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Date of STSM visit: 28.5.2017-11.6.2017

1. Background of the visit

During the 125th European Study Group with Industry (1st Study Group in Cyprus) in December 2016, two challenges were presented by the Cyprus Water Development Department (WDD) related to the management of the Germasogeia aquifer, which supplies water to a large part of Limassol: (i) Optimal recharge of the aquifer in order to compensate for the extraction of water from the aquifer and prevent sea water intrusion. (ii) Predicting contaminant transport in the aquifer in the case of pollutant spillage or leakage from the surrounding domestic areas. During the Study Group week preliminary mathematical models of the aquifer flow were developed. During the STSM, as a part of a team of researchers from Oxford University and the Cyprus University of Technology, and in close collaboration with hydrologists at the WDD, I have further developed the Germasogeia aquifer modeling framework.

2. Description of the work undertaken during the visit

The model of the fluid flow in the aquifer was developed using the well-known Darcy flow-model for porous media. The output of the model is the evolution of the water table with time, and inputs are the dam seepage, and the recharge and extraction rates. This aquifer can be accurately approximated as a long and thin aquifer, leading to a two-dimensional model (Dupuit-Forcheimer approximation). Additionally, the impermeable bed beneath the aquifer as flat and sloped at a small angle to the horizontal was considered. These simplifications led to a reduced mathematical model. There were 4 recharge point sources along the aquifer above the ground. The water was expected to be distributed through the unsaturated underground region, before it reaches the top of aquifer. Three different cases - symmetric Gaussian distribution, asymmetric chi-square distribution and point source- for distribution over the top of the aquifer were considered. There are 19 extraction boreholes along the aquifer, considered as point sources. The boundary conditions are: known seepage rate from dam, and fixed depth at the end towards the sea. The initial water table height was taken as that reported on 2nd October, 2013, as it was the first day of the period for which verification of simulated data was intended.

The model was validated using data provided by the WDD for a period of three years (Oct 2013 to Sep 2016). The data consists of water table level measurements at 37 locations, flow rates and locations of the 4 recharge points and 19 extraction points, and water levels of the Gegmasogeia dam. The seepage flow rate from the dam has been correlated to the dam water level using a *linear* relationship. For the recharge distributions, it was found that the Gaussian and Chi-squared distributions led to a better agreement than point sources. This suggests that a consideration of the axial spread of the recharge water is necessary, but also that the effect of the distribution tail due to the downhill advection is small. It was also confirmed that variable permeability does not affect the resulting water table compared to simulations with constant permeability. No sea water intrusion was confirmed from the positive velocity of the aquifer at the outlet. The validated model can be rerun to explore different scenarios of interest by the WDD, e.g. a much smaller dam seepage rate and larger recharge/extraction rates.

In the case of an accidental spillage occurring at the dam, the transport of contaminant in the aquifer in time was modeled. We obtain the velocity, using our first model above and we use a Convection-Diffusion equation (in non-dimensional form) for the contaminant concentration. The equations are subject to the boundary conditions, known concentration at the dam, and the outlet is at the end towards the sea. Initially, no contaminant is present throughout the aquifer. We predict that it will take around 9-10 years for the whole aquifer to be contaminated and 3 years for half of the aquifer to be contaminated. Note that because the speed of contamination decreases downstream any contamination originating upstream (let's say near the dam) will spread faster than any contamination further downstream. If the location of the spill is precisely known, this model can predict the spreading profile of the contaminant. From a dataset of detailed analysis for spillage at different locations, it can be predicted how far down the aquifer the contaminant will spread and after how much distance it will be safe to extract water.

3. Outcomes

To conclude, we have developed models which are applicable for studying any coastal aquifer, and used them to study in detail various aspects of managing the Germasogeia aquifer. There can be several variations in aquifer scenarios and the Germasogeia aquifer offers a unique case with many constraints. Our work provides important insights that can aid the WDD to manage the Germasogeia aquifer as efficiently as possible. A report summarizing our results has been delivered to the WDD. A comprehensive journal article on aquifer management using the Germasogeia aquifer as a case study is being written by the team working on this project. The possibility of future collaborations was discussed and applicable funding calls were identified.

4. Role of STSM funding for the research project

The research activities I have undertaken within this project have been fully funded by the STSM grant. My visit to Limassol, Cyprus was necessary to understand the real physical scenario, the challenges and the associated constraints. Frequent meetings with WDD personnel were very helpful in refining our mathematical formulation and simulation. Dr. Katerina Kaouri was instrumental in not only dealing with different mathematical modelling techniques but also in coordinating the logistics of this visit. The author is extremely grateful to MI-NET for being awarded this STSM grant.