2.0 PHYSICAL SETTING AND HYDROGEOLOGY

This section provides background information on the physical setting and hydrogeology of the Tumwater area based on previous investigations and interpretation of select area well logs. Since publication of the 1997 WHPP was completed, there have been subsequent studies that have helped to update the general understanding of the geology in the area. The primary sources of data used to characterize the hydrogeologic system for this WHPP includes the following (in chronological order of publication date):

- Geology and Ground-Water Resources of Thurston County, Washington, Volumes 1 and 2 (Wallace and Molenaar 1961; Noble and Wallace 1966).
- City of Tumwater Wellhead Protection Plan (EES and others 1997).
- Conceptual Model and Numerical Simulation of the Groundwater Flow System in the Unconsolidated Sediments of Thurston County (Drost and others 1999).
- Surface Geologic Maps of the Maytown and Tumwater 7.5-Minute Quadrangles (Logan and others 2009, Logan and others 2003, andWalsh and others 2003).
- Report on Barnes Lake Characterization (Golder 2009).
- City of Tumwater 2010 Water System Plan update (HDR 2011).

2.1 General Physical Setting

The City of Tumwater is located near the southern end of the Puget Sound Lowland in Thurston County, Washington. The area is characterized by low hills on the northwest and southeast reaching between 300 and 400 feet above mean sea level (ft. amsl) separated by a relatively flat upland prairie with an elevation of approximately 180 to 200 ft. amsl. The Deschutes River and Black River valleys are incised around the upland prairie.

The upland prairie (which includes the Salmon Creek area) is a remarkably flat glacial outwash plain with depressed areas that are prone to flooding during periods of prolonged or heavy precipitation. The surface soils and uppermost aquifer in this outwash plain consist of highly permeable materials that are recharged mostly by precipitation. Very little precipitation leaves the area as surface runoff because it is so effectively accepted by the soils.

2.2 Climate

Tumwater has a temperate marine climate characterized by dry, warm summers and wet, cool winters. Average annual rainfall recorded at the Olympia Airport was approximately 52 inches between 2005 and 2015, with more than 80 percent of precipitation falling from October through March. Total rainfall is generally greatest in January (approximately 9 inches) and lowest in July (approximately 0.5 inches). Air temperatures average 40 °F during the three coldest months of the year (December through February) and 62 °F during the three warmest months (NOAA 2016).

2.3 Surface Hydrology

The city limits of Tumwater are located within the Deschutes River Basin (Ecology Water Resources Inventory Area [WRIA] 13, Figure 2-6) with the southwestern portion of the study area in the Black River drainage, a sub-basin of the Northern Chehalis River Basin (WRIA 23, Figure 2-6). The Deschutes River flows north to discharge to Budd Inlet (Puget Sound) while the Black River flows southwest to discharge to the Chehalis River and ultimately to Grays Harbor (Pacific Ocean) (Figure 2-6). Thus, a basin surface water divide exists within the City limits on the upland area in the Southwest portion of the City.

Several kettle lakes are found in the study area, including Black, Barnes, and Trosper Lakes. Kettle lakes are formed when isolated blocks of glacial ice are deposited in conjunction with sediments, then melt at a later date to leave depressions in the sedimentary deposits. Black Lake is a large and relatively deep kettle lake just west of the City limits and forms the headwaters of the Black River drainage. Barnes Lake, Trosper Lake, and a string of smaller lakes extend along a southwest trend through the City west of I-5 and there are also several shallow wetland areas (Belmore and Kennydale County park areas). These features are kettle lakes interpreted to have formed by sediment-rich icebergs that were beached/stranded during glacial retreat.

2.4 Hydrogeologic Units

The understanding of groundwater in the study area based on a combination of an interpretation of hydrogeologic units/stratigraphy and observations of groundwater levels in wells. The surficial geology of the area is shown in Figure 2-2. The hydrogeologic stratigraphy in the Tumwater area has evolved over the years. Unconsolidated Quaternary glacial and non-glacial deposited over the bedrock form the major aquifer systems in the area. The unconsolidated geologic sequence consists of alternating layers of sand, sand and gravel, silt, clay and glacial till. In general, sand and gravel deposits form good aquifers for transmitting groundwater, while silt, clay and glacial till form aquitards, which have limited capacity for groundwater flow. Aquifers separated by aquitards can be considered separate bodies of water from a water rights perspective. Aquitards also create barriers to the movement of contaminants between aquifers or between the ground surface and underlying aquifers. Thus, the definition of stratigraphy and continuity of aquifer and aquitard units is important.

There are several bedrock outcrops in the study area. These are Tertiary volcanic rocks (primarily basalt and andesite) that outcrop in the northwest (Tumwater Hill), west (Black Hills) and south (near Offutt Lake) portions of the study area. Bedrock does not constitute an aquifer, but it does often form boundaries to aquifer systems that can have an effect on groundwater flow patterns.

The unconsolidated sedimentary sequence was initially characterized by Wallace and Molenaar (1961) and Noble and Wallace (1966) as a relatively simple “layer-cake” sequence composed of the following units (presented from surface to depth and identified as an aquifer or an aquitard):

- Surficial alluvial sediments (Qal(c)) – Aquifer
- Vashon glacial sequence:
  - Recessional outwash (Qgo) – Aquifer
  - Till (Qgt) - Aquitard
  - Advance outwash (Qga) - Aquifer
- Continental fine sediments (historically called the Kitsap Formation (Qpf) - Aquitard
- An older glacial sequence(s) (locally referred to as the "Sea Level Aquifer") (Qpg) - Aquifer
- Older undifferentiated sediments (TQu) – Aquifer
- Bedrock of primarily basaltic or andesitic volcanics, with minor marine sedimentary rocks (Tb) - Aquitard

The understanding and presentation of the stratigraphic sequence has been consistent with this simple interpretation as recently as the late 1990s (Drost and others 1998 and 1999). Discontinuities in the strata were recognized, especially in river valleys, but not well characterized. More recently, the stratigraphy has been recognized to be more complex. The Washington Department of Natural Resources (DNR) has remapped the surface geology in the project area (Figure 2-2; Walsh and others 2003; Walsh and Logan 2005, and Logan and others 2009). Recent interpretations of the stratigraphy have resulted in recognition that sediments deposited during several pre-Vashon glacial and interglacial periods exist in the area and are difficult to differentiate. For example, Logan and others [2009] replaced units Qpf, Qpg and TQu with a single undifferentiated unit called Pre-Vashon Drift [Qgp]. Similarly, Borden and Troost (2001) recommended discontinuing use of the term "Kitsap Formation" as a geologic unit. Geologic mapping has also identified several discontinuities in the Vashon Till (Walsh and others 2003, Logan and others 2009). These discontinuities in the till are one of the more significant advances in hydrogeologic understanding with respect to protection of the City's groundwater sources. Susceptibility to groundwater contamination is higher in areas where the till is absent.

The City's Palermo and Brewery Wellfields are completed in alluvial sediments deposited along the Deschutes River Valley. The City's Port, Bush and proposed Southwest Wellfields are completed in glacial sediments deposited on the upland prairie during the most recent glacial episode. Table 1-1 summarizes wellfield characteristics. Aquifer units are described in further detail in the following subsections. Updated geologic cross sections using well log records from the City's production and observation wells, as well as additional well logs available from the Ecology well log database, are presented in Figures 2-3 through 2-5, with cross section locations indicated in Figure 2-2.

2.4.1 Surficial Alluvial Aquifer (Qal)

Surficial alluvial sediments located in the northeast portion of the Tumwater area are interpreted to fill a deep erosional trough roughly paralleling the present day Deschutes River. This trough appears to be as deep as 500 feet below sea level and it extends approximately from the confluence of Spurgeon Creek with the Deschutes River to Budd Inlet of Puget Sound. The erosional trough is believed to have formed as a result of lowered sea levels during past glaciations. The Deschutes Valley may have been eroded and infilled several times, to varying degrees, following past glacial retreats. The sediments infilling the Deschutes Valley are generally coarse reworked alluvial sediments near the surface, underlain by finer-grained sand. Deeper portions of the valley sediment are generally coarser-grained sand. The full sequence varies in grain size distribution and silts and coarse sand pockets are present throughout.

The Palermo Wellfield and many of the productive wells of the former Olympia Brewery are completed in the Surficial Valley Aquifer at approximately 100 feet below ground surface (bgs). These coarse sediments are interlayered with discontinuous lenses of silty sand, silt, and clay. This aquifer is susceptible to contamination from existing and potential future surface spills because downward movement of contaminants is not impeded by an overlying aquitard. Discovery of chlorinated solvents into the Palermo Wellfield wells in 1993 illustrates the susceptibility of this aquifer to contamination.

2.4.2 Vashon Recessional Outwash (Qgo and Qgos)

Surficial deposits overlying much of the upland prairie between the Deschutes and Black rivers generally consist of loose, fine to coarse-grained sediments of Vashon recessional outwash (Qgo and Qgos). These sediments were deposited by meltwater streams discharging from the Vashon glacial front as it retreated northward at the end of the last ice age. The Qgos sediments are typically finer than the Qgo sediments, as they are composed primarily of sand and silt with minor interbeds of gravel. The Qgo and Qgos units are relatively thin over most of the area, typically on the order of 20 feet thick, with a maximum thickness of approximately 60 feet in the vicinity of the Port wellfield. The Qgo and Qgos are not significantly used for groundwater supply, with most wells in the area completed in the deeper and more transmissive Qga and Qpg aquifers.

2.4.3 Vashon Till (Qgt)

The Vashon Till (Qgt) is a variably compressed mixture of poorly-sorted rock debris that underlies the Qgo and Qgos units and forms a low-permeability protective layer (aquitard). The Qgt deposits are generally composed of a mixture of sands, gravels, cobbles, and boulders within a compact matrix of silt and clay. Drillers commonly refer to these deposits as “hardpan”, “cemented”, or “boulder clay”. The Qgt unit is found underlying the Qgo and Qgos in much (but not all) of the upland prairie and it is exposed at the surface near Black Lake and south of the Tumwater area (Figure 2-6). The thickness of the till generally ranges between 8 and 50 feet thick.

Recent work has identified the presence of outwash channels in the southern part of the study area (Walsh and Logan 2005). These outwash channels often erode the till aquifer and thus eliminate the protective layer for underlying aquifers. Well logs on file with Ecology were used to identify areas where the protective till layer (aquitard) is not present. The till appears to have been eroded away in areas coincident with these channels. Figure 2-6 shows where the till appears to be absent at depth based on wells logs, which are included in Appendix A.

Areas where till is absent are more susceptible to contamination from surface spills than areas with a till layer present. For instance, the Palermo wellfield does not benefit from an overlying layer of till and is considered more susceptible to surface contamination. The Vashon Till decreases in competency from north to south across the study area because the northern area was over-ridden by a thicker ice sequence than the south, which compressed and over-consolidated the till. The till in the Bush Wellfield appears to be less competent than at the Port Wellfield. The till in the future Southwest wellfield area may have “holes” or “windows” in the till, based on mapping by Logan and others (2009).

2.4.4 Vashon Advance Outwash Aquifer (Qga)

The advance outwash (Qga) sediments were transported and deposited by meltwater streams discharging from the Vashon glacial front as it advanced into the Tumwater area. The Qga may also include sediments deposited by meltwater streams from large valley glaciers that formed on Mt. Rainier, though these sediments are likely confined to smaller paleo-stream channels along the Deschutes River. The Qga is a permeable aquifer unit consisting generally of gravel in a matrix of sand with some sand lenses. The Qga is widespread throughout the area and ranges in thickness between 10 and 67 feet in the vicinity of City production wells.

The Qga is the primary aquifer for the Port, Bush, and proposed Southwest Wellfields. The aquifer is interpreted to be relatively thin and confined in the vicinity of the Port Wellfield, becoming progressively thicker and “leaky” in a southward direction in the vicinity of the Bush Wellfield (PGG 1997) and Southwest Wellfield (PGG 2004). The interpretation of leakage to the Qga from overlying units corresponds with interpretations of the till being less-consolidated and/or absent in some areas toward the southern portion of the study area.

In the region near the planned Southwest Wellfield the Washington DNR has mapped several “holes” in the till layer and the Qga is exposed at the surface (Logan and others 2009). As shown on Figure 2-6, DNR has mapped an area south of the planned Southwest Wellfield where the Qga and Qgo are in contact with each other, without an intervening till layer. The lack of a till layer in this area is a potential susceptibility concern for the planned Southwest Wellfield, especially since I-5 traverses the area.

2.4.5 Deeper Stratigraphic Units

The Qga is underlain by a series of Quaternary sediments deposited during several pre-Vashon glacial and interglacial periods over a basement of Tertiary bedrock. The City does not currently produce groundwater from these deeper hydrogeologic units. Well 7, the City's deepest well, was interpreted to have been completed in the deeper sediments, but its use has been discontinued due to naturally occurring high concentrations of iron and manganese, and the presence of hydrogen sulfide.

2.5 Groundwater Flow System

Groundwater flow systems are influenced by recharge/discharge relationships, aquifer properties, aquifer and aquitard thickness/extent, and the location of hydraulic boundaries like lakes, rivers, and bedrock. Groundwater flow systems are described and measured using water levels in wells, from which maps of groundwater elevations and hydraulic gradients can be analyzed to determine groundwater flow directions, groundwater flow velocities/travel times, and groundwater flow volumes.

Rainfall infiltration is the dominant source of recharge to the unconsolidated sedimentary aquifer system of the Puget Lowland in the vicinity of Tumwater. Annual precipitation at the Olympia Airport averages 50.9 inches (WRCC 2013) and annual groundwater recharge is estimated to be approximately 25 inches (Drost and others 1998). Groundwater recharge also occurs from the Deschutes River to the Deschutes Aquifer system. In August 2003, the Deschutes River between the confluence with Spurgeon Creek and 84th Street (RM 6.8) was interpreted to be a losing reach by Sinclair and Bilhimer (2007), providing groundwater recharge to the sedimentary aquifer system on the order of 1.4 cubic feet per second (cfs) during the period of measurement in August 2003 (Reach 5 presented in Plate 2 of Sinclair and Bilhimer 2007).

The most extensive spatially distributed water level measurements across the study area took place in December 1995 and March 1996 (PGG 1997). Hydrographs developed from this data were presented in the 1997 WHPP and indicate that groundwater flows radially west, north, and east from a roughly north-south trending groundwater divide inferred to coincide with the main surface water (or WRIA) boundaries. Groundwater flow in the vicinity of the Tumwater Wellfields is generally from the groundwater divide toward the Deschutes Valley, and down the valley to Budd Inlet (Figure 2-7). Horizontal gradients have been reported in the range of near 0 in the vicinity of the Bush Wellfield to approximately 0.02 in the vicinity of the Palermo Wellfield (PGG 1997). Vertical groundwater flow gradients were measured in select well pairs at approximately 0.02 downward (PGG 1997).

Groundwater levels in the Qal and Vashon sedimentary deposits (Qgo/Qgos, Qgt, and Qga) occur between approximately 100 and 200 ft amsl within the study area (Figure 2-7). Water level monitoring by Thurston County indicates approximate 10-foot seasonal fluctuations and that the inter-annual water levels have remained relatively constant, with no discernible long-term trend upward or downward.