Climate change impact on freshwater resources in a deltaic environment: A groundwater modeling study

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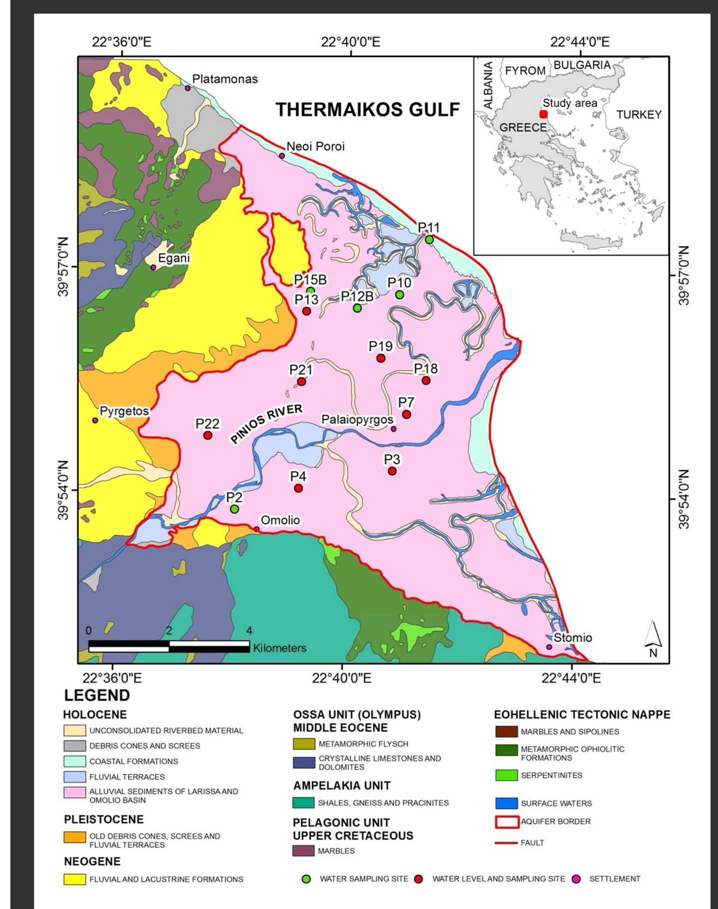
Abstract

Climate change is expected to affect the hydrological cycle, altering seawater level and groundwater recharge to coastal aquifers with various other associated impacts on natural ecosystems and human activities. As the sustainable use of groundwater resources is a great challenge for many countries in the world, groundwater modeling has become a very useful and well established tool for studying groundwater management problems. This study investigates the impacts of climate change on the groundwater of the deltaic plain of River Pinios (Central Greece). Geophysical data processing indicates that the phreatic aquifer extends mainly in the central and northern parts of the region. A one-layer transient groundwater flow and mass transport model of the aquifer system is calibrated and validated. Impacts of climate change were evaluated by incorporating the estimated recharge input and sea level change of different future scenarios within the simulation models. The most noticeable and consistent result of the climate change impact simulations is a prominent sea water intrusion in the coastal aquifer mainly as a result of sea level change which underlines the need for a more effective planning of environmental measures.

Introduction



The deltaic plain of Pinios River is located in Central Greece (Thessaly). In this part of the basin, the river flows in a WSW-ENE direction discharging into Thermaikos Gulf. The deltaic plain is mostly occupied by Quaternary alluvial sediments (e.g., sands, clays) which host a shallow groundwater system. The water needs for agricultural purposes are mainly covered by groundwater and river water abstraction.

Objective

The objective of the present study is to evaluate the potential impact of climate change on the freshwater resources of the deltaic plain by developing groundwater flow and contaminant mass transport models of the shallow aquifer.

Materials and methods

Two 2-D groundwater flow and mass transport simulation models were developed based on FEFLOW algorithm. The conceptual model was spatially discretized in the horizontal level in 32030 nodes and 55604 triangular elements. Geophysical data was used to define a single layer of variable thickness with a maximum depth of 10 m, which corresponds to the alluvial deposits hosting the shallow aquifer. The geophysical results showed that the aquifer extends mainly in the central and northern parts of the region.

The groundwater-flow simulation model was calibrated for the steady-state condition and then for the transient condition. The steady-state calibration was performed by using the observed hydraulic heads of October 2012. Transient calibration and validation were performed based on monthly hydraulic head and chloride concentrations data for the period October 2012 to August 2014.

The predicted values were compared to their measured counterparts using global statistical metrics that quantify the prediction error such as Mean Absolute Error (MAE), Modified coefficient of model efficiency (E'), Modified Index of Agreement (IoA'), Root Mean Square Error (RMSE), Bias and Reliability Index (RI).

$$RMSE=\sqrt{\frac{\sum_{i=1}^{N}(P_i-O_i)^2}{N}} \qquad Bias=\frac{\sum_{i=1}^{N}(P_i-O_i)}{N} \qquad IoA'=1-\frac{\sum_{i=1}^{N}|P_i-O_i|}{\sum_{i=1}^{N}\left(|P_i-\bar{O}|+|O_i-\bar{O}|\right)}$$

$$RI=exp\sqrt{\frac{\sum_{i=1}^{N}\left(log\frac{O_i}{P_i}\right)^2}{N}} \qquad E'=1-\frac{\sum_{i=1}^{N}|P_i-O_i|}{\sum_{i=1}^{N}|O_i-\bar{O}|}$$

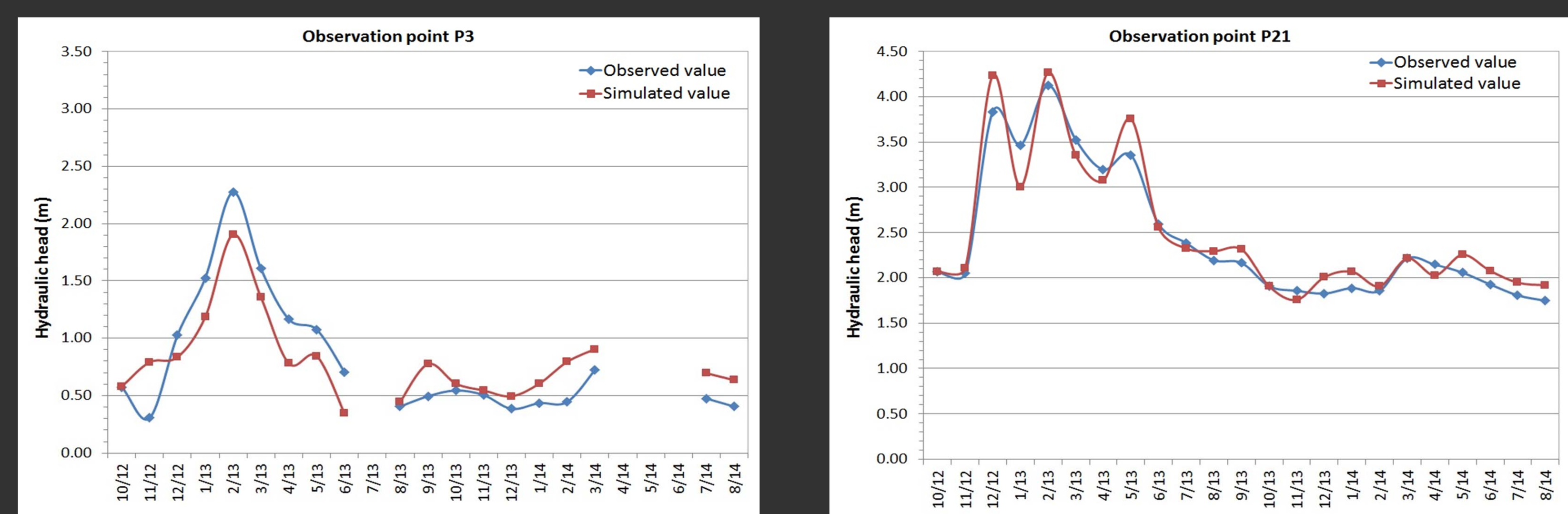
where, P the predictions and O the observations associated by the respective mean values

Results & Discussion

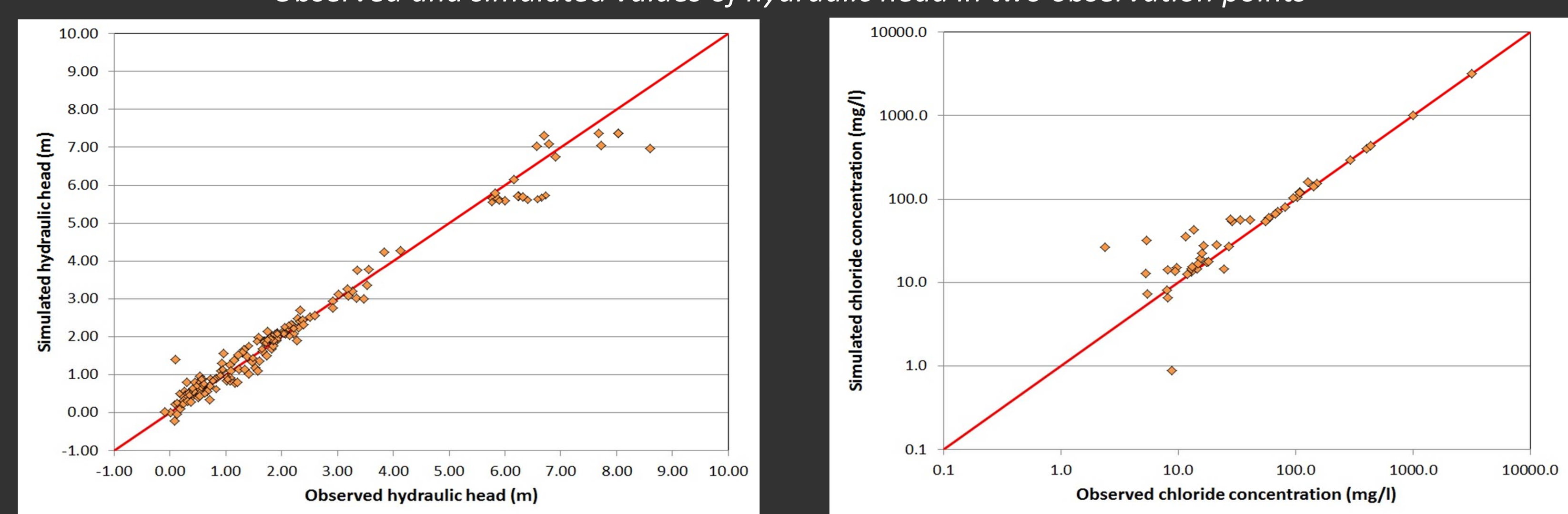
Groundwater simulation models

The rough comparison of the observed and calibrated hydraulic heads and chloride concentration in the observation points are indicative of a reasonably good match between the observed and the simulated values of the two variables. FEFLOW showed difficulty in simulating areas with high variations of the two variables probably due to local lithological heterogeneities.

FEFLOW delivered very good calibration and validation results regarding groundwater flow and chloride mass transport having almost all statistical indices very close to the optimal values.



Observed and simulated values of hydraulic head in two observation points



Observed vs. simulated values of hydraulic head (left) and chloride concentration (right)

Error and goodness of fit results of simulated parameters at observation points

Statistical measures	FEFLOW (hydraulic head)	FEFLOW (chloride concent.)
MAE (least possible)	0.22 m	9.6 mg/l
E' (1 optimal)	0.85	0.95
IoA' (1 optimal)	0.92	0.97

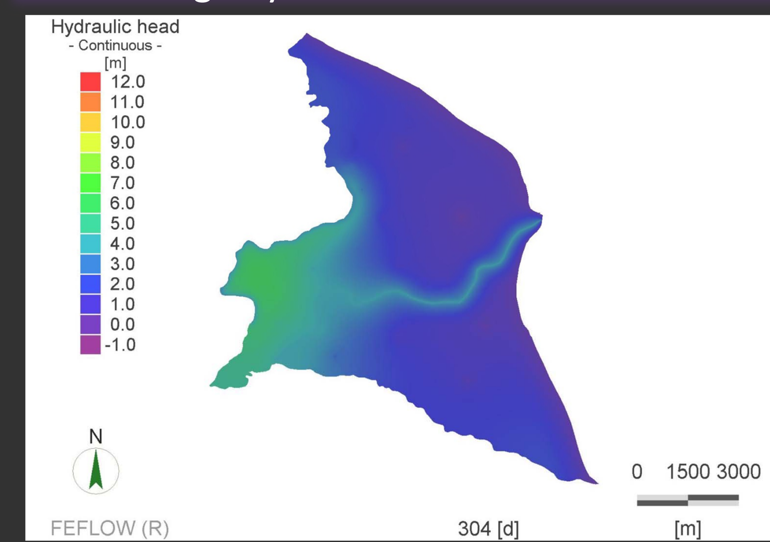
Statistical measures	FEFLOW (hydraulic head)	FEFLOW (chloride concent.)
RMSE (least possible)	0.024 m	2.3 mg/l
Bias (least possible)	0.007 m	8.3 mg/l
RI (1 optimal)	1.16	1.39

Climate change scenarios

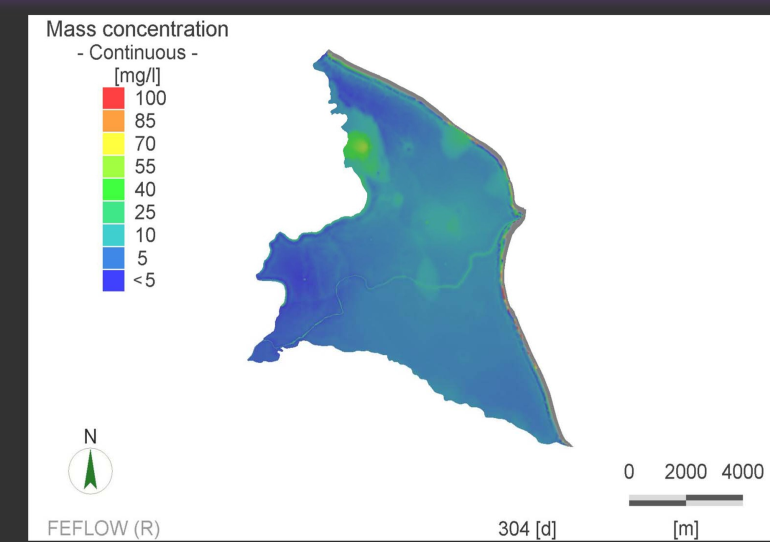
Scenario 1: Constant climate conditions until 2100

Scenario 2: Decrease of the recharge by 5% and 15% until 2050 and 2100, respectively, and sea level change by +0.25 m

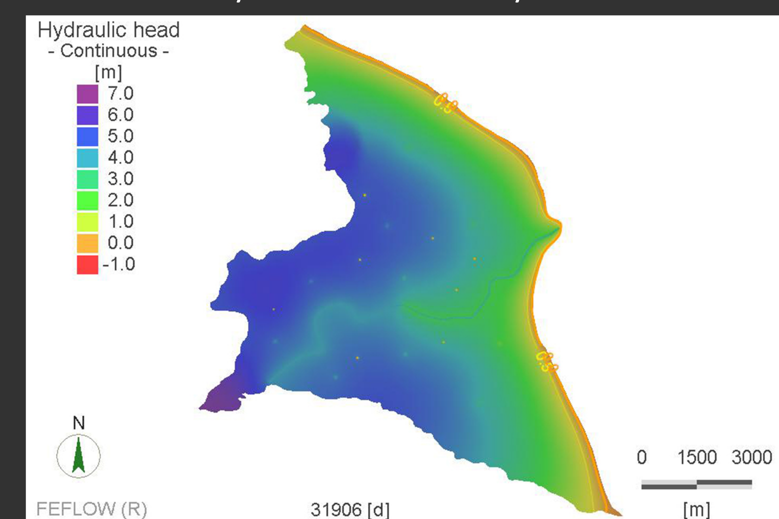
Scenario 3: Decrease of the recharge by 5% and 15% until 2050 and 2100, respectively, and sea level change by +1.0 m



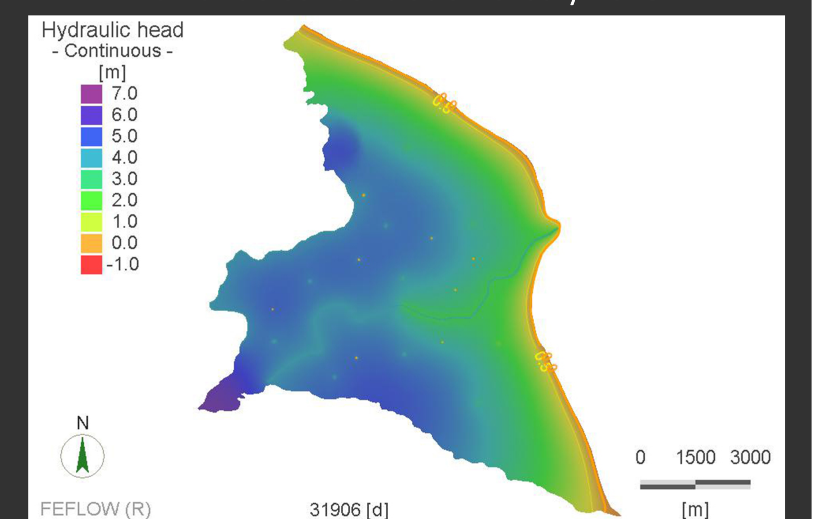
Hydraulic head of July 2013



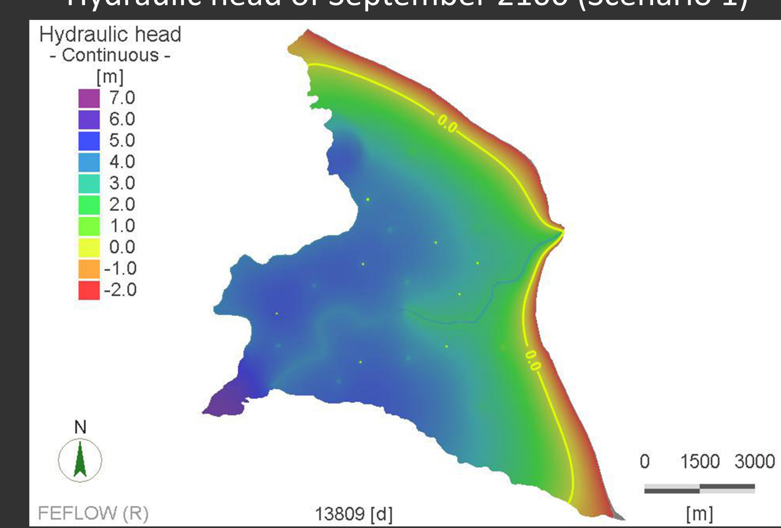
Chloride concentration of July 2013



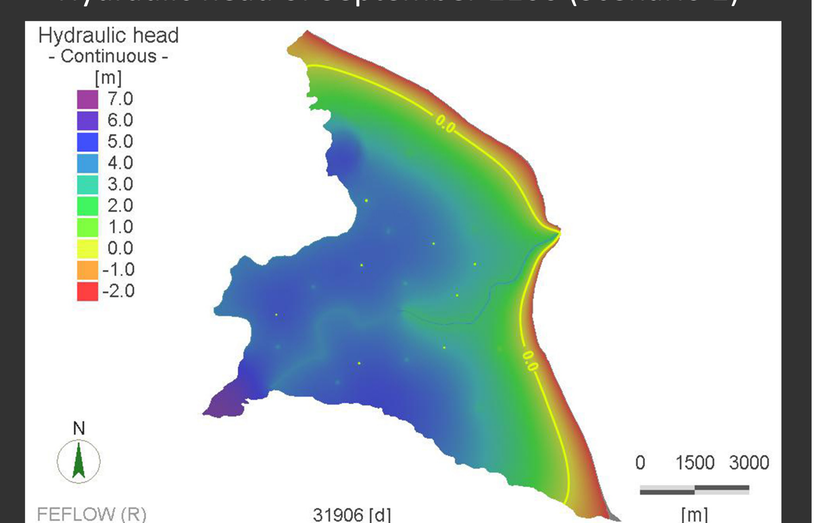
Hydraulic head of September 2100 (Scenario 1)



Hydraulic head of September 2100 (Scenario 2)



Hydraulic head of September 2050 (Scenario 3)



Hydraulic head of September 2100 (Scenario 3)

Conclusions

Groundwater flow simulation under different climate change scenarios showed that a decrease of up to 15% in groundwater recharge regime and a sea level rise of 0.5 m until 2100 will not have serious impact on the water quality of the shallow aquifer due to the lithological structure of the coastal zone and especially the sand dune system which forms barriers preventing sea water intrusion. However, a sea level rise of 1.0 m would cause significant seawater intrusion of hundreds of meters in the deltaic plain even by 2050.

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References

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