Modeling Ground Water/Surface Water Interactions

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Modeling GW/SW Interactions

- Losing streams
- Gaining streams
- Perched streams
- Lakes and ponds
- Coast
- Estuaries

Modeling GW/SW Interactions

- A model is a simplified representation of reality
  - Physical models
  - Analog models
  - Mathematical models
- Models vary in complexity and data requirements
  - Generic models for screening
  - Site-specific models for decision making

Modeling GW/SW Interactions

- Ground water models
  - Ground water flow
  - Multiphase flow
  - Dissolved contaminant transport
- Surface water models
  - Stream flow
  - Hydrodynamics
  - Water quality

Modeling GW/SW Interactions

- Ground water models
  - Analytical (with many assumptions)
  - Numerical (more adaptive)
    - Finite difference
    - Finite element

Modeling GW/SW Interactions

- Ground water models
  - MODFLOW (USGS)
  - WhAEM2000 (EPA)
  - FLOWPATH (U. of Waterloo)
  - and many more

Modeling GW/SW Interactions

- Surface water models
  - Watershed-scale loading
  - Field-scale loading
  - Receiving water
  - Integrated systems

- HSPF, QUAL2E, SWMM, CREAMS

Modeling GW/SW Interactions

- MODFLOW
  - Modular 3-dimensional finite-difference ground water flow model (since 1980s)
  - Continuous enhancements by USGS and other researchers
  - Linkages to surface water

Modeling GW/SW Interactions

- USGS OFR 88-729 “Documentation of a Computer Program to Simulate Stream-Aquifer Relations Using a Modular, Finite-Difference, Ground Water Flow Model”
- USGS OFR 99-217 “Modifications to the Diffusion Analogy Surface-Water Flow Model (DAFLOW) for Coupling to the Modular Finite-Difference Ground Water Flow Model (MODFLOW)”
- USGS OFR 02-455 “User Guide for the PULSE Program”

Modeling GW/SW Interactions

- MODFLOW
  - Ground water flow equation -- partial-differential equations
  - Replaced with a finite set of discrete points – difference equations
  - Require spatial discretization of an aquifer system (i.e., cells)
  - Iteration methods to obtain solutions
  - Boundary conditions – constant head and inactive (or no flow) cells

Modeling GW/SW Interactions

- MODFLOW
  - River package – simulate effects of flow between surface water feature and ground water systems
    - Streams are divided into reaches so that each reach is completely contained in a single cell
    - Stream-aquifer seepage is simulated between each reach and the model cell that contains that reach
    - Characterize streambed conductance

Modeling GW/SW Interactions

- MODFLOW
  - Drain Package – simulate effects of features such as agricultural drains, which remove water from the aquifer at a rate proportional to the difference between the head in the aquifer and some fixed head or elevation
    - Convergent flow toward the drain
    - Flow through material of differential conductivity
    - Flow through the wall of the drain

Modeling GW/SW Interactions

- MODFLOW (based coupled models)
  - MODBRNCH
    - BRANCH simulates stead or unsteady flow in a single open-channel reach (branch) or throughout a system of branches (network) connected in a dendritic or looped pattern by solving the one-dimensional equations of continuity and momentum for the river flow
    - Channel-aquifer flows are leakage through a confined layer or riverbed

Modeling GW/SW Interactions

- MODFLOW (based coupled models)
  - MOFLOW/DAFLOW
    - DAFLOW routes flows through inter-connected one-dimensional channels (branches and subreaches)
    - Exchange between each subreach and a specific ground water cell – computed using stream-aquifer head difference, streambed thickness, stream width, and streambed hydraulic conductivity

Modeling GW/SW Interactions

- MODFLOW (based coupled models)
  - Florida Institute of Phosphate Research (FIPR) Hydrologic Model (FHM) – University of South Florida (http://cmhas.eng.usf.edu/models/FHM/)
    - Use HSPF (Hydrological Simulation Program – FORTRAN) simulates the surface water system including basin, reach, and reservoir water budgets
    - Integration codes (Arc/Info interface) provide the processes and pathways that govern the vadose zone connecting surface water and ground water

Modeling GW/SW Interactions

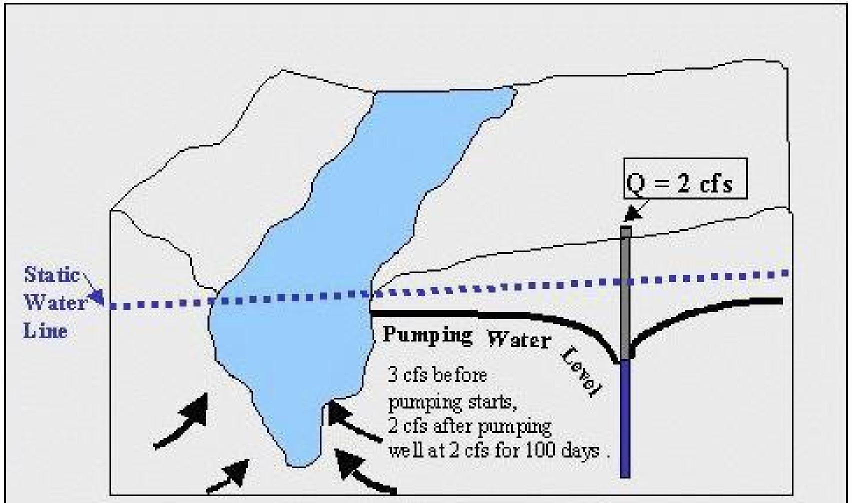
- HSPF
  - Origin in the Stanford Watershed Model (Crawford and Lindsley, 1966)
  - EPA commissioned development of HSPF in mid-1970s
  - USGS developed HSPEXP (interactive version)
  - Simulate hydrologic and associated water quality processes on land surfaces, streams, and impoundments
  - Basin presented as land segments and reaches/reservoirs

Modeling GW/SW Interactions

- Other models
  - FlowThru (for calculating groundwater flow regimes near shallow surface water bodies)
    - http://www.townley.com.au/
    - Handles 17 flow-through regimes, 11 recharge regimes, and 11 discharge regimes
    - Assume water bodes are shallow relative to the thickness of the aquifer (infinitesimally thin layer of constant head lying at the top surface of the aquifer
    - Combines and displays a set of pre-computed solutions using triangular finite element model

Modeling GW/SW Interactions

- Application http://www.if.uidaho.edu/~johnson/ifiwrri/sr3/rspfunc.html
  - Response functions for gaining streams



River Aquifer Response Ratio

River gains decrease from 3 to 2 cfs as a result of pumping after 100 days. The response ratio is :

$$\frac{\text{change in stream flow}}{\text{well discharge}} = \frac{3 - 2\ (\text{cfs})}{2\ (\text{cfs})} = .5$$

Modeling GW/SW Interactions

- Response function
  - Time dependent
  - Base flow input = 3 cfs
  - After 100 days of pumping at 2 cfs, base flow input = 2 cfs
  - Change in stream flow = 3 – 2 cfs = 1 cfs
  - Response ratio = (3-2)/2 = 0.5
  - Can be applied under different pumping rates

Modeling GW/SW Interactions

- Controls of response function
  - Proximity of stream and well
  - Degree of interconnection
  - Aquifer properties (e.g., transmissivity)
  - Geology and well depth
  - Relationship to other connected water bodies
  - Distance to low permeability aquifer boundaries

Modeling GW/SW Interactions

- How to determine response function?
  - Direct measurement
    - Only possible under specific circumstance (close proximity of well and stream)
  - Analytical methods
    - Unrealistic assumptions (fully penetrating streams and wells, homogeneous and infinite aquifers)
  - Numerical methods
    - MODFLOW

Modeling GW/SW Interactions

- Using MODFLOW to generate response functions
  - Calibrated MODFLOW model of the area
  - Remove all recharge and discharge from input and eliminate all hydraulic gradients (Hubbell et al., 1997 – GW, 35(1), p. 59-66)
  - Multiple simulations are used to develop responses

Modeling GW/SW Interactions

- Use of response function
  - Depict impact of ground water withdrawal on stream reaches
  - Water rights and conjunctive management
  - Allow integration of ground water information with surface water information

Modeling GW/SW Interactions

- Summary
  - Existing tools
  - Understanding of uncertainties and model/data limitations
  - Requiring good QA and documentation
  - Maintaining scientific integrity