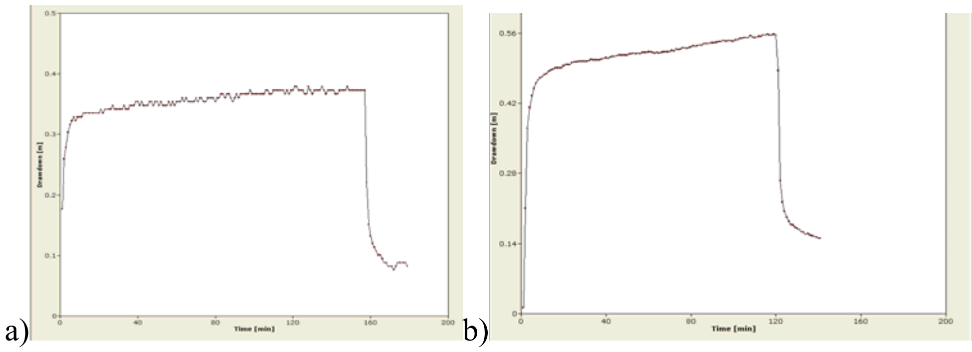


Fig. 3 water level variation diagram during pumping out process on a) #1 and b) #2 borehole

Recorded row data during pump test had been processed by the specific programme Aquifertest pro 4.2.

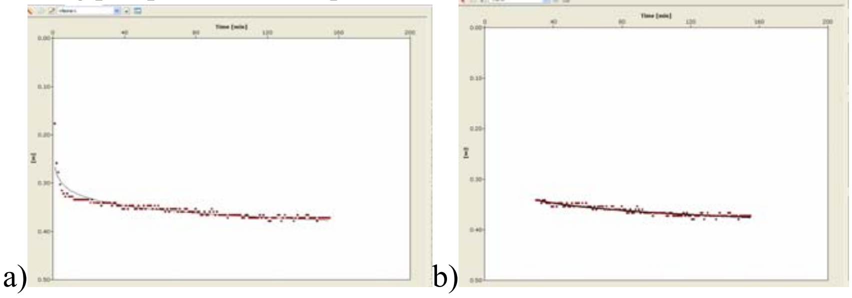


Fig. 4 The logarithmic curve of water level variation for 1 (a) and 2 (b) boreholes

In order to calculate the parameters of our interest we used Taisy-Jacob ' s method. For this purpose on the curve of water level drop we choose straight sections.

In order to verify the results, data had been processed also manually using Borevsky's method (4) , which is also based on Taisy-Jacob's equation. By inputting in the equation the data of water level dropping during pumping up making a plot x=lg$t$ *and* y= D and D=k*lg(t)+b, where the unit of t is day and for water dropping – meter.

On the dropping curve we can see the straight section, where the equation Y=k*x+b works. We can calculate also the transmisivity T=0.183*Q/k, where Q is water discharge m^3/day. We can also calculate logarithmic data of conductivity lg(a)=2lg(r)-0.35+b/k, where r is the distance between the boreholes and at the end we calculate coefficient of specific yield using equation lg(S)=lgT – lg(a)

As a result we got following values:

Table 3 . Calculated parameters

Parameters (bore 1)	**Data**	**Parameters (bore. 2)**	**Data**
k (coeficient)	0.0456	k	0.1442
b (coeficient)	0.4183	b	0.7139
r (distance,meters)	20	r (distance,meters)	20
Q (extruct m^3/day)	1200	Q (extruct m3/day)	2400
Transmissivity (m^2/day)	4815	Transmissivity (m2/day)	3045
Storativity S	1.8*E-08	Storativity S	1.9093E-4

As a result there is an entire consentaneity between manually and using software package calculated data.

Table 5. 1st step, pump out , # 1 borehole

	Transmissivity (m^2/day)	Storativity	Coefficient of filtration (m/day)
AquiferTestPro (method Theis with Jacob corrections)	4340	1.07*E-7	330
Borovsly's method	4815	1.8*E-08	370

Table 6 . 2nd step, pump out, # 2 borehole

	Transmissivity (m^2/day)	Storativity	Coefficient of filtration (m/day)
AquiferTestPro (method Theis with Jacob corrections)	3550	5.04*E-5	275
Borovsly's method	3045	0.191*E-5	250

As we can see, the permeability of # 1 borehole is much more than # 2 one. Mentioned borehole has not been under exploitation for a long period of time and most likely it is polluted with sand and clay. Thus, its important the further detailed studies and the borehole should be cleaned (washed) to avoid the problems of its functioning.

In order to verify the existing data in the both boreholes had been done synchronous pump tests during two weeks (1-15 april). On #1 and #2 boreholes with the pumps of capacity correspondingly 50 and 80 m^3/hour (Fig. 5). The process has been under the technical control.

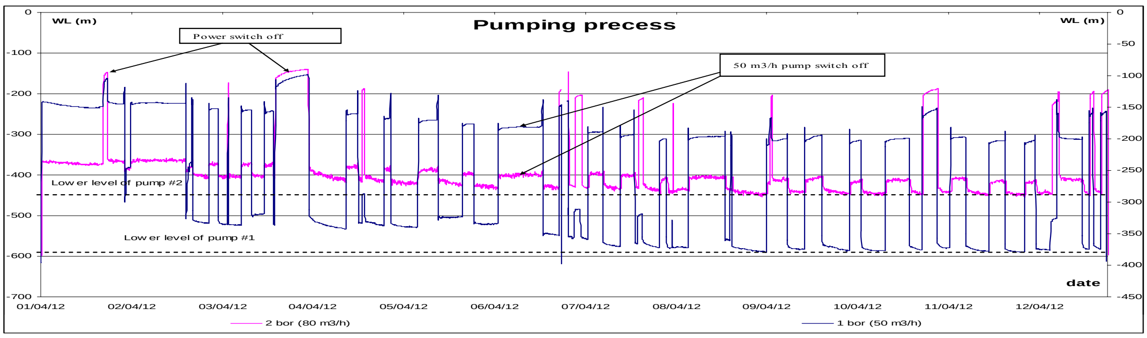


Fig. 5 Water level variation diagrams for #1 and # 2 boreholes

Slag testing by injecting into new drilled # # 3, 4, 5, 6, 7, and 8 boreholes

In order to reinject water pumped out from ## 1 and 2 boreholes after removing heat, on the territory of airport had been drilled 6 boreholes. Before testing the head of boreholes were constructed. On all boreholes were installed registration equipments (water level, temperature, conductivity, discharge). Recorded data gave us possibility to study the background processes. ## 1 and 2 boreholes were connected with a special pipeline with ne drilled boreholes.

In order to determine the value of permeability injection process was done with several steps. The first step was to pump out water from # 1 borehole and reinject into one of the new well with different discharge. Before starting of testing process one day earlier, in order to get real background value, the pumping out of water from ## 1 and 2 boreholes had been stopped.

In contrast to calculations done for ## 1 and 2 boreholes, for "injection"- pump in " the hydrodynamic parameters were calculated by Nesterove's method, where the coefficient of filtration is calculated by the equation:

$$K=0.123\ Q/h^2 \lg 2h/r$$

Where K is coefficient of filtration, Q- discharge, h- water level increase during injection, r- radius of borehole.

Statistical analysis of determinant factors of water level variation

As it was mentioned above, after slug-test all boreholes had been under monitoring. Data of water level, atmospheric pressure and temperature variation had been recorded. For better understanding of all factors that may influence the aquifer "living" conditions, also data from meteorological service (precipitation and discharge of main river Rioni) had been inquired.

After review all data we determined all factors which have and influence on aquifer: atmospheric pressure and precipitation. The last one plays the main role. Fig. #6.

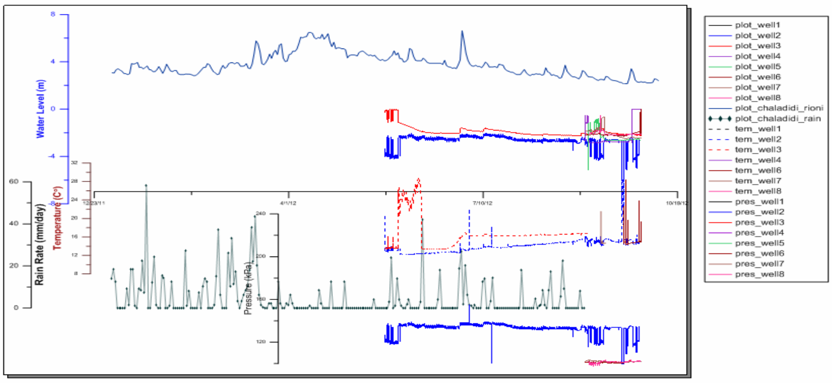


Fig. 6 Multiparametral variations in borehole

Fig. 6 shows the good correlation between amount of precipitation, discharge of river Rioni and water level variation in boreholes. Almost for all boreholes it is more visible the correlation between river discharge and water level variation in boreholes. This is caused by the accumulation of precipitation by river which feeds aquifer by its side.

For each borehole had been carried out the statistical analysis in order to determine the relation between variations of Rioi discharge, precipitation and water level as well as the character of those variations.

Exapmle of analysis of correlated ratio of water level variation, r. Rioni and precipitation Borehole # 3

In order to compare data from borehole # 3 with precipitation, data had been normalized in diapasone [0: 1]. For precipitation data the weighted average method was used (blue line, fig. 7)

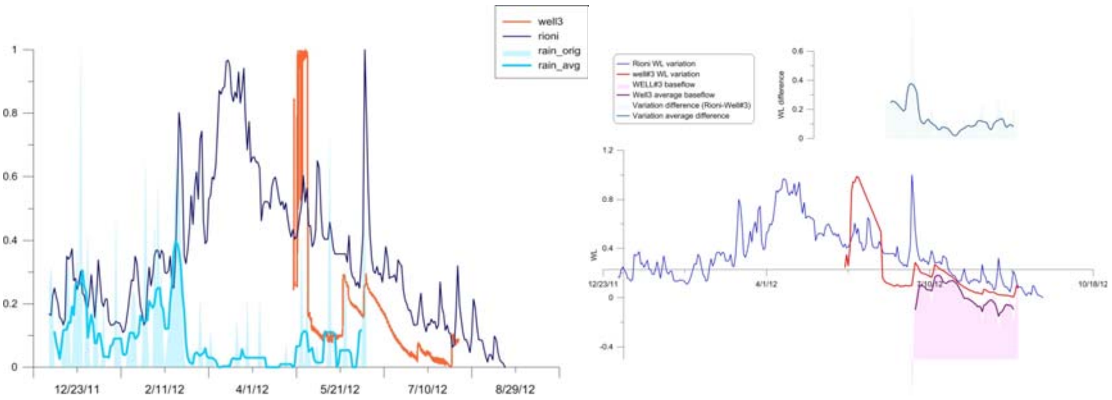
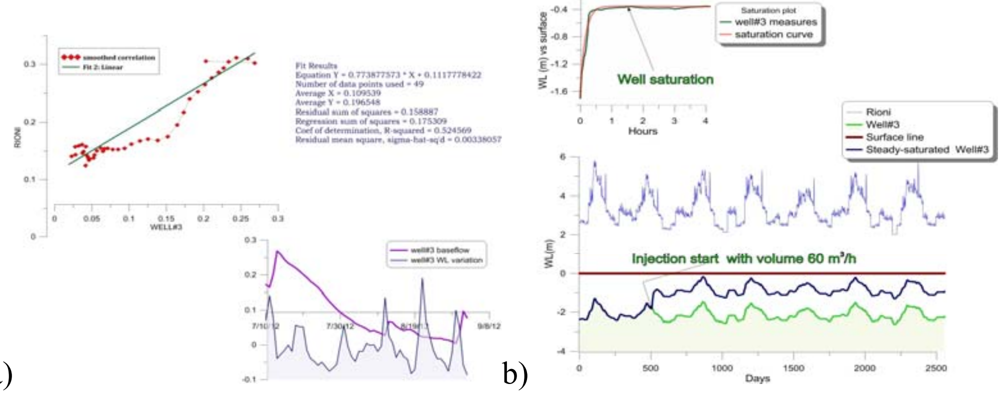


Fig. 7 Borehole 3; water level , Rioni river and precipitation variations

Borehole #3 minute data were averaged to daily series (red line in Fig. 7). Rate of variation difference between water level in Rioni and Borehole #3 is shown on upper plot in Fig. 7. Borehole #3 baseflow is calculated as difference between well#3 variation and rate difference.



a) b)

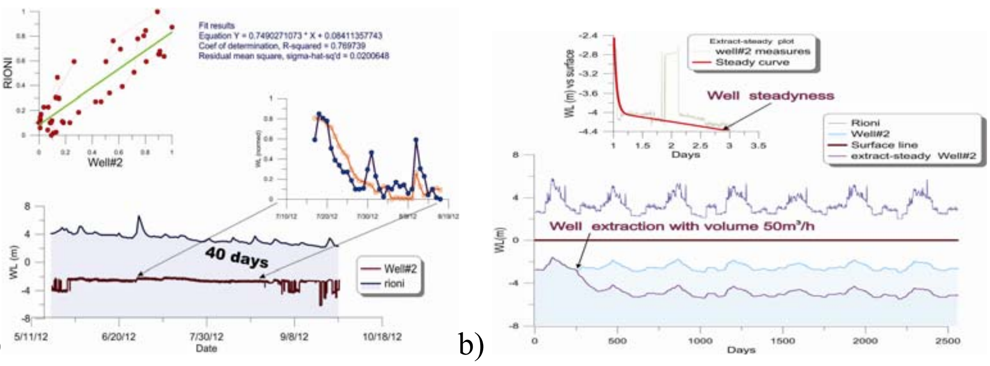
Fig. 8 Borehole # 3, a) water level variation background series plot b) Plot of potential water level variations

Correlation plot of Rioni and borehole #3 water level variations is shown in Fig. 8. Statistics shows that data are correlated. Borehole # 3 baseflow on lower plot is calculated by extraction linear trend (correlation line) from water level variation.

Based on carrelated ration and slag-test data, we have calculated the potential water level variations in boreholes for the next 25 years.

After starting water injection into borehole #3 with volume 60 m3/h water levels rises to saturation within 2 hours. Water increase with such a volume is about 1.3 meter. The further water level variations are conditioned by the background variation.

Example of Statistical analysis of data - Borehole # 2



a) b)

Fig. 9 a) Correlated ratio of water level variation in Borehole # 2 and rioni river discharge b) Borehole 2- Prognostic curve of water level potential variations

For regressive analysis was selected water level variation of period of 40 days. Calculated coefficient of filtration equals 0.77. The results show that the water level variations in Rioni River and in borehole # 2 are correlated. After pumping out of water with volume 50m^3/hour from borehole #2 the water level stabilaized during 3 days on the level of 2.25 m. This regime will be kept in future.

Table 13 Summary hydrodynamic parameters of borehles

Name	Screen, m	K m/day	Max discharge m3/h +out from boreholes; - into boreholes.	Injections, m^3/hour	Water level increasing , m	Amount of discharge for 1 m	for 1.5 m	for 2.4 m	Injection in Bor. #5 and influance on the #7, 8, 6	Injection in bor. #7 and influance on the #3, 8,5	Injection in bor. #6 and influance on the #3
Borehole #1	15	350	+70-80								
Borehole #2	15	350	+70-80								
Borehole #3	13	423	-70-80	60	1.05	57.14	85.71	137.13		11.43	28.57
Borehole #4	14	69	-25-30	27	2.1	12.86	19.29	30.86			
Borehole #5	15	470	-80-100	48	1.1	43.64	65.45	104.74	48.00		
Borehole #6	13	156	-40-50	50	2.34	21.37	32.05	51.29	4.27	4.27	34.19
Borehole #7	15	368	-70-80	51	1.3	39.23	58.85	94.15	11.77	51.00	
Borehole #8	15	159	-25-30	25	1.7	14.71	22.06	35.30	4.41	2.94	
Total						188.94	283.41	453.47	68.45	69.64	62.76

As we can see the amount of water that the boreholes are able to receive varies with seasons. For instance, for low water level, 2-4 m (summer), boreholes can receive the maximum total volume of water 453 m^3/hour, and for hight level, 1.5 m (spring) – less- 283 m^3/hour.
Also, coefficient of interrelation varies between 1.4-1.8, which means that in case of simultaneously reinjection in several boreholes the maximum value of injection will decreas and accordingly equals 177 m^3/hour and 283 m^3/hour.

Conceptual Model

The modeling has been done by the software Feflow 5.3, which gives possibility to calculate 3D model of study area. First of all the digital map of a surface has been done (ArcMap 9.2 and ArcView 3.2a).
For study area the boundary conditions were defined. The recharge area at its North border is fed by precipitation. As to east and west borders, the source of feeding is Rivers rioni and Gubis Tskali. The discharge area is the River Rioni bed, which is located to the south as well as boreholes # 1 and # 2 on the territory of the airport. The study site has an area of 314 square kilometers- the length of the east part is 10.5 km, the west part – 23 km and south part- 31 km.

Callibration

As it was mentioned, the main source of recharge area is precipitation which is plenty because of subtropical climate. In the table bellow is represented some data from Kutaisi meteorological station of precipitation for last 7 years

Tab. # 14 precipitation mm/year

Years	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
mm/year	1668	1363	1555	1252	1420	1387	1459

In order to calculate the amount of precipitation which reach the aquifer, the modeling had been done as well as some initial conditions were set. For water level value in rivers was considered the geographic elevation of points. According to measurements in the borehole # 1 the water level is 1 meter bellow from the surface (45 m). Afterwards the modeling was done.

According to model to reach the mentioned water level it is necessary $12.23*10^{-4}$ m/day of precipitation for per square meter of study area, which is 446 mm/sec, water penetration is (446/1459)*100=30%.

Hydrodynamic head

The digital map of study area was designed based on satellite data. The next step was the calculation of static hydrodynamic pressure distribution in aquifer. In program were inserted absolute value of boreholes and water level data, as well as water level value in rivers for recharge and discharge areas, which varies from 125 m (to the north-west, recharge area) till 24 m (to the south-west , discharge area).

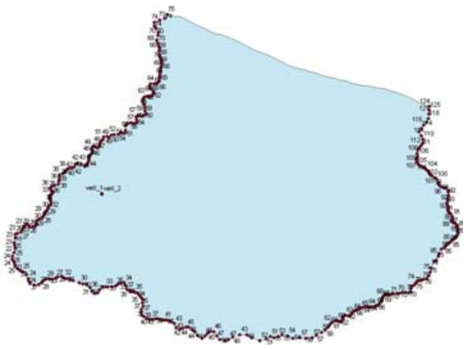


Fig. #10 Isoplines of hydrodynamic head Fig. 67 Outline of hydrolic head of recharge and discharge areas

The next step was the calculation of season variation of hydrodynamic head based on water level varioation data in Rioni river from meteorological stations

According to those data, the season water level season variations in Rioni river vary from 2.1 m (minimum October) till 5.8 m (maximum March-April). The mean value of water level is 3.8 m. accordingly above mentioned data was used for whole recharge and discharge areas and the variable of hydrodynamic head of aquifer had been calculated. There were also defined 8 waterprof and permable layers, with total thickness 40 m.

Table # 15 Thickness of defined horisonz

. N layer	1	2	3	4	5	6	7	8
Thickness,m	3	4	2	1	8	2	10	10

Based on all those data the 3D model had been created

Hydrodynamic parameters

After slag testing of boreholes we determined the hydrodynamic parameters of aquifer they open. Mentioned gave us possibility to assess the coefficient of filtration for each borehole as well as of aquifer.

After inserting data into model, program calibrated model and corrected some parameters. For instance, by the program was recalculated the coefficient of filtration according to observed water level variation data during reinjection in ## 3,4,5,6,7 and 8 boreholes.

We conceded that in the model the coefficient of filtration is Kx=Ky and Kz=0.1*Kx

For each borehole was calculated the coefficient of filtration. For all boreholes for upper clay layer we got common coefficient (blue color) Kx=$0.02*10^{-4}$ m/sec

Borehole #1 and #2 - Kx=$35*10^{-4}$ m/sec ;Borehole #3 Kx= $4.2*10^{-3}$ m/sec.;Borehole #4 Kx= $7*10^{-4}$ m/sec ;Borehole #5 Kx= $4.7*10^{-3}$ m/sec ;Borehole #6 Kx= $1.6*10^{-3}$ m/sec.;Borehole #7 Kx= $3.7*10^{-3}$ m/sec ;Borehole #8 Kx=$1.6 *10^{-3}$ m/sec ;

Programme also gives possibility to estimate the distribution of coefficient of filtration for whole aquifer by the interpolation.

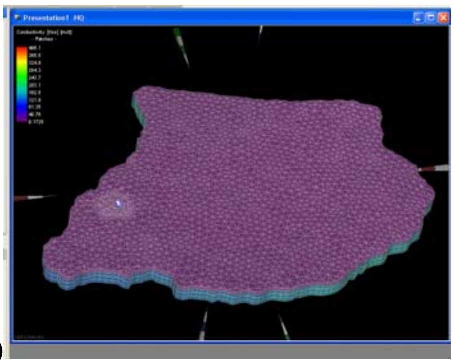
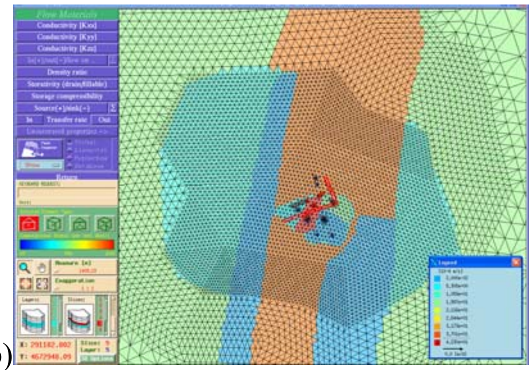
a) 
b) 

Fig. # 11 a) distribution coefficient of conductivity on all the territory and b) Distribution coefficient of conductivity

Modeling

After all calculations we were ready to make some model simulations in order to determine the required scenarios of event developing. For instance, the case of pumping out maximum 70 m^3/hour water from ## 1 and 2 boreholes and reinjecting in ## 3 and 7 boreholes with 50 m^3/hour, and into # 5 with 40 m^3/hour. Figures show the flow directions in boreholes.

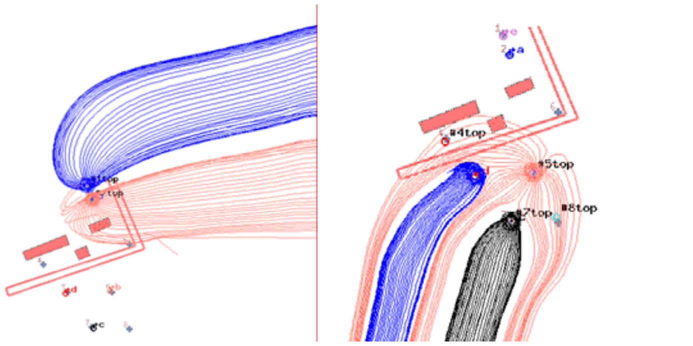


Fig. 12 flow directions in ## 1 and 2 boreholes (left) and ## 3, 5 and 7 boreholes (right)

As we can see, that recharge area for ## 1 and 2 boreholes, as it was expected, is located to the North-east direction, as to ## 3,5 and 7 boreholes, flow direction is to the south-wes to the discharge area.

Model calculated the system functioning perspective under above mentioned regime for the next 25 years.

Fig. 13 water level potential variations in boreholes

As we can see on the figures, water level variations in boreholes are of seasonal nature – by the amount of precipitation and river discharge seasonal vatriations. Water levels in boreholes vary in parallel regime. The other kind of influence we cannot ebserve, and in fact the system is able to operate under this regime.

Therefore there should be calculated the acceptable regimes for producteve and reinjection boreholes. In case of needs for more volume of water, we recomend to use #6 borehole as a productive one together with #1 and #2 boreholes. Exploatation of those three boreholes is possible under the regimes given below in the table 16. In this case the flow diection and exploitation conditions should not change.

In these calculations the maximum volume of pumped uot water is 140 m^3/hour, but probably it is also possible to increase the volume. In this case the the slag testing with increased discharge must be done as well as new calculations. It is also possible to decreas the discharge upon request of course.

Tab. 16 the different cases of productive boreholes exploitation regimes

Version #		Boreholes #		
		#1	#2	#6
1	Pumping (m³/h)	70	70	-
2		60	60	20
3		50	50	40
4		60	50	30

As to reinjecting boreholes, we can review many cases of borehole exploitation. We have chosen charachterizing figures of borehole exploitation with different discharge and flow direction always following the main flow direction as well as the ineligible regime case, when "new" flow crosses the main flow and reinjected water flows back to the productive boreholes.

For instance, under the same regim we pumped out 50 m^3/hour volume water from ## 1 and 2 and from # 6 borehole 40 m^3/hour and reinjected 50 m^3/hour volume water into ## 3 and 7 and into # 5 40 m^3/hour volume water (fig. 14). This is the most acceptable version because of its simplicity.

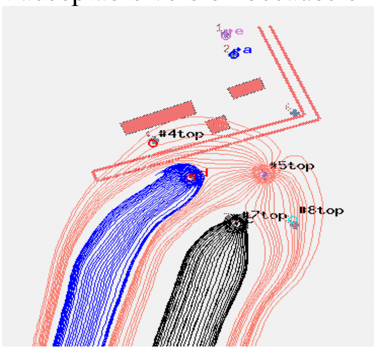


Fig. 14 water flow directions from ## 3, 4, 5,and 7 (right) boreholes

As we can see the main flow direction does not change, It neither changes if we pump out 60 m^3/hour volume water from ## 1 and 2 boreholes and 20 m^3/hour volume water from # 6 borehole and reinject into # 3 - 50 m^3/hour, # 4 - 10 m^3/hour, # 5 - 20 m^3/hour, #7 - 40 m^3/hour and # 8 - 20 m^3/hour.

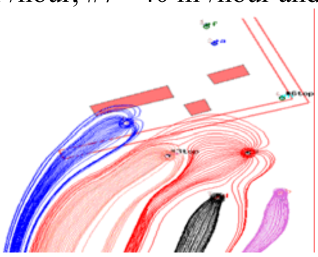


Fig. 15 water flow directions for ## 3,4,5,7 and 8 boreholes

As it was expected, the main flow direction does not change if we decreas pumping out vlume.

In the table below are given few version of acceptable exploitation regimes for operating n boreholes

		Boreholes					
#	Injection (m^3/h)	#3	#4	#5	#7	#8	Sum
1		50		40	50		140
2		50	10	20	40	20	160
3		50		40	50		140
4		50		30	40	20	140
5		50		20	50	20	140

Thus, the most acceptable version for regime is to pump out 50 m^3/hour volume water from operating ## 1 and 2 boreholes and reinject into ## 3 and 7 ones with appropriate discharge and in case of needs of additional 40 m^3/hour discharge, to pump out needed volume of water from # 6 borehole and reinject it into # 5 borehole or use the given into table other varsions.

Main resultes

- In order to creat the aquifer hydrodynamic model had were studied the geological, hydrogeologicl, geophysical and meteorological data of study area.
- During long term pumpin out for each borehole was determined value of permeability and use to new methodology statistical analyz for calculate maximum value of hydrodynamic parameters.

- Created the aquifer conceptual model and during modeling determined the water flow directions, the expectable borehole exploitation regimes for the next 25 years;

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Методика создания цифравой модели современного алювиального водоносного горизонта

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Резюме

Для внедрения системы отопления Кутайского Международного Аэропорта с помощью теплового насоса, было организовано тестирование уже существующих двух и вновь пробуренных шести скважин, что дало возможность выяснить их фильтрационные свойство и создать цифровую модель водоносного горизонта. Моделирование включала в себя ступеньки колибрации и симуляции, что позволило изучить возможные сценарии эксплуатации водоносного горизонта и развития процессов во времени.

ალუვიური წყალშემცველი ჰორიზონტის ციფრული მოდელის შექმნის მეთოდიკა

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რეზიუმე

ქუთაისის საერთაშორისო აეროპორტის თბური ტუმბოს მეშვეობით გათბობის სისტემის დანერგვისთვის ორგანიზება გაუკეთდა უკვე არსებულ ორ და ახლად გაბურღულ ექვსი ჭაბურღილების ტესტირებას, რამაც საშუალება მოგვცა დაგვედგინა მათი ფილტრაციული თვისებები და შეგვექმნა წყალშემცველი ჰორიზონტის ციფრული მოდელი. ციფრული მოდელირება მოიცავდა კალიბრაციის და სიმულაციის რამოდენიმე საფეხურს, რამაც საშუალება მოგვცა შეგვესწავლა ჰორიზონტის ექსპლოტაციის სხვადასხვა სცენარები და პროცესების დროში განვითარება.