Golder Associates

TECHNICAL MEMORANDUM

Date: December 10, 2009

To: Stephanie Ray, Program/Project Manager

From: Phil Brown, LHG
Kenneth Janssen

cc: Steven Thomas, LHG

RE: THOMPSON CREEK CONCEPTUAL HYDROGEOLOGIC MODEL

Project No.: 093-99058

Company: City of Yelm, WA

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1.0 INTRODUCTION

The City of Yelm, WA (City) is developing new source capacity to meet growing demand, and altering historic withdrawals to limit the impact of groundwater pumping on the watershed. As part of their water-supply planning, the City has applied for new water rights, and working to acquire existing private water rights for transfer to municipal use. The hydrologic impact to the region's aquifer system (and surface water) resulting from new pumping and transfers has been evaluated using the 2008 version of the McAllister Wellfield Model (model). The original U.S. Geological Survey (USGS) version of the model was originally updated by the City of Olympia, WA to assess possible hydrologic impacts of a planned wellfield located near McAllister Springs (CDM, 2002a; CDM, 2002b), and was later updated and improved for use by the City of Lacey, WA to evaluate pumping impacts (Golder, 2006). Golder further updated and improved the model for the Yelm area to simulate groundwater pumping scenarios for the City (Golder, 2007).

As part of the model improvements, the main surface water features in the Yelm area (e.g., Yelm Creek, Nisqually River, and Deschutes River) were refined, with the exception of Thompson Creek. Thompson Creek was not included in the original model or any of the later versions. Including Thompson Creek as part of the most recent model updates for the Yelm pumping scenarios was discussed amongst stakeholders, but due to the creek's ephemeral nature and the lack of data it was not specifically represented. This construction was accepted for use by the stakeholders (the Washington State Department of Ecology (Ecology), City of Lacey, and City of Yelm and Tribes) and used for impacts analysis.

Through a recent water rights transfer application evaluated by Ecology, the City was asked to assess the hydrologic impacts to Thompson Creek. Ecology received a letter of concern (Appendix A) that senior water rights may be impaired by the transfer, and that concern was based on a consulting report that

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presented arguable opinions. As a result, the City of Yelm has requested that Golder Associates Inc. (Golder) review existing information to develop a data-based conceptual hydrogeologic model for Thompson Creek, so that any additional discussion of impairment can be put into the correct hydrologic context.

1.1 Purpose and Approach

This technical memorandum describes the conceptual hydrogeologic framework of the shallow groundwater system in the area of Yelm and its interaction with Thompson Creek. This memorandum:

- Provides a summary of available data describing the physical and hydrogeologic characteristics of the Thompson Creek study area;
- Presents a conceptual hydrogeologic model of Thompson Creek developed from data compiled from a variety of existing reports and files, and illustrated with geologic cross-sections, block diagrams, and groundwater/surface water data;
- Presents groundwater flow directions and discusses the interaction between Thomson Creek and the shallow groundwater system; and
- Identifies additional data needs and tasks to better define the hydrologic system of Thompson Creek and its interaction with shallow groundwater.

1.2 Study Area

The City of Yelm is located along the western margin of Yelm Prairie approximately 15 miles southeast of the City of Olympia in northeastern Thurston County, Washington. The study area includes Thompson Creek and its immediate surrounding area. Thompson Creek is located along the intersection between the eastern margin of Thurston Highlands and the western margin of Yelm Prairie, and drains northward from a wetlands complex empting into the Nisqually River northwest of Yelm (Figure 1) approximately 2.5 miles downstream.

1.3 Geologic Setting

The study area is situated in the south-central portion of the Puget Sound Lowland. The Puget Sound Lowland is a north-south-oriented basin that has experienced repeated deposition, erosion and reworking of geologic sediments during glacial and interglacial periods. The basin is bounded on the west by the Olympic Mountains and on the east by the Cascade Range and extends from Canada's Fraser River to the southern margin of Pleistocene glaciation near Centralia, WA (Morgan and Jones, 1995). The repeated glacial advances and retreats covered the study area with layered, unconsolidated glacial and non-glacial deposits (Figure 2; Drost, 1999). Extensive geologic studies of Thurston County and the Yelm area were conducted by Mundorff et al. (1955), Wallace and Molenaar (1961) and Noble and Wallace (1966), with more recent investigations conducted by Drost et al. (1998), Drost et al. (1999), and Robinson and Noble (2001).

The most recent glacial advance into the Yelm area took place approximately 13,500 to 15,000 years ago and is known as the Vashon Stade of the Fraser Glaciation. As the glacier advanced, meltwater streams discharging from the glacier carried and deposited outwash deposits of sand and sand and gravel. The advance outwash deposits (Qva) are typically buried in the Yelm area, but are extensive at depth throughout the area (Figure 3; Drost, 1999).

An unsorted mixture of rock debris known as glacial till was picked up and transported by the glacier and deposited over the Qva as the glacier continued its advance into the area. The glacial till deposits (Qvt) are composed of a mixture of sands, gravels, cobbles, and boulders within a compacted matrix of silt and clay. Drillers commonly refer to these deposits as “hardpan”, “cemented”, or “clay boulder”. The till is exposed at the surface west of Yelm and forms the eastern portion of the Thurston Highlands along the western margin of Yelm Prairie (Figure 2). Contrary to the implications of recent consulting reports that claimed no significant differentiation between aquifer and low-permeability aquitards in the vicinity of Thompson Creek, the till is found at depth throughout the Yelm area (Drost, 1999; Figure 4) and confines groundwater within the Qva. Drost et al. (1999) indicated, consistent with our review of area well logs, that the Qvt unit is between 50 and 100 feet thick in the vicinity of Thompson Creek.

As the glacier continued to advance, the Yelm Lobe of the glacier converged with the Olympia Lobe west of Yelm and north of Rainier, WA (Noble and Wallace, 1966). The convergence resulted in an elongated deposit of till known as a moraine. The Vashon moraine deposits (Qvrm) make up the central and western portion of the Thurston Highlands (Figure 2; Drost, 1999), and exhibits hummocky topography with kettle-type depressions referred to as kettle lakes when filled with water. The moraine deposits can have grain-size and permeability characteristics similar to Qvt.

As the glacier retreated the Yelm area, meltwater streams carried and deposited recessional outwash deposits (Qvr) of sand and sand and gravel on top of the Qvt. These deposits are widespread at the surface and make up most of Yelm Prairie (Figures 2 and 5; Drost, 1999). With the exception of alluvial sands and gravels found along many of the local streams, the recessional outwash is the youngest geologic deposit in the study area.

Deposits underlying the upper Vashon glacial sequence in order of increasing depth below the Qva unit include the Kitsap (Qf), Salmon Springs(?) drift (Qc) and TQu formations (Drost et al., 1999 and Robinson and Noble, 2001). The Kitsap Formation (Figure 6) is a low-permeability, fine-grained confining layer that separates the overlying Qva unit from the lower Qc and TQu units. The Qc unit (Figure 7) consists primarily of coarse sand and gravel, and is called the Salmon Springs(?) Drift by Noble and Wallace (1966) because its stratigraphic relationships mapped in Thurston County are similar to the Salmon Springs Drift type-section mapped in Pierce County and north of Tacoma, WA. The TQu consists of layers of fine-grained confining beds and coarse-grained aquifer units.

1.4 Soils

Soil types within the study area are generally loamy (i.e., composed of sand, silt, and clay), but range from clay and muck soils to gravelly sandy loams depending upon the parent material from which the soils were derived (USDA, 1990; Figure 8 and Table 1). Because Thompson Creek lies along the margin of Yelm Prairie where both surface topography and geology transition, the creek defines a transition in soil types as well:

- Areas west of Thompson Creek are generally categorized as Everett, Yelm and Tenino Series soils. Everett and Yelm soils have textures that range from fine sandy loam to gravelly sand and are typically associated with Qvt and some Qvrm deposits. Tenino Series soils generally range from gravelly loam to extremely gravelly sandy loam and have a cemented horizon within the soil profile. Tenino soils are dominantly associated with Qvrm deposits.
- Areas east of Thompson Creek are predominately Spanaway Series soils, which have gravelly/sandy textures and are largely associated with Qvr deposits.
- Areas south and southwest of Thompson Creek are mapped as Alderwood Series soils consisting of gravelly sandy loam. Alderwood soils include a weakly cemented hardpan and generally correspond with Qvrm and Qvt deposits.

Other soil types mapped within the study area include McKenna, Indianola, Shalcar, Skipopa, and Tisch soils (Figure 8 and Table 1).

1.5 General Hydrology

1.5.1 Climate

The Yelm area has a climate characterized by dry, warm summers and wet, cool winters (WRCC, 2009). Average annual rainfall totals 50.8 inches, nearly 85 percent of which falls during the months of October through April. Total rainfall is generally greatest during the month of November (8.1 inches) and lowest during July (0.8 inches). Air temperatures average 38.9 °F during the three coldest months of the year (December through February) and 61.5 °F during the three warmest months (July through September).

1.5.2 Thompson Creek

Yelm is located within the Nisqually River drainage and is bordered to the east by Yelm Creek and to the west by Thompson Creek. Both creeks drain northward and discharge to the Nisqually River north of Yelm. Thompson Creek flows along the western margin of Yelm Prairie along the base of the Thurston Highlands west of Yelm. Thompson Creek is shown by the USGS (1990a and 1990b) to originate from a wetland complex southwest of Yelm near the base of the highlands. Thompson Creek is described as flowing somewhat continuously (i.e., perennial stream) throughout its upper reaches, but has been observed to go dry by Golder Associates each summer since beginning work in this area in 2004. Thompson Creek is well documented as ephemeral over its lower reaches, flowing only during periods of prolonged rainfall. The creek's upper reach is more vegetated than its intermediate and lower reaches.

Thompson Creek likely receives some tributary discharge from small drainage basins that drain the eastern slopes of the upland area (T17N, R1E, Sections 14, 23, and 26; Figure 1). Some tributary sources have been identified southwest of Thompson Creek's headwaters area (T17N, R1E, Sec. 26) by Thurston County (2008). None of the upland tributary streams are mapped by the USGS and likely represent ephemeral sources from runoff as they drain areas with mapped low-permeability till units at the surface.

1.5.3 Groundwater

The groundwater system in the study area has been described as being composed of seven major hydrogeologic units (Drost, et al., 1999). The hydrogeologic nomenclature of Drost, et al. (1999) is used for this study to remain consistent with previous work, including the peer-reviewed groundwater flow modeling efforts of Olympia, Lacey, and Yelm. A table summarizing the lithologic and hydrologic characteristics of each unit is presented in Table 2 (Drost et al., 1999).

Groundwater in the study area is derived primarily from Vashon advance outwash deposits (Qva), older glacial deposits generally identified as the Salmon Springs(?) Drift (Qc), and unconsolidated and undifferentiated deposits of the TQu. Groundwater in the Qva is confined by the overlying, low-permeability till layer (Qvt), and separated from the lower Qc and TQu layers by the confining Kitsap Formation (Qf). Groundwater in the Qvr is generally unconfined, though may perch locally, especially in the Thurston Highlands, where Qvrm deposits are prevalent and dense/cemented soil horizons exist.

The shallow groundwater system consists of the Vashon sequence of glacial deposits, whereas the deeper, regional groundwater system consists of the Qc and TQu hydrogeologic units. Studies conducted by Robinson and Noble (1995; 2001) indicated that the groundwater elevations and groundwater flow direction of the deeper system are different from those in the shallow system beneath Yelm. Groundwater within the shallow system generally flows in a northerly direction across Yelm Prairie toward the Nisqually River, whereas groundwater in the deeper system moves northwest away from the Nisqually River toward McAllister Springs near Olympia, WA. Locally, groundwater in the shallower portion of the system flows from topographic highs of the Thurston Highlands toward the topographic lows of Yelm Prairie.

2.0 HYDROGEOLOGIC ASSESSMENT

A conceptual hydrogeologic model of Thompson Creek was developed from an extensive review of available data sources that incorporated all of the most significant hydrogeologic characteristics. These characteristics included the glacial hydrostratigraphy unique to the region, boring logs, groundwater and surface water elevation data, streamflow, soil types, and general topography.

2.1 Data Sources

The geology of the area has been described in numerous studies. Key studies related to the geology and hydrogeology include those by Mundorff et al. (1955), Wallace and Molenaar (1961), Noble and Wallace

(1966), Drost et al. (1998), Drost et al. (1999), and Robinson and Noble (2001). Soil data were obtained from the United States Department of Agriculture for Thurston County (USDA, 1990). The physical characteristics of the surface and sub-surface geologic deposits presented in these reports were used as the basis for identifying lithologic and stratigraphic control points when evaluating borehole logs and developing geologic cross-sections.

Borehole logs from water wells, monitoring wells, and piezometers were obtained from Ecology and recent hydrogeologic investigations conducted by PGG (2008) and Thurston County (2008). Ecology's Well Log Database provides well locations limited to the quarter-quarter, quarter, or whole section scale. Land surface elevations at the Ecology wells were obtained from a 10-meter digital elevation model of the area. Piezometers and monitoring wells reported as part of the hydrologic investigations conducted by PGG (2008) and Brown and Caldwell (2008) were surveyed for spatial location and elevation.

Surface water and groundwater hydrologic data at locations within the study area are available from recent investigations conducted by PGG (2008), Brown and Caldwell (2008), and Thurston County (2008). The locations of the monitoring points are shown in Figure 9 and summarized in Table 3. These investigations report surface water data collected from staff gauges and stilling wells installed in Thompson Creek and neighboring wetlands, and groundwater elevation data from monitoring wells and piezometers installed in the Thurston Highlands and in the shallow groundwater system adjacent to Thompson Creek. The monitoring frequencies and durations limit the utility of the data set. At some locations the monitoring does not cover a full water year, and/or surface water measurements are not concurrent with groundwater measurements. Additionally, the groundwater and surface water data recorded at the Thurston County monitoring locations (Thurston County, 2008; Table 3) cannot be used to evaluate elevation relationships. None of the Thurston County staff gauges or monitoring wells were surveyed for elevation and the water-level elevations were approximated using topographic maps (Biever, M., Thurston County Environmental Monitoring Program Supervisor, written communication, August, 2009). The range of accuracy for this approach is typically considered to be +/- 5 feet, limiting the reliability of assessing recharge/discharge relationships where elevations are similar and topography is variable.

A review of the USGS National Water Information System and Ecology's Statewide Flow Monitoring Network did not reveal any historic or current stream stage or flow data for Thompson Creek. The only known discharge data are available from a temporary monitoring station installed by EnviroVision in the upper reaches of Thompson Creek approximately 100 feet downstream of the Tahoma Terra Bridge (Brown and Caldwell, 2008). The purpose of this evaluation was to assist in evaluating the impacts associated with stormwater infiltration and runoff from the planned Tahoma Terra development. Stream stage data were limited to one seven-month monitoring period beginning in late-December 2007. EnviroVision converted stage measurements to discharge using a stage-flow rating curve developed from instantaneous flow measurements. The instantaneous flow measurements and rating curve were not available for review by Golder. Despite the lack of flow data, correspondence with Thurston County (Biever, M., Thurston County Environmental Monitoring Program Supervisor, written communication, September, 2009), historic observations recorded on water rights documents (Application for Change 7053-A; Appendix A), and anecdotal evidence confirm that Thompson Creek flow is variable and during many years flow ceases by mid-summer or for most of the year. During the wet season, Thompson Creek has been observed to experience some periods of localized flooding. High Groundwater Hazard Areas (HGHAs) have been delineated by Thurston County in some areas along the creek's upper reaches and in a catchment east of the creek's headwaters. These areas are sensitive to high groundwater levels.

Precipitation data concurrent with the groundwater and surface water hydrologic data were obtained from a weather station established along 93rd avenue near Thompson Creek (Thurston County, 2008) and from a station located near the headwaters of the creek (Weather Underground, 2009; Station ID: KWALACEY1).

2.2 Conceptual Hydrologic Framework

This section describes the hydrologic framework used in developing our conceptual model of Thompson Creek. The conceptual model is presented as a simplified representation of the hydrologic system based on data compiled from a variety of existing reports and files, and is illustrated with geologic cross-sections, block diagrams, and groundwater/surface water data.

2.2.1 Hydrogeology

This section briefly describes the hydrogeologic conditions of the Thompson Creek study area, including identification of hydrostratigraphic units and their general properties. Characteristics of the units and geologic cross-sections were derived from an inventory of local well logs and hydrogeologic reports. The hydrostratigraphic relationships apparent in the well logs are consistent with those previously published for the area (e.g., Drost et al., 1999; and Robinson and Noble, 2001). The locations of the cross-sections with respect to Thompson Creek are shown in Figure 9 and illustrated in Figures 10 through 12. Borehole logs and well data used in developing the cross-sections are provided in Appendix B and obtained from recent investigations hydrologic investigations conducted by PGG (2008) and Thurston County (2008).

The interpreted hydrostratigraphic units of the shallow groundwater system, as shown on the cross-sections include:

- Vashon recessional outwash and moraine deposits (Qvr and Qvrm);
- Vashon glacial till (Qvt); and
- Vashon advance outwash (Qva).

The Vashon recessional outwash deposits blanket most of Yelm east of the Thurston Highlands. The Qvr sediments are composed primarily of sand and gravel. Well logs indicate the thickness to range between 10 and 50 feet – thinning to the west near Thompson Creek. Vashon moraine deposits (Qvrm) are included in the Qvr geohydrologic unit of Drost et al. (1999), and are exposed in the central and western portions of the Thurston Highlands west of Thompson Creek (Figure 2). The Qvrm deposits have characteristics similar to till, and are indicated by the absence of a compacted matrix at depth, although some dense or cemented conditions may exist in shallow soil horizons in some areas (e.g., in areas mapped as Alderwood and Tenino soils west, south, and southwest of Thompson Creek). Groundwater in the Qvr is unconfined and may perch in areas of Qvrm where low-permeability soils (e.g., Alderwood and Tenino) are present. The Qvr unit is generally too thin to support groundwater supply wells along the western margin of Yelm Prairie; most wells in the area are completed in the deeper, more transmissive Qva aquifer.

Underlying the Qvr is a confining layer of glacial till (Qvt). The Qvt deposits are exposed at the surface and form the eastern portion of the Thurston Highlands along the western margin of Yelm Prairie, and are widely distributed in the subsurface throughout Yelm (Drost, 1999). The Qvt unit is composed of a mixture of sand, gravel, cobbles and boulders in a compacted matrix of silt and clay, and is known to have some lenses of sand and gravel. The presence of Qvt is indicated on driller's logs by descriptions including "hardpan", "cemented", or "clay boulder". The thickness of the Qvt deposits range between 35 and 80 feet, and exceed 100 feet in areas west and southwest of Yelm (Figure 4). The Qvt is considered a confining bed (i.e., aquitard) that limits the downward movement of groundwater and produce locally perched water conditions. Where lenses of clay-free sand and gravel are present, it can yield useable amounts of water.

The advance outwash deposits (Qva) lie beneath the Qvt till. The Qva is a relatively permeable aquifer unit consisting generally of gravel in a matrix of sand with some sand lenses, and is confined by the overlying Qvt deposits. The Qva is widespread throughout the subsurface and many of the domestic wells in the study area use it a source of water. The Qva unit in the area of Thompson Creek is thickest near its upper and lower reaches (between approximately 35 and 85 feet) and thinnest along the creek's intermediate reach (between approximately 15 and 35 feet).

Beneath the Vashon sequence are older glacial and non-glacial deposits. These deposits make up the deeper, regional groundwater system. Golder reviewed area well logs, compared log descriptions to published unit descriptions, and prepared geologic cross-sections presented in Figures 10,11, and 12. The unit boundaries and thicknesses are consistent with work completed by Drost et al. (1999) and Robinson and Noble (2001), but not the speculative undifferentiated hydrostratigraphy described by Aspect Consulting (Appendix A). The interpreted hydrostratigraphic units of the older glacial and non-glacial deposits underlying the Vashon sequence of deposits include:

- Kitsap Formation (Qf);
- Salmon Springs(?) drift (Qc); and
- Unconsolidated and undifferentiated deposits (TQu).

Underlying the Qva deposits is the Kitsap Formation (Qf). The Qf hydrostratigraphic unit is a confining layer composed predominately of clay and silt, with some layers of sand and gravel, and may include some till or till-like deposits and minor amounts of peat and wood. The Qf layer is extensive throughout the Yelm area (Drost, 1999; Figure 6) and its thickness within the study area ranges between approximately 25 and 80 feet. Based on Golder's review of area well logs, the thickness of the Qf beneath Thompson Creek ranges from approximately 40 feet in its upper and intermediate reaches to between approximately 25 and 35 feet in its lower reaches. This range of thickness is consistent with the 20- to 70-foot thickness range given by Drost et al. (1999).

Below the Qf unit is the Salmon Springs(?) Drift hydrostratigraphic unit (Qc). The Qc unit consists mainly of coarse-grained sand and gravel stained red or brown (i.e., iron-oxides). The Qc unit is extensive throughout the Yelm area (Drost et al., 1999) and its thickness typically ranges between 15 and 50 feet. Groundwater in the Qc is confined by the overlying Qf unit and is a supply source for some wells.

The next deepest hydrostratigraphic unit is the unconsolidated and undifferentiated deposits of the TQu. The TQu are glacial and non-glacial deposits of clay, silt, sand, and gravel, and is known to consist of layers of fine-grained confining beds and coarse-grained aquifer units. The TQu unit is widespread throughout the region, but its thickness is not known.

2.2.2 Shallow Groundwater System

Groundwater recharge to the shallow groundwater system occurs primarily through the direct infiltration of precipitation. Any precipitation not lost to evapotranspiration either (1) moves across the land surface as direct runoff, or (2) infiltrates to become subsurface interflow or groundwater recharge. Interflow can move laterally within the unsaturated soil zone and discharge to streams and springs, or can recharge groundwater when it enters the saturated zone at the water table. Groundwater will ultimately discharge to streams and springs, or move as groundwater flow to deeper units depending upon the hydraulic properties of the underlying geologic layers and hydraulic head differences. Underlying geologic layers with low-permeability characteristics (e.g., compacted silt and clay) will tend to impede the downward migration of groundwater compared to layers that are more permeable (e.g., sand and gravel). Where underlying low-permeability conditions exist, groundwater movement will primarily move laterally along the low-permeability interface rather than vertically. Most groundwater recharge in the study area occurs during the fall and winter wet season when precipitation is greatest and evapotranspiration is lowest.

Topographically upgradient of the headwaters of Thompson Creek is a relatively large catchment that serves as a recharge source for Yelm Prairie Qvr sediments (Figure 13). The catchment resides partially within the Qvrm, Qvt, and Qvr surficial deposits mapped west of the creek's headwaters. Underlying the Qvrm and Qvr surficial deposits are low-permeability Qvt sediments. Because the surface topography of the catchment area within the highlands is hummocky, slopes eastward and contains low-permeability Tenino and Alderwood soils, precipitation is likely to move primarily laterally downgradient toward the prairie, where it is funneled through a topographic constriction formed by Qvt till. This constriction is immediately upgradient of the headwaters of Thompson Creek (Figure 14) and the associated wetland complex. Because this drainage area captures a large volume of precipitation and funnels it into a relatively small area, shallow groundwater occurs in this area resulting in the wetlands, which are drained to the north by Thompson Creek.

Groundwater flow directions and gradients were estimated using groundwater elevation data reported by PGG (2008) for piezometers and monitoring wells completed in the upland catchment area (i.e., P3, P16, and MW1) and in Yelm Prairie immediately east of the upper reaches of Thompson Creek (i.e., P19, P20, and Thompson Creek MW). The piezometers and monitoring wells were completed within Qvr sediments, are of similar depth/elevation and construction, and were surveyed for wellhead elevation.

The direction of shallow groundwater flow west of the upper reaches of Thompson Creek varies seasonally, but is predominately eastward toward Yelm Prairie and the upper reaches of Thompson Creek (Figure 15). March 2008 water-level elevations observed in piezometers and monitoring wells (i.e., P3, P16, and MW1; PGG, 2008) indicate a flow direction generally toward the east-northeast with a hydraulic gradient (i.e., hydraulic head loss per unit distance of flow, *dh/dl*) of approximately 0.0037 ft/ft (19.7 ft/mile). During the summer (August 2008 water-level elevations; PGG, 2008), the hydraulic gradient is similar (*dh/dl* = 0.0043 ft/ft, or 22.8 ft/mile), but the flow direction shifts mainly toward the east. Given the observed groundwater flow directions and the relatively low vertical permeability of the underlying Qvt unit, vertical movement of infiltration on the Thurston Highlands appears impeded by the low-permeability Qvt, and moves primarily in a sub-horizontal direction downgradient where it discharges to surficial prairie floor Qvr sediments (which thicken to the east) and/or surface water features such as streams and wetlands.

The direction of shallow groundwater flow within the prairie floor sediments immediately east of the Thurston Highlands is northeastward. The flow direction appears consistent seasonally, but the gradient steepens during the summer (Figure 15). March 2008 water-level elevations observed in piezometers and monitoring wells completed near the upper reaches of Thompson Creek (P19, P20, and Thompson Creek MW; PGG, 2008) indicate a northeastward flow direction with a gradient of approximately 0.002 ft/ft (10.3 ft/mile). During the summer (August 2008 water-level elevations; PGG, 2008), the flow direction is nearly identical, but the gradient steepens to approximately 0.007 ft/ft (37.2 ft/mile). The steeper gradient suggests that shallow groundwater is spreading laterally within the unconstrained and extensive prairie floor after it discharges from the upland catchment. Given the general flow direction and the relatively low vertical permeability of the underlying Qvt unit, groundwater within the Qvr deposits covering Yelm Prairie appears to move primarily in a sub-horizontal direction northeastward away from the uplands toward more regional discharge points such as Yelm Creek and the Nisqually River.

Thompson Creek likely receives some tributary discharge along its intermediate and lower reaches from the eastern slopes of the uplands area (T17N, R1E, Sections 14, 23, and 26; Figure 1), but unlike the creek's upper reach, there is much less surface area contributing concentrated recharge to any particular reach. The Qvr unit pinches out at the western margin of Yelm Prairie, and the surficial materials to the west of the creek are low-permeability Qvt. The Qvr thickens to the east, allowing recharge moving off the Qvt tills to move vertically downward and toward the discharge points of Yelm Creek and the Nisqually River.

Groundwater within the Qvr blanketing Yelm Prairie is separated from the deeper Qva aquifer by the Qvt. The Qva unit is widespread throughout the subsurface, but is not found at the surface within the study area. Groundwater in the Qva is confined by the overlying Qvt and underlying Qf, and its primary recharge source locations are likely outside the area of study. According to Drost (1999), Qva groundwater generally flows toward marine waters and major streams. Groundwater in the deeper Qc and TQu aquifers are separated from the overlying Qva aquifer by the low-permeability, confining Qf unit, and discharge northwest away from the Nisqually River toward McAllister Springs.

2.3 Thompson Creek

Thompson Creek is located in a topographic depression along the eastern base of the Thurston Highlands at the western margin of Yelm Prairie. The creek resides in a thin layer of permeable Qvr sediments throughout its entire length, which overlies a thicker sequence of low-permeability Qvt. Along the upper reaches of Thompson Creek, the Qvr deposits are approximately 15 feet thick, and vary between 10 and 25 feet thick along its intermediate and lower reaches (Figure 12). The Qvr unit pinches out at the western margin of Yelm Prairie, and the surficial materials to the west of the creek are primarily Qvt and Qvrm. The thickness of the low-permeability Qvt unit below Thompson Creek varies between approximately 35 and 85 feet (Figure 12).

Soil types mapped along the course of Thompson Creek vary from its headwaters west of Yelm to its confluence with the Nisqually River. The downstream progression is generally from poorly-drained and moderately permeable Norma and Muckilteo Series soils at its headwaters to highly permeable Everett and Spanaway soils at its mouth (Figure 2 and Table 1). The intermediate reaches include moderate to highly permeable Spanaway and Nisqually soils. This would suggest that as water drains from the wetlands complex to the north during wet periods, increasing soil permeability will allow increased seepage from Thompson Creek into the Qvr sediments with lower groundwater elevations along its intermediate and lower reaches. This is consistent with the observation that Thompson Creek is a losing stream north of the wetlands complex.

The available streamflow and stage data suggest that Thompson Creek discharge is seasonally and spatially variable. Brown and Caldwell (2008) present discharge data collected in the upper reach of Thompson Creek over a roughly seven-month period beginning in late December 2007 (Figure 16). Streamflow during this time reached its peak in early-February (approximately 4.5 cfs) and declined steadily after mid-April. Flow in the creek decreased below 1 cfs (the minimum instream flow) by mid-June in 2008. By the end of the monitoring period (July), flow had decreased to approximately 0.2 cfs. The relatively constant rate of streamflow decline from mid-April to the end of the monitoring period suggests that flow may cease by mid-to-late summer even at this location near the headwaters, and that when precipitation rates decline groundwater discharge to the creek is likely less than 0.2 cfs in the upper reach.

In the lower reaches, Thompson Creek is commonly known to go dry by mid-summer each year. Thurston County (2008) present stage data from two staff gauges located along the creek's intermediate and lower reaches (Figure 17), but data are only available for a portion of the water-year (Table 3). Stage data collected at the 93rd avenue gauge along the creek's intermediate reach indicate no-flow conditions for the first month of monitoring (November) despite steady precipitation events and water in the creek channel observed at the upper gauging locations (Figure 18A). Water in the creek at the 93rd avenue gauge was first recorded in early-December following a significant precipitation event and fluctuated throughout the remainder of the monitoring period (ending in late-April), largely in response to precipitation. Concurrent stage observations spanning a shorter monitoring period recorded along the creek's lower reach at the HWY 510 gauge show intermittent periods of wet and dry conditions (Figure 17), even in the spring months (March and April). Approximately 50 percent of the monitoring record observed at the HWY 510 gauge indicates that the creek channel is dry, and flow appears to occur only in response to significant or prolonged precipitation events.

2.4 Groundwater and Stream Interactions

The interaction between groundwater and streams can take place in three basic ways: (1) a stream can gain water from the inflow of groundwater (i.e., gaining stream), (2) a stream can lose water to groundwater via seepage (i.e., losing stream), or (3) a stream can gain water in some reaches and lose water in other reaches. A gaining stream will receive groundwater inflow if the groundwater-level elevation near the stream is higher than the stream stage. Alternatively, a losing stream will lose water to groundwater if the groundwater-level elevation is below the stream stage. The interaction between Thompson Creek and Qvr groundwater is discussed in the creek's upper, intermediate, and lower reaches below.

2.4.1 Upper Reaches of Thompson Creek

Creek stage and groundwater elevation data indicate that precipitation recharges a thin layer of Qvr sediments where it flows sub-horizontally along the surface of the Qvt and intersects the upper reaches of Thompson Creek as it migrates from the Thurston Highlands toward Yelm Prairie. Groundwater elevations observed in Qvr monitoring wells located within the catchment upgradient of the upper reaches of Thompson Creek (MW1 and MW2; Figure 18A) are consistently higher than those observed in Qvr piezometers located immediately downgradient of Thompson Creek (P12, P19, and P20; Figure 18B). Sub-horizontal flow directions along the surface of Qvt are indicated by water-level observations made at a Qvt monitoring well (MW3). Water-level data collected at MW3 indicate dry conditions throughout its entire monitoring period with the exception of one recorded during mid-January (Figure 18A). MW3 is located upgradient of Thompson Creek near MW1 and MW2, and the borehole log shows that the well is screened in the Qvt (Appendix B). The predominantly dry conditions observed at MW3 during the recharge period indicates that groundwater preferentially flows laterally within the Qvr unit atop the low-permeability Qvt rather than vertically downward. The interaction between Qvr groundwater and Thompson Creek was evaluated by analyses of water-level elevations recorded at creek staff gauges and a Qvr Thompson Creek monitoring well (i.e., Thompson Creek MW). These measurements indicate the following in the headwaters area:

- During the winter months, the headwater's wetlands and creek intercepts Qvr groundwater migrating downgradient from the Thurston Highlands toward Yelm Prairie, which drains to the north along the channel; and
- The headwaters area loses surface water to the Qvr sediments during the summer months.

These head and stratigraphic relationships are illustrated in water-level hydrographs (Figure 18) and a block-flow diagram (Figure 19). The block diagram shows the downgradient movement of Qvr groundwater along the Qvr/Qvt interface and its intersection with Thompson Creek. The amount of Qvr groundwater entering the creek (GWin) is greater than the amount moving further into the valley sediments (GWout), with the difference discharging into the creek (a gaining stream). Some water in the Thompson Creek system is lost to surface water discharge (SWout) and evapotranspiration (ET) and gained through direct precipitation. Groundwater elevations recorded at the Qvr Thompson Creek MW located adjacent to and along the upgradient side of Thompson Creek in the headwaters area indicate that the creek likely receives discharge from groundwater beginning in late-fall (Figure 18A). The Qvr groundwater elevation observed in the monitoring well is consistently higher than the creek stage during the winter and spring months.

The net exchange of water between Thompson Creek and Qvr groundwater in the headwaters area varies seasonally. The upper reaches of Thompson Creek begins to lose water to the Qvr following the winter/spring recharge period. Beginning in early-summer, the groundwater elevation observed in the Thompson Creek MW falls below the creek stage indicating that the creek is losing water to the underlying Qvr sediments (Figure 18A). During this same period, Qvr groundwater elevations observed in piezometers located immediately downgradient of Thompson Creek (P12, P19, and P20) are lower in elevation compared to water-level elevations observed in MW1, MW2, Thompson Creek MW, and creek stage (Figure 18B). This indicates that Qvr groundwater continues flowing toward Yelm Prairie where the Qvr sediments thicken.

2.4.2 Intermediate and Lower Reaches of Thompson Creek

Recent water-level data collected at downstream monitoring locations (Thurston County, 2008) and historic evidence (Water Right Application for Change 7053-A; Appendix A) suggest that Thompson Creek is primarily a losing stream and a source of shallow Qvr groundwater recharge along its intermediate and lower reaches. Three monitoring wells (in downstream order: B3, B1, and B2) and one staff gauge (93^{rd} Ave. SE) were installed to monitor surface water and groundwater levels along the creek's intermediate reaches (Figure 9). Monitoring wells B3 and B1 are screened in the Qvr unit while B2 is screened in Qvt. Farther downstream, one monitoring well (B7; screened in the Qvt) and one staff gauge (HWY 510) were installed to monitoring surface water and groundwater levels along the creek's lower reaches (Figure 9). Although few staff gauge measurements were made concurrently with groundwater-level measurements, the following observations can be made:

- Estimated water-level elevations at B3 and B1 are consistently lower than Thompson Creek stage measured at neighboring upstream and downstream locations suggesting that Thompson Creek consistently loses water to the Qvr (Figure 20);
- Predominantly dry conditions observed at B2 throughout the monitoring period indicates that groundwater preferentially flows laterally within the Qvr unit atop the low-permeability Qvt rather than vertically downward;
- Stage data collected at the 93^{rd} avenue gauge indicate no-flow and losing stream conditions for the first month of monitoring despite steady precipitation events and water in the creek channel observed at the upper gauging locations (Figure 17); and
- Approximately 50 percent of the monitoring record observed at the HWY 510 staff gauge indicates that the creek channel is dry, and flow occurs only in response to significant or prolonged precipitation events (Figures 17).

Groundwater elevations and field observations made at the time the Thurston County monitoring wells were installed (April, 2008) indicate that the creek is perched: disconnected from the Qvr groundwater system throughout its intermediate and lower reaches by an unsaturated zone. Field observations recorded on the borehole logs (Appendix C) identify "dry" conditions at each location beneath the creek bed and above the water table. Streams that are disconnected from groundwater will not be impacted by pumping of shallow ground water near the stream and will not affect the flow of the stream near the pumped wells.

Groundwater flow paths and the net exchange of water along Thompson Creek's intermediate and lower reaches is conceptualized in a block-flow diagram presented in Figure 21. The block diagram shows the general movement of Qvr groundwater along the Qvr/Qvt interface and its interaction with Thompson Creek. The amount of Qvr groundwater leaving the creek (GWout) is greater than the amount gained (GWin) reflecting the flow lost from the creek. The field observations recorded during the installation of the Thurston County monitoring wells were made during the recharge period, and the disconnected/losing nature of the creek is likely to continue throughout the summer and fall periods when recharge to the creek and groundwater-levels are typically lowest.

3.0 SUMMARY AND CONCLUSIONS

This technical memorandum describes the conceptual hydrogeologic framework of the shallow groundwater system and its interaction with Thompson Creek. Golder's work includes a thorough independent review of well logs, hydrologic and hydrogeologic data, previous hydrogeologic studies, documented reproducible methodology consistent with best hydrogeologic practice, and develops conclusions supported by data and observation. Golder has provided:

- A complete summary of available data describing the physical and hydrogeologic characteristics of the Thompson Creek study area;
- An improved understanding of the local hydrostratigraphic units consistent with work produced by previous investigations conducted in the study area, and;
- A conceptual hydrologic model for Thompson Creek recharge/discharge relationships based a sound interpretation of the available data.

Thompson Creek is conceptualized as consisting of two basic hydrologic regimes: (1) a seasonally gaining and losing stream in the upper reaches of the creek, and (2) a losing stream in the creek's intermediate and lower reaches due to lower groundwater elevations and increasingly more permeable soil conditions downstream of the creek's headwaters. During the wet portion of the year, a relatively large volume of precipitation moves laterally downgradient toward the prairie and is funneled though a narrow gap in the Qvt till creating high groundwater conditions forming the wetlands complex at Thompson Creek's headwaters. Our conceptual understanding of Thompson Creek is summarized below:

- Given the general east-northeastward Qvr groundwater flow direction and the relatively low vertical permeability of the underlying Qvt unit, vertical infiltration from precipitation on the Thurston Highlands is vertically impeded as recharge encounters the till. Groundwater then moves laterally along the Qvt contact downgradient toward the prairie floor Qvr sediments and Thompson Creek;
- During the wet season when recharge and groundwater levels are typically greatest, shallow groundwater elevations in the headwaters area of Thompson Creek are consistently higher than creek stage, indicating groundwater discharge to surface water. In the summer and fall months, this condition reverses.
- Along its intermediate and lower reaches, Thompson Creek is primarily a losing stream and a source of recharge to the shallow Qvr sediments.

3.1 Implications

As part of a review of one of the City's water-rights transfer applications, Ecology appeared to give weight to a letter of concern (Appendix A) citing potential impairment to instream flows and senior water rights on Thompson Creek. As its basis, that letter cited a report prepared by a consulting firm (Appendix A) that contained unsupported re-interpretation of area hydrostratigraphy that was not consistent with the data reviewed by Golder or other hydrogeologic reports. This analysis finds that hydrostratigraphy will limit the potential for Qva pumping to impact flows on Thompson Creek. In addition, a more careful analysis of likely recharge/discharge relationships presents a conceptual model that limits the potential for impairment in two primary ways:

1. Precipitation on the highlands is the primary source of recharge to Thompson Creek, and flow in the creek in all areas is dependent on precipitation west of the creek rather than rising groundwater levels beneath the Yelm Prairie. Consequently, lowered shallow water levels beneath the valley floor may not have any effect on the occurrence or duration of Thompson Creek flow; and
2. Groundwater elevations and field observations suggest that over most of its length, the creek is disconnected from the Qvr groundwater system by an unsaturated zone and flows could not be reduced if shallow groundwater near the creek were lowered by pumping. This condition also suggests that lowering the shallowest groundwater elevation may not affect the occurrence or duration of flow in Thompson Creek.

These conditions do not indicate that an irrigation water right in the lower sections of the creek is likely to be impaired by the City shifting Qva pumping to the north, while lowering the rate and extending the duration. In fact, it seems unlikely that a senior irrigation right on Thompson Creek could be exercised due to the absence of flow in the lower section in most years, and the instream flow requirement that would further limit the period that water is available for appropriation during the irrigation season.

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