CHAPTER 5

Stream Flow and Hydrology Characterization

GOAL

Move toward normative flow conditions to protect and improve watershed and stream health, channel functions, and public health and safety. (Normative flow has the magnitude, frequency, duration, and timing essential to support salmonids and other resources.)

INTRODUCTION

Hydrology concerns the properties, distributions, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere. **Hydraulics** concerns the practical applications of water—the act of operating, moving, or employing water in motion. Both relate to how water flows: its volume, speed, and pressure. For example, precipitation and flooding are hydrologic conditions; levees are a hydraulic mechanism to control flooding. Because water moves downstream in a watershed, both upland and instream conditions affect water flow. Understanding the Columbia Slough Watershed's hydrology and hydraulics is essential in order to formulate effective management and restoration alternatives.

OVERVIEW

To fully understand the hydrology of the Columbia Slough Watershed, it is important to look back to the geologically significant, and recurring, Ice Age floods that drained glacial Lake Missoula repeatedly from 15,300 to 12,700 years ago. They are frequently referred to as the Bretz floods in honor of J. Harlan Bretz, a University of Chicago geology professor and researcher responsible for developing the theory of the floods. Glacial Lake Missoula formed by ice dams at the southern terminus of the Cordilleran Ice Sheet and occupied a maximum area of 500 square miles (the size of Lake Erie and Lake Ontario combined). When the ice dams failed, the lake drained catastrophically in as little as 3-5 days with the outburst floods traveling at a maximum speed of 90 miles per hour. These floods carved large areas of eastern Washington (called the channeled scablands) and filled the Columbia River Gorge with up to 800 feet of water. When the floodwaters reached a narrow section of the Columbia River near present-day Kalama, Washington, they backed up and inundated the Willamette Valley to an area south of Eugene. During this era, glacial "erratics" (large boulders) were deposited by the floodwater. Winds subsequently deposited fine loess soils in the Willamette Valley. These repeated floods deposited gravels and fine sediments in the Portland area and formed the topography of, among other features, the Alameda Ridge that gently slopes north to the Columbia Slough.

The end of glaciation, approximately 10,000 years ago, resulted in a rise in sea level and also the development of a more gentle and broad floodplain surrounding the Columbia River, in which side channels were formed and abandoned by the changing river, and within this environment the present-day Columbia Slough formed.

In the upper portion of the watershed, the mainstem Slough channel was seasonally connected with the Columbia River during high water near the present-day “Big Four Corners” area (NE 174th and Airport Way). Fairview Creek and its tributaries historically discharged through seasonal wetlands into the Columbia River near Fairview Lake and Blue Lake. In the early 20th century, a channel was dug from the wetlands at Fairview Lake to the Columbia Slough, and thus Fairview Lake and Fairview Creek became part of the Slough watershed. In the lower watershed, Pearcy Island (now Kelley Point Park) was seasonally flooded and a Slough channel separated it from the north Portland (USC&GS 1888).

Until 1917, the Columbia Slough was part of the active floodplain of the Columbia River and was seasonally inundated, forming and re-forming side channels, wetlands, sloughs, and shallow lakes. Dozens of streams flowed north from the slopes of the Alameda Ridge and drained into the Columbia Slough. Over the years, development for agriculture and then urban uses has drastically altered the watershed hydrology and the flow characteristics of the mainstem channel and associated waterways. To control flooding and enable development to occur in the floodplain, the waterway has been channelized, fill has been placed in the floodplain, and levees and large pumps have been constructed.

In 1917, local property owners established three drainage districts – Peninsula Drainage District No. 1 (Pen1), Peninsula Drainage District No. 2 (Pen2) and Multnomah County Drainage District No. 1 (MCDD) – to eliminate seasonal flooding and promote agricultural development in the floodplain. At the direction of these drainage districts, farmers and community members began building levees along the Columbia River to protect farmland, and later urban development, from seasonal floodwaters. In a 1918 letter to the US Army Corps of Engineers, the MCDD Board of Supervisors wrote:

> The sole object of the proposed district improvement is to make productive by creating conditions favorable to its full use for agricultural purposes…Such an improvement will be an aid to the development of the enclosed and adjacent lands for industrial and commercial purposes and can in no way interfere with such development.

In addition to building levees, the drainage districts provided important services in the watershed, including maintaining and improving levees and pumping systems and managing the Columbia Slough. Today, an 11-person MCDD staff manages the levees, water levels, and flows of all three adjacent districts as a single environmental system (along with a fourth district, the Sandy Drainage Improvement Company, to the east). Detailed discussion of MCDD’s current management activities are discussed under “Water Level Management” in a later section of this chapter.

After the newly built levees isolated the Slough from the seasonal floodwaters of the Columbia River, sanitary and industrial sewage discharges caused excessive pollution in the Lower Slough. To address the pollution, the City of Portland dug the City Canal (now called Peninsula Canal) in 1919 to reconnect the Lower Slough to the Columbia River and flush sewage out of the waterway. This effort did not succeed, however, because the tidal effect and low gradient of the Lower Slough did not allow enough additional Columbia River flow to improve water quality. Furthermore, the opening to the Columbia River silted in quickly, most likely because it was perpendicular to the river’s flow.

With the seasonal flooding controlled, urban development began to accelerate in the managed floodplain. In 1941, the City of Vanport was constructed (where Portland International Raceway, Heron Lakes Golf Course, and the Expo Center are now located) by the Housing Authority of Portland to provide affordable housing for workers in the Kaiser Shipyards during World War II. The City of Vanport was Oregon's second-largest city and housed approximately 17,000 residents, including much of Oregon's minority population. After heavy rains, snowmelt and warm weather contributed to unusually high water levels, and the Vanport Flood occurred on Sunday, May 30, 1948. The Columbia River gauge at Vancouver, Washington, reached approximately 31 feet National Geodetic Vertical Datum (NGVD), which is nearly the 100-year flood level and 15 feet above flood stage. At approximately 4 pm, a 125-foot-wide railroad dike, located at N. Portland Road, failed, flooding the City of Vanport and displacing its residents (Maben 1987).

After the Vanport Flood, the U.S. Army Corps of Engineers (USACE) and the City of Portland plugged the Peninsula Canal at both ends to provide maximum flood protection. Levees have been strengthened numerous times since 1919. Following the flood of 1964, the mid-dike levee near NE 142nd Avenue was constructed to further protect developed areas within the floodplain.

Fill, draining, and conversion of both wetlands and agricultural lands have now occurred, and industrial and commercial businesses cover most of the historic floodplain. Between the 1960s and 1980s, approximately 500 acres of the historic Ramsey Lake, located between Smith and Bybee Lakes and the Willamette River, were filled with dredge spoils. This lake and floodplain wetland area historically comprised an area of 650 acres and included a seasonal stream (Gatton's Creek) that flowed west to the Willamette River and a channel connecting it to the Columbia Slough on the east (USC&GS 1888). Today, the Rivergate Industrial Area lies on the historic lakebed, as well as approximately 150 acres of wetlands along the Columbia Slough.

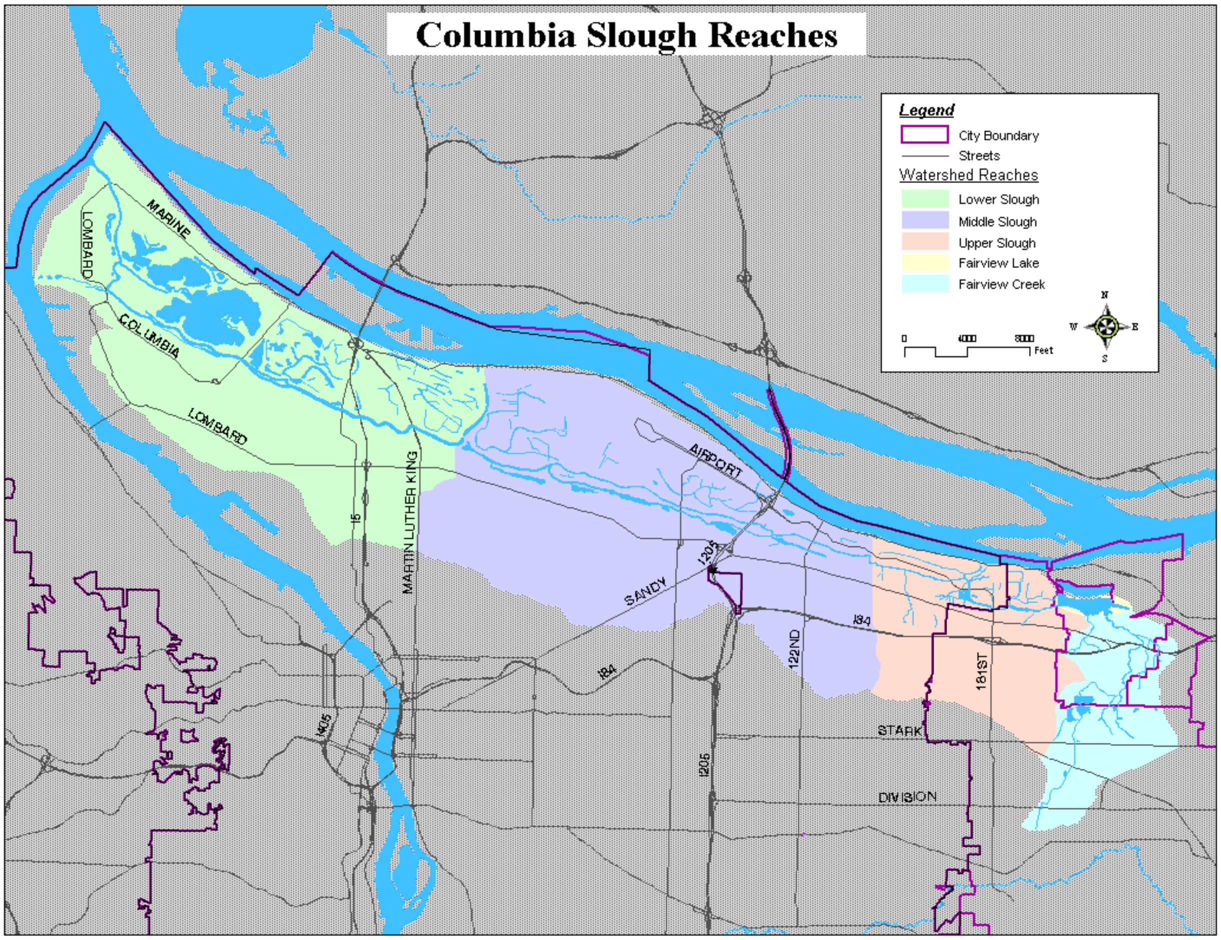
The Columbia Slough now comprises a 19-mile main channel that parallels the Columbia River, with several miles of hydrologically connected southern and northern channels as well as approximately 30 miles of secondary waterways. The Slough drains approximately 32,700 acres of land with diverse land uses, including industrial, commercial, residential, and agricultural. Much of Portland's industrial and commercial land is contained within the watershed's boundaries. (See Chapter 4: Land Use and Demographics.) Extensive development in upland areas includes primarily residential land use.

As a result of these changes, the current hydrology of the waterway is complex, and the highly managed nature of the Middle and Upper Slough significantly affects flow. In turn, the hydrology has an effect on physical habitat, water quality, and biological communities that are able to adapt to these conditions.

REACH AND SUBWATERSHED DESCRIPTIONS

The watershed is divided into five reaches, based on hydraulic characteristics (Figure 5-1):

Figure 5-1: Columbia Slough Reaches and Subwatershed Areas



Note: Subwatershed boundaries are approximate.

- **Fairview Creek** originates in a wetland complex at the base of Grant Butte, to the south near SE 181st and Powell Blvd. Fairview Creek and its tributaries flow into Fairview Lake. Flow from Osborn Creek also enters Fairview Lake.

- **Fairview Lake** is bordered by 223rd Avenue on the east, Interlachen Lane on the north, and Fairview Lake Way on the west. The lake flows into the Upper Slough through a culvert/weir system on the west side.

- The **Upper Slough reach** starts at Fairview Lake on the east and extends west to the mid-dike levee at NE 142nd Avenue.

- The **Middle Slough reach** extends from the mid-dike levee near NE 142nd Avenue to the Pen2 levee near NE 18th Avenue.

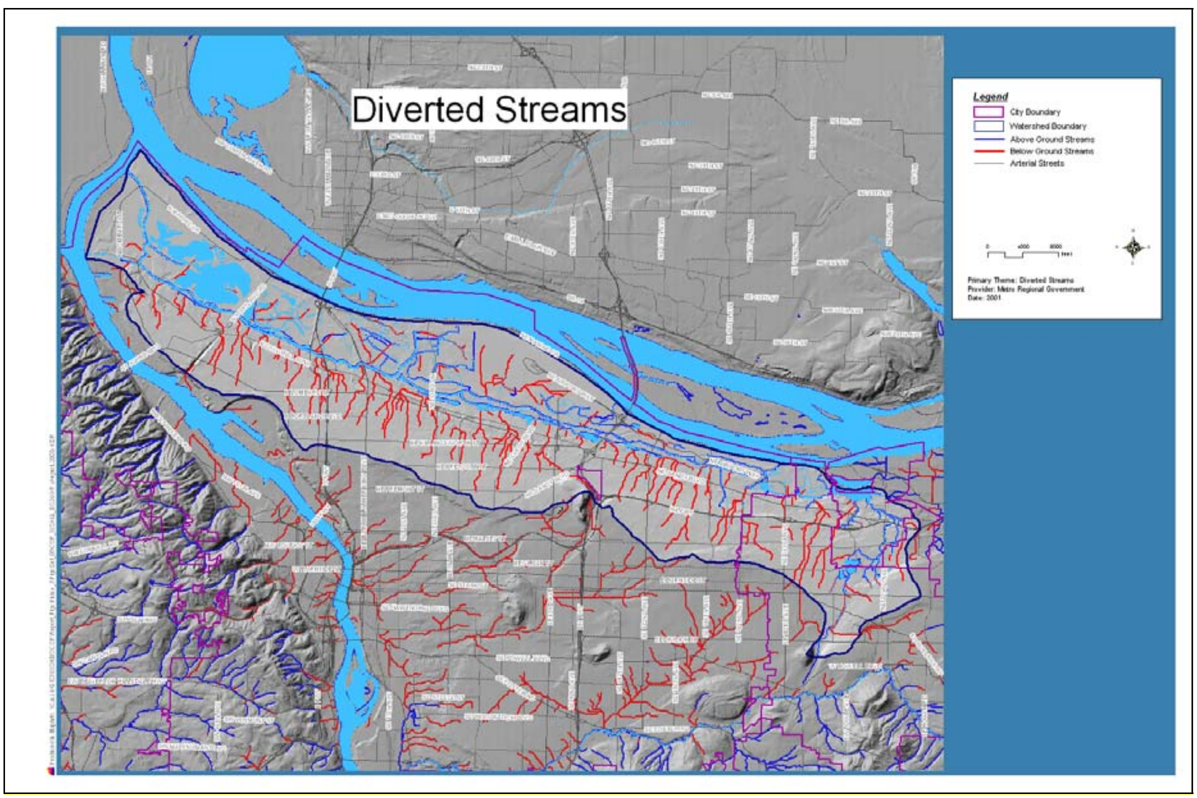
- The **Lower Slough reach** starts at the Pen2 levee and extends approximately 8.5 miles to its mouth at the Willamette River. This is the only portion that is outside of the managed floodplain and is influenced by tides in the Columbia and Willamette Rivers.

The topography of the Columbia Slough Watershed is generally flat near the Columbia River, with the elevation rising in the upland area south of the Slough (from Columbia Boulevard to the Alameda Ridge and similar upland features east of Rocky Butte). The gradient, or slope, of the Slough waterway channel is also nearly flat. As a result, the Slough can flow in both directions, depending on the tide and operation of the pumps and gravity gates in the levees. The Lower Slough is tidally influenced, and during high tide, the Columbia and Willamette rivers create a backwater effect upstream as far as NE 18th Avenue, preventing outflow from the Lower Slough.

Urbanization has increased impervious surfaces in the watershed. Approximately 54 percent of the watershed now consists of impervious area such as roads, parking lots, and rooftops (Evonuk 1999). These surfaces increase stormwater runoff volume and peak flows, altering the hydrography of the receiving water with its associated impacts on aquatic habitat. Impervious surfaces also decrease percolation into the soil and reduce groundwater infiltration into the system, effectively short-circuiting the hydrologic cycle.

Development in the watershed has also resulted in the diversion of many creeks and streams from natural channels to underground pipes. Only a few surface streams still exist: Fairview, Osborn, No Name, and Wilkes Creek, and the Alice Springs complex. All of these streams are in the eastern portion of the watershed. Figure 5-2 shows approximate locations of the dozens of historical streams that have been filled in the watershed.

Figure 5-2: Diverted Streams Map



Source: Metro

Lower Slough

To characterize current hydrology in the Columbia Slough, it is critical to note that the current stream flow patterns of the Columbia and Willamette Rivers are drastically different from historic conditions. Numerous dams spanning both rivers provide flood control, hydropower, and water storage. Historically, the Columbia River experienced spring freshets, or high flows, when snowmelt in the upper watershed occurred in late spring and early summer. Additionally, fall rains provided increased flows in the Columbia River. Today, management of dams is primarily for hydropower production and flood control, attenuating the high and low flows. This alteration directly affects flow in the Lower Columbia Slough. Water levels in the Lower Slough are affected to a lesser extent by the pumping regime at MCDD Pump Station No.1.

During incoming tides, water from the Willamette River travels up the Lower Slough. A 1-foot to 2-foot change in water surface elevation occurs on a 12-hour cyclical basis within the entire Lower Slough as a result of tidal influence (BES 1989). Flow direction in the Lower Slough varies with the tide. Rising tidal changes induce an upstream (easterly) flow that complicates the discharge of water from the Lower Slough to the Willamette River.

The channel bottom in the Lower Slough ranges from elevation 2.0 to 4.5 feet NGVD. The channel width varies from about 50 to over 400 feet near North Portland Road, with most of the reach between 100 and 200 feet (CH2M Hill 1995).

The Pen2 levee separates the Lower Slough from the Middle Slough. This location also marks the south end of the Peninsula Canal. MCDD Pump Station No. 1 is located on the Pen2 levee and pumps water from the Middle Slough to the Lower Slough. When the water level in the Lower Slough drops below 8 feet NGVD and below the water elevation in the Middle Slough, water can flow to the Lower Slough through the floodgates in the levee.

Pen1 and Pen2 border the north side of the Lower Slough and are separated from each other by Interstate 5. Multiple pump stations move water from drainageways and sloughs within these districts into the Lower Slough. While most development in this area is above the floodplain and other properties are located on fill, which places the properties above the 100-year floodplain, the Lower Slough contains the watershed area subject to 100-year flooding because it has low areas that are unprotected by levees.

Smith and Bybee Lakes border the Lower Slough. This complex of nearly 2,000 acres comprises the largest urban wetland in the United States. Bybee Lake is connected to the Lower Slough by the North Slough, a mile-long channel running between the St John’s Landfill and the south side of Bybee Lake. A water control structure, located where Bybee Lake and the North Slough connect, regulates the lakes’ levels and controls water flow between the lakes and the Lower Slough. This water control structure was constructed in 1983 to address an avian botulism problem in Smith and Bybee Lakes (Wells 1995). The structure was re-built in 1991 to prevent water from flowing into the lakes from the North Slough. The structure changed the dominant flow direction in this part of the Lower Slough. Formerly, the dominant, tidally influenced flow was through the North Slough to Smith and Bybee Lakes. The effect of the water control structure shifted the tidal flow to the Slough mainstem, which goes south of the St. John’s Landfill. Construction of a replacement water control structure that contains fish passage features and varied water level control features was completed in 2003. Velocities in the North Slough are expected to increase as Willamette River water again preferentially travels into the North Slough and lakes.

Middle Slough

The Middle Slough extends from the Pen2 levee to the mid-dike levee at NE 142nd Avenue and contains 6,848 acres. The Middle Slough includes a substantial southern arm complex of sloughs and lakes. These include Buffalo Slough, Whitaker Slough, Johnson Lake, Mays Lake, Whitaker Ponds, and Prison Pond. Whitaker Slough, Johnson Lake, Prison Pond, and Whitaker Ponds are active groundwater discharge areas, with visible springs. The Middle Slough receives water from the Upper Slough, stormwater outfalls, natural springs, overland flow from the south, and groundwater. Historically, dozens of free-flowing streams drained the Alameda Ridge and provided water to the Middle Slough. All of these have been piped or filled.

The Middle Slough and associated waterways are completely surrounded by levees and are contained within MCDD. As a result, the water can only reach the Lower Slough if pumped or allowed to flow through the levee's gravity gates in the Pen2 levee. The pumping regime at Pump Station No. 1 has a substantial impact on the Middle Slough's water movement and sediment quality. Shutting down the pumps for extended periods of the day results in a gradual stoppage of flows in the Middle Slough and eliminates flows into the Lower Slough. As the water slows down, fine sediments settle out of the water column near the pump station; when the pumps are restarted, these sediments may be re-suspended in the water column (CH2M Hill 1995).

In an average year, MCDD is able to allow Middle Slough water to flow through the floodgates into the Lower Slough by gravity for several months (generally late fall to early winter). During the other months, or when water levels in the Lower Slough are higher than those in the Middle Slough, water must be pumped against the gradient. Pump Station No. 1 has a pumping capacity of 250,000 gallons per minute (gpm).

The width of the Middle Slough mainstem waterway varies in general from 30-100 feet. A section just upstream of MCDD Pump Station No. 1 (where the Vanport Flood broke the levee and gouged out the channel) was 90 feet deep after the 1948 flood, but now is approximately 10 feet deep. The average channel bottom in the Middle Slough ranges in elevation from 2.0 to 4.0 feet NGVD (CH2M Hill 1995). Estimates of groundwater inflow in the Slough vary from 50 to 100 cubic feet per second (cfs).

Upper Slough

The Upper Slough extends from the NE 142nd Avenue mid-dike levee to Fairview Lake and contains approximately 2,560 acres. The Upper Slough includes a substantial northern arm that extends from the mid-dike levee to MCDD Pump Station No. 4 at NE 174th and Marine Drive in the Big Four Corners area. As described in the Overview section of this chapter, this location was the historic source of connection to the Columbia River and was the eastern boundary of the Columbia Slough. The Upper Slough waterway receives water from Fairview Lake, Wilkes Creek, stormwater outfalls, Alice Springs, groundwater, and overland flow from the south

Just like the Middle Slough, the Upper Slough waterway is completely surrounded by levees and is contained within MCDD. As a result, the water can only flow out of the Upper Slough through the gravity gates in the mid-dike levee (to the Middle Slough), or through the pumps at MCDD Pump Station No. 4 (to the Columbia River). Generally, MCDD leaves the gravity gates open, allowing Upper Slough water to flow into the Middle Slough. During – or in anticipation of – large storm events, MCDD may close the gates and pump water from the Upper Slough out to the Columbia River. The mid-dike levee was built to allow this flexibility in flow management. MCDD Pump Station No. 4 has the capacity to pump 275,000 gpm to the Columbia River. When in operation, the pump station subjects the Upper Slough to flow reversal, as the water flows from east and west toward this north outlet into the Columbia River. Pumping at Pump Station No. 4 varies with the year; in wet years, the pumps may be used daily for up to five months; in dry years, the pumps are used infrequently.

The widths, depths, and other characteristics of the Upper Slough are generally comparable to those of the Middle Slough.

Wilkes Creek is one of the three remaining creeks in the Columbia Slough Watershed. It originates from a perennial spring at the crest of the Alameda Ridge on an agricultural property adjacent to Interstate 84, and flows approximately two miles north through open space, residential, and agricultural areas to the Upper Columbia Slough near NE 154th Avenue. Although mostly free-flowing, it is intermittently piped.

Fairview Lake and Fairview Creek

As stated in the Overview section, Fairview Creek and its tributaries historically discharged through seasonal wetlands into the Columbia River near present-day Fairview Lake. In the early 20th century, a channel was dug from these wetlands to the Columbia Slough, and thus the Fairview Creek watershed became part of the Slough watershed (ONHIC 2002). In the 1960s, a weir/water control structure was built at the outlet of these wetlands, creating Fairview Lake and allowing this area to be managed for floodwater storage in the winter months and recreation in the summer months. The original water control structure was replaced by MCDD in fall 2004. Today, Fairview Lake is approximately 100 acres in size, has an average depth of 5-6 feet, and receives its primary flow from Fairview Creek and Osborn Creek.

Fairview Creek is 5 miles long, flowing from spring-fed wetlands on the northeast side of Grant Butte down to Fairview Lake, through the towns of Gresham and Fairview. Two tributaries are included in this reach: No Name Creek and Clear Creek. Osborn Creek is also included in the Fairview Creek reach, even though it drains directly to Fairview Lake instead of Fairview Creek. This creek is grouped in this reach because it is more similar in character to Fairview Creek than to Fairview Lake.

HYDROLOGIC CONDITIONS

Climate

The Portland area has a typical Pacific Northwest climate: wet, mild winters and springs and relatively dry summers. Maritime influence during the entire year generally moderates temperatures and prevents hot or cold extremes. The annual air temperature range is relatively narrow, with means of 37 ^{o}F in January and 67 ^{o}F in August. Temperatures are normally below freezing fewer than 30 days per year and above 90^{o}F fewer than 10 days per year.

Average annual precipitation for the Columbia Slough Watershed is approximately 40 inches, with about 70 percent occurring from November to March. July and August are normally the driest months, with less than four percent of the total annual rainfall.

Urban Development and Impacts on Hydrology

Historically, most precipitation falling on the Columbia Slough Watershed would be intercepted by vegetation, stored in wetlands, evaporated, or percolated into the ground, where it would either be taken up by plant roots or trickle down to the groundwater. Groundwater was recharged during the winter months and thus provided base flows to the streams and Slough channels during the dry summer months. Excess rainfall would run off into the dozens of streams located on the Alameda Ridge. Generally, water levels in the waterways reflected the seasonality of the precipitation, with low levels during the summer months and high levels during the winter months. Floodwaters from the Columbia River inundated the northern part of the watershed annually during late spring and early summer and resulted in the highest flows. The watershed was home to thousands of Chinook people, yet largely represented undeveloped, or minimally altered, hydrologic conditions.

Urban development has interrupted the natural hydrologic cycle. Buildings and paved areas are impervious and do not allow rainfall to percolate into the ground. Some of the rainfall may still evaporate or absorb to these surfaces, but for the most part it runs off impervious surfaces.

Today, much of Portland's industrial and commercial land is within the watershed's boundaries. Over the years, the watershed has developed from a natural system to agricultural, then industrial, commercial, and residential uses, and the ground has been covered by houses, streets, parking lots, warehouses, and industrial campuses. Development in the watershed has also resulted in many creeks and streams being diverted from natural channels to underground pipes. David Evonuk at Portland State University described the watershed in terms of six different land uses, from industrial to rural. The study estimated the percentage of total impervious area of the Columbia Slough Watershed to be 54 percent (Evonuk 1999).   The higher the amount of impervious area, the more runoff produced. In order to prevent localized flooding in the urban area, this runoff needs to be managed.

There are three major strategies used to manage stormwater runoff in the Columbia Slough Watershed:

- Retaining stormwater onsite
- Collecting stormwater in pipes and infiltrating it into the ground
- Collecting stormwater in pipes and discharging it to the surface water (creeks, lakes, rivers or sloughs)

Retaining water onsite can be accomplished by planting vegetation (tree canopy, eco-roofs, etc.) to intercept it, directing water into vegetated areas to infiltrate it, or collecting water in cisterns for non-potable uses.

Stormwater runoff that does not stay onsite is collected by the piped infrastructure and can be discharged to the ground through drywells (also called sumps) if the infiltration rate is high enough.

Stormwater runoff collected in pipes can also be discharged to creeks, lakes or sloughs. This last management strategy has two consequences to the hydrologic cycle: it increases the intensity of flows to the water bodies, and decreases the recharge of groundwater. This results in increasing peak flows during the wet season and decreasing low flows during the dry season.

Stormwater runoff volume in all areas of the Columbia Slough Watershed has changed with the increased development. According to MCDD staff, stormwater runoff now enters the Slough through the storm sewer system within hours of rainfall, instead of over the course of days, which was the case during more undeveloped conditions. This has necessitated recent upgrades in pumping capacity to MCDD's pump stations. Development within the watershed has resulted in the Slough's evolution such that it behaves now more as a flashy urban stream.

In another alteration to the natural hydrologic cycle, some of the stormwater runoff from the edges of the Slough watershed boundary is actually collected into piped systems that discharge to the Willamette and Columbia Rivers.

It is important to note that the piped sewer system is, in some places, designed to operate differently based on amount of precipitation. For instance, in the combined sewer area of North Portland, during most storms, much of the stormwater runoff goes to the Columbia Boulevard Wastewater Treatment Plant and from there discharges to the Columbia River (bypassing the Slough altogether). However, during very large storms (25-year storms and larger), some of this material may flow into the Lower Columbia Slough.

Stormwater Jurisdictions

The Oregon Department of Environmental Quality (DEQ) is delegated by the US Environmental Protection Agency (EPA) to implement the Clean Water Act (CWA). As part of the CWA, DEQ regulates stormwater runoff entering surface waters and groundwater through municipal and private infrastructure.

The Cities of Gresham, Wood Village, and Fairview have stormwater inputs to Fairview Creek and Fairview Lake. The Cities of Portland and Gresham are responsible for municipally owned stormwater infrastructure that enters the Columbia Slough waterway. The City of Gresham has six stormwater outfalls that discharge directly to the Upper Slough. The City of Portland is responsible for dozens of municipal outfalls that discharge to the Slough within City boundaries. The Port of Portland owns nine outfalls that discharge to the Middle Slough from Portland International Airport and several more that discharge from Port-owned property in the Lower Slough. In addition, there are numerous privately owned stormwater outfalls throughout the Slough system.

Overlying these jurisdictions are the Pen1, Pen2 and MCDD drainage districts. Drainage district staff members operate the pumps and gravity gates to convey the water out of the districts into the Lower Slough and the Columbia River. Their primary mission is flood control and protection of property, although they also work in concert with agencies and landowners to improve the environmental conditions of the Slough.

Figure 5-3 shows Columbia Slough jurisdictions and drainage districts. Table 5-1 shows the size of the drainage districts.

Surface Water

In general, water levels in the Lower Slough are not managed. The flow in the Lower Slough is dominated by the tides, and is affected to a lesser degree by the management of the dams upstream on the Columbia and Willamette Rivers and by the water flowing in from the drainage districts. The exception to this is the water levels of Smith and Bybee Lakes. Metro manages the water levels in Smith and Bybee Lakes to mimic natural hydrologic conditions to the extent possible to support native plant communities while controlling reed canarygrass. This management regime also provides habitat for myriad wildlife, including western painted turtles, amphibians, birds (particularly waterfowl, shorebirds and neotropical migratory songbirds), mammals such as river otters, and juvenile salmonids (coho, Chinook, and steelhead).

The Peninsula Drainage Canal acts as a closed system. It is bounded on all sides by levees, with no inputs or outlets except for direct rainfall and evaporation.

Water levels in the drainage district areas are managed primarily for flood control, but also for water quality and wetland habitat.

Water Level Management

Historically, water levels in the Slough system mirrored those in the Columbia River, rising in the winter and especially during the spring freshet, and receding in the summer. Groundwater would have been a major component of the remaining flow, as well as tidal influence near the Willamette and Columbia Rivers. Current water level management results in conditions that are very different from historic conditions.

In summer, Fairview Lake levels are allowed to rise for summer recreational use. The lake's weir structure is closed in early May to maintain the lake’s water elevation at about 10 feet NGVD. Beginning in early October, the lake’s water elevation is lowered to an elevation of 8.5 feet NGVD for the winter months to provide flood control storage capacity.

In summer, the Upper Slough water level is kept relatively high to maintain water for surface water withdrawals. Water rights require the Slough to be maintained at a minimum elevation of 7.5 feet NGVD during the summer months. The mid-dike levee can be left open unless the Middle Slough water levels fall below this level. As water rights are abandoned or reconfigured with the development of this area, this restriction may diminish.

During the rainy season, the Upper Slough water levels can be drawn down in anticipation of rain events. If necessary, MCDD can close the mid-dike levee and use Pump Station No. 4 to pump the Upper Slough water into the Columbia River.

Figure 5-3: Columbia Slough Jurisdictions and Drainage Districts

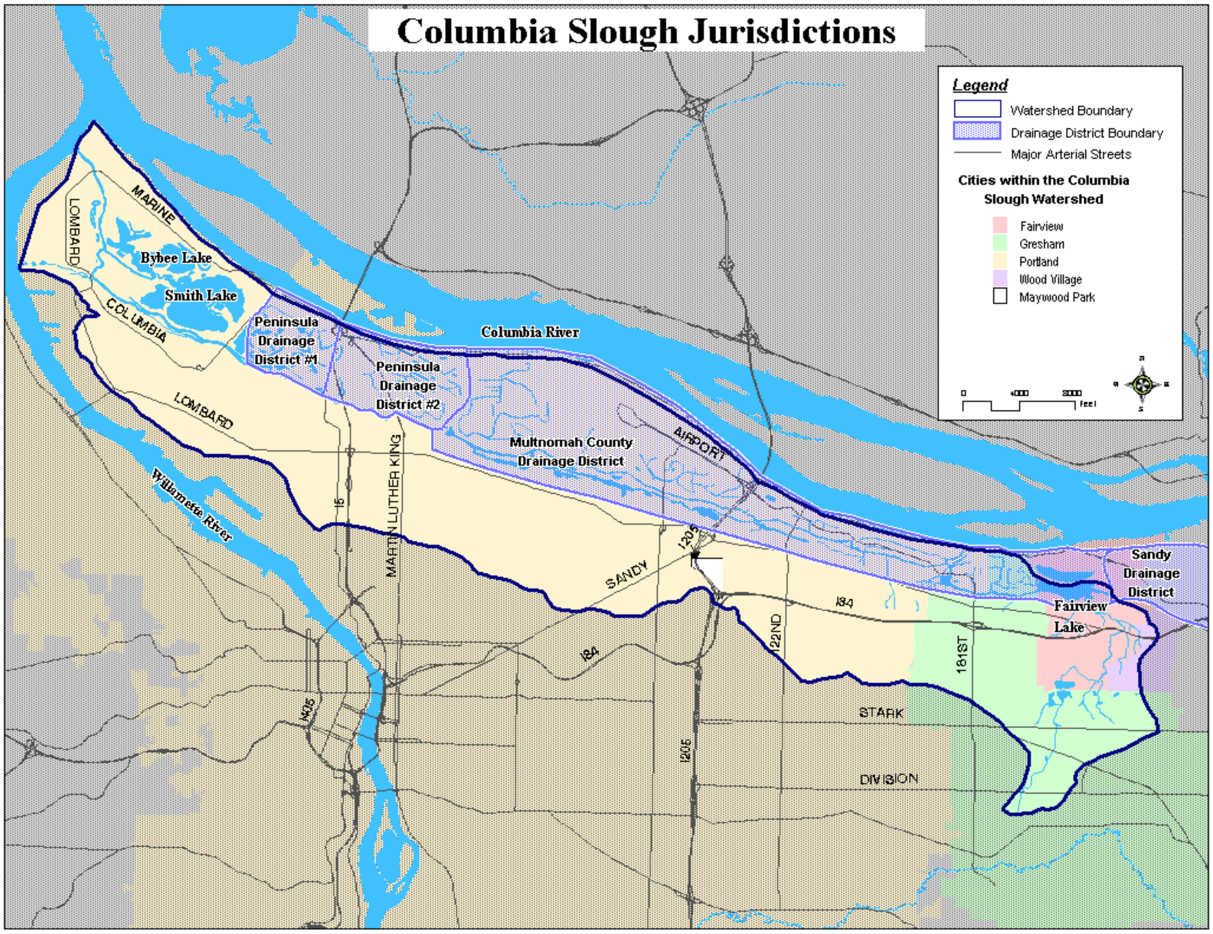


Table 5-1: Drainage District Sizes

Drainage District	Acres	Acres in Watershed	Acres in City of Portland	Base Flood Elevation* (NGVD**)
Peninsula Drainage District No. 1	901	901	901	11 ft
Peninsula Drainage District No. 2	1,475	1,475	1,475	5 ft
Multnomah County Drainage District No. 1	8,832	8,429	6,474	14 ft
TOTAL	**11,208**	**10,805**	**8,850**	

*The BFE refers to the elevation associated with the 100-year flood (a flood with a 1 percent chance of occurrence in any given year).
**NGVD – National Geodetic Vertical Datum (approximately mean sea level)

Water levels in the Middle Slough are typically maintained at 5 to 6 feet NGVD. When the water level in the Lower Slough drops 15 inches below the water level in the Middle Slough, water can flow from the Middle to the Lower Slough through the gravity gates in the Pen2 levee. The 15-inch gradient is necessary to provide enough pressure to push open the floodgate to the Lower Slough. When the water level in the Lower Slough is above this level, water must be pumped against the gradient to move it from the Middle to the Lower Slough.

In fall and winter, MCDD manages the water in the Middle Slough to help the Port comply with its permit discharge limits for de-icing materials. The permit limits are flow-based. Thus, the water is held back as long as possible before the event to provide greater flow during the event.

MCDD maintains a system of small pump stations to control water levels in the secondary waterways that discharge to the main arms of the Lower, Middle and Upper Sloughs. Pen1 levels are kept lower than their corresponding base flood elevation (BFE), as are Pen2 water levels.

Impoundments and Flow Augmentation

Flow – or the impoundment of flow – in the managed areas of the Columbia Slough (Pen1, Pen 2, Middle Slough, Upper Slough, Fairview Lake) has a marked effect on water quality. Impoundments contribute to increased temperature and algal growth. The first reason is because holding the water back increases the residence time, or the time the water stays in any one place. This allows the water to heat up in the sunlight, and algae can grow prolifically in this high-nutrient, warm environment. The second reason is because higher water levels decrease the amount of groundwater seeping into the channel. Even in the summer, the temperature of groundwater is relatively constant at about 10 degrees Celsius, while the surface water of the Slough regularly reaches 20 degrees Celsius or more. Since groundwater can cool the Slough off significantly, increased groundwater flow is desirable.

The impoundments in the Columbia Slough system are the levees themselves, the weir at Fairview Lake, culverts throughout the system, water rights withdrawal needs, and management agreements such as between MCDD and the Port for the airport's deicing discharge.

The stagnant nature of the diked Columbia Slough has long been seen as a problem. There have been several major attempts to address this problem. These have been called "flow augmentation" strategies because they involve bringing in more water to flow through the system. One such attempt, mentioned earlier, was the excavation of Peninsula Drainage Canal to connect the Lower Slough with the Columbia River. In this case, Columbia River water was meant to augment the flow in the Lower Slough, to flush out the sewage, industrial waste and other pollutants. This attempt did not work mainly because the opening would silt itself in frequently.

Another flow augmentation strategy was field tested in 1994 and 1995. Water was continuously pumped out from the Middle Slough throughout the summer to lower the water level elevations in the Upper and Middle Slough, allowing more groundwater to flow into the system. The velocity of the water in the Upper and Middle Slough increased, decreasing its residence time. The shorter residence time did reduce the algal growth in the Middle and Upper Sloughs.

However, the clearer water enabled sunlight to penetrate deeper into the water column, allowing dormant macrophyte[1] seed to flourish. The macrophytes quickly established themselves in the Middle Slough. Currently, they clog the main channel from NE 122nd Avenue to NE 18th Avenue from about mid-May until they die off at the end of September. Macrophytes themselves become impoundments because they grow so thickly they actually cause water to build up behind them. MCDD removes approximately 90 to 100 tons of macrophytes from pump station trash racks each year.

It is postulated, though not known, that the macrophytes provide habitat for epiphytic macroinvertebrates. It is also postulated that the macrophytes may dampen the daily pH fluctuations as a result of the form of carbon used in their biochemical processes. (See Chapter 6: Water and Sediment Quality Characterization.)

The most recent effort concentrates on removing six impoundments (five culverts and one water right) throughout the Middle Slough, while simultaneously creating a deeper, central meandering channel. The deeper, central channel will discourage macrophyte growth and allow the water levels to be drawn down lower, thus increasing cooler groundwater flow into the system.

Groundwater

The shallow groundwater, contained primarily within the overbank flood deposits in the Columbia Slough system, provides significant inputs to the Upper and Middle Slough, as well as some input to the Lower Slough and nearby lakes and wetlands. Groundwater discharges are most evident in the Middle and Upper Slough, with an estimated flow range of 50 to 100 cubic feet per second (cfs). A 1993 water level test found that groundwater reached a steady state of 65 cfs with the pumped discharge from MCDD Pump Station No. 1 (Wells and Berger 1994). A large portion of the groundwater input occurs in the south arms of the Upper and Middle Slough. This shallow groundwater is recharged by infiltration of precipitation. Where impervious surfaces prevent infiltration, recharge of the surficial aquifer can be disrupted. In many areas of the watershed, sumps (drywells) direct runoff from impervious areas into the ground, restoring some of the groundwater inputs. Additional information on sumps is included in Chapter 6: Water and Sediment Quality Characterization, and Chapter 8: Public Health and Safety Characterization.

Unlike surface water, groundwater can and often does exist as layers. Aquifers are layers underground where the substrate is relatively permeable (such as gravel, sand, or loam), allowing the groundwater to flow from high gradient to low gradient. Aquitards are layers of relatively impermeable substrate (such as heavy clays) that significantly slow the movement of groundwater.

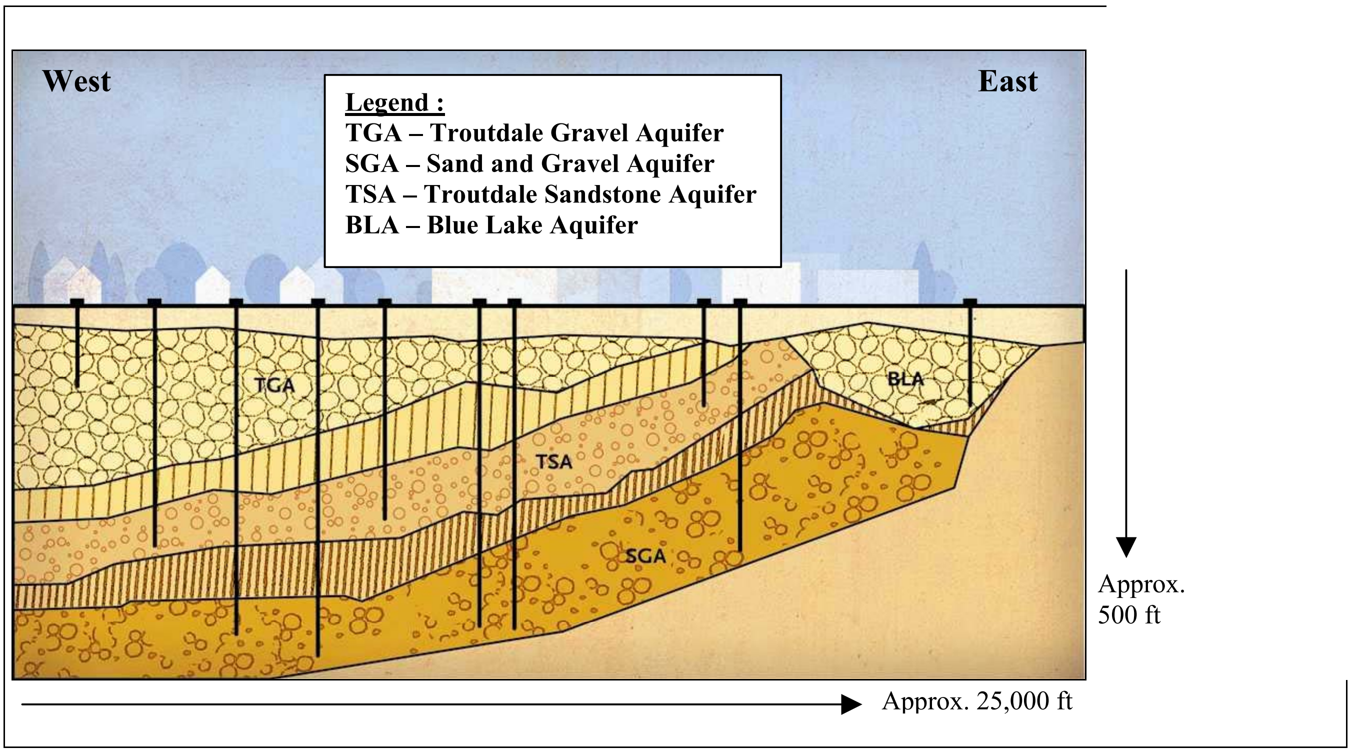
During the catastrophic Bretz floods of approximately 12,000 years ago, layers of substrate were laid down over the basalt bedrock. Five major aquifers and three aquitards have been identified

[1] Algae and macrophytes are the two types of aquatic plants that have the greatest impact on the flow in the Columbia Slough. Algae are simple plants that lack roots, stems, and leaves; macrophytes have these features. Macrophytes can be rooted in the sediment or floating.

in the Columbia Slough area (Figure 5-4). Recharge of these aquifers occurs from a variety of sources; in general, the deeper the aquifer, the further away the recharge source.

Portland receives supplemental water from the groundwater aquifers located underneath the Columbia Slough watershed.[2] The City of Portland's Water Bureau manages the groundwater wells in the Columbia South Shore Well Field (Figure 5-5). These wells were drilled from 1976-1985 and 2000-2003 and serve as a regional backup and summer augmentation water supply for the City's Bull Run system. In drier years, when the City's Bull Run storage system cannot meet the drinking water demand, or during an emergency or turbidity event, groundwater from the wells in the Columbia South Shore Well Field is used.

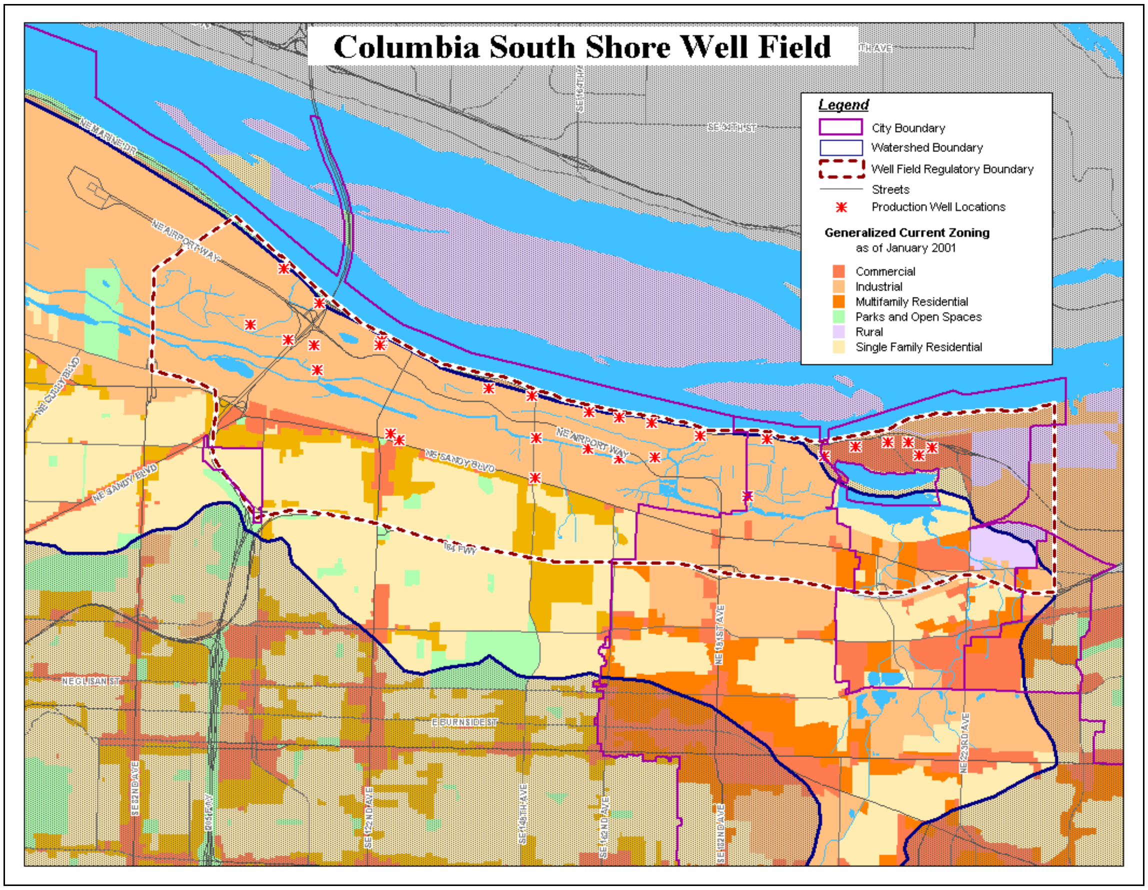
Figure 5-4: Geologic Strata in the Columbia South Shore Well Field



Source: Wells et al. 1996

[2] The City of Portland receives most of its drinking water from the Bull Run Watershed, located near Mount Hood. In another example of disconnecting the hydrologic cycle (this time of the Bull Run Watershed), water is piped from the Bull Run Reservoir to the residents of Portland, and then eventually flushed to the Wastewater Treatment Plant and from there directly to the Columbia River.

Figure 5-5: Columbia South Shore Well Field



As of 2004, there are 25 active wells drawing water from four aquifers (Figure 5-4). These aquifers are 60 to over 600 feet deep and produce as much as 100 million gallons of water per day. The City has water rights to more than 300 million gallons per day in the well field. The well fields produces nearly 70 percent of its flow from the deeper aquifers – the Troutdale Sandstone Aquifer and the deeper Sand and Gravel Aquifer. The well field's water is pumped from production wells – most of these are near the Columbia Slough – up to the Powell Butte Reservoir, where it is mixed with Bull Run water and distributed.

An additional three wells have recently been drilled near the Upper Slough by the Rockwood Water District and City of Fairview, all in the Sand and Gravel Aquifer. The City of Portland, or other water purveyors in the Gresham or Fairview area, may drill additional wells in the future. Pumping of the Portland well field is likely to have a negligible effect on groundwater influx to the Columbia Slough (Wells and Berger 1999). Groundwater flows into the Columbia Slough from shallow aquifers, while the well fields pump primarily from the deeper aquifers in the area, as described above. Leakage across the confining units is generally not significant enough to be measurable in the shallow aquifer when the deep aquifers are pumped.

Over the years, DEQ and the Portland Water Bureau have discovered a number of contaminated sites near the Portland well field. Working in partnership with DEQ, the Portland Water Bureau is investigating the impacts to the well field and methods to correct each situation. Most of the contamination is in the shallower aquifers. Contamination affecting the deeper aquifers near the Boeing and Cascade facilities in Gresham has been under control for a number of years and does not constrain use of the well field.

In 2003, the cities of Portland, Gresham, and Fairview adopted the same wellhead protection regulations to better protect groundwater quality. The revised Columbia South Shore Well Field Wellhead Protection Program Reference Manual enlarged the protection area and changed the requirements for affected businesses operating within that boundary.

CONCLUSIONS

The hydrology of the Columbia Slough Watershed has changed drastically from its historical condition. The watershed once had numerous streams, ponds, and wetlands. Today, upland development has eliminated all but three small surface streams (Wilkes, Osborn, and Fairview Creeks). Floodplain development has resulted in an extensively managed surface water system that includes levees, pumps, and other water control structures. The timing of peak flows and the quantity of both peak and low flows have changed.

These changes have had negative impacts on both water quantity and water quality. Management of the Slough system for flood control and water withdrawal supply has resulted in long residence times, causing increased algal growth, increased temperatures, and other water quality problems.

Management of water bodies for stormwater and flood control also impacts the hydrology, health, and sustainability of a watershed. Flood control structures and mechanisms alter detention times, hydrologic connectivity, and flow patterns.

The current and future level of development and the constraints imposed by flood protection in the watershed pose ongoing water management challenges. No management actions will be able to achieve a return to pre-development hydrologic patterns. This would not be possible even if the levees were removed, since dam construction and operation on the Columbia and Willamette Rivers have changed the river stages. However, projects that mimic historic conditions may improve hydrologic function.

As the need for surface water withdrawals in the Upper Slough diminishes, additional opportunities may emerge to modify the management of the Slough to improve water quality. The tradeoffs between flood control and environmental benefits, along with consideration of endangered species issues, will continue to make viable hydrologic management alternatives a challenge.

REFERENCES

Brown and Caldwell (for CH2M Hill). 1992. *Columbia Slough Flow Augmentation Project, Draft Summary Report.*

CH2M Hill. 1995. *Part I Water Quality Assessment, Water Body Assessment, Columbia Slough TMDL Development.*

City of Portland, OR, Bureau of Environmental Services (BES). 1989. *Columbia Slough Planning Study Background Report*.

Evonuk, David. 1999. *Columbia Slough Storm Water Quality*. Technical Report EWR-3-99, Department of Civil Engineering, Portland State University, Portland, Oregon.

Maben, Manly. 1987. *Vanport*. Oregon Historical Society Press, Portland, Oregon.

Oregon Natural Heritage Information Center (Christy, J. et al.). 2002. Pre-settlement vegetation map for the Willamette Valley, Oregon, compiled from records of the General Land Office Surveyors (c.1850). Oregon Natural Heritage Information Center, Portland, OR.

U.S. Army Corps of Engineers. 2001. *Columbia Slough, Section 1135 Feasibility Study*.

U.S. Coast and Geodetic Survey (USC&GS). 1888. Map.

Wells, S.A. 1992a. *Assessment of Management Alternatives for Water Quality Improvement in the Columbia Slough System, Volume 1: Technical Report*. Technical Report EWR-001-92, Department of Civil Engineering, Portland State University, Portland, Oregon.

Wells, S.A. 1992b. *Analysis of Management Alternatives for Improving Water Quality in North Slough Adjacent to the St. Johns Landfill*. Technical Report EWR-008-92, Department of Civil Engineering, Portland State University, Portland, Oregon.

Wells, S.A. 1995. *Analysis of Impacts of Flow Augmentation from Smith and Bybee Lakes on North Slough Dissolved Oxygen Conditions*. Technical Report EWR-1-95, Department of Civil Engineering, Portland State University, Portland, Oregon.

Wells, S.A. 1997. *The Columbia Slough*. Technical Report EWR-2-97, Department of Civil Engineering, Portland State University, Portland, Oregon.

Wells, S.A. and Berger, C. 1994. *Upper and Lower Columbia Slough Water Level Test: September 1 through October 29, 1993*. Technical Report EWR-002-94, Department of Civil Engineering, Portland State University, Portland, Oregon.

Wells, S.A. and Berger, C. 1999. *Hydraulic and Water Quality Modeling of the Columbia Slough Volume 1: Model Description, Geometry, and Forcing Data*. Technical Report EWR-2-99, Department of Civil Engineering, Portland State University, Portland, Oregon.

Wells, S.A. et al. 1996. *Impact of Groundwater Contamination in East Multnomah County on the Interlachen Community*. Technical Report EWR-3-96, Department of Civil Engineering, Portland State University, Portland, Oregon.