Polish Journal of Environmental Studies Vol. 13, No. 5 (2004), 521-524

Examination of the Effect of Altering Model Complexity on Representing Groundwater Flow

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Received: 21 March 2003
Accepted: 17 April 2004

Abstract

This research evaluated how modifying the conceptual model of a groundwater system affects simulated results. At the first stage, mathematical model of groundwater flow in Gdansk aquifer system was built. In the next stage, 3 analytical schemes resulting from aquifer aggregation were defined. Then the flows and groundwater balances were computed and compared to flows and balances computed in the overall model of the Gdańsk aquifer system.

Keywords: hydrogeology, aquifer, groundwater flow, numerical modeling

Introduction

In the past 20 years the application of numerical simulation models has become a basic tool for solving groundwater's problems. Numerical modelling offers several advantages including analysis of a very complex system. The model can be used as a database and it is possible to simulate future scenarios. However, it is very important to remember that a mathematical model is imperfect and is only a simplification of reality.

The geometry and hydrogeological properties of multiaquifer systems are often very complicated and usually collected data are incomplete. Therefore, groundwater conditions and regime usually have to be simplified. In Polish and foreign hydrogeological bibliographies there are some publications about accuracy of numerical analysis [1-8], but none address the effect of aquifer aggregation on mathematical model calculations.

The aim of this research was to evaluate the effect of altering model complexity on the representation of the groundwater flow system.

At the first stage, the mathematical model of groundwater flow in the Gdańsk aquifer system was built. In the next stage, 3 analytical schemes resulting from aquifer aggregation were defined. Then the flows and groundwater balances computed in aggregated schemes were compared to flows and balances computed in overall model of the Gdańsk aquifer system.

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Research Area

Characterization of Gdańsk Aquifer System

Within the area of the Gdańsk region there are several morphologic units formed during the Pleistocene and postglacial period. They are as follows: moraine hills, the Vistula Delta, marine terrace, and the Reda ice marginal valley. The diversified topography and geological structure have had an impact on the differentiation of components of the groundwater flow system. In the Gdansk region the groundwater appears in Cretaceous, Tertiary (Miocene and Oligocene) and from Quaternary formations. The Cretaceous sand forms an extensive artesian basin. The Tertiary formation represents a major link in intermediate and regional groundwater systems. It forms a link between water from the Cretaceous to the Quaternary formation in the area of low-lands and from the Quaternary to the Cretaceous formation in the moraine hills (in the recharge area). The conditions of groundwater occurrence in the Quaternary deposits are diversified in the area of the moraine hills, in

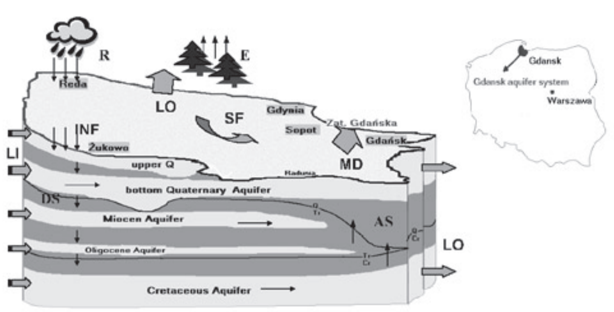

Fig. 1. Scheme of Groundwater circulation in Gdańsk aquifer system.
R – rainfall, E – evapotranspiration, INF – recharging infiltration, SF – surface outflow, RD – river drainage, AS – ascent seepage, DS – descent seepage, LO – lateral outflow, LI – lateral inflow, MD – marine drainage.

the Vistula Delta, in the Marine Terrace and in the ice marginal valley of the Reda River.

The ground water flow system in the Gdansk region discharges to the sea, which is a fundamental drainage base for the whole groundwater circulation system [9, 10].

Results and Discussion

Mathematical Model of Groundwater Flow in Gdansk Aquifer System

In regional hydrogeological mathematical modelling it is usually not possible to define a complete three-dimensional model. Collected data are often not sufficient. In such cases it is better to build a multi-layer model - quasi three-dimensional [7]. Based on the knowledge of hydrogeology of Gdansk aquifer system, a 5-layered mathematical model was built. The first layer represents Quaternary aquifer, which covers only the area of moraine hills. The second layer also represents the Quaternary aquifer, but it covers the whole modelling area. Both of the Quaternary layers are connected with a system of drains and rivers and are recharged by infiltration water. The remaining 3 layers are Miocene, Oligocene and Cretaceous aquifers.

The main tool of analysis was program MODFLOW presented in the GMS software. This computer code solves the groundwater flow equation and it is based on the finite different method [11,12].

This 5-layer mathematical model was calibrated and also sensitivity analyses were checked. The measure of calibration errors is the differences between the initial heads and calculated heads:

$$N = \sum_{i=1}^{n} | H_i - H_c |$$

Usually three kinds of calibration errors are considered [1]: mean error, mean absolute error and root mean squared error. The average value of mean absolute error for the whole area was about 2 m, but the bigger differences were in the area of the edge of moraine hills. On the area of Marine Terrace and on moraine hills values of this error were about 0.5 m. Since calibration showed good results, based on this model groundwater balance was estimated (Fig. 2).

Calculated value of effective infiltration rate is about 90 mm/a which is over 16% of total rainfall on this area.

Groundwater Flow Simulation Under Conditions of Aquifer Aggregation

In the next stage, 3 analytical schemes resulting from aquifer aggregation were defined. In the first aggregation the

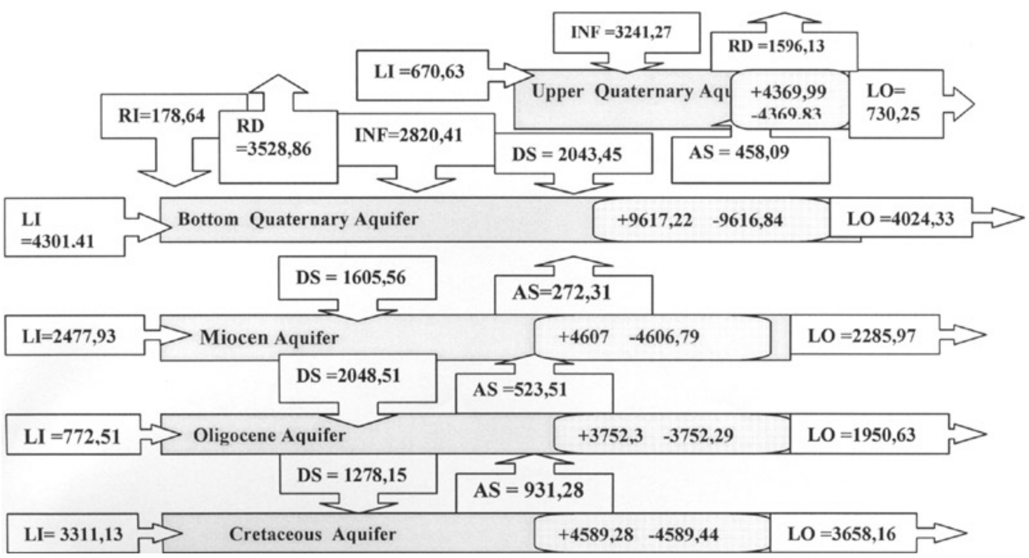

Fig. 2. Scheme of groundwater flow balance - the result of model calculation [m^3/h].
INF – recharging infiltration, RD – river drainage, RI – river infiltration, AS – ascent seepage, DS – descent seepage, LO – lateral outflow, LI – lateral inflow.

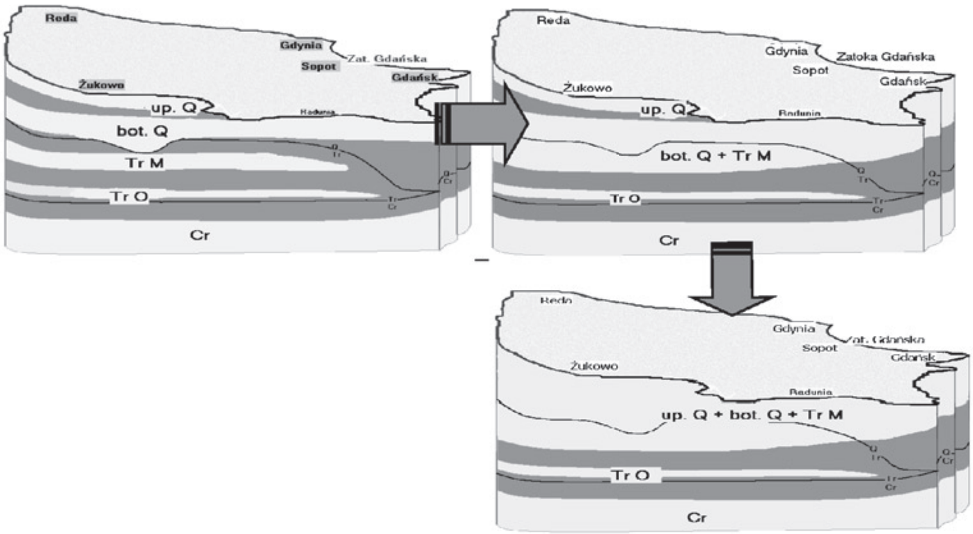

Fig. 3. Scheme of Gdańsk aquifer system after the first and the second aggregation.

Table 1. Comparison of groundwater balances in the each aggregation

Aggregations	Number of layers	Groundwater balance in the overall model (5 layerd) [m^3/h]	Groundwater balance in aggregated schemes [m^3/h]	Difference [m^3/h]	Difference [%]
I	4 (up. Q, bot. Q + Tr M, Tr O, Cr)	25117.23	25057.62	59.61	0.23
II	3 (up. Q + bot. Q + Tr M, Tr O, Cr)	22706.07	22556.08	149.99	0.66
III	4 (up. Q, bot. Q, Tr M + O, Cr)	24431.2	25410.49	979.29	4

bottom Quaternary layer (bot. Q) and the Miocene layer (Tr M) were connected (Fig. 3). Both of these layers have similar hydrogeological properties and in some areas they contact each other. After the first aggregation aquifer system consist of 4 layers. In the second aggregation both Quaternary layer (up. Q & bot. Q) and the Miocene layer (Tr M) were connected. Also in the second aggregation connected layers have similar hydrodynamic and hydrogeological properties. After the second aggregation the aquifer system consists of 3 layers.

In the third aggregation both Tertiary layers (Tr M & Tr O) were connected. In this case connected layers have different hydrodynamic and hydrogeological properties. After the third aggregation the aquifer system consists of 4 layers.

The flows and groundwater balances computed in aggregated schemes were compared to flows and balances computed in overall models of the Gdańsk aquifer system.

In Table 1, value of balance in the overall model for each aggregation means the value of total balance without inside flow between aggregated layers.

In the first and the second aggregations the differences between the total balances were less than 1%. In the third aggregation the difference was about 4%. But in this calculation there was not enough data in Tertiary aquifer for complete calibration of the model.

The differences between particular flows (lateral inflow and outflow, ascent and descent seepage, river drainage and infiltration, recharging infiltration) in ag-

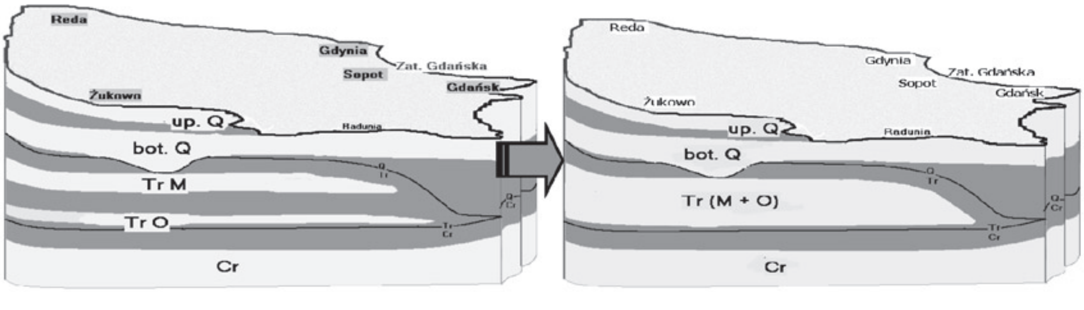

Fig. 4. Scheme of Gdańsk aquifer system after the third aggregation.

gregated schemes and in the overall model were from 0% to 5 %. The mean difference in the first aggregation was 1.68%, in the second 1.49 % and in the third aggregation 1.6%. Such a small discrepancy suggests models are comparable.

Conclusion

Results of model calculations under conditions of aquifer aggregation with similar hydrodynamic and hydrogeological properties show that aquifer simplification did not significantly change the total water balance for the aquifer. The differences between balances were less than 1%. Any changes can only be visible in the flows inside the system.

However, aggregation of aquifers with different hydrodynamic and hydrogeological properties give bigger differences between groundwater balances in aggregated system – about 4%.

This suggests that it is more important to approximately represent filtration parameters (like hydraulic conductivity) than the geometry of the aquifers.

This research confirms the conviction that modelling of regional aquifer systems is a very complex and difficult problem. The progress depends on collection of the data, which should be subordinated to requirements of mathematical models. Particularly important is to collect filtration parameters and to evaluate credibility of this initial data. This can be a measure of credibility of the model calculations.

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