Hydrocomplexity: New Tools for Solving Wicked Water Problems
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Increasing complexity of USGS hydrological modelling: GSFLOW, a coupled groundwater and surface water flow model

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An interdisciplinary approach is needed to assess the effects of variability in climate, biota, geology, and human activities on water availability and flow. A new groundwater and surface-water flow model (GSFLOW) integrates the US Geological Survey Precipitation–Runoff Modelling System (PRMS) and the US Geological Survey Modular Groundwater Flow Model (MODFLOW-2005). GSFLOW: (1) builds on existing science and technology; (2) is easily extensible; (3) provides mechanisms for modelling over different spatial and temporal scales; and (4) provides for integration between science and management objectives. Future versions of GSFLOW can include additional models to simulate other environmental and anthropogenic processes, such as climate, water quality, ecology, geochemistry, and management strategies.

Due to the increasing complexity of environmental and water-resource problems, modelling techniques are required that simulate, on a basin scale, both the surface and subsurface hydrology. Precipitation–runoff models have been used to generate groundwater recharge information for subsurface models; however, incompatibilities in the spatial and temporal resolutions have been a significant impediment to a robust coupling of these models. Surface- and groundwater models need to be integrated to provide the feedback between the models to achieve the water balance necessary to answer complex questions. Specifically, GSFLOW addresses the following questions: What is the impact of finer (space and time) resolution evaporation, soil moisture, and infiltration information on groundwater simulation? What is the impact of a rising or declining water table on surface water processes? What is the dynamic of surface- and groundwater interaction in springs, wetlands, and riparian areas? What is the source of streamflow? What is the impact of different climate (floods and droughts) scenarios on the surface- and groundwater system? What is the impact of different management (conjunctive use, urbanization, and irrigation) scenarios on the surface- and groundwater system?

GSFLOW consists of the integration of three components: one component partitions precipitation into surface evapotranspiration, overland flow, interflow, and infiltration (PRMS); a second component routes surface flow in channels (SFR2); and a third component computes vertical unsaturated flow, exfiltration, and groundwater flow (MODFLOW). GSFLOW is developed according to these principles:

– Use existing PRMS modules and MODFLOW-2005 packages where possible;
– Use a flexible and adaptive modular design that incorporates both PRMS and PRMS-2005 programming frameworks so that existing and new PRMS and MODFLOW-2005 simulation techniques can be added to GSFLOW in the future;
– Use general design procedures that can be used for integrating other simulation models into GSFLOW;
– Allow simulations using only PRMS or only MODFLOW-2005 within the integrated model for the purpose of initial calibration of model parameters prior to a comprehensive calibration using the integrated model;
– Solver equations governing interdependent surface-water and groundwater flow using iterative solution techniques;
– Compute model-wide and detailed water balances in both time and space;
– Allow flexibility in the spatial discretization of the homogeneous response units used for

PRMS and the finite-difference grid used for MODFLOW-2005; and

- Allow model boundaries to be defined using standard specified-head, specified-flow, and head-dependent boundary conditions to account for inflows to and outflow from the modelled region.

As sciences mature, integration of them becomes increasingly possible and powerful. Addressing the ever-increasing range and complexity of environmental resource management and policy development problems requires an interdisciplinary and adaptive approach that builds on existing science and technology, is easily extensible, provides mechanisms for modelling over different spatial and temporal scales, and provides for integration between science and management objectives. These are the primary design criteria for the GSFLOW development which provides a means for computer simulation of the water cycle and associated processes of small watersheds to regional basins using global, regional, and local data. While the main reason for developing GSFLOW was to build a tool to quantify and predict spatial and temporal variability of interdependent atmospheric, surface and subsurface hydrologic fluxes of precipitation, solar radiation, evaporation, transpiration, runoff, infiltration, interflow, recharge, storage, and discharge, its extensible programming structure allows for integration with other scientific disciplines and environmental processes. Future work on GSFLOW will focus on incorporating geochemical, water quality, conjunctive use and river system management, streamflow with fate and transport of constituents, and ecosystem and habitat modelling.

REFERENCES

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