Prepared in cooperation with the
BUREAU OF INDIAN AFFAIRS and
WASHINGTON STATE DEPARTMENT OF ECOLOGY

# Groundwater and Surface-Water Flow Modeling of Chamokane Creek Basin, Stevens County, Washington

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## Introduction

Chamokane Creek basin is a 179 square-mile area that borders and partially overlaps the Spokane Indian Reservation in northeastern Washington State (fig. 1). Primary aquifers within the basin are part of a sequence of glaciofluvial and glaciolacustrine fill within an ancient paleochannel eroded into Miocene basalt and Cretaceous to Eocene granite. The mean annual streamflow of Chamokane Creek is 62.5 cubic feet per second.

In 1979, most water rights in the Chamokane Creek basin were adjudicated by the United States District Court requiring regulation in favor of the Spokane Tribe of Indian's senior water right. A court-appointed Water Master regulates junior water rights and the basin is closed to further groundwater or surface-water appropriation, with the exception of permit-exempt uses of groundwater.

The Spokane Tribe and senior right holders are concerned about the effects of future groundwater development in the basin and the potential effects of this growth on Chamokane Creek. To evaluate these concerns, the U.S. Geological Survey is using a coupled groundwater and surface-water flow model (GSFLOW) to investigate the aquifer-creek interactions and simulate the effects of current and potential groundwater withdrawals on Chamokane Creek. In addition to measured streamflow and water levels, the model is constrained by snow course data and evapotranspiration estimated from an automated agricultural weather station and derived from a coupled remote sensing and Simplified Surface Energy Balance approach.

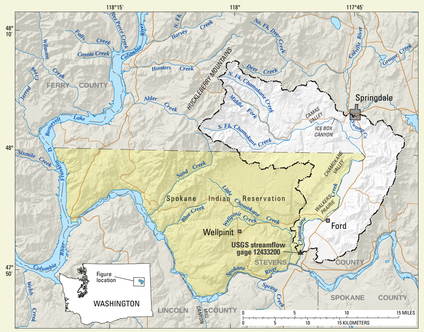



**Figure 1.** Location of the Chamokane Creek basin, Stevens County, Washington.

## Methods

A two-part (Phases 1 and 2) investigation was designed (1) to characterize the hydrogeologic setting and groundwater and surface-water interactions in the basin, and to obtain hydrologic data sets to support subsequent computer modeling (Kahle and others, 2010), and (2) to build and apply a coupled groundwater and surface-water flow model in order to evaluate the possible regional effects of different groundwater-use alternatives on the surface-water system.

## Hydrogeologic Framework

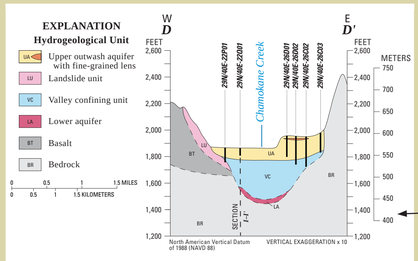



**Figure 2.** Hydrogeologic section *D-D′*. Section five times map scale.

Six hydrogeologic units were identified in the basin using well logs, geologic mapping, and field observations (figs. 2 and 3). The Upper outwash aquifer is an unconfined aquifer along the valley floors of the study area, and consists mostly of sand, gravel, and cobbles. The Landslide unit is composed of poorly sorted deposits of broken basalt and sedimentary interbeds along the basalt bluffs in Walkers Prairie. The Valley confining unit mostly is a low-permeability unit consisting of glaciolacustrine silt and clay at depth throughout the valley bottoms of the study area. The Lower aquifer is a confined aquifer consisting of sand and gravel at depth below the Valley confining unit. The Basalt unit is composed of Columbia River Basalt and sedimentary interbeds. Water is contained in cracks and fractures and from zones between lava flows. The Bedrock unit includes rocks older than the Columbia River Basalt and commonly includes granite and quartzite with small and often unreliable yields.

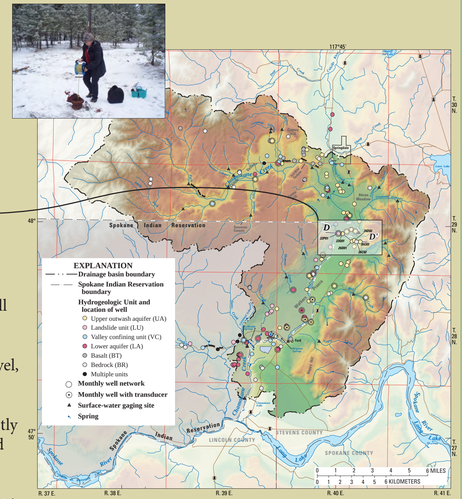



**Figure 3.** Location of project wells with hydrogeologic unit, surface-water measurement sites, and Agrimet station; graphs showing water levels in wells, precipitation measured at the Agrimet station, and discharge data from USGS streamflow-gaging station 12433200; Chamokane Creek basin, Stevens County, Washington.

## GSFLOW Model Description

The USGS coupled groundwater and surface-water flow model (GSFLOW; Markstrom and others, 2008) is an integration of the USGS Precipitation-Runoff Modeling System (PRMS) with the 2005 version of the USGS Modular Groundwater Flow Model (MODFLOW-2005). GSFLOW simulates flow within and among three regions (fig. 4; Markstrom and others, 2008). The first region is bounded on top by the plant canopy and on the bottom by the lower limit of the soil zone; the second region consists of all streams and lakes; and the third region is the subsurface zone beneath the soil zone. PRMS is used to simulate hydrologic responses in the first region and MODFLOW-2005 is used to simulate hydrologic processes in the second and third regions.

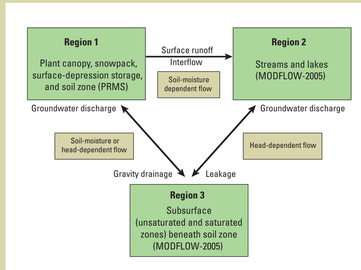
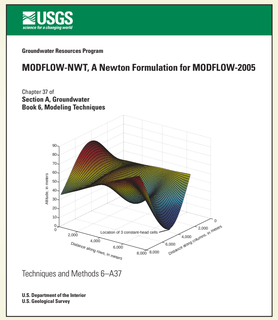



**Figure 4.** Schematic diagram of the exchange of flow among the three regions in GSFLOW (from Markstrom and others, 2008).

A new package and solver for MODFLOW-2005 is utilized in the Chamokane Creek model. The Upstream Weighting (UPW) Package is an internal flow package for MODFLOW-2005 intended to be used with the Newton Solver (NWT) for problems involving drying and rewetting nonlinearities of the unconfined groundwater flow equation (Niswonger and others, 2011).

The UPW Package calculates inter-cell conductances in a different manner from the Block-Centered Flow (BCF), Layer Property Flow (LPF) or Hydrogeologic-Unit Flow (HUF) Packages. The UPW Package treats nonlinearities of cell drying and rewetting by use of a continuous function rather than the discrete approach of drying and rewetting that is used by the BCF, LPF and HUF Packages. This further enables application of the Newton solution method for unconfined groundwater flow problems because conductance derivatives required by the Newton method are smooth over the full range of head for a model cell.




## Chamokane Creek Model

GSFLOW is being used to investigate the aquifer-creek interactions, provide water budgets, and simulate the effects of groundwater and surface-water withdrawals on Chamokane Creek. The model is constructed using the hydrogeologic framework, stream geometry, and water-use estimates from Phase I (fig. 5). The model consists of a horizontal grid of 106 columns and 102 rows that are a uniform 1,000 feet per side. Vertically, the model domain was subdivided into 8 model layers.

Measured precipitation and air temperature are the major factors used to compute evaporation, transpiration, sublimation, snowmelt, surface runoff, and infiltration.

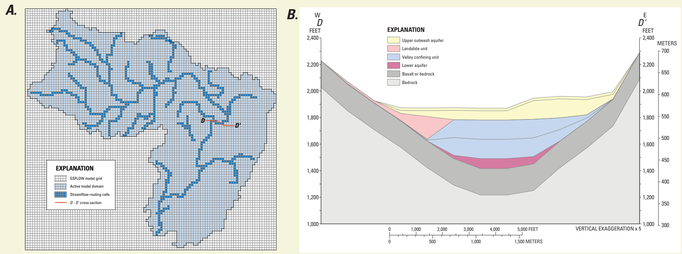



**Figure 5.** Extent of the GSFLOW model, location of streamflow-routing cells (*A*), and simplified model cross section (*B*), for the Chamokane Creek basin, Stevens County, Washington.

## Initial Model Results

The model is being calibrated to the transient conditions for the 31-year period from October 1979 through September 2010 using the iterative parameter estimation software package PEST (Doherty, 2010). The model is constrained by streamflow values measured at the USGS streamflow-gaging station and a series of synoptic streamflow measurements, and miscellaneous, monthly, and continuous water levels (fig. 3). Evapotranspiration was estimated independently from an automated agricultural weather station (figs. 3 and 6) and derived from a coupled remote sensing and Simplified Surface Energy Balance approach (fig. 7; Senay and others, 2009).

Figure 8 shows initial model fit from the automated calibration process. The final calibrated model will be used to assess the potential effects of water resource management strategies.

**Figure 6.** Agrimet station located in Chamokane Creek Basin.

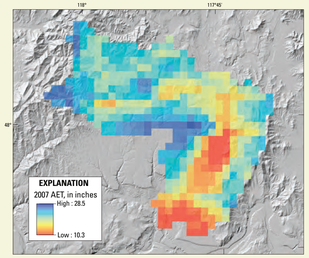
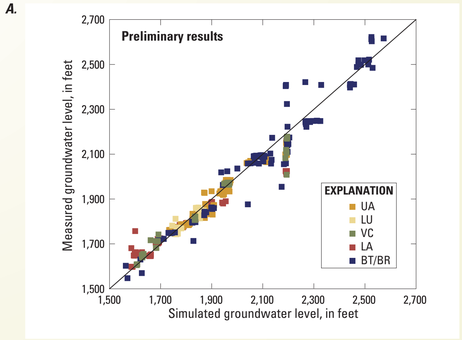



**Figure 7.** Estimates of actual evapotranspiration (AET) for 2007 from the Simplified Surface Energy Balance approach.



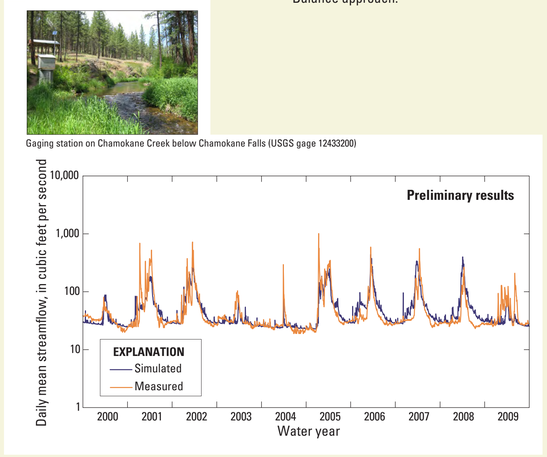




**Figure 8.** Initial results of model calibration for (*A*) groundwater levels and (*B*) streamflow.

## References Cited

Doherty, J.E., 2010, PEST, Model-independent parameter estimation—User manual (5th ed., with slight additions): Brisbane, Australia, Watermark Numerical Computing.

Kahle, S.C., Taylor, W.A., Lin, Sonja, Sumioka, S.S., and Olsen, T.D. 2010, Hydrogeologic framework, groundwater and surface-water systems, land use, pumpage, and water budget of the Chamokane Creek basin, Stevens County, Washington: U.S. Geological Survey Scientific Investigations Report 2010-5165, 60 p.

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW-coupled ground-water and surface-water FLOW model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p. (Also available at http://water.usgs.gov/nrp/gwsoftware/gsflow/gsflow.html).

Niswonger, R.G., Panday, Sorab, and Ibaraki, Motomu, 2011, MODFLOW-NWT, A Newton formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6–A37, 44 p.

Senay, G.B., Budde, M.E., Morgan, D., and Dinicola, R., 2009, Characterizing landscape evapotranspiration dynamics in the Columbia Plateau using remotely sensed data and global weather datasets, *in* Proceedings of the 8th Biennial USGS Pacific Northwest Science Conference Integrating Science for a Changing Pacific Northwest, Portland, Oregon, March 3-5, 2009.

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