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Numerical simulation of seasonal groundwater pumping

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Increasing scarcity and contamination of water recourses require innovative water management strategies such as combined water system. The combined water system is a complex technology comprising two separate wells, major catchment-zone well and compensation pumping well, located inside a single stream basin. The major well is supplied by the well's catchment zone or surface flow, thus depleting the stream flow. The pumping rate of a major well is determined by the difference between the current stream flow and the minimum permissible stream flow. The deficiency of the stream flow in dry seasons can be compensated for by the short-term pumping of groundwater. The compensation pumping rate is determined by the difference between water demand and the permissible water withdrawal of the major well. The source for the compensation well is the aquifer storage.

The estimation of streamflow depletion caused by compensation pumping is major question to evaluate the efficiency of the combined water system. Short-term groundwater pumping can use aquifer storage instead of catchment-zone water until the drawdown reaches the edge of the stream.

Traditionally pumping simulation calculates in two-step procedure. Natural conditions, an aquifer system is in an approximate dynamic equilibrium, describe by steady-state model. A steady-state solution provides an initial heads, a set of flows through boundaries, and used as initial state for transient solutions, when pumping is imposed on an aquifer system. The transient solutions provide the total change in flows through the boundaries. A difference between the transient and steady-state solutions estimates the capture and the streamflow depletion.

Numerical modeling of cyclical compensation pumping has special features: the periodic solution, the seasonal changes through the boundaries and the importance even small drawdown of stream level.

When seasonality is a modeling feature, traditional approach leads to mistaken values of streamflow depletion. In this case three-step procedure is used. The first step is usual construction steady-state model. Then steady oscillatory model is constructed in which heads and flows through boundaries vary through the seasons but repeat from year to year (from cycle to cycle). Steady oscillatory solutions are used as initial conditions for transient pumping model. The stream flow depletion is estimated by difference between the transient solution and steady oscillatory solution.

The purpose of these investigations was to evaluate the error, caused by using non-periodic solution as initial conditions for transient pumping model and to determine number of cycles required to reach steady oscillatory solution. For this study seasonal numerical models were constructed using ModTECH 2.3 and MODFLOW-2000.

The developed models showed significant errors of stream depletion value, when non-periodic solution is used, miscalculation exceed 70 percent and more. It was obtained equations to estimate required number of cycles (N):

for confined aquifer$N = 0.2 \cdot z + 9$

for unconfined aquifer$N = 0.0051 \cdot z - 0.3$

$$z = \frac{(L + L')^2 \cdot S}{T}$$

where $T$and S are transmissivity and specific yield of the aquifer (or storage coefficient for a confined aquifer), L' is stream leakance and L is riverbank size.