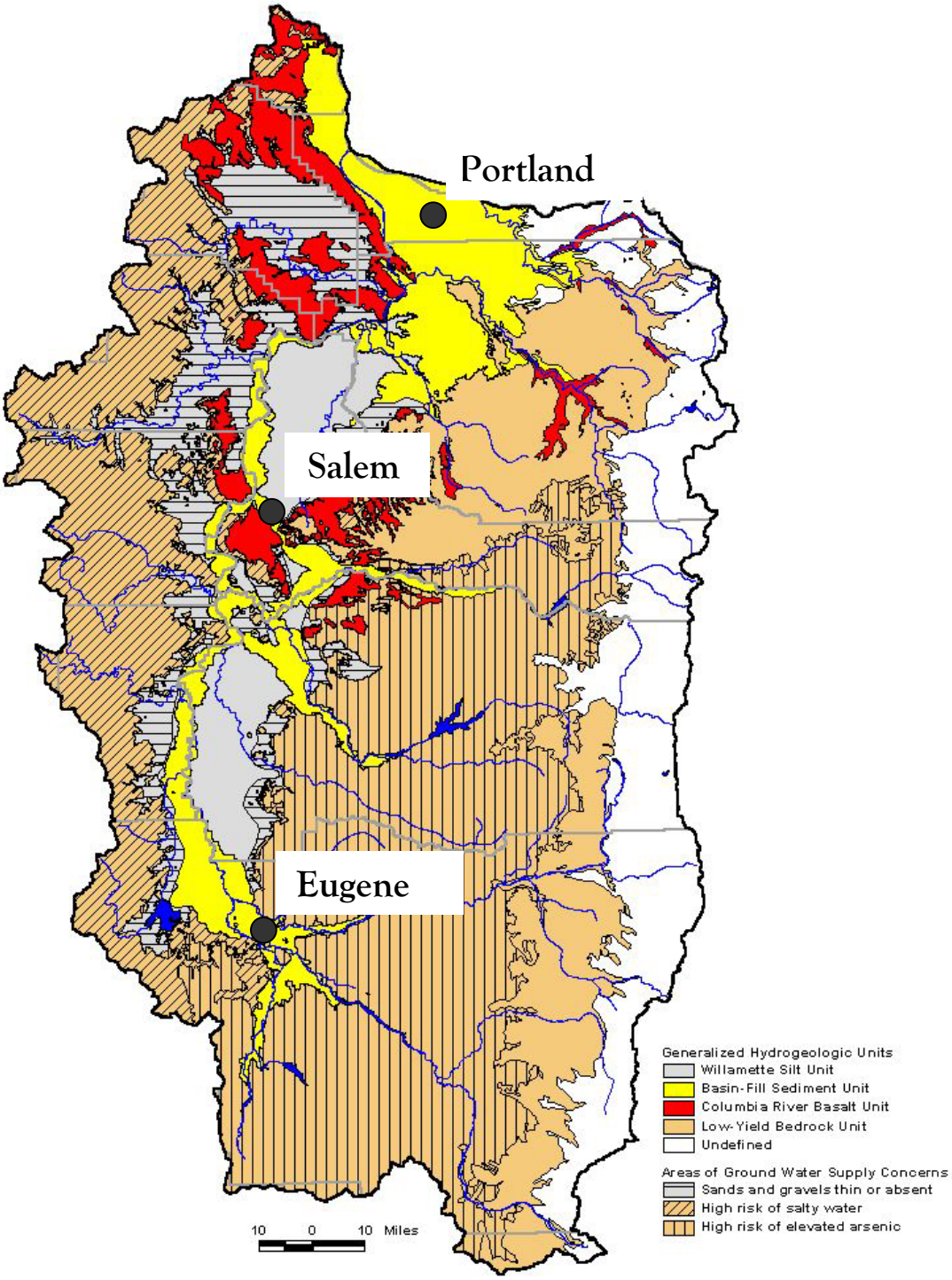
GROUND WATER SUPPLIES IN THE WILLAMETTE BASIN



September 2002

Oregon Water Resources Department
Oregon Department of Land Conservation and Development

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GROUND WATER SUPPLIES IN THE WILLAMETTE BASIN

INTRODUCTION

More and more frequently, the Water Resources Commission (WRC) and Water Resources Department (WRD) are asked to address ground water supply problems in the Willamette Valley. These requests usually involve wells serving expanded or new rural housing developments and other relatively small uses that are statutorily exempt from the requirement to apply for a water right. Ground water supply issues have developed where these new uses are located in areas of the valley where ground water resources are limited by natural factors and often where significant rural development has already occurred. In these areas, additional rural development – even that which requires relatively small amounts of water – can threaten the stability of the ground water supply.

This report provides a synopsis of our current understanding of ground water supplies in the Willamette Valley and an outline of tools available to address ground water supply issues at the state and local level. Appendices to the report provide detailed background information on ground water concepts (Appendix A) and the hydrogeology of the Willamette Basin (Appendix B). Useful references for additional information on ground water resources are included in Appendix C.

GROUND WATER SUPPLIES IN THE WILLAMETTE VALLEY

The Willamette Valley includes the drainage basins of the Willamette and Sandy rivers. For the purposes of this report, the entire area is referred to as the Willamette Basin. The Willamette Basin occupies the region between

the crests of the Coast Range and the Cascade Range (Figure 1). It is bounded on the north by the Columbia River and on the south by the convergence of the Coast and Cascade ranges. Within the basin, ground water

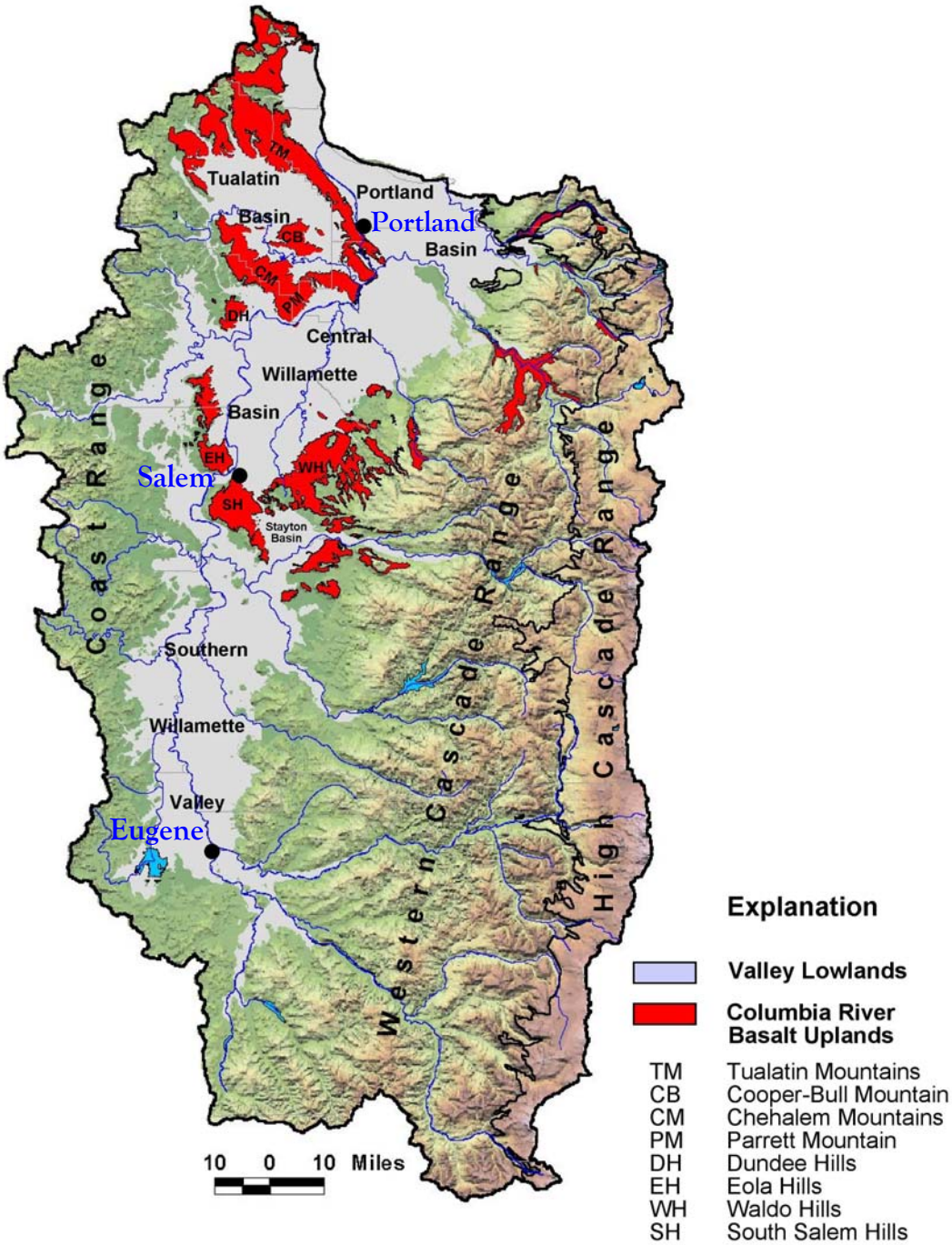

Figure 1. Physiographic setting of the Willamette Basin, Oregon.

supplies can be limited by geologic factors and by climate. Four regional hydrogeologic units can be defined for the Willamette Basin: 1) the low-yield bedrock unit, 2) the Columbia River Basalt unit, 3) the basin-fill sediment unit, and 4) the Willamette Silt unit. Each unit contains one or more geologic units that have similar properties over widespread areas. The locations of these units within the basin are shown in Figure 2.

Water supply problems within these units can take several forms. Production from individual wells may decline with time. Adjacent wells may interfere with each other such that neither gets enough water. Water levels in aquifers may decline if pumping is excessive. Use may gradually induce the inflow of saline water rendering the water supply unusable. These types of ground water supply limitations along with the distribution and general characteristics of each unit are described below and outlined in Table 1. An understanding of ground water occurrence and supply problems within each of these geologic units will be improved by the brief introduction to ground water concepts provided in Appendix A.

Low-Yield Bedrock Unit

Distribution. The low-yield bedrock unit is exposed at land surface in the Coast Range and the Western Cascade Range but also occurs at depth beneath other hydrogeologic units (Figure 2).

General Characteristics. The low-yield unit includes a wide variety of geologic formations and rock types with widely varying properties. In general, the rocks in this unit do not readily transmit water and have very little porosity, meaning there is low storage capacity in this unit. The unit is able to provide sufficient water for domestic uses but well yields are typically less than 10 gallons per minute and commonly less than 5 gallons per minute. In many areas, wells may be capable of supplying enough water for household use but are not able to provide enough water to irrigate a lawn and garden.

Table 1. General characteristics of hydrogeologic units in the Willamette Basin.

Characteristic	**Willamette Silt Unit**	**Basin-Fill Sediment Unit**	**Columbia River Basalt Unit**	**Low-Yield Bedrock Unit**
Porosity	High	Moderate to High	Low to Moderate	Low
Dominant Porosity Type	Intergranular	Intergranular	Intergranular	Fracture
Storage Capacity	High	Moderate to High	Low	Low to Very Low
Horizontal Permeability	Low	High	High	Very Low
Vertical Permeability	Low	Moderate	Very Low	Very Low
Well Yields	NA	Moderate to High	Low to High	Very Low to Low
Pumping Impacts	NA	Local to Intermediate	Widespread	Local
Overdraft Potential	NA	Low	High	High but Localized
Miscellaneous Problems		Sands and gravels thin or absent in some areas High arsenic in some areas	Porous zones may not be laterally extensive Porous zones not always present between lava flows Local aquifer boundaries common Salty water at depth in some areas	Fractures may close over time High salinity is common High arsenic in some areas
Pitfalls	NA	High potential for stream interference	High yields but low storage capacity	Initial yields not representative of long-term yields
Uncertainty of Resource Capacity Predictions	NA	Low	Moderate	High

While this unit is generally characterized by low storage and low production, wells in the low-yield unit that intersect fractures can have yields that are considerably higher than typical of the surrounding area. Fractures make up a very small percentage of the total aquifer volume and, therefore, do not store much water. However, they are able to transmit water readily so it is not unusual for wells encountering fractures to initially produce 10—20 gallons per minute. However, WRD's experience with the fracture permeability is that with time—one to two years—the fractures cease to be permeable, or transmit water, and production may drop back to a few quarts per minute. The latter production rate is more typical of the low- yield aquifers when fractures are not intersected by wells. Pumping from high yield fractures can also lead to hydraulic interference between wells, seasonal or long-term depletion of the aquifer, and permanent reductions in well yields. These issues along with the low storage and low production generally observed in this unit combine to make use of the low-yield bedrock aquifers susceptible to supply problems. Moreover, the distribution of fractures within the unit is difficult to predict or determine, making it difficult to determine the hydrologic properties at any given location within the unit. It is not uncommon for a landowner to drill several "dry" holes before finding a zone capable of supplying a household with water.

Other concerns. In addition to low ground water production and storage, the low-yield bedrock unit can also produce ground water with high natural salt or arsenic levels. These areas are outlined in Figure 2, but boundaries are not well known for arsenic. High salinity water is common at depths below 100 ft in the marine sediments and marine volcanics of the unit. Limited sampling indicates that the distribution of high arsenic levels is highly variable, even at the local scale. However, the occurrence of arsenic in areas of the low-yield unit is probably associated with certain types of volcanic rocks but these geologic controls are poorly understood at present. Limited data suggest that the risk of encountering elevated arsenic levels in the low-yield bedrock unit is higher in south-central and eastern Lane county and eastern Linn county.

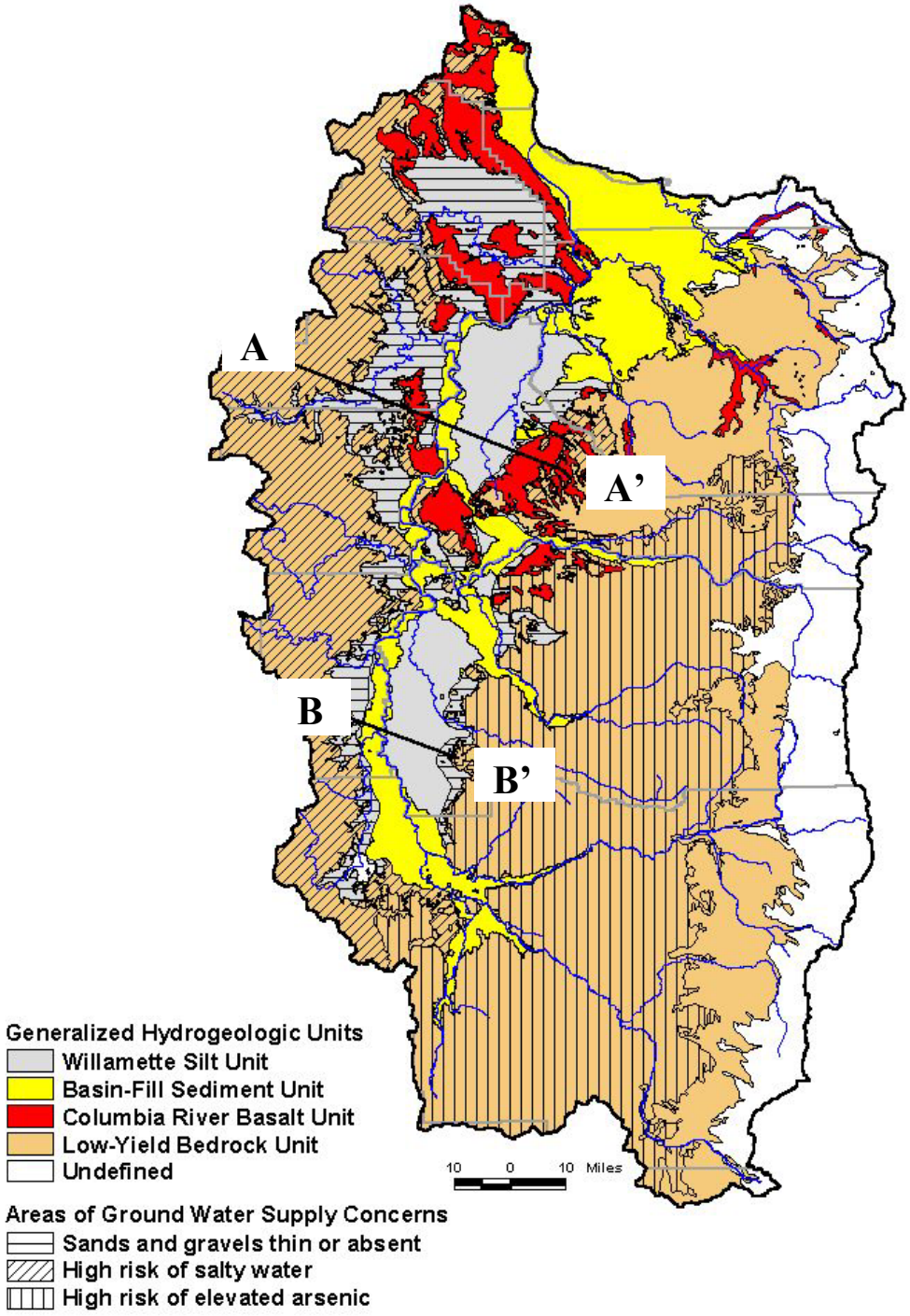

Figure 2a. Generalized hydrogeology of the Willamette Basin. Map showing areas with ground water supply concerns.

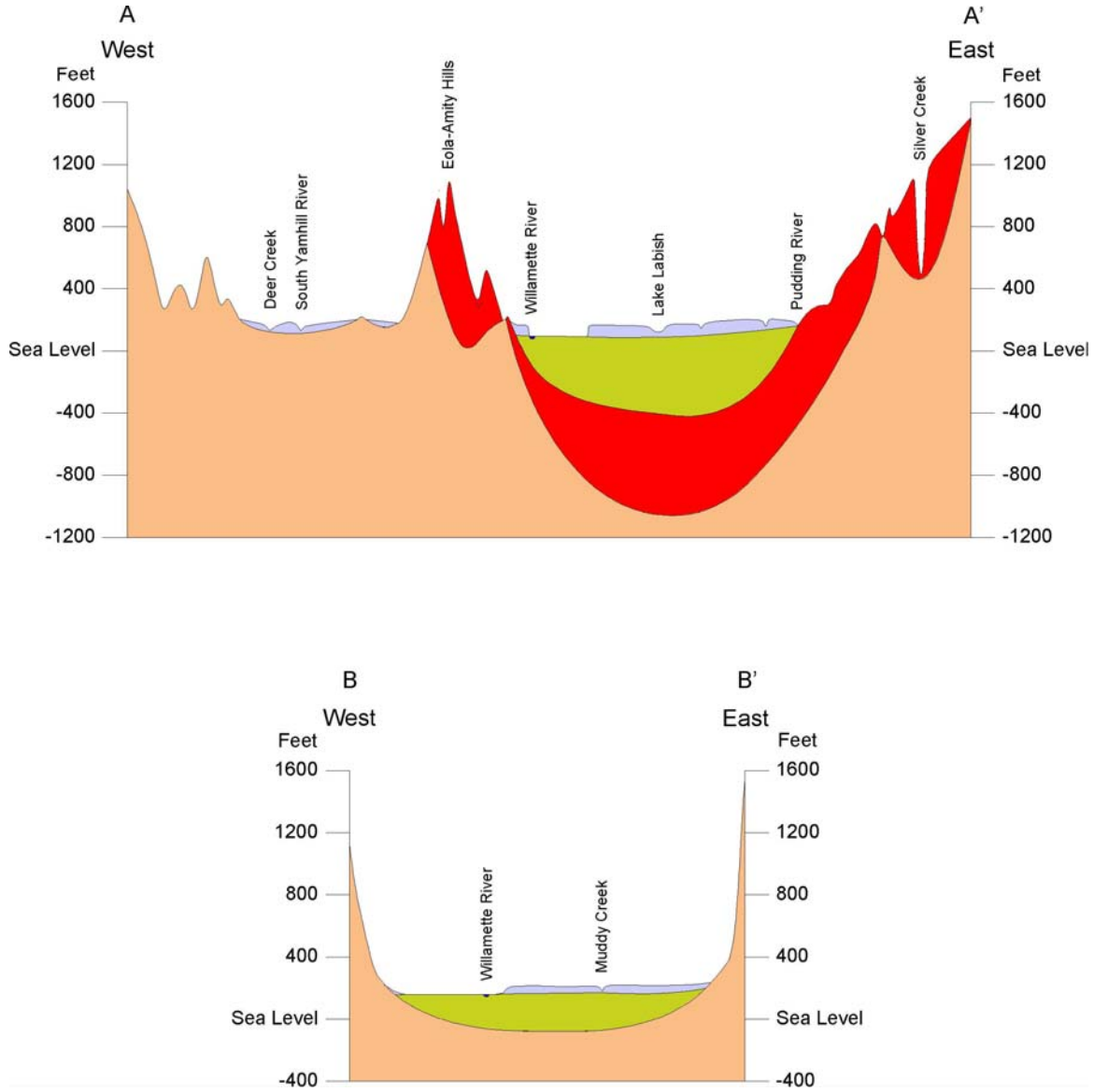

Figure 2b. Generalized hydrogeologic units. Vertical cross-sections showing subsurface distribution of units.

Columbia River Basalt Unit

Distribution. The Columbia River Basalt unit is exposed at land surface in bedrock highs between Salem and Portland; it also occurs at depth beneath younger sediments in the Portland, Tualatin, central Willamette, and Stayton basins (Figure 2). The western edge of the unit occurs in eroded uplands along the western margin of the Tualatin Basin, the southwestern margin of Chehalem Mountain, and the western margins of the Dundee, Eola-Amity, and South Salem hills. The southernmost extent occurs in the vicinity of the town of Jefferson.

General Characteristics. The Columbia River Basalt unit consists of a series of stacked lava flows. Individual flows are usually 40 to 100 feet thick but may locally exceed 200 feet in thickness. Productive aquifers within the unit are generally limited to thin zones of porous rubble that form at the top or base of some flows (Figure 3). These interflow zones commonly have moderate to high horizontal permeability, meaning that water is readily transmitted horizontally. Flow interiors, which make up the bulk of the rock, have very low permeabilities, making it difficult for water to move vertically through the basalts.

Wells that intersect one or more aquifers in the basalt unit are capable of moderate to high yields. Large-diameter irrigation and public-supply wells commonly produce more than 250 gallons per minute, and six-inch domestic wells are generally capable of producing 20 gallons per minute.

Recharge to the basalt aquifers is limited. Most recharge appears to occur in upland areas where the basalt flows are exposed at land surface. Shallow basalt wells in the uplands commonly show a direct response to precipitation which suggests that rainfall is able to rapidly infiltrate into the upper, unconfined portion of the basalt unit. However, because basalt flow interiors are dense and non-porous, water does not readily percolate downward into successively lower interflows.

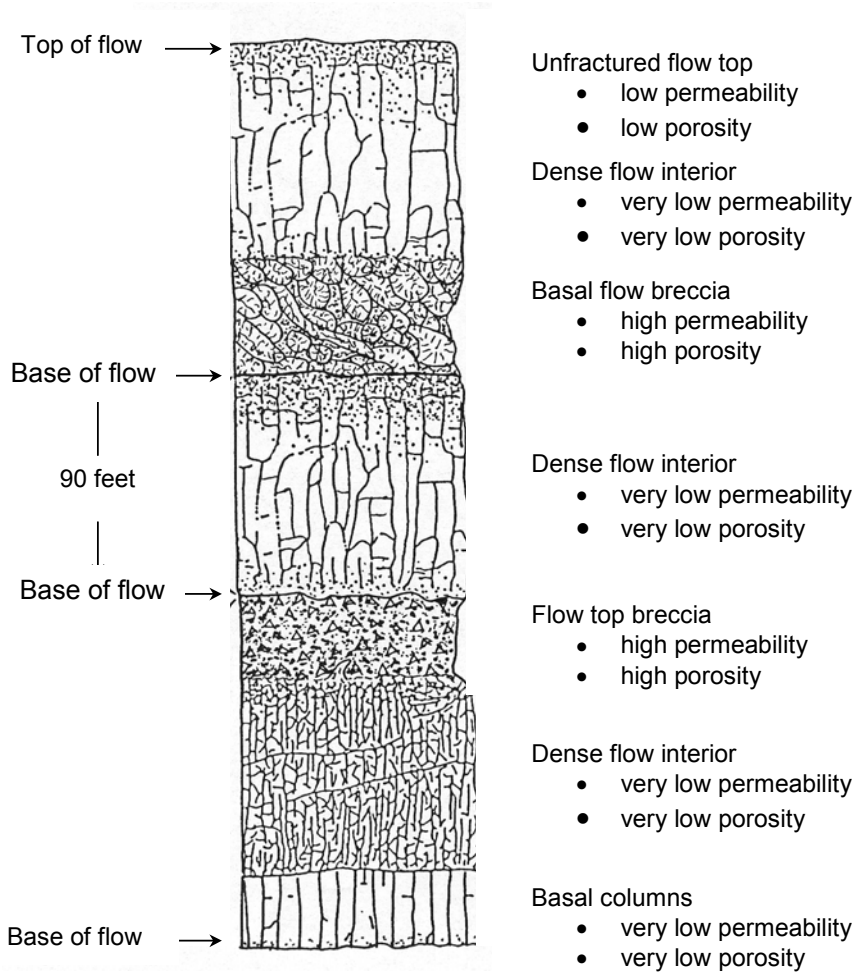

Figure 3. Common internal structures of Columbia River Basalt flows.

The limited recharge, low storage, and high production capacities combine to make these aquifers susceptible to overdraft. Put another way, it's difficult for water to get into these aquifers, it's easy to take water out, and there's not much water in storage to begin with. Multi-year water-level declines in the basalt aquifers have occurred in many areas of the basin, especially in the vicinity of high-volume production wells. Near the city of Wilsonville, for example, water levels declined by as much as 50 feet

between 1960 and 2002 (Figure 4). City basalt wells were the main pumping wells in the area and the sole source of water for the city through April 2002. In late April 2002, a new surface-water plant, drawing water from the Willamette River, became the main source of water for Wilsonville. After the switch to surface water, water levels in the basalt aquifers began to rise over an area that extended out at least 6 miles in some directions. This indicates that the pumping impacts from these wells extended over the same area. Recovery from long-term pumping in the Wilsonville area is expected to occur over years, if not decades.

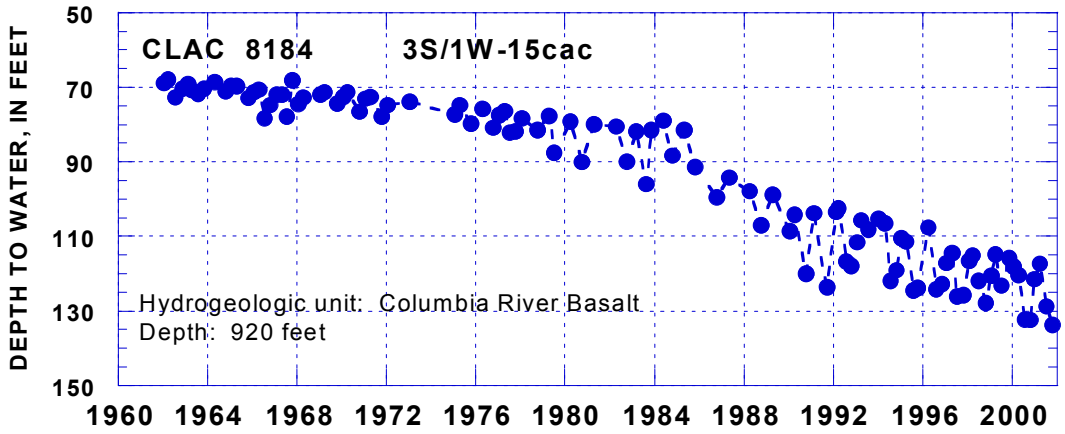

Figure 4. Long-term water-level decline in a well near Wilsonville, Oregon.

Although water-level declines in the basalts are common near high-capacity wells, declines have also been observed in rural residential areas where only domestic wells are located. Some of these declines may be caused, or contributed to, by high-volume pumping at a distance. However, local pumping of domestic wells, especially in areas where the capacity of the aquifers is limited, may also cause declines. Excess pumping will exacerbate any ground water instability resulting from the limited storage or production capacity of the basalt aquifers. In many areas, these aquifers may not be capable of sustaining irrigation of large yards and gardens. Many well owners mistakenly

assume that high well yields in the basalts are an indication of a large resource that has a long-term production potential. This is not a valid assumption given our general knowledge of the hydrologic characteristics of the basalts. The long-term production capacity of these aquifers cannot be assessed without monitoring water levels over time, especially in areas which are undergoing increased development. Because water-level monitoring is uncommon, most well owners are unaware of developing problems until the water level in their well drops below the pump intake. Because many of these problems develop over a period of years, it may take years of restricted pumping to stabilize water levels or reverse the declines.

As with the low-yield bedrock unit, the production and storage capacity of the Columbia River Basalt unit and its capacity to accept recharge are difficult to predict at any locality because hydrologic properties vary throughout the unit. Although general hydrologic properties of the unit are known (low storage and high production capacity), site-specific information on the thickness, extent, and properties of the various aquifers are generally poorly known and difficult to extrapolate over any distances. Because prediction uncertainties will always be high, the response of these aquifers to development can only be determined with certainty by collecting water level and production data before, during, and after development occurs.

Other concerns. The common practice of commingling aquifers in a single well in the Columbia River Basalt unit produces a high-permeability vertical pathway that allows water to migrate between aquifers on a continuous basis. The draining of ground water from shallow aquifers in this manner decreases the amount of water available for wells that produce exclusively from these zones. It also increases the risk of contamination from surface pollutants and reduces the amount of water available to springs that sustain local streamflow.

Another common problem in the basalt unit is the occurrence of saline water, especially in the deeper aquifers of the unit or in the centers of basins where ground water flow is upward. The extent of salinity problems in the basalts is not known with certainty because the occurrence of saline water is generally not reported on well reports but is discovered by happenstance in conversations with drillers, well owners, or consultants. However, known occurrences are widely scattered throughout the basin and are only associated with areas underlain by marine rocks. This places an additional limitation on the development of the basalt aquifers over much of their extent. Ground water pumpage from deeper basalt aquifers may induce the upward flow of deep saline water into the basalts causing salinities in the basalt aquifers to increase over time.

Basin-Fill Sediment Unit

Distribution. The basin-fill sediment unit consists of some sands and gravels interlayered with silts and clays. These sediments are limited to the lowland areas of the Willamette Valley (Figure 2). The unit includes all sediments that occur above the Columbia River Basalt unit, or above the low-yield bedrock unit where the basalts are absent, except for the Willamette Silt unit, described in the next section. The basin-fill unit is exposed at land surface in the Portland Basin and in the floodplains of the Willamette River and its major tributaries but is overlain by the Willamette Silt unit in most other lowland areas of the valley. Productive water-bearing zones occur in the sands and gravels whereas the silts and clays act as confining beds. Thicknesses greater than 100 feet are common in many areas of the valley.

General Characteristics. Collectively, the basin-fill sediment unit contains the largest volume of ground water in storage and has the highest production capacity of all of the hydrogeologic units in the basin. In general, the sands and gravels of the basin-fill unit have high porosities and high permeabilities. The most productive part of the unit

occurs in unconsolidated sands and gravels in the floodplains of the major streams. The shallow sand and gravel aquifer in these areas is unconfined and well-connected to adjacent streams. Wells in these areas generally have localized pumping impacts and high levels of interference with nearby streams. Highly productive water-bearing zones also occur in older sands and gravels which are present at depth below the flood plains of the major streams and beneath the Willamette Silt. Because these zones are commonly semi-confined to confined, pumping impacts tend to be more widespread. In the area between Salem and Wilsonville, for example, overlapping interference from irrigation wells causes water levels to drop up to seventy-five feet in the summer.

Ground water production rates in the basin-fill sediments are limited in areas where the unit is very thin or where it contains little sand and gravel. Areas that generally have less than twenty feet of sand and gravel are delineated in Figure 2. Most of these areas are west of the modern floodplain of the Willamette River, where the basin-fill unit thins as it approaches the foothills of the Coast Range. Similar thinning occurs along the eastern margin of the valley at the base of the Cascade Range. Also, in the Tualatin Basin, the basin-fill unit has very little sand and gravel. Wells in these areas commonly have low yields. If no productive zones are present, wells are generally drilled into the underlying basalt or low-yield bedrock units.

Other Concerns. Elevated arsenic has been detected in some wells in the basin-fill unit. Most occurrences of greater than 50 µg/l are associated with areas where only a thin layer of basin-fill sediments overlies the low-yield bedrock unit. An exception occurs in the central lowland area of the Tualatin Basin (not depicted in Figure 2) where the basin-fill sediments are thick. Scattered occurrences of arsenic levels between 10 and 50 µg/l are also found throughout the basin-fill sediment unit. The factors that control the distribution of arsenic in the basin-fill unit are poorly understood. Therefore, it is not possible to reliably

predict the distribution of areas where the risk of encountering elevated arsenic is high in this unit.

Willamette Silt Unit

Distribution. The Willamette Silt Unit overlies the basin-fill sediment unit throughout most of the lowland areas south of the Portland Basin except where it has been removed by erosion in the floodplains of the Willamette River and its main tributaries (Figure 2). Throughout most of the central valley, between Salem and Wilsonville, the silt is greater than 100 feet thick but it thins greatly at the margins of the valley floor. In the southern valley, between Eugene and Albany, the unit is generally less than 20 feet thick. Although the silt forms thick deposits in the Tualatin Basin, it cannot easily be distinguished on well logs from the fine-grained basin-fill deposits that underlie it. For this reason, it is not treated as a separate unit in the Tualatin Basin but is lumped into the basin-fill unit.

General Characteristics. The Willamette Silt unit is composed of silts and clays, resulting in an aquifer that has high porosity but low permeability. Because of its low permeability, the unit is seldom exploited as an aquifer. However, shallow pit wells dug into the silt were an important water supply for many early settlers in the Willamette Valley. These wells had low yields but were able to supply enough water for domestic needs. Although not important as an aquifer, the Willamette Silt acts as a wet sponge that stores large quantities of ground water. The silt is recharged by precipitation during the winter months and slowly releases water to streams and underlying aquifers throughout the year. Ground water stored in the silt acts as a buffer to even out the effects of the irregular distribution of rainfall during the year. Because of its low permeability, the Willamette Silt also helps to protect underlying aquifers from contamination that occurs at land surface.

Ground water supply issues within the Willamette Valley can be addressed reactively or proactively. Tools available to the state, through the Water Resources Department, either limit future ground water development or reduce existing usage. Local governments, through land use planning and other tools, also have opportunities to prevent overuse of the resource. State and local partnerships utilizing a combination of these tools will be most effective at addressing ground water supply concerns within the Willamette Valley.

The State's Role

The waters of the state belong to the public. The Water Resources Department and Water Resources Commission are charged with maintaining and protecting water resources. By statute, ground water users are required to obtain permission via a permit from the state to withdraw all but the smallest quantities of water. These smaller uses are exempt from the permitting requirement and are therefore referred to as "exempt uses." Exempt uses include single or group domestic use up to 15,000 gallons per day, non-commercial irrigation of up to one-half acre, stock watering, and commercial and industrial use up to 5,000 gallons per day.

WRD has the responsibility to review permit requests for new water uses to ensure that the proposed ground water withdrawal will not adversely affect the sustainability of the resource or otherwise harm existing users. Exempt uses are not subject to such a review. Consequently, the possibility exists of considerable withdrawal in rural residential areas without a review of the status of ground water resources. In these areas, WRD's role has historically been limited to addressing problems after they are identified. Ground water supply problems in these areas can be addressed through administrative tools outlined in Oregon law. These tools are described in detail below and include designation of critical ground water areas, restrictive

classification of ground water limited areas, ground water withdrawals, permit conditions, and enforcement.

Administrative actions to address limited ground water supplies within the Willamette Basin are depicted in Figure 5 and described in Table 2. Beyond these designated areas, ground water supply issues continue to develop in aquifers within the Willamette Basin. However, it may be many years before the Water Resources Department develops the scientific data and analysis needed to support further restrictive classifications or withdrawals.

The assumption is often made that where WRD has not restricted development of the ground water resource, the resource is capable of sustaining additional water use. This assumption is frequently invalid and land use decisions made pursuant to that assumption may exacerbate water supply problems by allowing additional water-dependent development. For these reasons, WRD and local land use planners must work together to prevent rural water supply problems.

Critical Ground Water Area. A critical ground water area (CGWA) designation is a powerful tool available to the state for the control of ground water use. Those controls can address substantial interference between wells, excessive water level declines, and water quality degradation. The CGWA can also create preferences of use without regard to water right seniority, or deference to the order in which water rights were granted. Because a CGWA can require use reductions, it can be difficult to establish. There is one CGWA in the Willamette Basin in the Beaverton area, the Cooper Mountain- Bull Mountain CGWA. In this area, the CGWA reduced ground water pumping by 50 percent, prevented new water right issuance, and limited the density of additional domestic ground water development. In general, critical ground water area designations control ground water supply problems by reducing or eliminating individual rights to use ground water.

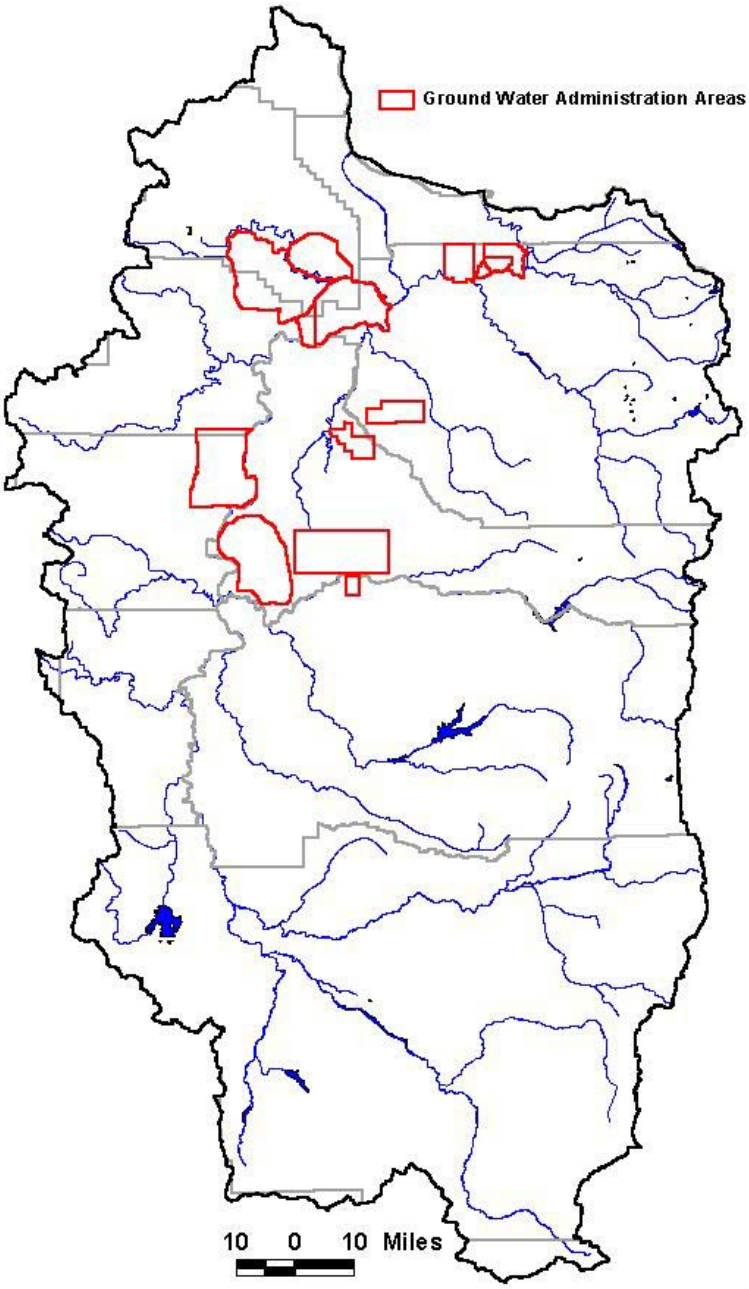

Figure 5. Ground water administration areas.

Ground Water Withdrawal Area. Through administrative withdrawal, the Water Resources Commission can withdraw a supply source from further appropriation for any or all uses. It can accomplish the same things as a restrictive classification, or it can completely eliminate any further development of a ground water resource. Victor Point, adjacent to Silverton, is the only ground water withdrawal area in the Willamette Basin. Withdrawal does not affect legal uses already established at the time the withdrawal takes effect.

Permit Conditions. Permit conditions offer a way to manage use at the individual permit level. New permits are commonly conditioned with water level decline conditions. These require water level measuring and reporting with triggers to cause reduced pumping if negative impacts result to water right holders with older priority dates. Some permits are time-dated and can be extended under satisfactory aquifer conditions. The individual permit can be uniquely conditioned to suit a specific situation. All new permits for Columbia River Basalt aquifer use contain trigger conditions. Many new permits for basin-fill or low-yield bedrock aquifer use also contain trigger conditions. Potentially, such permit conditions can be effective at managing ground water resources in areas where supply issues are developing or anticipated. However, this administrative tool is not effective for ground water uses that are exempt from the requirement to apply for water rights.

Enforcement. WRD has the authority to regulate water use and well construction for compliance with statutes, administrative rules and orders. A detailed description of the role of well construction in managing ground water resources is provided in Appendix D. WRD has additional authority via the imposition of civil penalties. Such fines occur after much contact with an individual who displays a pattern of non-compliance with water use or water construction regulations.

Table 2. Designated ground water areas and areas of supply concern in Willamette Valley counties.*

County	Critical Ground Water Areas (CGWA)	Aquifers with Restrictive Classifications (GWLA)	Ground Water Withdrawal Areas	Ground Water Problems	Areas under Investigation
Benton		None		Contains LYU and thin BFS; High salinity is common	
Clackamas		Sherwood/Dammasch/ Wilsonville CRB Gladtidings CRB Damascus CRB Damascus BFS Sandy/Boring BFS		Contains LYU and CRB	CRB aquifers near Wilsonville
Columbia		None		Contains CRB and LYU	
Lane		None		Contains LYU; High Arsenic common in south-central and eastern areas	
Linn		Kingston CRB		Contains LYU; High Arsenic common in eastern areas	LYU aquifers near Lebanon
Marion		South Salem Hills CRB Stayton/Sublimity CRB Mt. Angel CRB	Victor Point CRB aquifers	Contains CRB and LYU; High salinity common in some areas	South Ridge LYU; Enchanted Way CRB aquifers
Multnomah		None		Contains CRB	
Polk		Eola Hills CRB		Contains CRB and LYU; High salinity common in many areas	LYU aquifers near Perrydale
Washington	Cooper Mtn./ Bull Mtn. CRB	Sherwood/Dammasch/ Wilsonville CRB Chehalem Mtn. CRB		Contains CRB, LYU, mostly fine-grained BFS; High salinity common	CRB aquifers near Wilsonville
Yamhill		Chehalem Mtn. CRB Parrett Mtn. CRB Eola Hills CRB		Contains CRB, LYU, and generally thin BFS; High salinity is common	Walnut Hills CRB

* LYU = Low-yield bedrock unit
CRB = Columbia River Basalt unit
BFS = Basin fill sediment unit

Local Government's Role

Local governments, principally counties, make decisions that affect ground water resources by planning for and permitting land uses that are exempt from WRD ground water permitting requirements. The most common of these is new rural residences. There are several options for counties to proactively address ground water concerns as described below.

Well monitoring. Any action a county chooses to take should begin with accumulation and generation of information about the ground water resource. WRD has a network of monitoring wells, but this network may not be of sufficient density to provide the specific information needed within a given area. Counties can develop new data through well monitoring where there is inadequate information to make reasoned decisions regarding planning needs. For example, a county could develop agreements with property owners to monitor their wells periodically, or even for property owners to do it themselves. In order for the data to be useful, the monitoring must be performed correctly, so some training is involved, and someone must maintain the data. To be useful, monitoring should include specific capacity tests, i.e. pumping tests with drawdown measurements, for new wells and periodic water-level measurements in representative wells and in dedicated monitoring wells. Any of the tools described below would benefit from an on-going well monitoring program.

Education. Education is a cost-effective tool that counties can use to alert prospective and existing property owners about ground water supply issues. The rural residential areas that rely on individual wells from potentially sensitive aquifers can be identified. New and existing residents in those areas can be apprised of the hydrogeology and presented with options for water conservation.

Land Use Regulations. Ideally, counties would have known the carrying capacity of the ground water resource when comprehensive plans were originally being formulated. With that information, minimum lot sizes could have been set at a level that would not result in over-use of ground water resources. However, that information was generally not available and is still not available in most places. Therefore, counties are faced with difficult choices: neglect potential problems until local users demand a solution, collect data, or require applicants for new land uses to demonstrate their proposal will not result in harm to the ground water resource. All of these options can result in considerable expense.

Existing state land use regulations require counties to address water supply in certain circumstances. Oregon Revised Statute Chapter 92 requires a declaration of water availability for any new subdivision or partition. This is primarily for consumer protection as it allows creation of new lots with demonstration of an adequate long-term supply. Statewide Goal 5, through administrative rule, requires counties to update their plans at periodic review to "protect significant ground water resources," which are defined for supply purposes as critical ground water and ground water limited areas only (OAR 660-023-0140). However, problems can arise outside these designated areas. Sufficient data to justify a restrictive classification takes considerable time and resources to gather, and some areas in the Willamette Valley are experiencing supply problems even though the areas are not designated as "significant" Goal 5 resources.

For other areas, the county may address ground water problems under statewide Goal 2. Goal 2 directs local governments "to establish a land use planning process and policy framework as a basis for all land use decisions and actions related to use of land and to assure an adequate factual base for such decisions and actions."

The goal requires all land use plans to include:
(1) identification of issues and problems;
(2) inventories and other factual information for each applicable statewide planning goal;
(3) evaluation of alternative courses of action; and
(4) ultimate policy choices, taking into considerations social, economic, energy and environmental needs.

These ultimate policy choices and plan policies are the basis for specific implementation measures, which are the basis to carry out the plan. Goal 2 defines two general types of implementation measures: (1) management implementation measures (e.g., ordinances, regulations or project plans); and (2) site or area specific implementation measures (e.g., permits).

In many cases, other statewide planning goal requirements have assisted in minimizing conversion to more intensive land uses. These include Goals 3 (agricultural lands), 4 (forest lands), 7 (natural hazards), 11 (public facilities and services) and 14 (urbanization). However, in certain cases rural development is still occurring in areas where ground water, as a domestic water source, is inadequate. Goals 2 and 5 provide local governments with the best tools to establish measures to help assure that a reliable source of ground water is available for planned development and to provide a reasonable level of certainty that the carrying capacity of the ground water supply will not be exceeded.

Some examples of possible land-use regulations are described in the following sections.

Conservation. Local governments may consider implementing water conservation requirements. This tactic would limit the quantity of water used, rather than limiting land uses. Regarding rural residential use, indoor water conservation is addressed through the building code (e.g., low-flow shower heads and toilets). Outdoor conservation is another area where important gains could be made. Limiting the size of irrigated landscaping and requiring timed sprinklers are two measures that could

benefit resource sustainability. This tool may be best employed when the proposed use is permitted by zoning, such as a new dwelling in a rural residential zone.

Supply Studies. In some cases, it may be desirable for a county to require that an applicant demonstrate a sustainable long-term water supply before granting certain land-use approvals. This can be a fairly expensive undertaking, so it is best used only when the proposal would be eligible for a considerable amount of exempt use water, such as a subdivision. It assumes that the long-term supply can be estimated with reasonable accuracy, which may be more likely for some aquifers than others. Another problem to avoid is "dueling consultants," which can arise when opponents to a proposed application provide expert testimony that conflicts with that submitted by the applicant. A neutral, third-party reviewer may be required, adding to the expense.

Alternative Supply. In certain circumstances, it may be appropriate for a local government to encourage development of alternatives to individual exempt use wells for rural residential development. Provision of a shared water source adds complications for developers and residents because the supply then becomes subject to regulation from other state agencies (*i.e.*, Health Division and Water Resources Department). Rural water systems are not limited by land-use laws, but counties cannot allow increased residential density because a community water supply is available.

CONCLUSIONS

Additional rural residential development will occur in the Willamette Basin. Some will be on existing lots of record. Some will be on new lots created via the subdivision or partitioning process. Water to supply development will likely rely on ground water sources, much of which may be exempt from state water use permitting requirements. While not all development in rural areas will generate

ground water supply issues, some areas can anticipate supply issues based on the potential for new development and on limitations in local ground water supplies.

Addressing ground water supply issues and maintaining an acceptable degree of stability in rural ground water resources will require joint attention and action by WRD and local governments. Likely a multi-pronged approach will be necessary which may include education, water supply monitoring, factoring water supply considerations into land use decisions, and a host of other actions.

APPENDIX A

GROUND WATER CONCEPTS

All soil, sediments, and rocks beneath the earth's surface have open spaces that are filled with fluids such as air, water, oil, or natural gas (Figure 6). At shallow depths, pore spaces are filled partly with air and partly with water. At some depth, all pore spaces are completely filled, or saturated, with water. The top of the fully saturated pore space is referred to as the water table and the underlying water is referred to as ground water. The surface of the water table is not flat but generally mimics land surface topography (Figure 7). Differences in the elevation of the water table provide a potential energy gradient, driven by gravity, that causes ground water to flow from areas of high to areas of low water level. Water-table highs generally correspond to upland areas where recharge water infiltrates into the ground water system. Water-table lows correspond to lowland areas where ground water discharges to lakes, streams and wetlands. Because the water table is not flat, ground water is in a constant state of motion, flowing from recharge areas to discharge areas.

An aquifer is generally defined in functional terms as a body of sediments or rock that is able to yield ground water in usable quantities to wells or springs. Thus, an aquifer serves as an

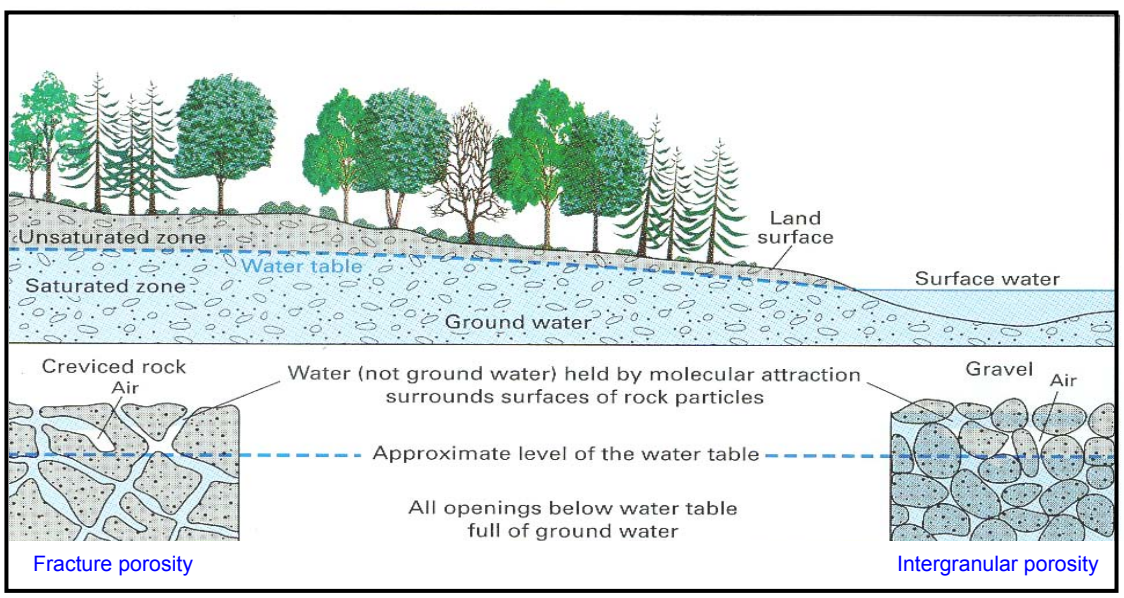

Figure 6. Ground water occurrence.

underground reservoir that can be exploited for human usage. However, an aquifer also serves as a conduit which naturally transmits water from recharge areas to discharge areas. Natural flow rates in aquifers are quite slow, generally ranging from a few feet to a few hundred feet per year, because of the frictional resistance to flow that occurs when water travels through small pore spaces. This frictional resistance tends to even out the effects of seasonal recharge and produces relatively stable discharge rates over time. In essence, an aquifer acts like a quickly saturated sponge that slowly releases water by seepage over an extended period of time. Similarly, aquifers will accept seasonal recharge, such as rainfall or snowmelt, and release the water from storage over extended times as discharge to springs, streams, and lakes. In this manner, the flow of many streams is sustained in dry summer months by discharge from aquifers that are mainly recharged by winter precipitation.

The principal source of recharge to aquifers is generally rainfall or snowmelt but recharge can also occur by leakage from streams and lakes and by infiltration of applied irrigation water. Natural discharge from ground water systems occurs to streams, lakes, springs, and wetlands. In areas where the water table is near land surface, discharge also occurs by evaporation or by transpiration in plants. Water is also discharged from aquifers by pumpage from wells.

The water table, or surface at the top of the saturated pore space, of an aquifer is free to rise and fall as the amount of water stored in the aquifer changes over time. These changes in storage are reflected in the water levels in wells. Water-level fluctuations are caused by uneven distributions of recharge and discharge over time. In the Willamette Valley, for example, aquifer recharge is

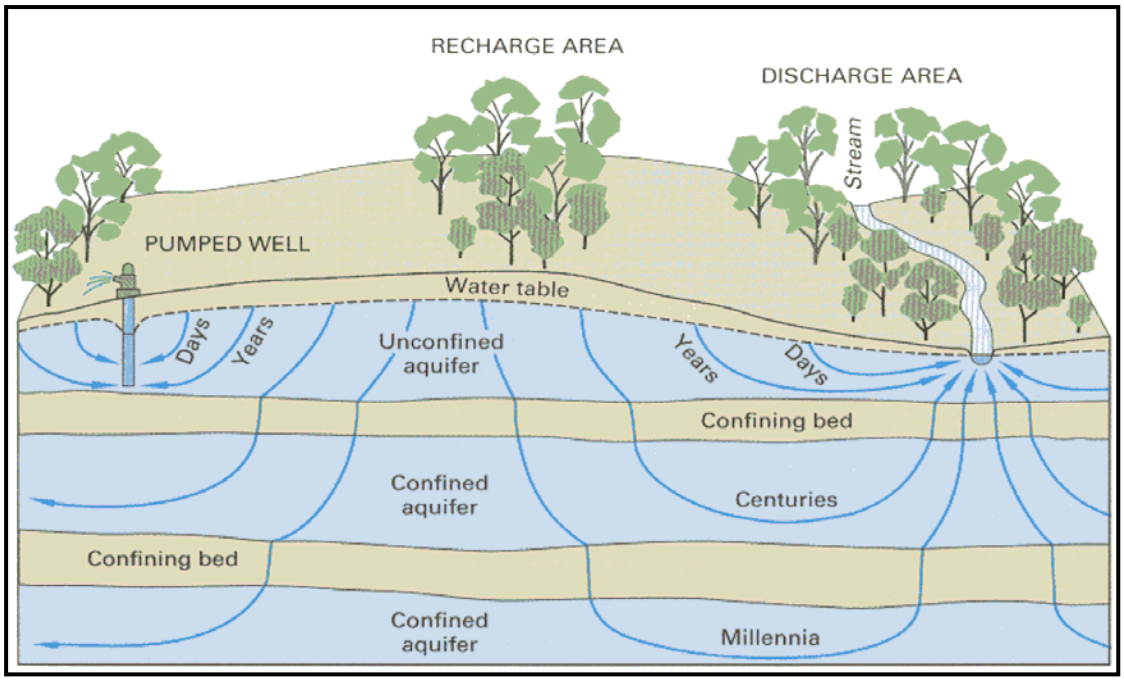

Figure 7. Schematic of ground water flow system showing direction and rate of ground water movement.

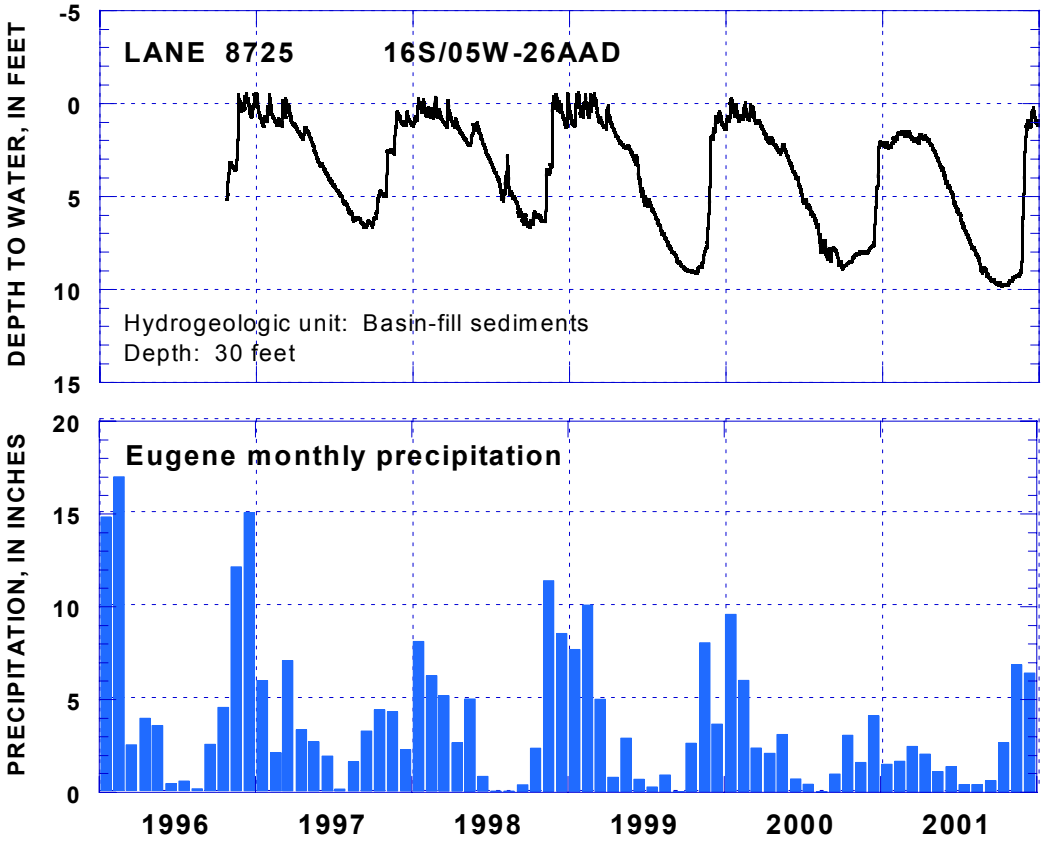

Figure 8. Impact of seasonal precipitation on water levels in a shallow well in the southern Willamette Valley, Oregon.

largely limited to the winter months when rainfall rates are high and evaporation rates are low. This is reflected in the seasonal water levels in shallow wells which show higher water levels in the winter and lower water levels in the summer (Figure 8). Changes in storage can also occur as the result of long-term climatic cycles which have multi-year patterns of above or below normal rainfall (Figure 9). Under natural conditions, the balance between recharge and discharge is stable over the long term and the volume of water in storage remains relatively constant. Well pumpage removes water from storage and upsets this natural equilibrium by increasing the overall discharge rate from the aquifer. If pumping withdrawals are not excessive, a new equilibrium between recharge and discharge may be reached and water levels will stabilize at a lower level; however, this is usually done at the expense of decreasing the natural discharge to streams. If pumping withdrawals are excessive, the aquifer may not be able to reach a new equilibrium and water levels will progressively drop over time (Figure 4 on page 12). When this happens, the aquifer is effectively being mined of its water and will eventually go dry if pumping is not reduced. It is this condition that must be prevented in order to sustain use of the

resource. The goal of sustainability means that the aquifer must be periodically renewed by replacing water that has been pumped out.

The capacity of an aquifer to serve as a renewable resource is largely dependent upon the hydrologic properties of the aquifer materials. Two key properties of aquifers are the ability to store and transmit water. Both are dependent upon physical factors controlled by the geology of the local rocks and sediments. The main geologic factors that influence these properties are porosity and permeability.

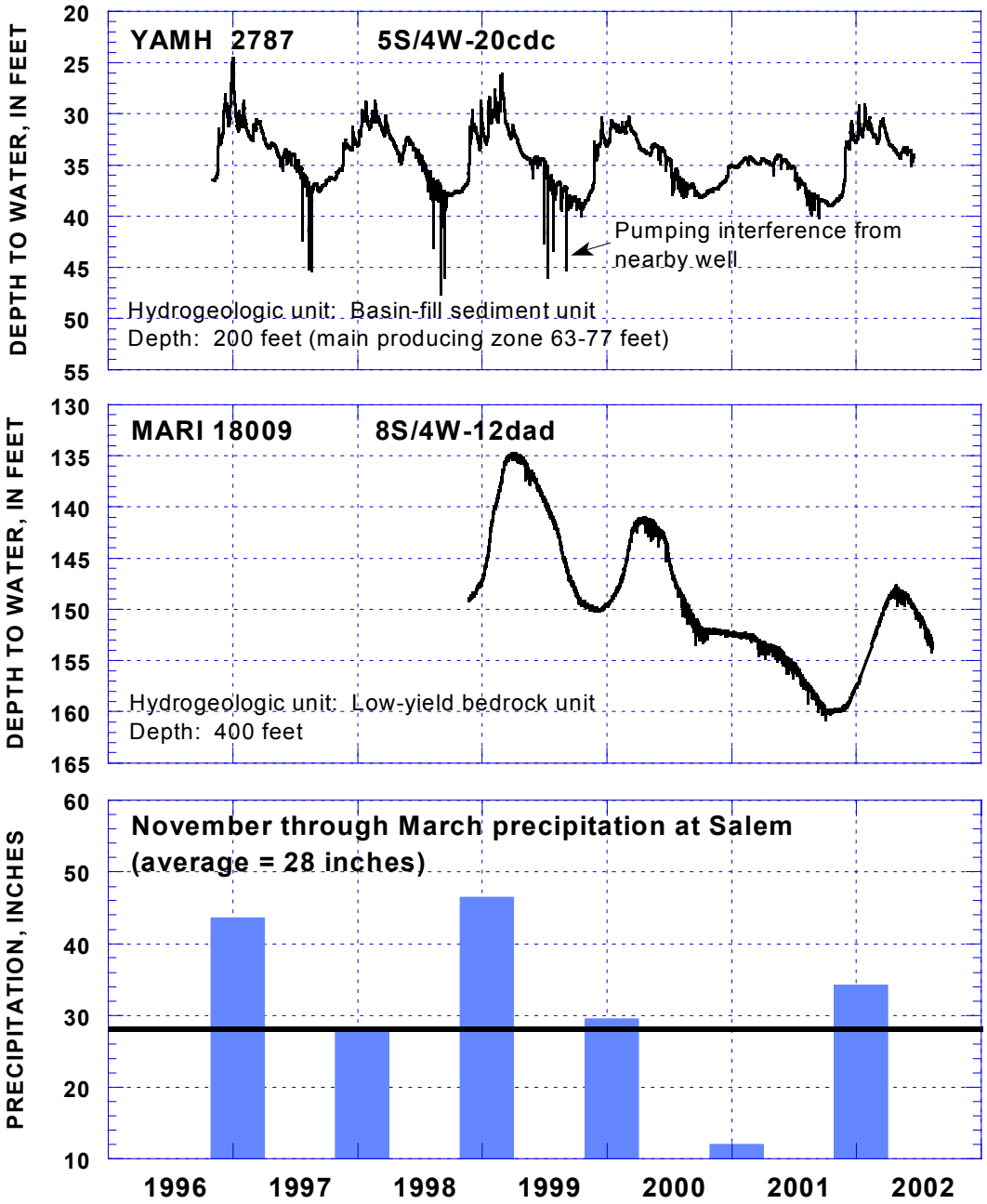

Figure 9. Impact of climatic cycles on water levels in wells in the Willamette Valley, Oregon.

Porosity is the relative volume of open space in sediments or rocks and is a general measure of the storage capacity of an aquifer. Permeability is a measure of the ease with which fluids can flow from pore space to pore space through the aquifer and indicates the capacity of an aquifer to transmit water.

Open spaces in the subsurface generally occur as intergranular pores between soil or sediment grains or as planar fractures in rock. These contrasting styles of occurrence are generally referred to as intergranular porosity and fracture porosity (Figure 6 on page 27).

Intergranular porosity is typical of sediments deposited in lakes, oceans or the floodplains of rivers. The intergranular porosity of freshly deposited sediments can be as high as 50%. Intergranular porosity is generally evenly distributed within a given layer of sediments such as a sand or gravel bed. As sediments are buried and converted to rock over time, intergranular porosity will decrease as the sediments compact and as dissolved minerals precipitate from solution to fill pore spaces. As a general rule then, older sediments tend to have lower porosity than younger sediments and older rocks tend to have lower porosity than younger rocks.

Fractures are planar cracks or joints caused by the brittle deformation of rocks when they are subjected to physical stresses that deform the earth's crust. Fractures can be created in crystalline bedrock, such as granite, or in sedimentary rocks, such as sandstone or claystone, that are rigid enough to undergo brittle deformation. Within a given rock unit, fractures are generally more common and more open near land surface. The width of fracture openings tends to decrease with depth because of compression caused by the weight of the overlying rock. Therefore, fracture porosity generally decreases with depth. The distribution and orientation of fractures are controlled by the orientation of geologic stresses in the earth's crust and by physical properties of the fractured rock. Because fractures are planar features, they commonly have a preferred orientation. However, the distribution of fractures throughout a volume of rock is generally quite variable and difficult to predict. Because fractures commonly represent less than 1% of the total rock volume, fracture-dominated aquifers typically have low storage capacities. Because the distribution of fractures is generally not uniform throughout a rock body, nearby wells in fracture-dominated aquifers can have widely different production capacities depending upon whether or not fractures are intersected in the well bore.

The permeability of sediments and rocks varies widely in nature. High permeability materials, such as gravels, contain large, well-connected pores that cause little frictional resistance to flow. Low permeable materials such as silts and clays have very few interconnected pores or have very small pores that create a large frictional resistance to flow. Materials that have high permeabilities generally make good aquifers whereas materials with very low permeabilities are commonly referred to as confining beds. A confining bed impedes the movement of water into or out of adjacent aquifers. Although subsurface materials are commonly classified as aquifers or confining beds, the distinction is somewhat subjective. A thick bed of silt might be considered a confining bed

if it occurs above a sand and gravel aquifer but it could be considered an aquifer in an area containing only silt and clay deposits.

If an aquifer is not overlain by a confining bed, the water table is free to rise and fall as the volume of water in storage changes over time. Such aquifers are referred to as unconfined, or water table, aquifers (Figure 10). If an aquifer is completely filled with water and overlain by a confining bed, the aquifer is described as a confined or artesian aquifer. Water levels in shallow wells that penetrate an unconfined aquifer will rise to the level of the water table. Pressures in a confined aquifer are sufficient to cause the water levels in wells to rise above the top of the aquifer. The degree of confinement of an aquifer is dependent upon the thickness and permeability of overlying confining beds. A thick, low-permeability clay can sustain higher confining pressures than a thin layer of silt. Although it is convenient to think of aquifers as either unconfined or confined, the natural world contains a full spectrum of aquifers that range from unconfined to partly confined to highly confined.

The capacity of an aquifer to store water is generally related to the relative volume of pore space in the aquifer but is also affected by the degree of aquifer confinement. In unconfined aquifers, water is released from storage by the draining of pore spaces as the water table drops. In contrast, confined aquifers are always fully saturated and water is released from storage by the expansion of water and the physical compression of the aquifer framework material as pressure is decreased in the aquifer. Since water and rocks are not very compressible, confined aquifers have a much lower capacity to store water than unconfined aquifers.

When water is pumped from a well, the water level in the well drops below the water level in the adjacent aquifer. This difference in water levels creates a pressure gradient that causes water to

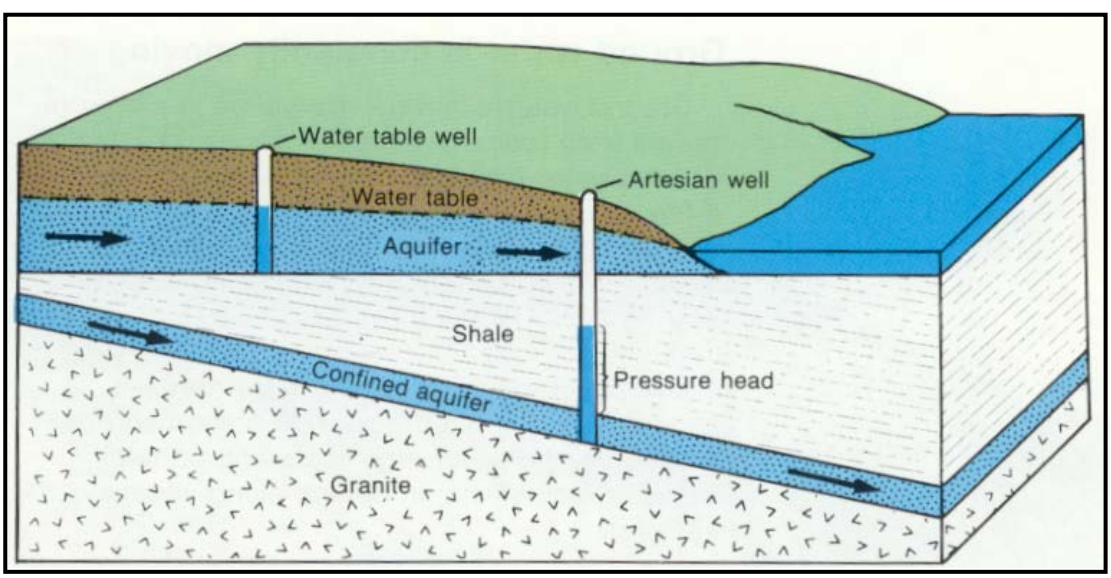

Figure 10. Unconfined (water table) and confined (artesian) aquifers.

flow into the well from the surrounding aquifer. As pumping continues, the water level in the well continues to drop and the rate of flow of water from the aquifer continues to increase until a balance is reached between the inflow rate and the pumping rate. As water flows into the well, water levels in the surrounding aquifer drop in the vicinity of the well. The drop is greatest immediately adjacent to the well and decreases with distance from the well. The resulting depression of the water table surrounding the pumping well is referred to as the cone of depression (Figure 11). As pumping continues, the cone of depression will continue to expand but the rate of expansion will decrease with time as the volume of aquifer that provides water to the well increases.

Pumpage from wells removes water from storage in an aquifer. Because the storage capacity of confined aquifers is very small compared to unconfined aquifers, water is removed from a much larger volume of a confined aquifer compared to an unconfined aquifer when pumping at an equivalent rate. Another way of saying this is that the cone of depression will expand at a faster rate and to a greater distance in a confined aquifer compared to an unconfined aquifer. All else being equal, then, a well pumping from a confined aquifer will cause greater drawdowns in surrounding wells than a well pumping from an unconfined aquifer. A well pumping from confined aquifers will also impact other wells at a greater distance than a well pumping from an unconfined aquifer.

Although pumpage from wells initially removes water from aquifer storage, pumping effects are eventually propagated out to the boundaries of an aquifer where they impact recharge or discharge (Figure 12). Under most

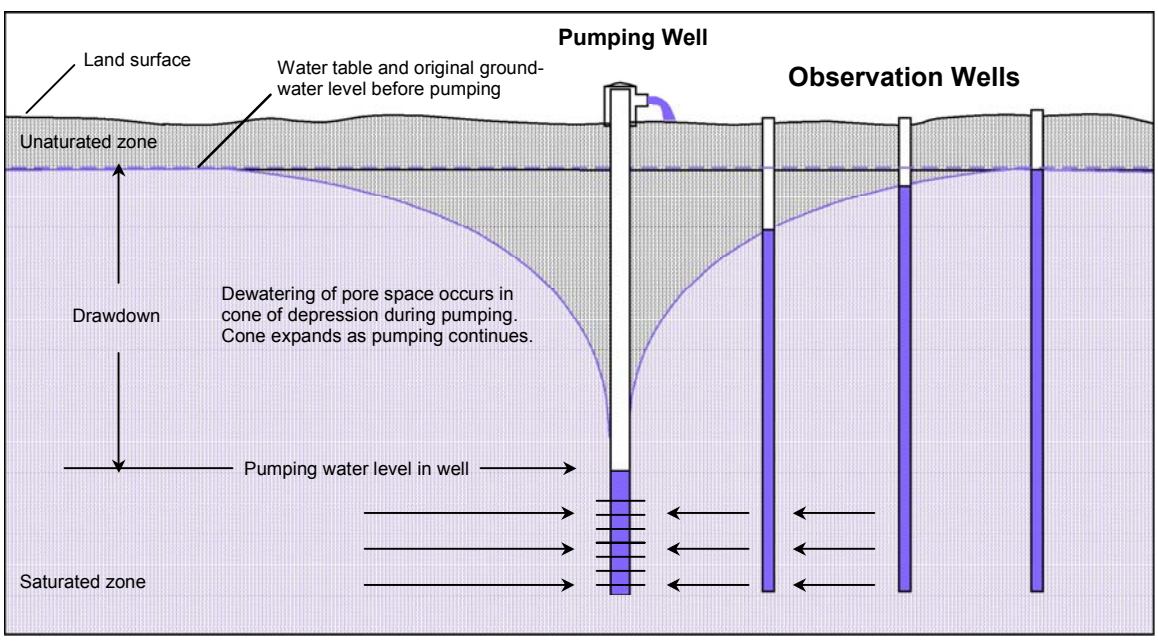

Figure 11. Cone of depression caused by pumping in an unconfined aquifer.

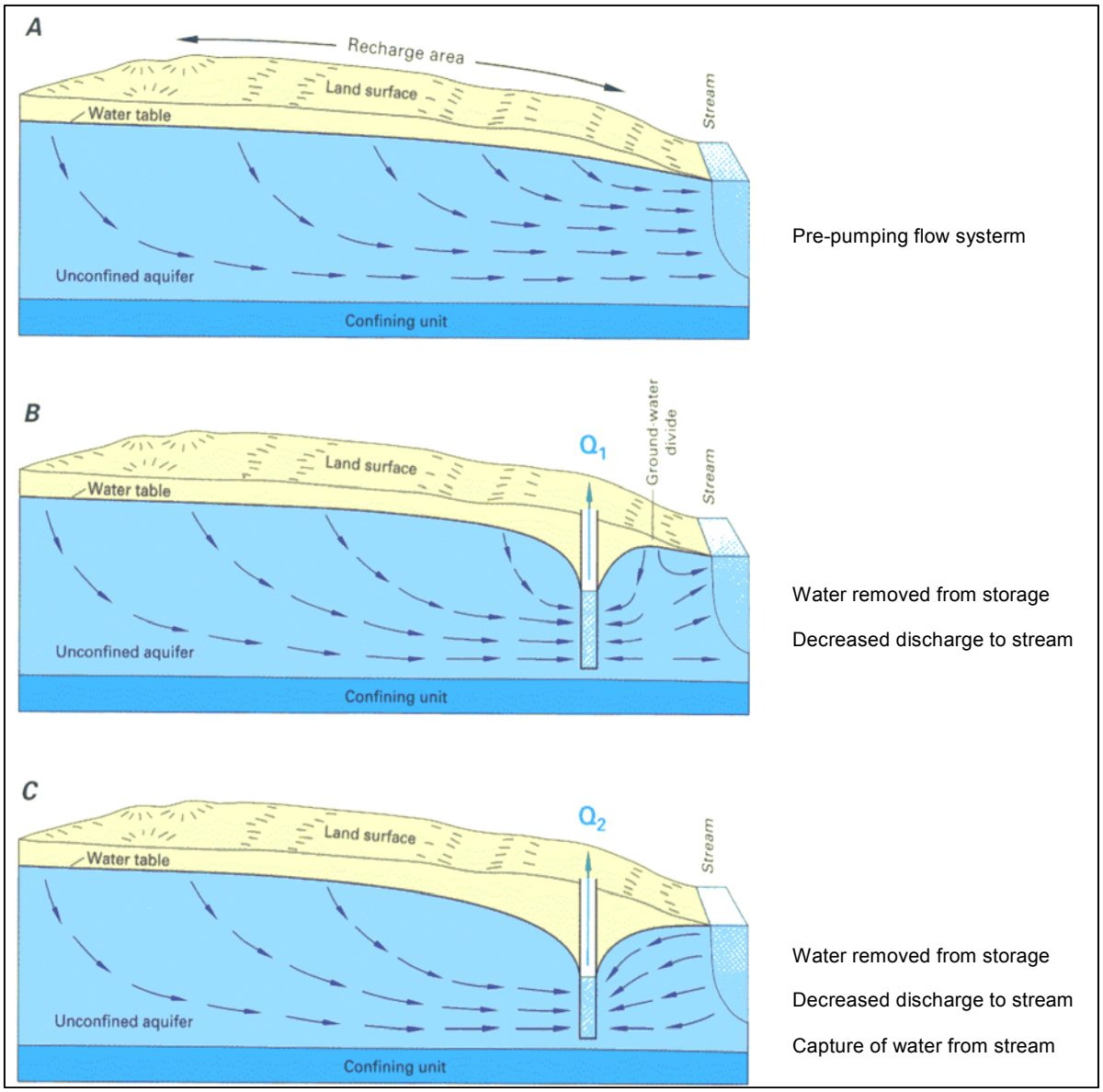

Figure 12. Sources of water to wells.

circumstances, pumping captures water that would have discharged naturally from the ground water system. Pumpage from wells that are close to lakes or streams can also reverse the natural discharge of water and induce water to flow from the surface water body toward the well. In either case, the natural rate of ground water discharge is decreased and surface water supplies are diminished.

Wells, like most man-made products, have a lifespan and a life cycle. Although the lifespan of a well may exceed 50 years, older wells are not likely to perform as well as they did when they were newly installed. Changes in well performance or production capacity are generally described in terms of well efficiency. In an efficient well, there is very little resistance to the flow of water from the

aquifer into the well and the water level in the well during pumping will be close to the water level in the aquifer directly adjacent to the well (Figure 13). Inefficient wells have conditions that impede the flow of water from the aquifer into the well bore. The pumping water level in an inefficient well will be lower than the water level in the aquifer directly adjacent to the well. The most common causes of lost well efficiency are the precipitation of minerals from solution or the growth of bacteria in or near the well. Either circumstance leads to some blockage or constriction of the pathways from the aquifer to the well making it more difficult for water to enter the well.

As a well loses efficiency over time, the amount of drawdown during pumping will increase. Also, the time needed for the well to recover from pumping will increase. Over time, if the well is shallow or the pump is set to a shallow depth, the water level in the well may drop below the pump intake. When this occurs, air will enter the pump column and the withdrawal of water will cease. Because losses in well efficiency occur slowly over time (years to decades) and because most well owners are unable to observe water level changes in their well, an owner may be unaware that a problem is developing in a well until it begins to pump air. When this happens, it appears to be an instantaneous development and a common tendency is to look for external causes. Many well owners attribute this problem to a "drying up" of the aquifer. In fact, however, efficiency losses can cause a well to go "dry" during pumping while the water level in the surrounding aquifer remains at or near historic levels (Figure 13).

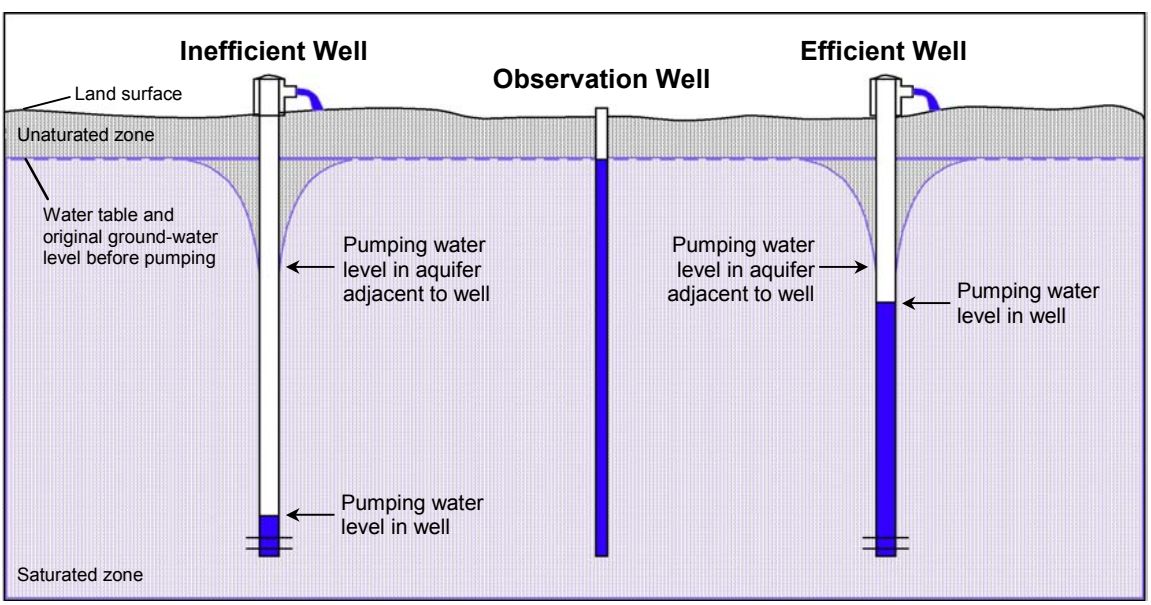

Figure 13. Effect of well efficiency on pumping levels in wells.

Changes in well efficiency over time can be assessed by comparing current well yield and drawdown to the original yield and drawdown at the time the well was drilled. Unfortunately, these data are not generally available for wells that have been drilled using compressed-air rotary drilling rigs, the most common method of well construction since the early 1970s.

Wells drilled by air rotary rigs are generally tested by lowering the drill stem to the bottom of the hole and blowing compressed air through the drill pipe to force water out of the well bore. This test method, referred to as an air test, is a very rough way of estimating the potential pumping rate of a well and does not provide any information about drawdown that might occur during pumping. For these reasons, an air test is not a reliable estimate of the sustained pumping capacity of a well. The common use of air tests to estimate well yield in new wells limits one's ability to predict the production capacity of an aquifer and makes it difficult to assess changes in well efficiency over time.

APPENDIX B

HYDROGEOLOGY OF THE WILLAMETTE BASIN

Geologic Framework

The Willamette drainage basin (Figure 1 on page 4) occupies the region between the crests of the Coast Range and the Cascade Range. It is bounded on the north by the Columbia River and on the south by the convergence of the two mountain ranges. The Coast Range is composed of rocks that were originally deposited as sediments on the seafloor or as oceanic volcanic deposits erupted from submarine or island volcanoes. The Cascade Range is largely a collection of rocks and debris erupted from continental volcanoes and is subdivided into the Western Cascades and the High Cascades. The Western Cascades are composed of older volcanic deposits that are heavily weathered and eroded. The source vents for these rocks have generally been obscured or removed by erosion. The High Cascades are younger volcanic deposits that are largely limited to the crest of the range, on the eastern side of the Willamette basin.

During the initial formation of the Cascade Volcanic Range around 35-40 million years ago, the ancestral oceanic shoreline was positioned near the eastern margin of the current valley floor. As the ancestral Cascade Range continued to rise by the accumulation of volcanic debris, east-west compressive forces began to uplift the area occupied by the current Coast Range and depress the area currently occupied by the Willamette Valley. Thus, the Willamette Basin is a regional downwarp formed between the Coast and Cascade Ranges. The basin is underlain by a thick floor of oceanic sediments and volcanic deposits shed from the rising Cascade Range to the east.

Continued uplift in the Coast Range isolated the Willamette basin from the ocean and created a lowland that began to fill with sediments deposited from rivers that drained the emerging highlands. Continued downwarping over time has allowed the accumulation of a sedimentary fill that ranges up to 1600 feet thick in the deeper portions of the basin. This process continues through the present time.

Early in the formation of the Willamette Basin, around 17 million years ago, tremendous volumes of fluid, basaltic lava erupted from linear fissures in eastern Oregon and Washington. Many of these eruptions were so large that individual lava flows spread out over vast areas to cover most of the landscape in eastern Oregon and Washington and western Idaho. The rocks formed by these eruptions are collectively referred to as the Columbia River Basalt Group, or less formerly as the Columbia River Basalts. Some of these basalt lavas entered the northern Willamette Valley through a lowland in the Cascade Range and flooded the valley floor as far south as the town of Jefferson in Linn County.

In the Portland area, the basalt flows accumulated to a thickness of greater than 1000 feet. Fewer flows were able to penetrate into the Salem area where the basalts collectively average about 400 feet in thickness.

During and after the emplacement of the Columbia River Basalt lavas, localized subsidence in the northern Willamette Valley resulted in the creation of four depressions, or subbasins, within the basalt lavas. These are the Portland Basin, the Tualatin Basin, the central Willamette Basin, and the Stayton Basin (Figure 1 on page 4). The magnitude of the down warp in these basins is illustrated by the present location of the upper surface of the basalt lavas. The top of the basalts occurs at about 1600 feet below sea level in the deepest parts of the Portland and central Willamette basins, more than 1200 feet below sea level in the Tualatin basin, and more than 200 feet below sea level in the Stayton basin.

As the northern Willamette Valley was subsiding, the southern valley, from Eugene to Albany was gradually uplifted to its present position. This uplift caused the developing stream system to erode a shallow trough into the marine sediments. Lowland areas in the trough were filled with sediments eroded from the Cascades and Coast ranges. Since Columbia River Basalt lavas did not extend this far to the south, the southern valley is underlain by older marine rocks.

After the deposition of the Columbia River Basalt lavas, sediments eroded from the Coast and Cascade Ranges continued to fill low lying areas throughout the Willamette Basin. Most of this sedimentary fill is composed of silts and clays. The main sand and gravel beds were deposited by streams that drained the Cascade Range. As a result, sands and gravels are thickest along the eastern and southern margin of the valley and thin to the west.

Around 15,000 years ago, at the peak of the last major glacial epoch in North America, a large lake was impounded behind a glacier that blocked the drainage of the Clark Fork River near Missoula, Montana. Periodic failure of the ice dam between 15,000 and 12,700 years ago produced enormous floods that swept across eastern Washington and stripped away most of the soil and loose rock at land surface. These floods are variously referred to as the Missoula Floods or the Bretz Floods. As each flood poured through the lower Columbia River drainage system, water was backflooded into the Willamette Valley to form a temporary lake. Particles suspended in the lake waters settled out during each flood to produce a widespread unit of bedded silts and clays that ranges up to 130 feet thick. Referred to by geologists as the Willamette Silt, the upper part of this deposit forms the relatively flat surface of the modern valley floor in the area south of Wilsonville.

After each of the ice age floods that produced the Willamette Silt unit, the Willamette River and its main tributaries were able to cut through the silt to re-establish their former floodplains. Between Eugene and Wilsonville, the modern floodplains of these streams are entrenched within the silt to levels below the adjacent valley floor. Over the last 12,000 years, the deposition of sands and gravels has largely been restricted to the narrow bands defined by these entrenched floodplains.

Smaller streams, such as the Calapooia and Pudding rivers, were not able to cut

completely through the silts and their modern streambeds now rest directly on beds of the Willamette Silt.

Hydrogeologic Units

Geologic units that have similar hydrologic properties over widespread areas can be grouped into hydrogeologic units. The four regional hydrogeologic units defined in the Willamette Basin are: 1) the low-yield bedrock unit, 2) the Columbia River Basalt unit, 3) the basin-fill sediment unit, and 4) the Willamette Silt unit. Figure 2 on pages 8 and 9 shows the distribution of these units at the earth's surface and several diagrammatic cross-sections showing their distribution in the subsurface. The low-yield unit is exposed at land surface in the Coast Range and the Western Cascade Range but also occurs at depth beneath the other units. The Columbia River Basalt unit is exposed in upland areas surrounding the Portland, Tualatin, and central Willamette basins and occurs at depth beneath these basins but does not occur in the southern Willamette basin. The basin-fill sediment unit is limited to the lowland areas of the Willamette Valley. The Willamette Silt unit overlies the basin-fill sediment unit throughout most of the lowland areas south of the Portland Basin except where it has been removed by erosion in the flood plains of the Willamette River and its main tributaries. Each unit is discussed below in order from oldest to youngest. Table 1 on page 6 summarizes general characteristics for each unit.

<u>Low-Yield Bedrock Unit</u>

The low-yield bedrock unit includes marine sedimentary and volcanic rocks that were deposited in the ancestral ocean that bordered the Cascade Range prior to the formation of the Willamette Basin. The unit also includes volcanic rocks and associated sediments of the Western Cascades. The marine rocks are exposed at the surface in the Coast Range and in a thin sliver in the lower foothills of the Western Cascade Range; they also occur in the subsurface between the Coast and Cascade Ranges where they underlie younger units (Figure 2 on page 8).

The low-yield unit includes a wide variety of geologic formations and rock types with widely varying properties. In general, however, most of the primary intergranular porosity in these deposits has been destroyed and the unit is dominated by fracture porosity. Individual fractures can have high permeability but the permeability of the matrix material is typically very low. The unit is generally able to provide sufficient water for domestic uses but well yields are typically less than 10 gallons per minute and commonly less than 5 gallons per minute.

Wells that intersect a major fracture or group of fractures in the low-yield unit may have yields that are considerably higher than normal in an area. Wells that fail to intersect major fractures can have yields that are considerably lower. In some areas, it is not uncommon for a landowner to drill several "dry" holes before finding a zone that is capable of supplying a household with water. These so-called dry wells probably intersect portions of the aquifer that have no fracture porosity and extremely low matrix porosity and permeability. Water is probably capable of seeping into the well at extremely low rates but not fast enough to satisfy the capacity of a

domestic pump. In many areas, wells may be capable of supplying enough water for household use but are not able to provide enough water to irrigate a lawn and garden. Well owners commonly learn to live within the capacity of the local resource by adjusting their water-use practices over time as they gain experience with the limitations of their well and aquifer.

In general, the low-yield bedrock unit has low permeability and porosity. Therefore, wells tend to develop steep cones of depression and the effects of pumping are localized around the vicinity of the well. If a well intersects a major fracture or a zone of fractures with high permeability, the yield of the well may be higher than normal in the area and pumping effects can be propagated out to greater distances. In these cases, the effects of pumping will spread more quickly along the direction of the permeable fracture zone but less quickly in the surrounding matrix material. If a nearby well is producing out of the same fractures, direct interference between the wells is more likely. Well owners who are lucky enough to drill a high-yield well under these conditions generally make the false assumption that the high yield indicates a large ground water resource that is not connected to the surrounding low-yield aquifer that supplies their neighbors' wells. However, within a fracture-dominated system, water pumped from major fractures must be supplied by minor fractures that, at some scale, are supplied by water from matrix pores. In the human body, this can be compared to the pumping of blood from the lungs to the heart through the pulmonary vein. As the heart pumps, blood is initially withdrawn from the pulmonary vein but this is replaced by blood from many smaller blood vessels in the lung. Ultimately, these smaller vessels are supplied by blood from numerous capillaries which extend throughout the lungs. Unlike the lungs, however, the volume of interconnected pathways and the capacity to transmit fluid may be very small in the bedrock matrix. This may delay, but not eliminate, impacts to the surrounding matrix.

Because of the low storage potential in the low-yield unit, small changes in water use or recharge can result in large changes in water levels. For example, extensive use of a new high-yield well in an area characterized by low yields can cause water levels to drop substantially in the surrounding aquifer. Also, several years of below normal precipitation can cause water levels to drop much lower than typical during years with normal precipitation. The latter phenomenon is reflected in the observation that water-level trends in the low-yield unit commonly mimic long-term climatic cycles (Figure 9 on page 30). Natural lows in these cycles will be accentuated by local pumping.

Declines in well production capacity over time are common in the low-yield bedrock unit and can be caused by problems inherent to the well, problems that are external to the well, or to a combination of these factors. Differentiating between the potential causes can be difficult without a record of well yield and water level change over time. Problems inherent to the well are generally related to physical problems with the pump or to losses in well efficiency that occur over time as described in the above section on ground water concepts. Well efficiency losses are caused by any process that decreases the ability of water to flow from the

aquifer into the well bore. Typical causes are the precipitation of minerals or the growth of bacteria in or around the well. These factors will cause an increase in drawdown at a given pumping rate (Figure 13 on page 35) and a corresponding increase in the time it takes to recover from pumping.

A similar loss in production capacity can occur in aquifers dominated by fracture porosity. Pumping in these systems reduces the hydrostatic pressure in fractures near the well which may cause the fractures to close over time, a process that is likely to be irreversible. When fractures close, well yield will drop to a rate that can be sustained by the matrix permeability which is likely to be much lower than the fracture permeability. Because of these factors, the initial yield of a well in the low-yield bedrock unit is unlikely to reflect the long-term yield of the well. In this environment, well efficiency is critical. A low-yield aquifer may be able to supply sufficient water to an efficient well but not to an inefficient well (Figure 13 on page 35).

Well production problems can also be caused by a water-level drop in an aquifer. Any change in water level in the aquifer will be reflected by a corresponding change in water level in a well. A drop in ground water levels will decrease the driving pressure available to move water into a well; it will also decrease the available drawdown space in a well. For example, if a 100-foot deep well normally draws down 50 feet after pumping for 1 hour and the water table is normally at 10 feet below land surface, the pumping level in the well after one hour will be 60 feet below land surface (Figure 14). If the water table is 20 feet lower in a dry year, the pumping level

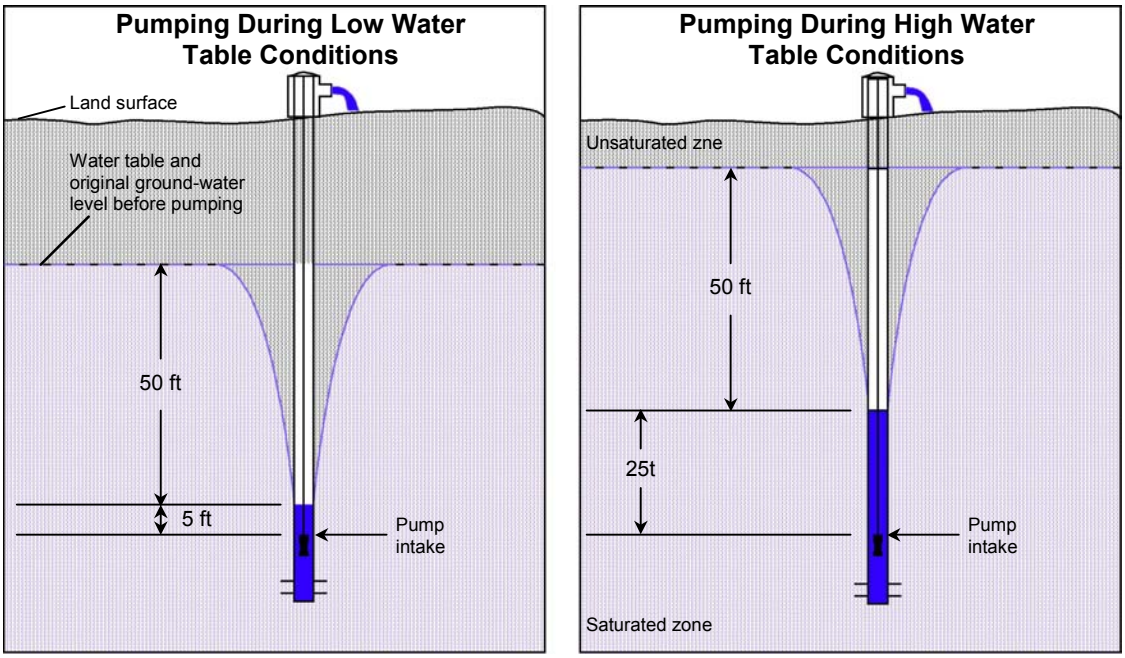

Figure 14. Effect of ground water levels on pumping levels in wells.

after 1 hour will be 80 feet. If the pump is set at 85 feet below land surface, there will be 25 feet of water over the pump in a normal year but only 5 feet of water over the pump in the dry year. A slight increase in the pumping rate, a longer duration of pumping (greater water use), a decrease in well efficiency, or pumping interference from nearby wells will increase the drawdown in the well. All of these factors may not cause a problem in a normal or wet year but may cause a problem in a dry year when the water table is lower than normal.

Many of the factors discussed above make it difficult to predict the production and storage capacity of the low-yield bedrock unit at any particular locality. In addition, the unit is composed of a wide variety of geologic formations that vary in their hydrologic properties. Although general properties of the unit are known (low storage and low production capacities), specific hydrologic properties are not usually known, or easily determined, at any given locality. In particular, the distribution of fractures is difficult to determine or predict. These factors also make it difficult to predict the local ability of the unit to accept recharge. Furthermore, because of losses in well efficiency and the closure of fractures over time, initial yields in new wells are not likely to represent long-term production potential. Site-specific water level and production data will allow better predictions to be made, especially if data are available for several years. However, the uncertainties of predicting long-term production and storage capacities for this unit will always be high.

High salinity water is common at depth in the marine sediments and marine volcanics of the low-yield unit. These areas are delineated in Figure 2 on page 8. The high salt content mainly reflects high concentrations of dissolved sodium, calcium, and chloride. Saline water in the bedrock unit originated as seawater that was trapped in the pore spaces of buried sediments. High salinity water is common at depths below 100 ft and deep oil exploration wells have found saline water at depth wherever porous sands were encountered in these rocks. Fresh water in the shallow part of the unit is relatively young ground water that is recharged by precipitation. Because of the low porosity and permeability of the unit, fresh water is unable to circulate deep into the rocks to flush out saline waters. Consequently, once saline water has been encountered in a well, fresh water is unlikely to be found at greater depth.

Arsenic is a common natural constituent in ground waters of the low-yield bedrock unit. Concentrations above 10 micrograms per liter (µg/l; about 10 parts per billion) are common, concentrations above 50 µg/l are not unusual, and concentrations above 500 µg/l have been observed. The current Environmental Protection Agency (EPA) drinking water standard is 10 µg/l for public water supplies but arsenic is not regulated in private wells by the federal or state government. Arsenic is a known carcinogen with well-documented, high-risk incidence rates compared to other common carcinogens in drinking water.

Limited data suggest that the risk of encountering elevated arsenic levels in the low-yield bedrock unit is higher in south-central and eastern Lane county and eastern Linn county. These general areas are outlined in Figure 2 on page 8

but the boundaries are not well known. The occurrence of arsenic in these areas is probably associated with certain types of volcanic rocks but these geologic controls are poorly understood at present. Limited sampling indicates that the distribution of high arsenic levels is highly variable, even at the local scale. Not all wells in the designated areas are likely to have arsenic problems and high arsenic wells may occur in the close vicinity of wells with little or no arsenic. Because standard water-quality tests do not include arsenic as a measured constituent, the distribution of arsenic in the low-yield unit is somewhat uncertain and its occurrence in other areas of the unit cannot be precluded. For the same reason, owners of many contaminated wells are probably unaware of the elevated levels of arsenic in their drinking water.

Because of the uncertainties discussed above, it is difficult to predict the occurrence of elevated arsenic in ground waters of the low-yield bedrock unit. The best way for well owners to protect themselves is to have their well water tested for arsenic, preferably before the well is put into use. Periodic testing is recommended in high risk areas as studies have shown that arsenic concentrations can change over time in any given well.

Columbia River Basalt Unit

The Columbia River Basalt unit consists of a series of stacked lava flows that flooded lowland areas in the northern Willamette Valley during the early stages of the creation of the Willamette basin. The unit is exposed at land surface in bedrock highs between Salem and Portland; it also occurs at depth beneath younger sediments in the Portland, Tualatin, central Willamette, and Stayton basins (Figure 2 on page 8). The western edge of the unit occurs in eroded uplands along the western margin of the Tualatin Basin, the southwestern margin of Chehalem Mountain, and the western margins of the Dundee, Eola-Amity, and South Salem hills. The southernmost extent occurs in the vicinity of the town of Jefferson. Along the eastern margin of the central Willamette Valley and the Portland Basin, younger sediments and volcanic rocks overlie the unit. The total thickness of the basalts ranges from about 400 feet near Salem to more than 1000 feet near Portland. More than a dozen flows are present in the Portland area but only about 8 occur in the Salem area. Although faulting and folding have deformed the basalt unit, it is generally inclined at less than 10 degrees to the horizontal in most areas.

Columbia River Basalt flows in the Willamette Basin typically range from 40 to 100 feet thick but flow thickness is highly variable and may exceed 250 feet in some areas. The main part of a flow consists of a dense interior that has very low porosity and permeability (Figure 3 on page 11). Zones of interconnected pore space are generally limited to rubbly zones of broken lava, referred to as breccias that form at the top or base of individual flows. Some flows are separated by a thin layer of sediment deposited during the time span between successive eruptions. The combination of a flow top, intervening sediments, and the base of an overlying flow is commonly referred to as an interflow zone. Broken rock, or breccias, in these zones are referred to as interflow breccias. Interflow breccias vary considerably in thickness and do not

occur between all flows. Where present, the porosity of these zones can be very high; however, because the dense interiors make up most of the flow volume, bulk porosity probably averages less than five percent, and perhaps as little as one percent in the unit.

The main ground water producing zones in the Columbia River Basalt unit occur within interflow breccias where horizontal permeabilities range from moderate to high. Because the basalts were emplaced as extensive sheet flows, water-bearing zones occur as sub-horizontal, tabular aquifers separated by low-permeability flow interiors that act as confining beds. The uppermost aquifer in a stack of flows is unconfined but lower aquifers are confined, making the overall storage capacity of the unit low. Storage is further reduced because porous interflow zones make up a small percentage of the entire mass of the basalt.

Because of the moderate to high horizontal permeabilities, Columbia River basalt aquifers have moderate to high production capacities. Large-diameter irrigation and public-supply wells commonly produce more than 250 gallons per minute and six-inch domestic wells are generally capable of producing 20 gallons per minute. In areas where interflow breccias are thin, production rates can be considerably less. Because horizontal permeabilities are generally high and storage capacities are low, pumping impacts spread rapidly and can occur over large distances. Pumping interferences from high-yield wells have been documented within 15 minutes of pump turn on at distances greater than 2 miles in several controlled tests within the basin.

Recharge to Columbia River Basalt aquifers is limited by the low vertical permeabilities of the flow interiors. The limited recharge, low storage, and high production capacities combine to make these aquifers susceptible to overdraft. Put another way, it's difficult for water to get into these aquifers, it's easy to take water out, and there's not much water in storage to begin with. Multi-year water level declines in the basalt aquifers have occurred in many areas of the basin, especially in the vicinity of high-volume production wells. Near the city of Wilsonville, for example, water levels declined by as much as 50 feet between 1960 and 2002 (Figure 4 on page 12). City basalt wells were the main pumping wells in the area and the sole source of water for the city through April 2002. To put this in perspective, consider that the city withdrew an average of about 2.5 million gallons a day from these wells in 2000, the equivalent of a continuous pumping rate of about 1700 gallons per minute. In late April of 2002, a new surface-water plant, drawing water from the Willamette River, became the main source of water for Wilsonville. After the switch to surface water, water levels in the basalt aquifers began to rise over an area that extended out at least 6 miles in some directions. This indicates that the pumping impacts from these wells extended over the same area. Recovery from long-term pumping in the Wilsonville area is expected to occur over years, if not decades.

Although water-level declines in the basalts are common near high-capacity wells, declines have also been observed in rural residential areas where only domestic wells are located. Some of these declines may be caused, or

contributed to, by high-volume pumping at a distance. However, local pumping of domestic wells, especially in areas where the capacity of the aquifers is limited, may also cause declines.

Typical factors that limit the capacity of the basalt unit include 1) the presence of only one or two aquifers in an area with only a few basalt flows, 2) the lack of local breccia development in interflow zones, 3) the presence of faults that offset breccia zones against low-permeability flow interiors, 4) the occurrence of abrupt flow boundaries at eroded flow margins, and 5) local truncation of basalt flows on hillsides because of incision by local streams. The latter two factors are common in many of the upland areas where the basalts are exposed at land surface (Figure 2 on page 8). Basalt aquifers that are truncated in this manner have local boundaries that limit their size. All else being equal, drawdowns will be greater in wells near these boundaries than in wells that are not adjacent to such boundaries. The exposure of interflow breccias at land surface allows ground water to discharge as seeps and springs. These discharges sustain the summer flows of streams that originate in the dissected uplands. Ground water pumpage from interflow zones that sustain springs in these areas will decrease the natural discharge to local streams. Truncated aquifers at eroded flow margins occur in broad exposures on the southwestern margin of Chehalem Mountain, the northwest margin of Parrett Mountain (just southeast of highway 99 west), the western margins of the Dundee, Eola-Amity, and West Salem Hills, and along the southwestern margin of the South Salem Hills. Examples of areas where aquifers are exposed by stream incision include the hillsides adjacent to Corral Creek on Parrett Mountain, Glenn Creek in the West Salem Hills, and Silver Creek at the town of Silverton. In the latter area, Silver Creek has cut completely through the basalt unit to expose older marine sediments in its bed. Over 500 feet of the basalt unit is exposed on the hillsides to the south.

Any factors that limit the storage or production capacity will be exacerbated by excess pumping. In many areas, these aquifers may not be capable of sustaining irrigation of large yards and gardens. Many well owners mistakenly assume that high well yields in the basalts are an indication of a large resource that has a long-term production potential. This is not a valid assumption given our general knowledge of the hydrologic characteristics of the basalts (high permeability and low storage capacity). The long-term production capacity of these aquifers cannot be assessed without monitoring water levels over time, especially in areas that are undergoing increased development. Because water level monitoring is uncommon, most well owners are unaware of developing problems until the water level in their well drops below the pump intake. Because many of these problems develop over a period of years, it may take years of restricted pumping to stabilize water levels or reverse the declines. Recovery to pre-pumping levels may not be possible in many cases.

Most recharge to the basalt aquifers appears to occur in upland areas where the basalt flows are exposed at land surface. Shallow basalt wells in these areas show a direct response to precipitation but deep wells commonly show no apparent response (Figure 15).

Also, within the uplands, water-level elevations in shallow wells are generally much higher than those in deep wells. This indicates a strong downward component in the potential energy gradient that drives ground water flow. Strong downward vertical gradients are consistent with recharge areas that have low vertical permeabilities. Stacked aquifers separated by confining beds in

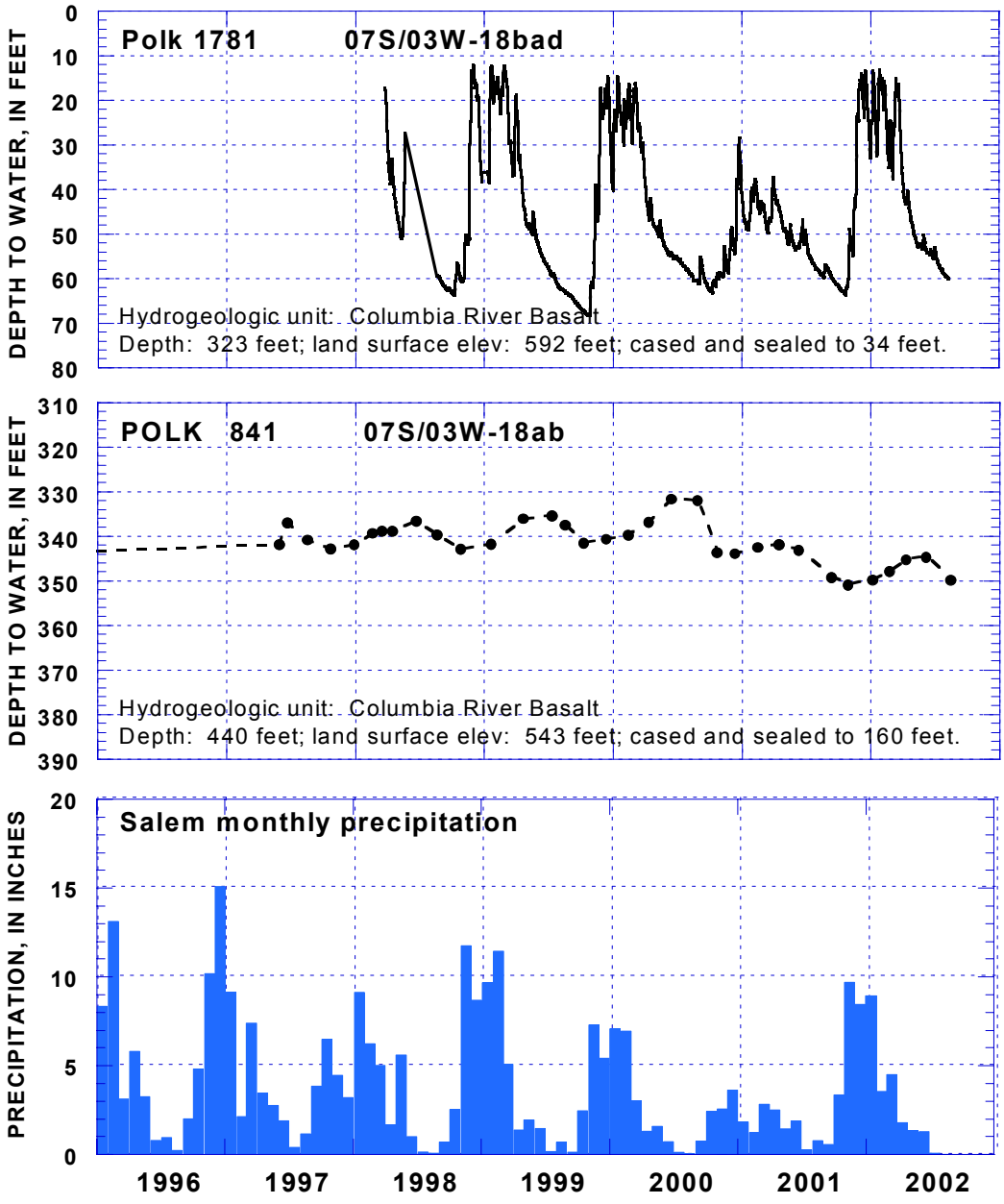

Figure 15. Impact of precipitation on shallow versus deep aquifers in the Columbia River Basalt unit (Wells are about 1000 feet apart).

these areas are expected to have significantly different water level elevations that decrease with depth. This is consistent with the available data but it is not generally apparent from the well logs of deep wells because it is uncommon for a driller to pack off each aquifer for independent water-level measurements. Instead, multiple aquifers are commingled which results in a composite water level in the well.

The common practice of commingling aquifers in the Columbia River Basalt unit produces a high-permeability pathway through the well bore that allows water to migrate from high to low pressure aquifers on a continuous basis. The draining of ground water from shallow aquifers in this manner decreases the amount of water available for wells that produce exclusively from these zones. It also reduces the amount of water available to springs that sustain local streamflow. Another consequence of commingling is the admixture of waters with different water qualities. As noted above, shallow basalt wells in the uplands commonly show a direct response to precipitation which suggests that rainfall is able to rapidly infiltrate into the upper, unconfined portion of the basalt unit. This also suggests that any pollutants at land surface will be able to rapidly infiltrate into the upper system. This is consistent with the general principle that shallow wells are usually at higher risk from land-based pollution sources than deeper wells. However, the commingling of multiple aquifers produces a short-circuit in well bores that allows water, and any associated pollutants, to travel much more quickly from upper aquifers to lower ones than would be possible under natural conditions. In a similar manner, the commingling of aquifers can allow the admixture of deeper saline water with shallow, less saline waters in areas where salinity is a problem in the basalts.

A common problem in the basalt unit is the occurrence of saline water, especially in the deeper aquifers of the unit or in the centers of basins where ground water flow is upward. The source of the saline water is probably pore water in the marine rocks that underlie the unit in many areas west of the foothills of the Cascades. The extent of salinity problems in the basalts is not known with certainty because the occurrence of saline water is generally not reported on well reports but is discovered by happenstance after the fact in conversations with drillers, well owners, or consultants. However, known occurrences are widely scattered throughout the basin and are always associated only with areas underlain by marine rocks. Therefore, the occurrence of saline water at depth in the basalts is probably more likely to occur in areas that are underlain by marine rocks. This places an additional limitation on the development of the basalt aquifers over much of their extent.

Ground water pumpage from deeper basalt aquifers may induce the upward flow of deep saline water into the basalts causing salinities in the basalt aquifers to increase over time. For example, salinities are reported to have tripled between 1969 and 1996 in two basalt irrigation wells in section 26, Township 1S, Range 1W (WRD unpublished data). Anecdotal reports suggest that similar increases are happening in a variety of areas but hard data are lacking because no reporting is required for this kind of information. Commingling of deep and shallow aquifers can also allow upflow of

saline water through well bores without pumping in areas where ground water flow is naturally upward due to high pressures at depth.

As with the low-yield bedrock unit, the production and storage capacity of the Columbia River Basalt unit and its capacity to accept recharge are difficult to predict at any locality because hydrologic properties vary throughout the unit. For example, an area with many interflow breccias or several thick breccias will probably be able to sustain greater development than an area with only a few, or very thin, interflow breccias. Although general hydrologic properties of the unit are known (low storage and high production capacity), site-specific information on the thickness, extent, and properties of the various aquifers are generally poorly known and difficult to extrapolate over any distances. As in the low-yield bedrock unit, site-specific water-level and production data will allow better predictions to be made, especially if data are available over several years. Because prediction uncertainties will always be high, the response of these aquifers to development can only be determined with certainty by collecting water level and production data before, during, and after development occurs.

Basin-Fill Sediment Unit

The basin-fill sediment unit includes stream and lake deposits that accumulated in the trough that formed as the rising Coast Range caused the ocean to recede from the Willamette lowlands. The unit includes all sediments that occur above the Columbia River Basalt unit, or above the low-yield bedrock unit where the basalts are absent, except for the Willamette Silt unit (Figure 2 on page 8). The basin-fill unit is exposed at land surface in the Portland Basin and in the flood plains of the Willamette River and its major tributaries but is overlain by the Willamette Silt unit in most other lowland areas of the valley. Sediments in the basin-fill unit include clays, silts, sands, and gravels. Productive water-bearing zones occur in the sands and gravels whereas the silts and clays act as confining beds. Most of the sands and gravels were deposited by streams that drained the Cascade Range. As a result, sands and gravels are thickest along the eastern and southern margin of the valley and thin to the west. Thicknesses greater than 100 feet are common in many areas of the valley. Collectively, the basin-fill sediment unit contains the largest volume of ground water in storage and has the highest production capacity of all of the hydrogeologic units in the basin.

In general, the sands and gravels of the basin-fill unit have high porosities and high permeabilities. The most productive part of the unit occurs in unconsolidated sands and gravels in the flood plains of the major streams. The shallow sand and gravel aquifer in these areas is unconfined and well connected to adjacent streams. Wells in these areas generally have localized pumping impacts with high levels of interference with nearby streams. Highly productive water-bearing zones also occur in older sands and gravels which are present at depth below the flood plains of the major streams and beneath the Willamette Silt. Because these zones are commonly semi-confined to confined, pumping impacts tend to be more widespread. In the central Willamette basin, for example, overlapping interference from irrigation wells causes up to seventy-five feet of water level drop in the summer in the

area between Salem and Wilsonville in the basin-fill unit.

Elevated arsenic has been detected in some wells in the basin-fill unit. Most occurrences of greater than 50 µg/l are associated with areas where only a thin layer of basin-fill sediments overlies the low-yield bedrock unit. An exception occurs in the central lowland area of the Tualatin Basin (area not depicted in Figure 2 on page 8) where the basin-fill sediments are thick. Scattered occurrences of arsenic levels between 10 and 50 µg/l are also found throughout the basin-fill sediment unit. The factors that control the distribution of arsenic in the basin-fill unit are poorly understood. Therefore, it is not possible to reliably predict the distribution of areas where the risk of encountering elevated arsenic is high in this unit.

Ground water supplies in the basin-fill sediments are limited in areas where the unit is very thin or where it contains little sand and gravel. Areas that generally have less than twenty feet of sand and gravel are delineated in Figure 2 (page 8). Most of these areas are west of the modern flood plain of the Willamette River, where the basin-fill unit thins to a featheredge at the foothills of the Coast Range. Similar thinning occurs along the eastern margin of the valley at the base of the Cascade Range. Also, in the Tualatin Basin, the basin-fill unit has very little sand and gravel. Wells in these areas commonly have low yields. If no productive zones are present, wells are generally drilled into the underlying basalt or low-yield bedrock units.

Willamette Silt Unit

The Willamette Silt Unit is composed of bedded silts and clays that were deposited by enormous floods that were periodically released from a large, ice-dammed lake in the Missoula, Montana area during the ice age. Each flood poured down the Columbia River drainage and backed up into the Willamette Valley to form a temporary lake. Silts and clays in the lake water settled out of suspension to cover the land surface on the valley floor.

The Willamette Silt mantles land surface throughout most of the Willamette lowlands except in the floodplains of the Willamette River and its main tributaries, where it has been removed by erosion (Figure 2 on page 8). Throughout most of the central valley, between Salem and Wilsonville, the silt is greater than 100 feet thick but it thins greatly at the margins of the valley floor. In the southern valley, between Eugene and Albany, the unit is generally less than 20 feet thick. Although the silt forms thick deposits in the Tualatin Basin, it cannot easily be distinguished on well logs from the fine-grained basin-fill deposits that underlie it. For this reason, it is not treated as a separate unit in the Tualatin Basin but is lumped into the basin-fill unit.

The Willamette Silt unit has high porosity but low permeability. Because of its low permeability, the unit is seldom exploited as an aquifer. However, shallow pit wells dug into the silt were an important water supply for many early

settlers in the Willamette Valley. These wells had low yields but were able to supply enough water for domestic needs. Although not important as an aquifer, the Willamette Silt acts as a wet sponge that stores large quantities of ground water. The silt is recharged by precipitation during the winter months and slowly releases water to streams and underlying aquifers throughout the year. Ground water stored in the silt acts as a buffer to even out the effects of the irregular distribution of rainfall during the year. Because of its low permeability, the Willamette Silt also helps to protect the underlying aquifers from contamination that occurs at land surface.

APPENDIX C

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APPENDIX D

WELL CONSTRUCTION

Well construction standards are a fundamental tool for managing and protecting ground water resources. The Water Resources Department licenses well constructors and develops and enforces rules for well construction. A properly constructed well prevents: 1) contamination from entering the well; and 2) the vertical movement of water within the well bore.

Surface runoff and shallow ground water are highly susceptible to contamination from septic effluent, agricultural chemicals, lawn and garden chemicals, gasoline, oil, solvents, and other pollutants. The well casing and seal prevent surface water or shallow ground water from entering a ground water resource through the well. The appropriate amount of surface casing and seal is dependant upon the geology at a site. A minimum of 18 feet is required, but more is prudent in many areas.

Wells are allowed to develop water only from one aquifer. If more than one aquifer is encountered during the construction of the well, the constructor must complete the well in such a manner as to allow use of water from only one aquifer. This prevents ground water from moving vertically within the well bore, which can result in the waste of water or possibly allow contamination or non potable water to move from one aquifer to another. In several areas in the state where well construction standards were routinely not met, artesian water at depth has been allowed to flow upward, via well bores, where it leaks into shallower aquifers and ultimately flows to waste into streams and rivers. This is equivalent to having a pump running 24 hours a day, every day, in the deeper aquifer. The result has been the depletion of the artesian resource. In other areas, brackish or saline water has been allowed to flow upward in well bores where it has leaked out into shallower aquifers and contaminated them.

When wells are no longer needed at a site or the well construction materials are failing, the well should be abandoned. This is to prevent contamination or waste of the ground water resource and to prevent loss of artesian head. Occasionally, animals or people fall into wells that have not been properly abandoned. This is of particular concern with shallow, hand dug wells.

The well constructor is responsible for the construction of the well for the first three years; a $4000 bond covers possible repairs. Beyond the initial three years, the constructor can still be required to repair the well, but ultimately the landowner of the property where the well is constructed is responsible for the condition, use, maintenance of setbacks, and abandonment of the well.