Appendix B. Estimation of Groundwater Recharge

B.1—Watershed Model

The Precipitation Runoff Modeling System (PRMS) watershed model (Leavesley and others, 1983; Leavesley and others, 1996) distributes daily precipitation over the land surface, uses daily air temperature to determine the rain/snow mix and evaporative losses, and partitions the remaining water through three interconnected subsurface reservoirs: the soil zone reservoir, subsurface reservoir, and the groundwater reservoir. Each reservoir drains at varying rates to the nearby stream with part of the groundwater reservoir also draining into the deeper groundwater system (groundwater sink) (fig. B1). In the watershed model, daily mean values are simulated for the storage in each reservoir, the rate of movement of water from one reservoir to the next, and the combined flow from the three reservoirs to the stream. Daily mean simulated streamflow was calibrated using observed daily mean streamflow from the Mosier Creek stream-gaging site (14113200, streamflow measurement site number 4, fig. 1). The groundwater sink represents water that drains from the groundwater reservoir that enters a regional aquifer or discharges to the stream downstream of the Mosier Creek gaging station, either to Mosier Creek or directly to the Columbia River. Groundwater recharge is the total amount of water entering the groundwater reservoir, and it equals the sum of the groundwater flow to nearby streams and the flow into the groundwater sink (fig. B1).

In this study, PRMS version 1.1.7 (Leavesley and others, 1983; Leavesley and others, 1996) was used to estimate recharge to the study area for 1955–2007. The model was developed and calibrated for the Mosier Creek gage basin, defined as the 41.5 mi^2 area upstream of the Mosier Creek gaging station for the period of available streamflow data from WY 1964–81, and 2006–07. Subsequently, the model area was expanded to include the entire basins of Mosier, Rock, and Rowena Creeks at their points of confluence with the Columbia River, and the simulation period was expanded to include available climate data so that recharge was estimated for all three basins for the entire period (1955–2007).

In PRMS, the model area is divided into smaller hydrologic response units (HRUs). Within each HRU, it is assumed that the hydrologic attributes controlling rainfall runoff and groundwater recharge are similar across the HRU. HRUs are delineated by the modeler in a manner that reflects spatially distributed attributes of elevation, slope, aspect, soils and land cover type. For the PRMS models created in this study, a combined total of 312 HRUs were delineated. The time-series data inputs to PRMS are daily total precipitation, and daily maximum and minimum air temperature. Climate data were obtained from the Hood River climate site (National Weather Service (NWS) site number 354003 (Oregon Climate Service, 2009) (fig. 1). PRMS requires a complete climate data set, so occasional gaps were filled by interpolation or by regression with nearby sites.

Precipitation over the gage basin diminishes from west to east in a transition from the relatively wet part of the Western Cascades to the dry interior, and from the southern, upland part of the basin to the relatively low-elevation northern part of the basin near the Columbia River. Daily total precipitation at Hood River was distributed over each HRU based on the ratio of long-term (1971–2000) monthly average precipitation at the climate site and at each HRU. The average precipitation was derived from the Precipitation Elevation Regression on Independent Slopes Model (PRISM), which provides annual and monthly precipitation estimates over an 800 by 800 m grid of the State of Oregon (PRISM Group, 2010). The grid was intersected with the polygons representing the HRUs using ARC/INFO algorithms, resulting in a monthly average total precipitation at each HRU. Overall, precipitation over the gage basin was about 10 percent greater than at the climate site at Hood River, and precipitation at the HRUs varied from 50 to 200 percent of the value at Hood River. The derived ratio of monthly precipitation at the climate site to monthly precipitation at each HRU was multiplied by the measured daily precipitation at the climate site, resulting in precipitation at each HRU for each day during the simulation.

The general distribution of the PRISM-derived precipitation was tested at two precipitation measurement sites relatively close to the gage basin as a means to verify the ratio method for determining precipitation at each HRU. The average difference between the PRISM precipitation and measured precipitation at The Dalles (fig. 1), and at Crow Creek reservoir (approximately 2.5 mi south of the Mosier-Rock-Rowena Creek watershed) for the same period (1970–2000) was about 15 percent (Oregon Climate Service, 2009; Wasco County Extension Service, written commun., 2009).

Daily maximum and minimum air temperature at each HRU was based on the daily maximum and minimum air temperature at the climate site. Monthly lapse rates were applied to the difference in elevation between the climate site and each HRU. For PRMS, lapse rates are defined as the change in air temperature (degrees Fahrenheit) for every 1,000 ft. The lapse rates were predefined by analyzing air temperature records from the surrounding Mosier region, and then incorporated into PRMS as model parameter values.

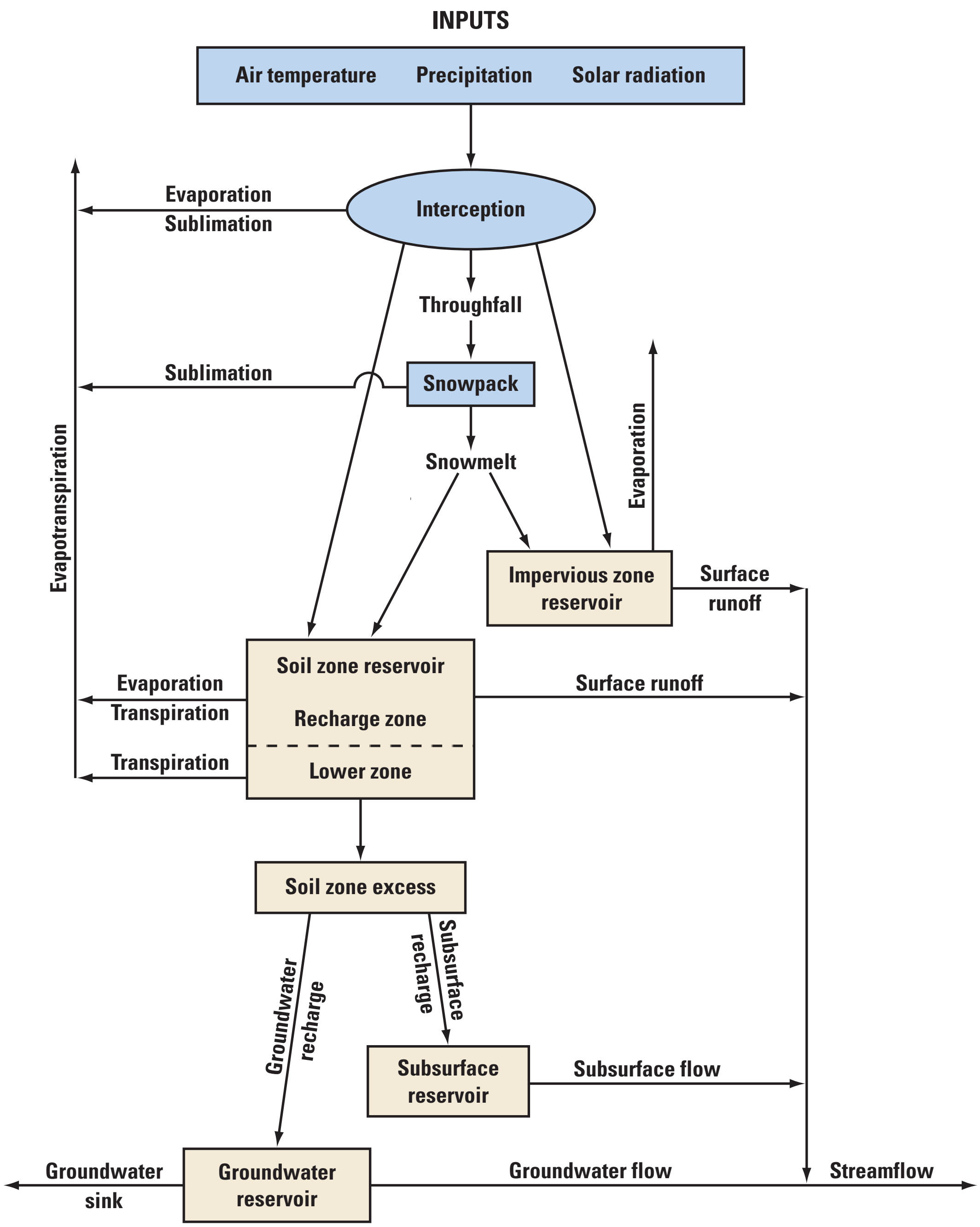


Figure B1. The Precipitation Runoff Modeling System (PRMS). (Leavesley and others, 1996).

The simulation of daily mean streamflow derived from the PRMS model of the gage basin was verified by comparison with the observed daily mean streamflow hydrograph and by comparison of annual flow volume. The shape of the streamflow hydrograph and particularly the recession characteristics of streamflow were an indicator of model fit (Leavesley and others, 1996). The components of streamflow include relatively rapid surface runoff, attenuated subsurface flow where precipitation infiltrates and discharges to the stream—delayed and prolonged compared to the timing of surface runoff, and an even more delayed local groundwater flow component. A realistic balance between these three components results in a reasonable fit with the observed seasonal streamflow hydrograph. Many parameter values in PRMS were based on the underlying GIS layers derived from the GIS Weasel processing procedure. GIS Weasel is a software system designed to aid users in preparing spatial information as input to lumped and distributed parameter hydrologic simulation models (Viger and Leavesley, 2007). These parameters were not adjusted in model calibration due to inadequate physical-process data needed to justify that approach. Calibration of the model was accomplished by adjusting parameters within recommended bounds, and primarily included those controlling the rate of movement of water from the subsurface to the groundwater reservoir, from the subsurface and groundwater reservoirs to the stream, and from the groundwater reservoir to the groundwater sink.

The model was calibrated for general streamflow characteristics. As such, the model does not simulate individual storm events well. Observed streamflow increases and decreases more rapidly than the simulated streamflow. During the several-month-long dry period, simulated streamflow often is less than observed streamflow, indicating a dry stream during periods of measured low flow. Figure B2 shows the ability of the model to simulate measured flows at the Mosier Creek gaging station for WYs 1973–77. This period was selected to represent a range of streamflow conditions of Mosier Creek. Total streamflows during WYs 1974 and 1975 were the highest and second highest during the simulation period. Alternatively, WYs 1977 and 1973 represented the lowest and second lowest total annual streamflows. A comparison of observed and simulated annual flow volumes (fig. B3) was the basis for determining the PRMS groundwater sink parameter value. The groundwater sink parameter was manually adjusted iteratively, until the difference between simulated and observed annual flow volumes was minimized.

Following development of the PRMS model for the gage basin, the model extent was expanded to include the Mosier, Rock, and Rowena Creek basins. Although the Mosier and Rock Creek basins are not physically connected at a single outlet point (they each flow directly into the Columbia River), it was possible to define them within PRMS as a single watershed model due to their close proximity. Because there is no stream routing component in PRMS and the ordering of the HRUs does not matter, HRUs from both basins were included in the same model parameter file. A separate model of the Rowena Creek basin was prepared. The same method of HRU delineation used in the gage basin resulted in 133 and 70 HRUs for the Mosier/Rock basin and the Rowena basin, respectively. Due to lack of observed streamflow data for the mouth of Mosier Creek, Rock Creek, and Rowena Creek, the same set of parameters applied to the gage basin was used for the expanded model area. Identical methods were used to distribute the climate data over these basins (fig. B4). The model was initialized with WY 1953–54 climate data, and water-budget components were derived for the simulation period, WYs 1955–2007.

Average recharge in the Mosier, Rock, and Rowena Creek basins for the simulation period was 9.6 in., and generally follows the pattern of precipitation. The greatest recharge was in the upland area to the south, at about 19 in. Recharge diminished from the western part of the basin toward the east, where the lowest recharge was about 4 in. Of the total recharge, the local groundwater flow and sink components represented 43 and 57 percent of recharge, respectively. The groundwater-flow model extent is slightly larger than the area encompassed by the watershed models, so non-intersecting areas were estimated based on adjacent values from PRMS.

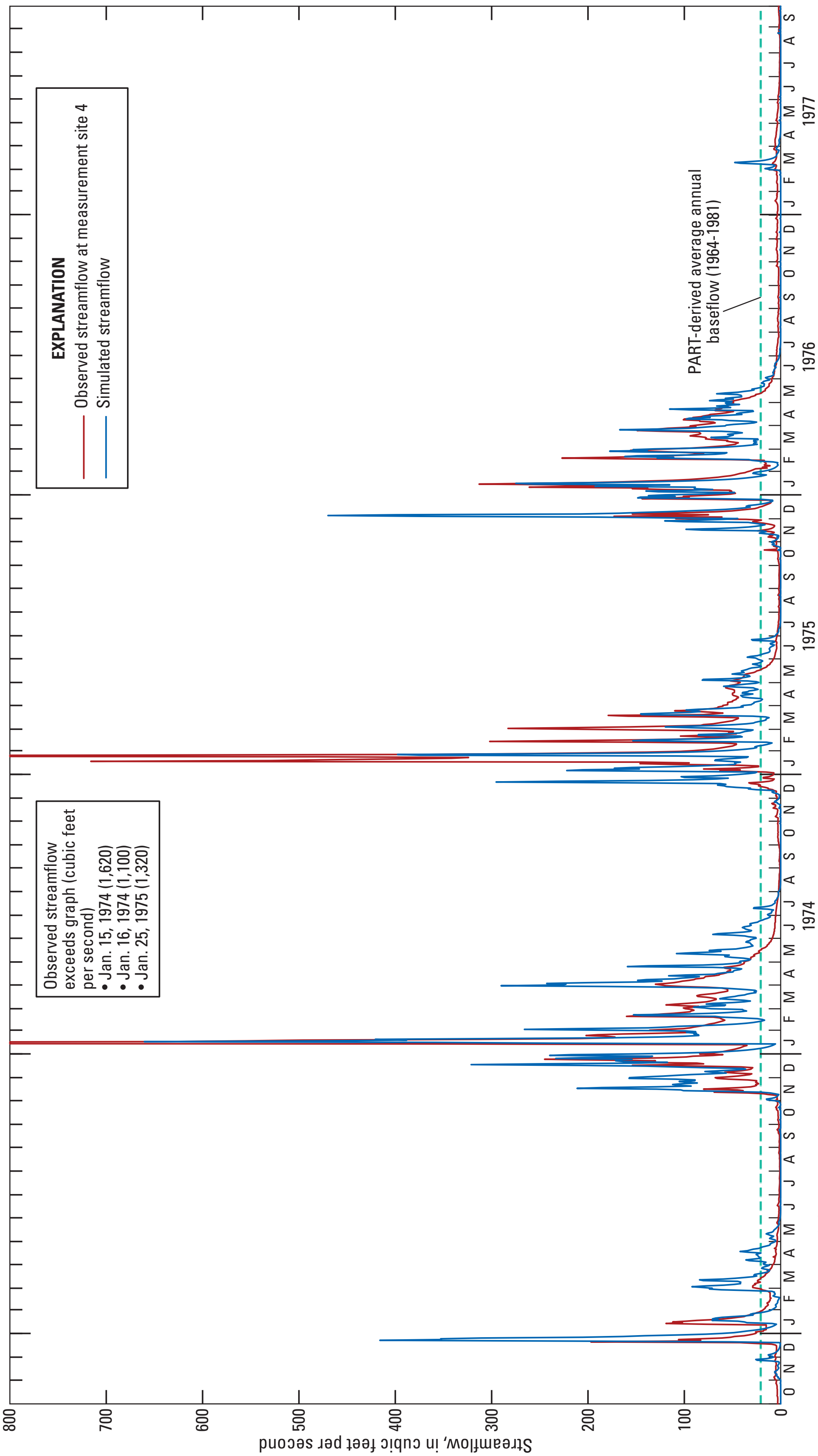


Figure B2. Measured and simulated daily mean streamflow of Mosier Creek near Mosier, Oregon.

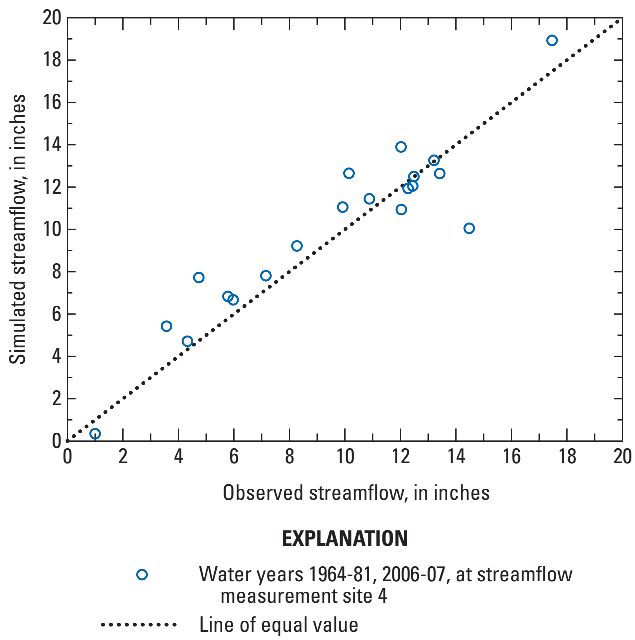


Figure B3. Measured and simulated annual mean streamflow of Mosier Creek near Mosier, Oregon.

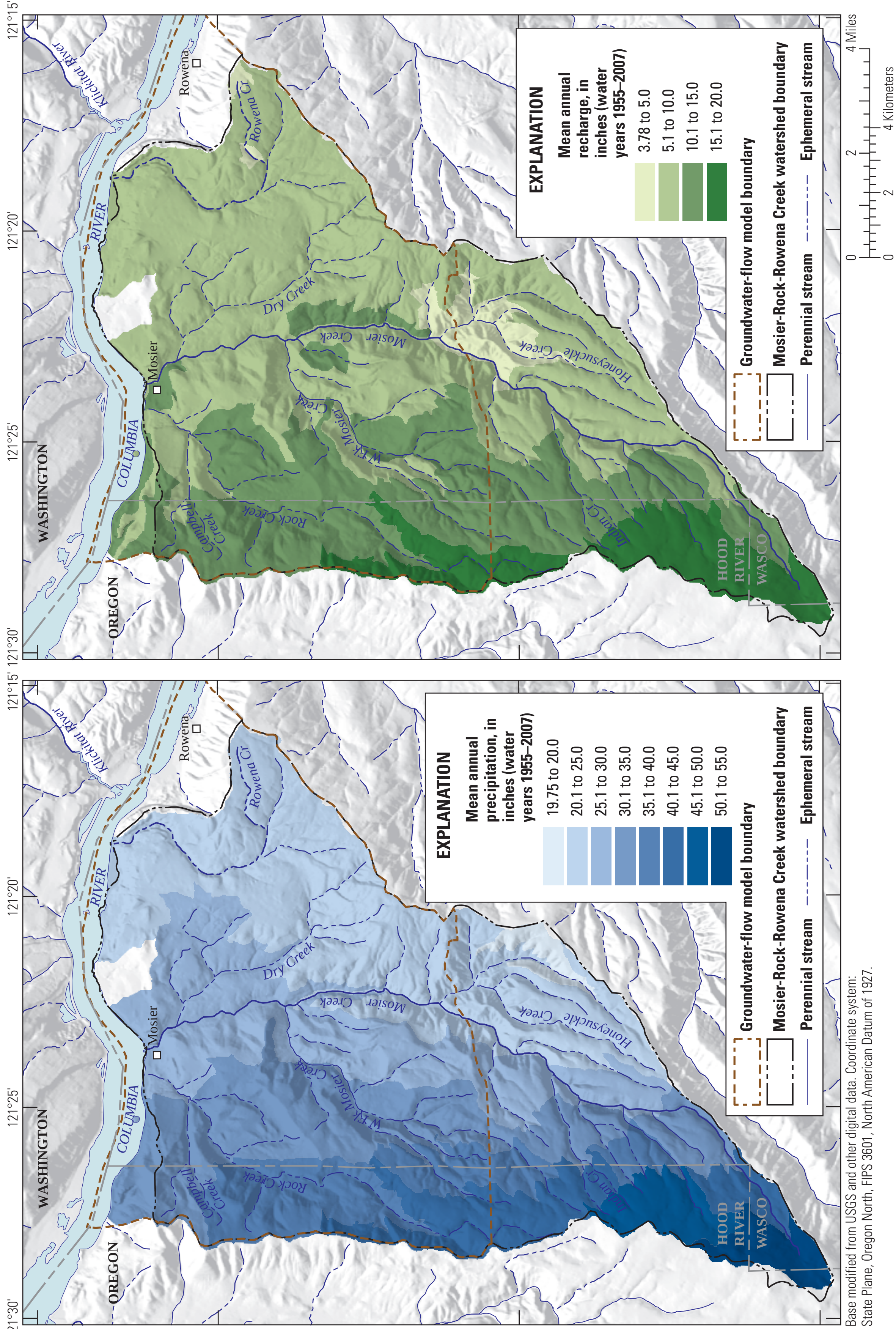
B.2—Hydrograph Analysis

An independent estimate of recharge in the gage basin was provided by analysis of streamflow hydrographs using the programs RECESS and RORA (Rutledge, 1998). RECESS is a semi-automated procedure to determine the master recession curve (MRC) of streamflow recession. Using daily streamflow records from the Mosier Creek stream gage (14113200, streamflow measurement location number 4 [fig. 1]) the MRC was created using a manual iterative process. The final MRC was based on 23 periods of streamflow recession, beginning on the sixth day following a given peak, and extending for 20 days. RORA uses the recession-curve displacement method, incorporating the MRC to estimate recharge for each peak in the streamflow record, providing a daily estimate of recharge that is summed to annual values. The annual average recharge from RORA from 1964 to 1981 and 2006 to 2007 was 8.1 in., and varied from 1.0 to 14.3 in.

B.3—Comparison of Recharge Estimates

Recharge estimates from PRMS and RORA represent a range of values for the gage basin, and suggest a range of values for the study area. The two methods of estimating recharge are not strictly independent, as they both rely on the recession characteristics of streamflow. RORA assumes all groundwater movement is toward the stream, and in particular, that groundwater recharge emerges as groundwater discharge upstream from the streamflow site. The water balance of the PRMS model of the gage basin indicated that although part of the groundwater recharge (the local groundwater flow component) emerged upstream of the streamflow site, more than half the recharge (the groundwater sink component) emerged downstream of the streamflow site. The average local groundwater flow component from PRMS was 4.2 in., compared to 8.1 in. from RORA. By adding the groundwater sink component (from PRMS) of 5.5 in., recharge ranged from 9.7 to 13.6 in. from PRMS and RORA, respectively. The difference may be attributed to a fundamental difference in the definition of recharge. Although RORA derives recharge from each individual peak in streamflow, PRMS recharge is relatively conservative because it does not include subsurface flow from individual storms.

The PRMS-derived recharge values are of most use for the purposes of this study, because the pattern of recharge may be extended beyond the time period and spatial extent of the data available at the streamflow gaging station. Although the limited temporal and spatial extent of streamflow measurements precludes use of the RORA-derived recharge values directly, comparison of the range of values provided by the two independent methods provides a reasonable range over which to vary PRMS-derived recharge estimates during groundwater-flow simulation modeling.



Base modified from USGS and other digital data. Coordinate system:
State Plane, Oregon North, FIPS 3601, North American Datum of 1927.

Figure B4. Model simulation results for precipitation and recharge in the Mosier, Rock, and Rowena Creek basins, Oregon, water years 1955–2007.