Optimization of well field management

Groundwater is a limited but important resource for fresh water supply. Different conflicting objectives are important when operating a well field. This study investigates how the management of a well field can be improved with respect to different objectives simultaneously. A framework for optimizing well field management using multi-objective optimization is developed. The optimization uses the Strength Pareto Evolutionary Algorithm 2 (SPEA2) to find the Pareto front between the conflicting objectives. The Pareto front is a set of non-inferior optimal points and provides an important tool for the decision-makers. The optimization framework is tested on two case studies. Both abstract around 20,000 cubic meter of water per day, but are otherwise rather different. The first case study concerns the management of Hardhof waterworks, Switzerland, where artificial infiltration of river water into infiltration basins and injection wells are essential for securing the production of drinking water. Inflow of contaminated water from surrounding urban areas is prevented, because the infiltration maintains a hydraulic gradient directed away from the well field. The objectives of the optimization problem are to minimize the amount of infiltration, and to minimize the risk of getting contaminated water into the production wells. The optimization problem is subjected to a daily demand fulfillment constraint. Constant and sequential scheduling optimization is performed on the Hardhof case. The constant scheduling keeps all decision variables constant during the evaluation period. This method shows good performance when the hydrological conditions and water demand are relatively constant during the evaluation period. Compared with historical operations the optimization problem can be improved with respect to both objectives. The sequential scheduling optimizes the management stepwise for daily time steps, and allows the final management to vary in time. The research shows that this method performs better than the constant scheduling when large variations in the hydrological conditions occur. This novel approach can be used in real-time operations of the waterworks, because the hydrological parameters for the model only have to be provided for one time step ahead. If the contamination risk is kept at the historical level both optimization methods show that it is possible to reduce the amount of infiltration water. It is also possible to reduce the contamination risk if the distribution of the infiltrated water is changed, so that more water is infiltrated in the basins and less in the wells. However, if the waterworks want to be sure to avoid infiltration of contaminated water it is necessary to increase the total amount of infiltration. The second case study considers the operation of Søndersø waterworks, Denmark. At Søndersø the optimization objectives are to minimize the energy consumptions of the waterworks, and to minimize the risk of getting contamination from the nearby contaminated Værløse Airfield into the well field. The decision variables are the relative speed of the pumps. The waterworks has to provide a certain amount of drinking water. A fully integrated hydraulic well field model, which predicts the flow of water in the aquifer, in the well, and in the pipe network has been developed. The well field model, WELLNES (WELL Field Numerical Engine Shell), is capable of predicting the power consumption at different wells. It captures the water level- and power dynamics in each well when pump speeds are changed. WELLNES is set up and calibrated for the Søndersø area. The WELLNES model shows good correspondence between observations and simulations in both calibration and validation periods. The optimization results for Søndersø shows that only minor energy savings can be achieved with the existing pumps. If all the existing on/off pumps are changed to new variable-speed pumps it is, however, possible to save between 25 and 40% of the specific energy (the energy consumption per cubic meter of abstracted water). This corresponds approximately to an energy reduction of 200 MWh per year. All optimization results show that it is possible to obtain significant reductions in the contamination risk. The research shows that the large potential for savings is mainly due to optimizing the variable-speed pumps rather than optimizing the new on/off pumps. The payback period of investing in new variable-speed pumps for Søndersø waterworks is only 3-4 years, which is an interesting time horizon for the waterworks. The developed multi-objective optimization framework has shown to be useful in optimizing the management of well fields, and it has successfully been applied to the two case studies, Hardhof and Søndersø waterworks. If the method is applied to all Danish waterworks it is estimated that 20-32 GWh/year could be saved, corresponding to 17-27 million DKK.