Suggestions for Future Study

Understanding the hydrology of the Willamette Basin is complicated by many factors: surface-water flows are managed, flow rates between surface and ground water are difficult to measure, irrigation water use is not generally reported, precipitation varies widely across the basin, well data are scarce in large portions of the Coast and Cascade Ranges, and ground-water flow within the Columbia River basalt unit is poorly understood. This study has provided information about the interaction of surface and ground waters, estimation of water use, geometry of the Columbia River basalt unit, spatial distribution of recharge, ground-water flow patterns, and variability in ground-water levels.

The scope of this study did not allow a complete understanding of all aspects of the ground-water hydrology of the Willamette Basin. For example, ground-water flow within the Columbia River basalt unit is believed to be largely controlled by permeable interflow zones and less permeable flow interiors; yet most studies, including this one, do not delineate the permeable and less permeable zones in the unit because interflow zones and their hydraulic connection laterally and vertically have not been identified. Identification of interflow zones and the hydraulic connection laterally and vertically between interflow zones should be assessed in future studies. Drilling test wells and collecting water-level measurements, geophysical logs, and well test data in wells open to the Columbia River basalt unit will provide insight into the permeability of interflow zones and the connection between interflow zones. Packer tests and downhole flowmeter logs can quantify the permeability and contribution of individual interflow zones.

Recharge to and discharge from the Columbia River basalt unit are assumed to be small, yet are uncertain. Possible recharge mechanisms include infiltration of precipitation in areas where the unit crops out, downward flow of ground water from basin-fill sediments into the unit, and seepage of surface water where streams are incised into the unit. The mechanism and rate of flow downward and upward through the fine-grained laterite and the low permeability flow interiors are unknown. Regionally, discharge is assumed to be from upward flow through basin-fill sediments to the Tualatin River in the Tualatin Basin, the Willamette River in the central

Willamette Basin, and the Willamette, Clackamas, and Columbia Rivers in the Portland Basin but has not been quantified.

The large vertical gradients where the Columbia River basalt unit crops out suggests that the role of flow interiors as confining units may be important, and subdividing the Columbia River basalt unit into multiple aquifers and confining units is necessary to better define and simulate flow in the unit. Stratigraphic mapping and correlating the basalt stratigraphy to hydrogeologic units would facilitate this effort.

Ground water within the lowland discharges to streams. The magnitude of this discharge was estimated as the residual of a water budget because the measured ground-water discharge to streams was often within the uncertainty of the measurement. More detailed studies may improve the quantification and location of ground-water discharge to streams. As discussed above, future measurements should be made in areas where focused discharge of ground water to major streams is expected, such as where the Willamette and Santiam Rivers flow through gaps in the basement confining unit near Albany. It will be important to obtain accurate measurements of seepage to and from streams in order to determine the effect pumping has on streamflows.

Saline water, often identified by high concentrations of chloride in ground-water, is found in some wells open to the basement confining unit and the Columbia River basalt unit. A component of this saline water represents connate water, ancient sea water that was trapped in the marine sediment deposited when the present-day Willamette Basin was covered by an ancient sea. Concentrations of chloride in ground water that are greater than that expected in connate water suggest that sources and processes have further modified the concentration of chloride in ground water. Further study could identify the sources and processes that result in high concentrations of chloride in ground water. These studies would aid prediction of areas where wells may encounter saline water or where pumping from wells may induce flow of saline water to a freshwater aquifer.

If faults create a barrier to horizontal flow in the basalt unit, they will probably have a large impact on the dynamics of ground-water flow when the unit is stressed by pumping since the propagation of pumping impacts will be limited across these boundaries. Location or drilling of wells open to similar interflow zones on opposite sides of mapped faults is necessary to evaluate the effect of faults on water levels and ground-water flow.

Summary and Conclusions

Ground-water flow in the Willamette Basin is controlled by geology, recharge from precipitation, withdrawals, and stream stage. The age, texture, type, and distribution of rocks and sediments affect the quality and quantity of water produced from the subsurface. These rocks and sediments were grouped into seven hydrogeologic units based on their hydrologic properties. Limited to the High Cascade area along the eastern edge of the basin, the High Cascade unit consists of young, permeable volcanic material. Precipitation can easily infiltrate into this unit, and both thermal and nonthermal springs sustain relatively stable streamflows throughout the year. Few wells are drilled in this remote, largely uninhabited area. In the lowland, rock and unconsolidated deposits provide ground water for major users. The upper sedimentary unit consists of thin, very permeable sands and gravels generally found at land surface in the floodplains of the major streams and in the Portland Basin. Covering much of the lowland and occurring at the land surface, the Willamette silt unit consists of silts and clays of low permeability. Beneath the Willamette silt unit and upper sedimentary unit, and at land surface as terrace deposits, the middle sedimentary unit is a permeable unit consisting of widespread semiconsolidated sands and gravels in alluvial fans and braided stream deposits. Underlying the upper and middle sedimentary units is the lower sedimentary unit consisting of fine-grained less permeable deposits. In general, the lower sedimentary unit is a confining unit, but in places, most notably in the Portland Basin and parts of the central Willamette Basin, the unit contains coarse-grained deposits that are productive aquifers. The Columbia River basalt unit, a series of flood basalt flows that were subsequently deformed, is present in the northern part of the lowland beneath sedimentary units and in the upland hills at land surface. Ground water is produced from interflow zones consisting of vesicular and brecciated basalt flow tops and bottoms.

Older altered volcanic and marine deposits of the low permeability basement confining unit define the bottom of the ground-water flow system. Where the unit is present at the surface, in the Western Cascade area and Coast Range, well yields are sufficient only for domestic use and where marine sediments are encountered high salinity water may be produced.

The upper and middle sedimentary and Columbia River basalt units are the major aquifers in the central Willamette and Portland Basins. The upper and middle sedimentary units are the major aquifers in the southern Willamette Basin and the Columbia River basalt unit is the major aquifer in the Tualatin Basin.

Most precipitation in the Willamette Basin falls from November to April, with very little precipitation during summer. Precipitation is greatest in the mountain ranges and generally decreases with elevation. The distribution of recharge mimics the distribution of precipitation. Recharge, simulated with watershed models, is greatest in the high altitude area in the Coast Range and Western and High Cascade areas, where the orographic effect results in large amounts of precipitation. Within these high precipitation areas, recharge is expected to be greater in the High Cascade area, where precipitation easily infiltrates into the young, permeable rocks of the High Cascade unit. In the Coast Range and Western Cascade area, recharge is less because the less permeable rocks of the basement confining unit and the deeply incised streams favor run-off over infiltration. Simulated recharge is least in the lowland where precipitation is least; however, ponding of water over large areas in the lowland probably enhances recharge. Temporally, recharge is greatest in the winter during the rainy months and negligible in the summer, when precipitation is small and evapotranspiration is high. Mean annual recharge for the basin is 22 in/yr. In the lowland, where water demand is the highest, mean annual recharge is 16 in/yr.

Downward hydraulic gradients indicate that recharge to the shallow ground-water system occurs throughout the lowland. Shallow ground water flows from topographically high areas and discharges to streams where upward gradients are observed. The direction of flow and elevations of water levels in the shallow system have changed little when compared to water-table maps from 1935.

Ground water discharges to streams throughout the year. In the lowland, ground-water discharge is a small component of total streamflow based on seepage runs. For smaller lowland streams that are underlain by the Willamette silt unit, slow drainage of ground water from the Willamette silt unit probably contributes to streamflow, but this flow is diffuse or insignificant relative to total streamflow. Most ground water in the lowland discharges to the Willamette River and its major tributaries, which have a good hydraulic connection to the upper and middle sedimentary units.

Ground-water withdrawals for irrigation, public, and industrial supply were estimated in the Willamette Basin. Approximately 300,000 acre-ft/yr, equivalent to a constant rate of 400 ft^3/s, is pumped from the hydrogeologic units mainly in the lowland. This annual rate of pumping represents 10 percent of average annual recharge in the lowland or 1 percent of average annual flow of the Willamette River at Portland.

Pumping for irrigation, which occurs from May to October, accounts for 81 percent of annual ground-water withdrawals. Most ground water is withdrawn from the upper and middle sedimentary units in the central Willamette Basin and southern Willamette Basin. Lesser amounts are withdrawn from the sand and gravel lenses in the lower sedimentary and Columbia River basalt units in the central Willamette Basin. Approximately 3 percent of ground-water withdrawals in the basin is from the basement confining unit.

Monthly pumping was estimated in the central Willamette Basin. Approximately 1,000 acre-ft per month is withdrawn in winter, mostly for public supply use. Ground-water withdrawals increase to 42,000 acre-ft in July when irrigation demand rises.

Ground-water withdrawals by wells remove ground water from storage in the aquifer or capture ground water that would otherwise discharge to streams. In the lowland, the effect of pumping from the middle sedimentary unit on flow in smaller streams underlain by the Willamette silt unit is small because these streams have a poor hydraulic connection with the aquifer. Ground-water withdrawals from the upper and middle sedimentary units capture water that would otherwise discharge to the Willamette River and its major tributaries, which have a good hydraulic connection to these units.

Ground-water levels in the basin-fill sediments generally do not show long-term declines from ground-water withdrawals. Seasonally, water levels naturally decline in summer as precipitation tapers off. Without pumping, natural seasonal fluctuations in water levels are generally less than 10 ft. Seasonal fluctuations continue to be less than 20 ft in the southern Willamette Basin, where the upper sedimentary unit is close to land surface and pumping occurs close to the Willamette River, which buffers the effect of pumping on water levels. Withdrawal of ground water results in seasonal water-level fluctuations of up to 65 ft in the central Willamette Basin, where pumping is widely distributed from the confined middle sedimentary unit. With recharge from winter rains, water levels generally return to their seasonal high levels in winter. Continued development of the aquifer will result in increases in the seasonal fluctuations of water levels.

The shape of the graph of water levels with time provides insight into stresses affecting water levels in the basin fill. Water levels in wells affected by pumping exhibit steep spring declines and gradual recoveries that begin before the onset of rains in the fall. Where water levels respond to precipitation and are unaffected by pumping, the hydrograph is characterized by gradual spring declines and rapid fall recoveries after the onset of rains. Response to decadal climate variability is evident for some hydrographs where pumping and seasonal fluctuations do not overwhelm the climate signal.

The Willamette silt unit plays an important role in the ground-water hydrology of the central Willamette Basin. Its relatively large thickness and low permeability confine the middle sedimentary unit in the central Willamette Basin. In this area, the Willamette silt unit hydraulically separates streams from the underlying middle sedimentary unit, and pumping from the unit has little effect on streamflows. The Willamette silt unit stores a great volume of water that probably discharges to streams or recharges the underlying middle sedimentary unit.

Water levels in the Columbia River basalt unit, where concentrated withdrawals occur, show long-term declines. Although the permeable interflow zones of the Columbia River basalt unit are productive initially, in areas where many wells withdraw a large amount of ground water over time, water levels decline up to 6 ft/yr because the unit has low storage properties and receives limited recharge. Large vertical hydraulic gradients occur in the uplands where wells probably are completed in different permeable interflow zones. The similarity of water-level fluctuations and elevations in the deeper zones of the Columbia River basalt unit beneath upland areas and those in the basalt unit in the basin suggests a direct connection between deep interflow zones in the uplands and the flow system beneath the valley floor.

This study provides an improved understanding and a framework of the regional hydrogeology of the Willamette Basin. The framework provides a basis and context for conducting more detailed studies. Based on the conceptual model of ground-water flow described in this report, regional and local ground-water models can test the concepts, simulate past and present ground-water flow, and predict the response of the hydrologic system to future pumping and recharge scenarios.

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