Technical Memorandum 10 (Task 8a)
WRIA 27/28 Watershed Plan
East Fork Lewis River Watershed
Groundwater/Surface-water Relationships

PREPARED FOR: WRIA 27/28 PLANNING UNIT

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LOWER COLUMBIA FISH RECOVERY BOARD

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Acknowledgments

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1 Introduction

The WRIA 27/28 Planning Unit is developing a watershed plan for Water Resource Inventory Areas (WRIAs) 27 and 28 under the auspices of the Watershed Planning Act. As part of the assessment phase, the Planning Unit decided to conduct specific studies to evaluate groundwater resources in the basin. Of primary interest to the Planning Unit was to evaluate to what extent groundwater development in the basin affects stream flows. The subject of this technical memorandum is the study of that question for the East Fork Lewis River Watershed with the following specific objectives:

- Assess the hydraulic connection between the regional groundwater system and the East Fork Lewis River and its primary tributaries

- Assess potential impacts on stream flow posed by planned groundwater withdrawals in the area

As part of the first objective, the hydrogeology of the East Fork Lewis River watershed was mapped to show where the main aquifers and the East Fork Lewis River and its tributaries are connected. Furthermore, in order to understand how the surface-water bodies in the basin interact with groundwater, specific tributaries throughout the study area were selected to assess where ground water discharges to surface water and where surface water recharges ground water. A study of this relationship aids in locating where ground water withdrawals are hydraulically connected to surface water, and where the withdrawals may impact stream flows. From this information, the effects of groundwater withdrawals on specific tributaries as well as the net effects on the East Fork Lewis River mainstem were interpreted. Lastly, historic water levels and pumping rates were evaluated to assess whether specific municipal withdrawals and exempt well use in the watershed have impacted or are impacting ground water levels and stream flows. Of specific interest were Clark Public Utilities' (CPU) Pioneer Area wells and the City of Battleground's proposed new wells.

The study area focus on the part of the watershed extending from the mouth of the East Fork to about river mile 27 at the confluence with Rock Creek (South). Figure 1 shows the extent of the study area. The principal tributaries of interest in the upper and eastern portion of the watershed are Yacolt Creek and Rock Creek (South). The western half of the East Fork Lewis River basin study area consists of a moderately dissected south sloping bench on the north side of the river, the East Fork Lewis River floodplain, and a barely dissected bench on the south side of the river. On the north side of the river along this reach, the major tributaries of interest are (west to east) Jenny, Brezee, Lockwood, Mason, and Rock (North) Creeks. On the south side of the river along this reach, the drainage area is much smaller than north of the river, and only three significant perennial tributaries are present – (from west to east) McCormick, North Mill, and Spring Creeks. Field work to measure base flows was conducted in these streams. An existing gage was used to assess flow conditions in the East Fork Lewis River.

Pacific Groundwater Group had briefly investigated groundwater/surface-water relationships at several places within the study area as part of water-supply development studies and test drilling by Clark Public Utilities and the City of Battle Ground. Otherwise, very little was known about these relationships in the basin. Based on their previous knowledge of the basin, PGG was retained by the Planning Unit to complete this study.

Information on surficial geology, subsurface hydrogeology, well logs, topography, surface-water rights, and measurements of streamflow gains and losses were used to estimate tributary baseflow (groundwater discharge) and potential capture of surface water by wells. Water-level trends were compared to annual withdrawals for municipal wells and to precipitation trends in order to assess areas of possible groundwater overdraft.

This study can be divided into the following major components:

- Description of the hydrogeology of the East Fork Lewis River watershed (Section 5). This information supports the development of a conceptual model describing the relationship between the groundwater and surface water interaction.

- Estimation of the baseflow in the principal tributaries of interest and where it occurs (Section 6). Baseflow is the component of streamflow fed by groundwater discharging to the stream. Groundwater discharge occurs as springs and seeps on slopes or as direct seepage to stream channels. By identifying the location and rates of groundwater discharges to the stream, an understanding can be made of the potential impact of ground water withdrawals on streamflow. Water rights information is also reviewed to assess whether flow gains and losses in a reach of stream is attributable to diversions or natural hydrogeologic conditions.

- Qualitative assessment of the potential capture of baseflow by wells (groundwater withdrawals; Section 7). Whereas Section 6 focuses on quantifying the baseflows, the assessment in Section 7 considers the hydrogeology, well depths, and well densities as indications of the areas where groundwater discharge potentially would be captured by wells.

- Discussion of the impacts of planned and existing groundwater withdrawals on principal tributaries in the watershed and on the mainstem East Fork Lewis River (Section 8)

The Planning Unit is interested in not only the direct findings applicable to the East Fork Lewis River watershed, but also the potential applications the findings may have for the other sub-basins in WRIA 27 and 28.

2 Summary of Findings

Groundwater – surface water interactions were investigated in the mainstem and tributaries in the western two-thirds of the East Fork Lewis River watershed (**Figure 1**) in order to: (1) assess the hydraulic connection between the regional groundwater system and the East Fork Lewis River and its tributaries; and (2) to assess potential streamflow capture by current and planned groundwater withdrawals.

The study included in this technical memorandum has collected a significant amount of detailed information on the hydrogeology of the area, baseflow measurements, and water rights information. The following points summarize the major findings:

- The majority of baseflow to the East Fork Lewis River and floodplain appears to come directly from the deeper aquifers, rather than from shallow aquifers via the tributaries. According to baseflow measurements in the tributaries and historical data from the mainstem, baseflow from the deeper aquifer appears to be at least four times that from the shallower aquifers via the tributaries.

- Wells drawing from the fine-grained sediment units in the upper reaches of the East Fork tributaries are directly connected to the tributaries and probably capture most of their water from the tributary watershed in which they are located. However, The East Fork tributaries are not significantly threatened by capture due to groundwater pumping, because total groundwater withdrawal from the area draining to the upper parts of the sub-basins is quite small.

- Based on the geologic data, wells completed in the Sand and Gravel Aquifer (SGA) probably capture most of their water from the East Fork Lewis River or from the lower ends of the tributaries where they cross the East Fork's floodplain. The SGA occurs beneath the shallow hydrogeologic units in the uplands. This confined aquifer supplies many of the exempt and municipal wells in the lower parts of the sub-basins, which generally are more than 200 feet deep.

- Exempt wells do not appear to significantly impact baseflows. Exempt well use is estimated to be about 8 percent (0.48 cfs) of total baseflows in the tributaries and 1 percent of baseflows in the mainstem at Heisson.

- Municipal groundwater withdrawals have been increasing in some areas and decreasing in others, in or near the East Fork watershed. Based on a cursory estimate, total municipal well capture from the East Fork Lewis River watershed from CPU's Pioneer area withdrawals and City of Battleground's withdrawals was approximately 2,305 acre-feet (or 3.2 cfs) in 2002.

- Measurements of streamflow in the East Fork tributaries showed that most of the streams appeared to gain baseflow throughout their length, so the tributary streams can generally be classified as "gaining" streams.

- Although measurements on the main stem of the East Fork Lewis River were no included in the scope of this study, data from other studies show differences in results as to whether the East Fork from Heisson gage at river mile 20 to approximately river mile 7 is “gaining” or “losing” reach.

3 Study Area

The study area is the western two-thirds of the East Fork Lewis River Basin in Clark County, Washington, which is part of Water Resource Inventory Area 27. The entire watershed covers about 212 square miles and includes the towns of LaCenter and Yacolt (**Figure 1**). The upper watershed consists of the forest-dominated foothills of the Cascade Mountains. Maximum elevation is 4,442 feet above mean sea level. Terrain is steep, with narrow bedrock-lined valleys, and channels dominated by bedrock and boulders (Wade, 2000). Principal tributaries of interest in this portion of the study area are Yacolt Creek and Rock Creek (South).

In contrast, the western half of the East Fork Lewis River Basin consists of a moderately dissected south sloping bench on the north side of the river, the East Fork Lewis River floodplain, and a barely dissected bench on the south side of the river. Rural residential, agricultural, and forestry land uses predominate. Below Heisson, the East Fork Lewis River occupies a broad valley up to 1.5 miles wide. On the north side of the river along this reach, the major tributaries of interest are (west to east) Jenny, Brezee, Lockwood, Mason, and Rock (North) Creeks. On the south side of the river along this reach, the drainage area is much smaller than north of the river, and only three significant perennial tributaries are present – (from west to east) McCormick, North Mill, and Spring Creeks.

A short distance below Daybreak Park Bridge, at river mile 10.2, the East Fork Lewis River's level (stage) is tidally influenced. Where the East Fork joins the North Fork Lewis River, at the margin of the Columbia River valley, the riverbed lies 4 feet below mean sea level.

The climate comprises warm, dry summers and cool, wet winters. Air temperatures are moderated by Pacific maritime air from the west. Mean annual temperature is about 52^{o}F. Typically, rainfall occurs in light to moderate intensity storms, with multi-day storms occurring from October through April. Average annual precipitation varies from about 45 in/yr at the mouth of the river (west end of watershed) to about 110 in/yr at the headwaters in the Cascade foothills.

This study used the tributary watershed (sub-basin) delineations by Clark County. The County's naming convention for un-named tributaries also was used, with the exception that the tributary identified by the County as "East Fork Tributary RM 9.6" is identified herein as Spring Creek, based on the U. S. Geological Survey topographic map and water-right records at Department of Ecology.

4 Study Methods

4.1 General Approach

Subsurface hydrogeologic units were identified and illustrated in cross-sections, based on surficial geologic mapping, driller's well logs, and topographic maps. Source aquifers for wells for various depths were interpreted from the geologic maps and hydrogeologic cross sections. Synoptic streamflow measurements (seepage runs) and estimates of surface-water rights for selected large sub-basins were used to estimate baseflows (groundwater discharge) and potential baseflow impacts for selected tributaries. Well depths and well densities were assessed for indications of the areas where groundwater discharge potentially would be captured by wells. Water-level trends were compared to annual withdrawals for municipal wells and to precipitation trends in order to assess areas of possible groundwater overdraft.

4.2 Conceptual Model of Surface Water Capture by Wells

The established theory for the capture of surface water by groundwater withdrawal (wells) was summarized by a technical committee convened by the Dept. of Ecology (1998). The phenomenon is often referred to as "hydraulic continuity", although this terminology is imprecise. Hydraulic continuity implies the interconnection between groundwater and surface water through geologic materials. This occurs nearly universally in humid temperate climates, wherever subsurface saturation is continuous throughout the hydrogeologic unit that lies beneath the bed of a surface-water body.

Hydraulic continuity is important wherever groundwater and surface water can exchange in meaningful amounts. This may involve groundwater discharge to surface water, which commonly occurs in spring-fed lakes, wetlands, and along "gaining" stream reaches. It may also involve surface water infiltrating to the subsurface and recharging groundwater. Throughout this document, the term "gaining" stream refers to a stream reach that receives ground water discharge, while the term "losing" stream refers to a stream reach where surface water infiltrates to recharge ground water. A stream can have gaining and losing segments throughout its entire length, depending on the relative difference in surface water and ground water levels at particular points along the stream.

The term "capture" in this case refers to situations where a quantity of water is prevented from moving to where it would naturally go as a result of withdrawal (pumping). Groundwater pumping "captures" surface water by reducing heads (i.e. water levels - see glossary) in the surrounding materials (Theis, C. V., 1940; Heath, R. C., 1983). Two types of capture are possible—either the well withdraws groundwater that otherwise would have discharged to the surface or it draws surface water into the adjacent aquifer. The relative head difference between surface water and groundwater at the interface (streambed, lakebed, etc.) during pumping determines which of these two capture mechanisms occurs. If the head in the aquifer is higher, the well withdraws water that would have discharged to the surface; if the head in the surface water body is higher, surface water is drawn into the aquifer. Thus, well pumping can result cause a gaining stream to become a losing stream, or at least reduce the amount discharged to the stream (i.e. reduce baseflows). Alternatively, well pumping can cause a losing stream to lose more water to infiltration, which also reduces stream flows.

Surface water capture by a well is delayed, because there is time lag between the groundwater withdrawal and the surface-water effect. Capture also generally occurs at a lower rate than the pumping rate, particularly when the withdrawal is intermittent. However, the total volume of capture eventually equals the total volume of groundwater withdrawn.

The difficulty of understanding specific groundwater/surface water interactions in any area is directly proportional to the complexity of the hydrogeology and topography. To identify capture, potentially affected surface water bodies must be identified. Because a near-surface, unconfined aquifer generally is dominated by local groundwater flow, withdrawals from it are more likely to influence nearby surface water bodies, irrespective of their size. Withdrawals from deeper confined aquifers that crop out along stream reaches outside the watershed where the pumping occurs, or that have no outcrop, are more likely to affect the regional flow system and capture water from stream reaches outside the watershed. Such capture could also be spread among numerous surface-water bodies.

The timing and magnitude of capture depends on several factors:

- Distance between the well and the surface-water body,
- Geometry and hydraulic properties of aquifers and aquitards between the well and the surface water body,
- Patterns of groundwater flow and recharge, and
- Well completion elevation.

Depending on these factors, capture from surface water bodies may occur almost instantaneously or it may be delayed by months, years, or decades. In general, the longest delays will be associated with deep wells that are located far from surface-water bodies in aquifers that are overlain by substantial aquitards.

4.3 Methods

GIS software (ArcView®) was used to map the stream-gaging locations, well locations, surface-water-right locations, hydrography, geology, and the WRIA and tributary basin boundaries. Based on the theory discussed above, the magnitude of potential stream capture from exempt well effects was estimated using the following sequence of steps.

Approximately 4,200 well logs were obtained in digital image format (scanned from original paper copy) from the Washington Dept. of Ecology's on-line well-log database. The well locations were identified from drillers' logs by township, range, section, and ¼-¼ section (an area 660 feet on a side, or 40 acres). Therefore, a number of wells may appear to be at the same location and the mapped locations may be inaccurate by hundreds of feet. Also, occasionally, well locations are misidentified by drillers. However, field verification of well locations was beyond the scope of this report.

Using GIS methods, the wells were mapped, counted, and classified by depth in 100-foot increments (**Figure 1**). The database of well locations and depths were used to select certain deeper logs along five alignments in order to interpret subsurface hydrogeologic units and illustrate the layering in cross-sections. The distribution of well depths for each sub-basin was charted as bar graphs to search for clusters of wells in certain depth ranges.

Both the location and depth distributions of the wells were compared to surficial geologic units and subsurface hydrogeologic units to assess the general clustering of wells in certain hydrogeologic units.

The latest groundwater pumpage and water level data was obtained from Clark Public Utilities and the City of Battle Ground. Annual precipitation data was obtained for the National Weather Service station at Battle Ground. The pumpage, water level, and precipitation data were charted and interpreted regarding potential groundwater overdraft.

4.4 Data Sources

The data and other information used in this study were obtained from a variety of sources, listed in the following:

- Well logs from Department of Ecology's on-line well database,
- Parcel GIS coverage from Clark County GIS,
- Hydrography GIS coverage from U. S. Geological Survey (USGS),
- Surficial geology GIS coverage from Geology and Earth Resources Division, Washington Dept. of Natural Resources, 1:100,000 scale,
- Pacific Groundwater Group (2001, 2002a, 2002b),
- Sub-basin GIS coverages from Clark County GIS and from the Lower Columbia Fish Recovery Board.
- GIS coverages from Clark County
- Water use and water levels from CPU and City of Battle Ground
- Geology from DNR and reports by Mundorff and Howard.
- Topographic map from compact disk.

5 Hydrogeology

The surficial geology map published by the Geology and Earth Resources Division of the Dept. of Natural Resources was used as the principal source of geologic information. The recently published surficial geology map for the Battle Ground quadrangle (Howard, 2002) was used as supplemental source of information, but could not be easily reconciled with the DNR map and so was not used to produce the surficial geology map (**Figure 2**).

5.1 Geology and Hydrogeology

The geology and hydrogeology of the East Fork Lewis River basin were investigated in order to interpret whether the pumping effects of wells could be related to source aquifers and their respective discharge areas. The surficial geology was mapped originally by Mundorff (1956). The first comprehensive geologic mapping in Clark County since the work of Mundorff (1964) is underway by the U. S. Geologic Survey. The west half of the watershed was recently mapped by the U. S. Geological Survey as part of its study to understand geologic hazards in the populous Puget Sound – Willamette Valley corridor (Pacific Northwest Project). However, only one quadrangle has been published to date (Howard, 2002). Geologic mapping by Russell Evert is continuing along the Columbia River valley and up to the Cascade foothills (Russell Everts, personal communication, 2003). This year he is mapping the Lacamas Creek, Camas, and Washougal Quadrangles. His geologic maps of the Aerial, Woodland, and Ridgefield quadrangles are in press, his map of the Amboy quadrangle is undergoing review, and his map of the Yacolt quadrangle map being prepared.

In general, for the East Fork Lewis River basin, Howard and Everts have further subdivided the unit that Mundorff identified as the Troutdale Formation and have added a few units, such as a second (older) glacial drift, and structural interpretations. This more accurate mapping promises to be of value in hydrogeologic interpretation. However, because only part of the new mapping has been published, it was not possible to produce a coherent map that combines the older and newer mapping.

Figure 2 shows surficial geology in the western part of the East Fork Lewis River Basin, as well as the alignments of five subsurface hydrogeologic cross-sections (**Figures 3 through 7).** These cross-sections illustrate the subsurface geology and hydrogeology. The older rocks crop out in the foothills and mountains in the eastern part of the study area and are buried beneath younger sediments in the western part. Downwarping of the older rocks in the western part of Clark County formed a basin in which various sediments were deposited. Some of the sediments are old enough and were buried deep enough to become semi-lithified (turned to rock) through chemical cementation and compaction. Contacts between the sedimentary units dip to the west in the study area and indicate continued downwarping during deposition. The sediments crop out on the terraces and upland slopes. The sediments constitute the principal aquifers in the area.

The representative geologic units, from oldest to youngest, are described below. The hydrologic properties of these units are explored in Section 2.4, "Principal Aquifers and Aquitards."

5.1.1 Recent Alluvial Deposits

Recent alluvium is generally encountered within the floodplains and low terraces along the floodplains of the rivers and creeks. The coarse-grained alluvium consists of loose, bouldery and cobbly gravel, composed mostly of Skamania Volcanics along the East Fork Lewis River. Along the creeks, the grain sizes range from sand to cobbles. This unit rarely serves as an aquifer because it is too thin and localized.

5.1.2 Boring Lava

Basalt of Battle Ground (Howard, 2002) occurs east and northeast of Battle Ground and is correlated with the Boring Lava. This unit consists of fine-grained, vesicular basalt of the upper Pleistocene, about 100,000 years old. The unit overlies both the upper Troutdale and glacial drift. The Boring Lava can be a moderately productive aquifer within its vesicular and scoriaceous interflow zones and within pyroclastic deposits.

5.1.3 Glacial Drift

Mundorff (1964) mapped glacial drift in the Yacolt and Daybreak Park areas and called it the Amboy Drift. Howard (2002) mapped the drift as extending westward several miles west of Rock Creek (North) and three miles south of the river east of Battle Ground. Howard noted that two tills are present, with the older till being deeply weathered. However, exposures of the drifts are sparse, so Howard did not have sufficient information to sub-divide the unit. Everts (personal communication, 2003) has subdivided the two drifts in his draft geologic map of the Aerial Quadrangle (in press). Everts examined some of Howard's reference outcrops in the Battle Ground Quadrangle and believes that the till west of Rock Creek (North) is mostly the older unit. No intervening outwash or other materials have been observed between the two tills. The deeply weathered older till also occurs at the surface east of Fargher Lake, on a small highland area.

5.1.4 Pleistocene Alluvial Deposits

The ancestral Columbia River deposited Pleistocene alluvium as a great deltaic fan emanating from the Columbia River gorge. Because the alluvium was deposited via catastrophic floods emanating from the ancestral Lake Missoula during the Pleistocene Epoch, the unit is sometimes referred to as Missoula Flood deposits or Pleistocene catastrophic flood deposits. Within the study area, they occur on the upland plains on the south side of the river and the lower part of the uplands on the north side of the river. The unit’s thickness ranges from a feather edge to about 150 feet (Figures 3 through 6) and consists of medium sand to silt, grading finer northward. The basal zone may contain pebbles and cobbles that were ripped up from the underlying Troutdale gravel (Howard, 2002).

5.1.5 Troutdale Formation

The Troutdale Formation overlies older bedrock and comprises unlithified and semi-lithified sediments. In the study area, the Troutdale is exposed along the East Fork valley and as much as half way up the south facing slopes on the north side of the river (**Figure 2)**.

The Troutdale Formation has been divided into stratigraphic or hydrostratigraphic units by Mundorff (1964), Carr and Associates (1985), Swanson and others (1993), and Howard (2002).

Mundorff divided the formation into upper and lower members, based on age and dominate grain size. The classifications proposed by Carr and Swanson were based largely on water-bearing properties, and they worked mostly south of Battle Ground, which lies south of the East Fork Lewis River Basin.

The current analysis uses a mix of the sub-divisions of Mundorff, Swanson, and Howard. Howard has done the most detailed surficial analysis, but his subdivisions cannot be easily distinguished using well logs, due to the recognition and recording of only the grossest geologic details by well drillers. All three authors recognize a partially cemented gravel unit at the top of the Troutdale Formation. It is as much as 100 feet thick. The unit functions as an aquifer. Howard sub-divides this gravel unit into (from top to bottom) alluvial-fan, volcanic-clast, and quartzite-clast members. For the current study, the unit is called the Upper Troutdale aquifer (Qtu).

A fine-grained unit, (equivalent to Mundorff's lower member of the Troutdale and Swanson, and others' Confining Units 1 and 2), underlies the upper member. Mundorff's interpretation does not extend below this upper confining unit, because a substantial number of wells had not penetrated below that depth at the time of his study. This unit functions as an aquitard and is referred to in the current study as the Upper Confining Unit (Qc1), but could not be identified in well logs, nor is was it identified by Howard in the Battle Ground quadrangle.

For materials below the fine-grained unit, both Carr and Swanson identify an intermediate sand-and-gravel unit within the Troutdale Formation. Swanson calls this unit the Troutdale Sandstone aquifer and correlates it to the lower part of Mundorff's upper member of the Troutdale Formation. The unit may correlate to Howard's quartzite-clast member. In the current study, the unit is referred to as the Lower Troutdale aquifer (QTl) and was identified in well logs only in the Battle Ground and Pioneer areas, south of the East Fork (**Figure 5**).

Below the Lower Troutdale aquifer, Swanson identifies a lower confining unit (Qc2 in this study). This appears to correlate with Howard's fine-grained member of the Troutdale Formation. This unit is found in some parts of the study area, but often is missing.

Below the lower confining unit, is a sand unit that farther south is called the Sand and Gravel aquifer by Swanson and others. Howard identifies this as a sand facies within the fine-grained unit, rather than as a separate member. For the current study, this sand is also called the Sand and Gravel aquifer (Qsg) and is referred to by the acronym SGA, although within the study area it contains little gravel. The SGA consists predominantly of fine and fine-to-medium sand, with lenses of silty sand and clay; locally, it contains some sand-and-gravel lenses. The unit is as much as 200 feet thick in the Battle Ground quadrangle and as much as 500 feet thick in the Pioneer area.

5.1.6 Older Rocks

Within the study area, the Older Rocks (bedrock) crop out mostly in the Cascade foothills and mountains and underlie the younger sedimentary rocks (**Figure 2**). Some bedrock units are exposed in a small area around LaCenter. The older rocks are late Eocene to Oligocene age (about 40 to 24 million years old) and include partly metamorphosed andesitic to basaltic lava flows. These rocks usually yield only small amounts of water to domestic wells but yield several hundred gpm in one municipal well a couple miles south of the study area (east of Battle Ground in the Salmon Creek basin).

5.2 Summary of Principal Aquifers

The hydrogeology of the area has been generalized into a few alternating principal aquifers and aquitards. The cross sections (**Figures 3 through 7**) illustrate the interpreted subsurface relationships among the various hydrogeologic units.

The principal aquifers in the East Fork Lewis River basin occur primarily within the Troutdale Formation, but also in younger glacial outwash in the Yacolt and Rock Creek (South) valleys.

Within the Troutdale Formation, the aquifers include (**Figures 2 through 7**) the Upper Troutdale aquifer (uppermost gravel unit), the Lower Troutdale aquifer (intermediate sand-and-gravel unit), and the Sand and Gravel aquifer (SGA; lowermost sandy unit).

6 Measurement of Tributary Baseflow

This section includes a discussion on the part of the study focused on measurement of tributary baseflow. As defined previously, baseflow is the component of streamflow fed by groundwater discharging to the stream. The groundwater discharge occurs as springs and seeps on slopes or as direct seepage to stream channels. The most direct way of measuring baseflow is to measure stream flows when no runoff is occurring. Thus, stream flow measurements were conducted during July 2003 as a way to estimate low flow (dry season stream discharge) and baseflow conditions in the watershed. The only previous measurements for East Fork tributaries were by McFarland and Morgan (1996). Data from this study for East Fork tributaries appear in **Table 1**. Additional stream flow measurements were not made on the mainstem, because the Heisson gage data was available. Flow information from the Heisson gage was used to interpret baseflow conditions on the mainstem. This information is then used as the basis for evaluating the potential for streamflow capture by wells during the dry season when water depth and velocity become critical for aquatic habitat (Section 7).

Usually, in humid climates, such as in Clark County, groundwater and surface water form a saturated continuous hydrologic system, a situation often referred to as hydraulic continuity. Groundwater discharges to streams along most stream reaches, called “gaining” reaches, such that from headwaters to mouth the baseflow component of streamflow continuously increases. However, in some geologic settings, it is possible to have losing reaches that occur when the groundwater level is lower than the stream level, this situation is found along the middle reach of Salmon Creek in Clark County (McFarland and Morgan, 1996). Therefore, one of the objectives of tributary streamflow measurements for this study was to assess where reaches of the East Fork tributaries lose water by seepage (infiltration) and where they gain water from baseflow (ground water discharge).

As discussed previously in Section 4.2, a stream reach might lose flow due to capture by wells, as a result of direct diversion from a surface-water right, or due to natural hydrogeologic conditions that would promote seepage loss. The effect of a withdrawal would generally be to capture flow that would naturally discharge as baseflow to a gaining stream or alternatively increase the infiltration or seepage to the subsurface in a losing stream. The estimates of baseflow and determination of whether a stream segment is a gaining or losing reach allows a better understanding of the relative quantities of flow that can be captured by each of these processes. For example, depending on the magnitude of the withdrawal capture, a gaining stream reach with a relatively large baseflow may continue to gain baseflow despite baseflow capture from the well. However, for gaining streams with relatively low baseflow under natural conditions, a significant rate of capture may convert the segment into a losing reach. In situations where a reach has alternating gaining and losing segments, a point where measurements are taken would consider the net effects over the entire reach.

Furthermore, the discussion to follow includes a review of surface water rights in the tributaries where flow measurements were taken. This is included to assess whether a measured loss might be attributed to the surface water diversions. The amount of water being diverted has a direct impact on the amount of baseflow measured in the stream, and can ultimately be the cause of the “lost” flow rather than a natural hydrogeologic condition. For example, the baseflow on a stream segment with surface water rights equal to less than 5 percent of the measured flow probably was not significantly affected by diversions at the time of the measurement. However, surface water rights making up more than 10 percent or so of the measured baseflows would more likely be the cause of the loss in the stream segment rather than natural seepage into the subsurface.

6.1 Synoptic Streamflow Measurements

To check for seepage gains or losses, discharge in selected East Fork tributaries was measured at two to six stations on each stream, during the period from July 7th through July 10th, and on July 23rd. All stations on a given stream were measured on the same day, or within less than 18 hours, if measured on two consecutive days. Though measurements were spread over a period of a few hours, it is assumed that these are synoptic measurements that represent essentially simultaneous streamflow at all points on a given stream. This assumption is justified, because no storms appeared during the period of measurements, and the streamflow consisted entirely of baseflow, so discharge would have varied only slightly.

Discharge was measured at sites as close as feasible to each tributary's mouth and headwaters. Stations in between were spaced far enough apart that some difference in flow was likely to be detected, generally at least ½ mile apart. The choice of stations was limited by accessibility due to steep terrain, heavy vegetation (particularly impenetrable blackberry patches), suitable streambed conditions, and private land ownership. Many stations are located along public road easements or at public road crossings. If a desired station was on private property, landowners were contacted. All landowners who were reached were cooperative; however, many were not at home, in which case discharge was not measured.

Streamflow was measured by a variety of methods. In the upper reaches, many road crossings of streams consisted of "hanging" culverts, a situation wherein substantial erosion has occurred at the downstream end of the culvert. The streambeds lie one to five feet below the culvert lips, resulting in a waterfall that often was convenient for very accurate measurements with a 1-gallon (or 5-gallon) bucket and a stopwatch. At other stations where discharge was less than about 1 cfs and the channel was narrow, a portable cutthroat flume was installed temporarily and used to measure flow. Measurements with this device are accurate to within a few percent. Where the discharge was higher and the channel wider, a Swoffer or Price AA current meter was used. The uncertainty of current-meter measurements is about 5 percent for a section with a relatively smooth streambed. Where stream depth was less than about 6 inches and the bed was covered with cobbles, the uncertainty may be 10 percent or more.

Steve Gustafson, of River Measurement, Inc., provided discharge data for the staff-gage sites at Brezee, Lockwood, Mason, and Yacolt Creeks, as part of his contracts with CPU and Clark County.

It should be noted that the seepage measurements do not represent the lowest possible baseflows in the tributaries. The measurements were carried out in July in order for the analysis to be completed within the schedule of the watershed planning process. The measurements by McFarland and Morgan (1996) occurred during October, which generally is the end of the dry season, and discharges were substantially lower than during the current project. The disadvantage of measuring this late in the season is that some tributaries dry up, and the opportunity to detect gains and losses is lost.

6.2 Gains and Losses in East Fork River Tributaries

The seepage measurement data for the East Fork tributaries are presented in **Table 1** and shown on **Figure 8**.

Surface-water rights for various points on the tributaries also are shown on **Figure 8** and listed in **Table 2**. Most of the rights are for less than 0.1 cfs, except on Spring Creek and Rock Creek (North). It is not known whether the rights were in use, or to what extent, during the measurement period. It also is possible that unauthorized diversions were taking place.

Most of the streams that were monitored appeared to gain baseflow throughout their length. The measurements also indicated potential losing reaches on Dean Creek, Rock Creek (North), Spring Creek, and Yacolt Creek. The baseflow conditions for each creek are discussed in the following.

6.2.1 Rock Creek (South)

Measured baseflow in Rock Creek (South) at station RCS-1 was 19.8 cfs, at a point about 2 stream miles above its mouth (**Table 1, Figure 8**). Upstream surface-water rights amount to only 0.24 cfs, approximately 2 percent of the measured baseflow (**Table 2, Figure 8**), indicating that the baseflow measurements are not significantly impacted by diversions. The measured flow indicates a unit-area baseflow of 0.74 cfs/mi^2 (**Table 3**).

6.2.2 Yacolt Creek

Yacolt Creek lost 0.30 cfs between stations YC-1 (0.52 cfs) and YC-2 (0.22 cfs). Some loss was expected, based on the analysis of groundwater levels by Hart Crowser (1996), which indicated that the streambed was perched above the water table in this vicinity. The lost streamflow was regained, and significantly more was added, in the subsequent downstream reach, between YC-2 and EF-09 (3.88 cfs). The latter reach passes through a large wetland that indicates a connection to the water table.

Baseflow in Yacolt Creek was 3.88 cfs, at a point about 1 mile above its mouth and a few hundred feet above the confluence with Weaver Creek (**Table 1, Figure 8**). The surface water rights upstream of this point are approximately 0.4 to 0.5 cfs (**Table 2, Figure 8**); however, the Town of Yacolt's wells may be capturing as much as 0.25 cfs (180 acre-ft/yr) from Yacolt Creek. This is equivalent to the Town of Yacolt's water rights and represents the upper bound on the amount of capture. The Town's groundwater rights represent approximately 11 percent of the total measured baseflow (**Table 3**). In this case, the surface water diversions may have more of a significant impact on baseflows than the ground water withdrawals.

6.2.3 Rock Creek (North)

Rock Creek (North) lost 0.31 cfs between RCN-2 (0.65 cfs) and RCN-1 (0.34 cfs). This may be due, in part, to diversions, because surface-water rights total 0.18 cfs in this reach. However, the lower station, RCN-1, was at a stream transect with bouldery cobble bedload and with an abruptly steepened gradient about 20 feet downstream. In such a setting, water often infiltrates the substrate at the tailout of the pool, flows through the sediment at depths of up to a few feet, and then reappears at the head of the next pool. With such a low discharge, it is possible that a majority of the flow was lost just upstream of the measurement station. The chosen transect was the best available in that area, due to a combination of channel braiding (multiple channels), low velocities in pools, and abundant large woody debris in the narrow, steep-banked floodplain.

6.2.4 Spring Creek

Spring Creek lost 0.11 cfs between stations SC-2 and SC-1. This was a 9 percent loss and exceeds the uncertainty of the measurements, and so is likely a true loss of at least several percent. Intervening water rights amount to 1.05 cfs, so diversions easily could have caused the loss. Along this reach, the stream gradient is relatively steep, and the channel cuts through the Upper Troutdale aquifer (Howard, 2002), so some baseflow gain would be expected.

6.2.5 North Mill Creek

Baseflow in North Mill Creek increased from zero to 0.63 cfs over a distance of one mile. The channel was dry at station NMC-1 on the relatively flat northern end of the Fourth Plains. Baseflow was gained in the canyon where the creek has incised into the Upper Troutdale aquifer (Howard, 2002). The lower station is about 1,000 feet above the East Fork floodplain, so additional baseflow may be gained from the Upper Troutdale aquifer in the lower canyon below the station.

6.2.6 Dean Creek

Dean Creek lost 0.07 cfs between stations DC-2 (0.07 cfs) and DC-1 (dry). This small loss may be due to diversions, because surface-water rights for this reach total 0.08 cfs. The creek channel is incised into the Upper Troutdale aquifer throughout most of its length (Howard, 2002); however, the creek does not receive as much baseflow as might be expected.

6.2.7 Mason Creek

The upper two-thirds of Mason Creek drains runoff from glacial till, the Upper Troutdale aquifer, and the SGA (Howard, 2002). Baseflow in Mason Creek at the edge of the East Fork floodplain was only 0.39 cfs, or about ½ of the estimated surface-water rights upstream. The unit-area baseflow was one of the lowest in the East Fork basin.

6.2.8 Riley Creek and Lockwood Creek

Riley Creek is the largest tributary to Lockwood Creek and contributed 0.5 cfs baseflow to the 1.15 cfs at station EF-06 on Lockwood Creek, at the approximate edge of the East Fork floodplain. The creek appears to gain baseflow throughout its length from the Upper Troutdale and SGA aquifers (Mundorff, 1964; Howard, 2002).

6.2.9 Brezee Creek

Brezee Creek apparently gains baseflow throughout its length. About 50 percent of the baseflow at BRZ080, on the edge of the East Fork's floodplain, was gained in the lowest ½ mile, where it flows through a deep canyon.

6.2.10 McCormick Creek

McCormick Creek apparently gains baseflow throughout its length. Approximately the lowest ¼ mile of the creek, where it crosses the East Fork's floodplain is tidally influenced, so measurement of baseflow gains and losses was not possible.

6.2.11 Jenny Creek

Jenny Creek apparently gains flow along the upper two-thirds of its drainage, but gains nothing in its lower mile between stations JEN-2 (0.63) and JEN010 (0.63 cfs). Surface-water rights for up to 0.42 cfs apply to this reach, so any gain may have been lost to diversions.

6.3 Baseflow Summary for East Fork Lewis River Tributaries

Measured baseflows in the larger East Fork Lewis River tributaries downstream of Moulton Falls ranged from 0.01 to 1.23 cfs, and totaled about 6.2 cfs (**Table 3, Figure 8**). These baseflows are the values measured at the point closest to the mainstem and represent the net contribution from each tributary. Baseflows during the annual dry season (June through October) can be even lower than measured in July 2003, as suggested by previous measurements, during October 1987 and October 1988, by the U.S. Geological Survey (**Table 1**). The measured baseflows for Yacolt Creek and Rock Creek (South), which are located above Moulton Falls, were much higher, at 3.88 cfs and 19.77 cfs, respectively.

Of this amount, more than 7 cfs is allocated to farms around Fargher Lake, an artificially drained wetland complex and former glacial lake which is near the headwaters of Rock Creek (north). Given the small area draining to Fargher Lake, it is likely that the total allocated amount may never be available for diversion at any one time during the annual low-flow period

Unit-area baseflows for the measured tributaries ranged from 0.01 to 0.73 cfs per square mile of drainage area (**Table 3**). The highest values were measured for the Rock Creek (South) and Yacolt Creek sub-basins. Yacolt Creek is underlain by glacial outwash with a high storativity. Rock Creek (South) may also have substantially coarse alluvium along some reaches. Otherwise, both tributary watersheds contain mostly fractured Older Rocks. It is possible that the baseflow contributing area in these sub-basins extends beyond the watershed boundaries. The latter may also be true for the Spring Creek sub-basin, which has a substantially higher unit-area baseflow than the other sub-basins underlain by thick sediments.

Diversions during the baseflow measurement period were not investigated in the field for this project. However, estimated surface-water rights at locations upstream from the measurement stations total about 13.2 cfs, for all the gaged tributaries (**Table 3, Figure 8**). Furthermore, the surface water rights as a percentage of measured baseflow range from 0 to 2,250 percent (**Table 3**). Without knowing actual use, it is difficult to gauge the impact of these diversions on the measured flows; however, because the total water rights are significant in some cases, it is likely that there were significant diversions of baseflow during the July 2003 seepage runs in sub-basins where the water rights exceed 100 percent of the measured flow, particularly in the Rock Creek (North) sub-basin.

6.4 Comparison of Tributary Discharge to East Fork Lewis River Discharge

During July 7th through 9th, 2003, while baseflow was measured in the tributaries, the flow in the East Fork Lewis River at the USGS gage near Heisson averaged 83 cfs. This data was obtained from the USGS web site. The area draining to this gage is 125 mi^2, so the unit-area discharge was about 0.66 cfs/mi^2. In comparison, the measured discharge in the larger tributaries below the gage at Heisson amounted to 6.2 cfs and 0.11 cfs/mi^2 for a drainage area of 55.5 mi^2 (**Table 3**). Therefore, the measured flow from these tributaries added only about 8 percent to the mainstem's baseflow. Furthermore, tributary areas not represented in the baseflow measurements encompass a drainage area of about 15.5 mi^2 (see **Table 5** for tributary drainage areas) and would not likely contribute a significant amount of baseflow assuming similar unit-area baseflows as the other tributary drainages. On the other hand, the estimated water rights below the Heisson gage (12.4 cfs) amount to 15 percent of the East Fork Lewis River baseflow at Heisson.

Baseflow from the deeper aquifers to the Recent alluvial and Sand-and-Gravel aquifers along the East Fork Lewis River channel and floodplain was not directly measured as part of this study. However, baseflow from these deeper aquifers may have contributed significantly to the river's discharge, as suggested by measurements during 1987 and 1988 (McFarland and Morgan, 1996; see **Table 4** in the present report**)**. Those measurements indicate that, between the Heisson gage and the mouth of Lockwood Creek, the river gained 23.5 cfs (71 percent gain) and 21.2 cfs (48 percent gain), respectively.

Based on these observations, the following general conclusions can be made:

- Baseflow from the deeper aquifers to the river channel and floodplain appears to be at least four times that from the shallower aquifers via the tributaries, as measured for the current study

- Direct surface water diversions below the Heisson gage can have a more significant impact than capture of baseflow by wells in the tributary watersheds. However, this is contingent on the actual use associated with the diversions.

The organization Friends of the East Fork Lewis River has been collecting stream flow data on the East Fork since 2000. Their results show that the flows near the Swanson Airstrip near RM 7 are consistenly lower than the flows at the Heisson gage near RM 20, which indicates that this is a "losing" reach. These data are in direct contradiction to the data collected in 1987 and 1988 shown in Table 4, which shows that this is a "gaining" reach.

For example, the October 1987 and October 1988 data show that flows at RM 20 as 32.8 cfs and at RM 6.5 as 40.2 cfs in October 1987, and 43.8 cfs at RM 20 and 58.1 cfs at RM 6.5 in October 1988. In contrast, the data from Friends of the East Fork show the flow at RM 20 as 34 cfs on

September 7, 2003 and only 28 cfs at RM 7. Another set of data from Friends of East Fork show the flow at RM 20 as 47 cfs on September 28, 2003 and only 34 cfs at RM 7.

It is unknown why these two sets of data appear to be contradictory, however, conditions in the flow regime of the East Fork may have changed in the time period between these two data sets (from 1988 to 2000).

7 Potential for Baseflow Capture

The previous section discussed the measurement of baseflows and the net contributions to the baseflow in the East Fork Lewis River from the tributaries and aquifers in the watershed. This section provides a discussion of the potential capture of baseflow based on the hydrogeology associated with each of the tributaries. Based on the hydrogeologic information and review of wells in the selected tributary watersheds, the following sections include preliminary conclusions about where streamflow capture due to groundwater withdrawals is likely to occur. The tributary watersheds downstream from Moulton Falls are sufficiently similar in topography and hydrogeology that they are discussed together in this section. Conversely, the Yacolt Creek and Rock Creek (South) watersheds upstream of Moulton Falls are sufficiently different that they are discussed individually.

7.1 Rock Creek (South) Watershed

This watershed contains a shallow, unconfined sedimentary aquifer (Recent alluvial deposits) that is tapped by a few scattered domestic wells and one prison supply well (**Figure 2**). The aquifer may not have sufficient yield for a municipal water supply. In any case, the area is sparsely populated, which limits potential impacts to local water resources. As in the Yacolt Valley, low yielding Older Rocks are found beneath the valley sediments and at the surface in the surrounding hills. Wells in either aquifer capture surface water from Rock Creek (South) or its tributaries, except at the lower end of the valley where wells probably capture surface water from the East Fork Lewis River.

7.2 Yacolt Creek Watershed

Groundwater in the Yacolt Creek Valley occurs in two principal units. The highest well yields (several hundred gpm) come from an unconfined, glacial outwash aquifer in the valley (**Figure 7**). Much smaller yields are found in the Older Rock that underlies the outwash and is exposed at the surface in the surrounding hills. Yacolt Creek gains baseflow in the foothills west of Yacolt, but then loses water in the vicinity of Yacolt, where the streambed is perched above the water table (Hart Crowser, 1996). Farther downstream, near the confluence with Weaver Creek, the stream intersects the water table, and baseflow increases approximately 20-fold. During low-flow periods, groundwater beneath the northern part of the valley flows northward to Cedar Creek, which is tributary to the North Fork Lewis River. Wells in either aquifer capture surface water from lower Yacolt Creek or Cedar Creek, or both, depending on well location.

7.3 Upland Areas of Tributary Drainages Downstream of Moulton Falls

On the uplands north and south of the East Fork's floodplain, the surficial or shallow hydrogeologic units (depths less than approximately 200 feet below land surface) are mostly fine-grained, low-yield sediments (glacial till and Pleistocene Flood deposits), terrace deposits with deep water tables, and bedrock, with lesser areas of the slightly more productive Upper Troutdale deposits. Few domestic or municipal wells tap these units, given their relatively low yields (**Figure 2**). These units connect directly to the upper reaches of the East Fork tributaries, which provide little baseflow. Wells drawing from these units capture some surface water from nearby tributaries.

Considering that few wells pump from the shallow aquifers, the East Fork tributaries are not significantly threatened by capture due to groundwater pumping, except perhaps where they cross the river's floodplain. However, the total groundwater withdrawal from the areas draining to the upper parts of the sub-basins is quite small and probably only limited surface-water capture occurs.

The SGA occurs beneath the shallow hydrogeologic units in the uplands, both north and south of the river (**Figure 3 through 6**). This confined aquifer supplies many of the exempt and municipal wells in the lower parts of the sub-basins. These wells generally are more than 200 feet deep and probably capture surface water from the East Fork Lewis River or lower ends of tributaries where the SGA unit crops out (**Figure 9**), as well as from Lake River and Columbia River. The proportion captured from each river cannot be estimated from available information and would vary by location of each well.

7.4 Lower Reaches of Tributary Drainages Downstream of Moulton Falls

As indicated in the hydrogeologic cross-sections of **Figures 3 through 7**, the base of the uppermost aquifer generally is less than 200 feet below the ground surface. Wells completed in the uppermost aquifer probably capture most of their water from the tributary watershed in which they are located. The number of wells less than 200 feet deep in each tributary is shown in **Table 5** and on **Figure 9**.

As indicated in the hydrogeologic cross-sections of **Figures 3 through 7**, the top of the confined (SGA) aquifer generally is greater than 200 feet below the ground surface. Wells completed in the SGA probably capture most of their water from the East Fork Lewis River or from the lower ends of the tributaries where they cross the East Fork's floodplain. The numbers of wells greater than 200 feet deep in each tributary are shown in **Table 5** and on **Figure 9**.

Approximately 3,550 exempt wells are present in the East Fork Lewis River watershed. Assuming that the consumptive water use for each exempt well is 87 gpd (EES 2002; Sapik et al. 1988), or 0.000135 cfs, then the total exempt water use in the entire East Fork Lewis River watershed would be about 0.48 cfs. (*Note: EES (2002) cites 290 gpd per household for exempt well use. Sapik et al (1988) assumed 70% of well withdrawal is return flow [30% of 290 gpd is 87 gpd]).* This is only about 8 percent as much as the measured tributary flow and less than 1 percent of the baseflow in the East Fork at Heisson during July 2003. Therefore, exempt wells do not appear to seriously deplete baseflow. In comparison, surface-water rights may be as much as 15.8 cfs, or more than thirty times as much as the exempt well use. But again, the true impact of surface water diversions is dependent on their actual use.

8 Municipal Well Withdrawals In and Near the East Fork Lewis River Watershed

This section includes a discussion of the potential impacts of municipal well withdrawals on baseflow conditions in the watershed. Municipal groundwater withdrawals have been increasing in some areas, and decreasing in others, in or near the East Fork Lewis River Basin. The well locations are shown in **Figure 10**. Annual water use and groundwater levels for the wells are shown in **Figures 11 through 17**. Details about these wells are presented in the following sections.

Table 6 lists the major water supply wells that are owned and operated by Clark Public Utilities (CPU) and the City of Battle Ground (BG) in the East Fork Lewis River watershed and adjacent areas to the south. The table summarizes well information including location, source aquifer, well yield, and current status. Municipal well locations are shown in **Figure 10**. Some of the municipal wells are depicted in the cross sections of **Figures 3 through 7**. The supply areas can be grouped as follows:

- Town of Yacolt (CPU Wells 403 through 407)
- Battle Ground Lake (CPU Wells 104 and 109)
- Lewisville Park area (CPU Wells 106 and 110)
- Town of La Center (CPU Wells 303 and 304)
- Pioneer Junction area (CPU Wells 29, 30, 32, and 34)
- City of Battle Ground (BG Wells 1, 2, 4, 5, 6, 7, and 8)

In the discussion below for each group of production wells, water levels in the aquifers associated with the well are discussed. Water levels provide an indication of an aquifer's response to groundwater withdrawals. In some instances, water levels remain stable despite an increase in production. This is an indication that the production rate is not overdrafting the aquifer's capacity to produce the water. Despite relatively stable groundwater levels from year to year, baseflow capture will still occur whenever wells are pumped. However, the stable water level trend indicates that the capture probably is not a large portion of the baseflow from the monitored aquifer.

The discussion is grouped in terms of wells operated by Clark Public Utilities and those by the City of Battleground.

8.1 Clark Public Utilities Municipal Supply Wells

CPU is the largest water supplier in the East Fork Lewis River watershed. The utility operates wells near Pioneer, La Center, Lewisville Park, Yacolt, and Battle Ground Lake. In addition, CPU operates several wells within the Salmon Creek basin, just south of the East Fork basin boundary.

8.1.1 Town of Yacolt

The Town of Yacolt has five water supply wells -- 403 through 407 (**Figure 10**). Well 403 provides the primary source, while the other wells are used as needed to meet demand. CPU took over operation of the Yacolt water system in 2000. All of the wells are screened in the unconfined outwash aquifer (Qal) in the Yacolt valley. Groundwater levels fluctuate seasonally by as much as 30 feet (**Figure 11**). The large fluctuations are attributed to variations in recharge, limited aquifer volume, and rapid drainage to surface water to the north and south (Yacolt and Cedar Creeks). During drought years, water levels in Wells 403, 404, 405, and 406 sometimes drop below the pump intake settings and create a severe supply limitation. Under these conditions, CPU shifts production to Well 407, which was specifically designed to allow operation under low water level conditions. Annual withdrawals from the unconfined aquifer have been relatively stable over recent years, and groundwater levels show no discernable trend over time (**Figure 11**).

8.1.2 Battle Ground Lake Area

CPU operates two wells near Battle Ground Lake, east of Battle Ground -- Wells 104 and 109. Both wells are completed in the fractured volcanic bedrock aquifers (Basalt of Battle Ground, correlated with the Boring Lava). Well 104 is used regularly, but Well 109 is operated only during critical supply periods, because withdrawals from this well can produce significant water level declines in neighboring domestic wells. These wells probably capture water directly from the East Fork Lewis River and, possibly, from Rock Creek and Woodin Creek in the Salmon Creek watershed. Withdrawals from these wells decreased, starting in 1997, and, in response, water levels have recovered 30 to 40 feet, on average (**Figure 12**).

8.1.3 Lewisville Park Area

CPU monitors groundwater levels in the unconfined Recent Alluvial deposits aquifer, in the Heitsch monitoring well, which is located close to Well 110 (**Figure 10**). Water levels in this aquifer show seasonal variability and, generally, follow the trend of annual precipitation (**Figure 13**).

CPU operates two wells near Lewisville Park. Well 106 is located on the south side of the East Fork Lewis River near 147^{th} Avenue, and Well 110 is located on the north side of the river near the Lewisville cemetery (**Figure 10**). These wells draw water from the confined Sand and Gravel aquifer (SGA), and their yields are moderately high (200 to 400 gpm). Withdrawals from the confined SGA have been increasing slowly over time, while water levels have remained relatively stable (**Figure 14**). This indicates that the production rates are not inducing significant drawdown in water levels that may increase the impact on baseflows.

8.1.4 Town of La Center

CPU took over operation of the La Center water system in 1992. At that time, the Town of La Center was operating three supply wells. Subsequently, CPU decommissioned two of these wells and built a supply line to interconnect the Pioneer area with La Center. CPU currently owns two production wells in the La Center area -- Well 303 (La Center Well 3) in town and a small-diameter well (CPU Well 304) near Mason Creek (**Figure 10**). Both of these wells are completed in the SGA system, have relatively low yields (i.e. < 110 gpm), and are currently inactive. Because higher yield wells in the Pioneer and at Lewisville Park are more efficient to operate, CPU intends to abandon the LaCenter sources once associated water rights have been transferred to the supply wells in the Pioneer area (applications pending).

8.1.5 Pioneer Junction Area

CPU operates four wells (29, 30, 32, and 34) in the Pioneer Junction area (**Figure 10**). These wells withdraw from the SGA (**Figure 3**) and have the highest yields in the East Fork watershed, ranging from 550 to 1,200 gpm. Wells 29 and 30 are operated year round under water right permits, whereas Wells 32 and 34 are operated seasonally (May through October) under temporary permits. The temporary permits allow CPU to withdraw water from the deep SGA in lieu of development from the Troutdale aquifers (QTu and QTl) in the Salmon Creek watershed to the south of the East Fork watershed. The shifting of production from shallow to deep source aquifers reduces the potential for capture of baseflows from Salmon Creek.

The Pioneer area wells capture water both from the lower East Fork Lewis River and from Lake River, which lies to the west. Both areas are tidally influenced, such that fish habitat is less affected by low base flow. Groundwater from these wells used by the Town of La Center would return to the river in part by way of the wastewater treatment plant discharge. Withdrawals from these wells have steadily increased since 1996 and, correspondingly, water levels in the SGA have steadily declined about 10 to 15 feet since 1996 (**Figure 15**). The shift of production from shallow to deep source aquifers reduces the potential for capture of base flows from Salmon Creek, but shifts the effects to Lake River and the lower East Fork Lewis River. However, both areas are tidally influenced, such that fish habitat is less affected by reduced baseflow.

8.2 City of Battle Ground's Municipal Supply Wells

Battle Ground's water supply wells are located within the Salmon Creek basin, just south of the East Fork Lewis River watershed. The City of Battle Ground operates seven wells in or near the City (**Figure 10**). Wells 1, 2, 4, and 5 are screened in the Upper Troutdale aquifer (QTu). Surface water capture by these wells is more likely to occur within the Salmon Creek basin, because of the proximity of Weaver Creek, but capture from the East Fork Lewis River, or its left-bank tributaries, is possible. Battle Ground's deeper wells (6, 7, and 8) withdraw from the SGA and probably capture flow from both the East Fork Lewis River and Salmon Creek.

Battle Ground relies mostly on Wells 1, 2, 6, 7, and 8. Wells 4 and 5 are used only intermittently. Some low VOC concentrations have been detected in Wells 1 and 2, so the City may at some point in the future elect to abandon these wells, in preference to additional deeper SGA production. At the time of construction, Wells 7 and 8 could each produce approximately 1,000 gpm. Production from both wells has been curtailed to about 600 gpm due to problems with iron and sulfur bacteria. Currently, the City is exploring for higher yields in the northwest part of their service area. The City intends to install an SGA test well there, and if sufficient yields are found, then the City will file a water right application for additional withdrawals. The City has also been negotiating a wholesale purchase agreement with Clark Public Utilities and the City of Vancouver, as a means for meeting long-term growth in demand.

Withdrawals from Battle Ground's Upper Troutdale aquifer wells have decreased since 1999 and, consequently, water levels have been recovering (**Figure 16**). The decreasing withdrawals also has resulted in decreased capture of baseflow from the East Fork. Withdrawals from Battle Ground's SGA well increased significantly in 1999, when they replaced some of the supply from the Upper Troutdale wells and as growth in water demand has risen (**Figure 17**). Water levels in the SGA have declined about 7 or 8 feet since 1999. Some of this decline may be associated with pumpage from CPU's wells in the Meadow Glade area. The resulting decrease in water levels in the SGA will induce recharge from the overlying Upper Troutdale aquifer, which in turn will increase the capture of water from the East Fork Lewis River. In either case, the net effect would be increased baseflow capture.

8.3 Summary of Potential Surface-Water Capture By Municipal Wells

Total withdrawals from CPU's supply wells during 2002 amounted to 3,194 acre-feet, which is equivalent to 1,984 gpm, or 4.4 cfs, if pumped continuously. The City of Battle Ground pumped about 1,138 acre-feet during 2002, which is equivalent to 707 gpm, or 1.57 cfs, if pumped continuously. As mentioned previously, the City of Battleground's wells are located in the Salmon Creek basin, just south of the East Fork Lewis River watershed, but their pumping and capture effects extend beyond the topographic watershed divide into the East Fork Lewis River watershed. Also, CPU's Pioneer area wells capture water both from the lower East Fork Lewis River and from Lake River, which lies to the west. Therefore, as a simplifying supposition and by professional judgment, it is assumed that ? of Battle Ground's withdrawals and ½ of CPU's Pioneer area withdrawals are captured from the East Fork watershed. In this case, the total municipal well capture from the East Fork Lewis River watershed would have been approximately 2,305 acre feet, or 3.2 cfs, during 2002.

As a relative comparison of the potential impacts of surface-water diversions versus the withdrawals from CPU and Battleground wells, the maximum instantaneous rate for surface water rights for the entire East Fork Lewis River watershed is approximately 55 cfs. However, as stated previously, a true comparison of the relative impacts should be based on actual diversions.

9 Water Quantity Monitoring in the East Fork Lewis River Basin

This section reviews the on-going water quantity monitoring in the East Fork Lewis River basin and considers any additional monitoring needed. Section 9.1 is quoted or paraphrased from Pacific Groundwater Group (2003). Only the water quantity parts of that report are included here.

9.1 Historic, Current, and Planned Monitoring

Washington Dept. of Ecology has monitored water quality on a monthly frequency in the East Fork Lewis River at Daybreak Park, north of Dollar Corner, since 1977, but discharge is not measured. Ecology has plans for installing a continuously monitoring stream gage at this site, but the plan is contingent on continued Federal funding through the Salmon Recovery Funding Board.

As part of the Long-term Index Site Projects (LISP), Clark County began monitoring in 2001 at two sites in the East Fork Lewis River watershed (Clark County, 2002) and Rod Swanson (personal communication, 2003). The sites are “Brezee Creek at LaCenter Bottoms” and “Rock Creek (North) at DNR Land Above Gabriel Road.” The goal of the LISP monitoring is to describe the conditions of smaller stormwater-influenced streams and provide information about long-term trends in storm conditions at the monitoring sites. Staff gages have been installed and streamflow will be measured periodically. Streamflow was measured at these sites for the current project.

As part of its Volunteer Monitoring Program for Ambient Stream Monitoring, Clark County installed a staff gage on Jenny Creek at Old Pacific Highway (**Figure 1**) during 2003. This program is described in the project Quality Assurance Project Plan (Clark County, 2003). Every three months, volunteers will measure discharge, observe habitat characteristics, and sample biological and water-quality parameters.

CPU currently monitors groundwater withdrawals (pumpage) and levels at its 11 active production wells and in five monitoring wells (**Figure 10 and Table 6**). The production and monitoring wells tap four aquifer systems including the Recent Alluvial aquifer, the Upper Troutdale aquifer, the Lower Troutdale aquifer, and the SGA (**Table 6**).

CPU also monitors wastewater discharge from the La Center Wastewater Plant into the East Fork Lewis River, as required in the NPDES permit.

CPU recently acquired the responsibility for water supply and wastewater management in the Town of Yacolt (currently served by on-site septic systems) and so recently began water level monitoring in Yacolt’s water supply wells.

During 2003, CPU installed a continuous recording stream gage and staff gage on Yacolt Creek at Railroad Avenue. CPU also installed staff gages on Lockwood Creek, Mason Creek, McCormick Creek, and Yacolt Creek above Yacolt (**Figure 10**). Measurements were made at these sites during the current study. Another staff gage will be installed during late 2003 on the East Fork Lewis River at Daybreak Park.

Finally, the USGS Heisson Gage continues to operate at RM 20 in the mainstem of the East Fork.

9.2 Recommended Additional Monitoring and Analysis

Based on our measurements in Spring Creek, northwest of Battle Ground, the baseflow discharge is relatively high per square mile of drainage area and probably should be monitored. The lowest reach of this creek, where it crosses the East Fork Lewis River floodplain, might be affected by Battle Ground's wells.

Otherwise, it appears that monitoring of discharge for perennial East Fork Lewis River tributaries, where significant development (farms, homes, towns) has occurred, is adequate for the foreseeable future. Tributaries farther upstream has affected mostly by forest practices.

Finally, it would be useful to measure low-flow discharge, at least once, in all of the tributaries at their mouths and also where they enter the East Fork's floodplain. This would give a more complete picture of the possible baseflow gains in the lower ends of the tributary canyons, where the SGA is exposed and likely to contribute significant baseflow. Access to the mouths of the tributaries might be mostly easily accomplished by boat from the East Fork. Currently, the staff gage stations for Brezee, Mason, and Lockwood Creeks are positioned at the edge of the East Fork's floodplain.

In the near future, when Russell Evert's geologic maps for the remainder of the study area are published, it may be possible to gain additional insight into the relationship between baseflow and geology, using the baseflow measurements presented herein.

9 References

Carr, J.R., and Associates, 1985. *Ground Water Management and Development Plan*. Report for Clark Public Utilities, J. R. Carr and Associates, Gig Harbor, WA.

Economic and Engineering Services, 2002, *Key Issues and Existing Plans for Major Water Users*. Technical Memorandum No. 1 (Task 2), WRIA 27/28 Planning Unit, Lower Columbia Fish Recovery Board, Aug. 23.

Everts, Russell, 2003. Personal communications to Linton Wildrick.

Hart Crower, 1996. *Yacolt Hydrogeologic Study, Yacolt, Washington*. Report J-4234. Prepared for the Town of Yacolt, January 4.

Heath, R. C., 1983. *Basic Ground-Water Hydrology*. Reston, VA: USGS Professional Paper 2220.

Howard, K. A., 2002. *Geologic Map of the Battle Ground 7.5-Minute Quadrangle, Clark County, Washington*. U. S. Geological Survey, Miscellaneous Field Studies MF-2395.

Johnson, Jim, 2003. *Personal communication to Marie Mills, Pacific Groundwater Group*, Jim Johnson, Clark County, July 21.

McFarland, W. D. and Morgan, D. S., 1996. *Description of the Ground-Water Flow System in the Portland Basin, Oregon and Washington*. U. S. Geological Survey Water-Supply Paper 2470-A.

Mundorff, M.J., 1964. *Geology and Ground-Water Conditions of Clark County, Washington, with a Major Alluvial Aquifer along the Columbia River.* U. S. Geological Survey, Water-Supply Paper 1600, 268 p., 3 plates.

Pacific Groundwater Group, 2002b. *Salmon Creek Watershed Assessment*. Prepared For Clark Public Utilities, October 2002.

Pacific Groundwater Group, 2003. *Monitoring Plan for the East Fork Lewis River Watershed*. For Clark Public Utilities.

Robinson & Noble, Inc., 1992. *City of Vancouver Investigations of the Sandy River Mudstone Aquifer*.

Sapik and Others, 1988. *Ground-Water Resources and Simulation of Flow in Aquifers Containing Freshwater and Seawater, Island County, Washington.* U.S. Geological Survey, Water-Resource Investigations Report 87-4182, Tacoma, WA.

Swanson, R. D.; McFarland, W. D.; Gonthier, J. B.; Wilkinson, J. M., 1993, *A description of hydrogeologic units in the Portland Basin, Oregon and Washington*. U.S. Geological Survey Water-Resources Investigations Report 90-4196, 56 p., 10 plates.

Theis, C. V., 1940. *The Source of Water Derived from Wells.* Civil Engineering, v. 10(5).

Washington Department of Ecology, 1998. *Draft Report of the Technical Advisory Committee on the Capture of Surface Water By Wells, Recommended Technical Methods for Evaluating the Effects of Ground-Water Withdrawals on Surface Water Quantity.* Publication number WR-98-154, August 1998.

10 Glossary

The following is a glossary of technical terms, acronyms, and abbreviations used in this report. The purpose of this glossary is to provide a reference for readers who are less familiar with terms often used in technical discussions about hydrogeologic concepts. This compilation includes a list of abbreviations and acronyms used throughout this report.

Alluvial deposits – A general term for all sedimentary deposits resulting from the operations of streams, including the sediments laid down in stream beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries.

Aquifer - A hydrostratigraphic unit that has relatively higher permeability and yields significant (economically feasible) amounts of water to wells; also called a "water-bearing" unit, even though aquitards (see below) also may hold substantial amounts of water.

Aquitard - A hydrostratigraphic unit that that has low permeability and does not yield significant amounts of water to wells. An aquitard can store large quantities of water, but it allows only *slow* horizontal and vertical movement of groundwater into other units. Because some aquitards are large in aerial extent, relatively large volumes of water may flow through them. Recharge to confined aquifers depends on leakage through aquitards.

Baseflow - The component of streamflow fed by groundwater discharging to the stream. Groundwater discharge occurs as springs and seeps on slopes or as direct seepage to stream channels.

Capture – *The well-founded theory that withdrawal of groundwater eventually results in an equal reduction in surface water, except in areas where the water might otherwise be transpired by deeply rooted plants.*

cfs – *Cubic feet per second.*

cfs/mi² – cubic feet per second per square mile of watershed that drains to the point of interest.

Confined aquifer - An aquifer that is overlain by an aquitard (a confining unit) and contains groundwater under sufficient pressure to rise above the top of the aquifer. Also known as an artesian aquifer. In some cases, groundwater levels may be above land surface, and wells completed in the confined aquifer may flow.

Ecology - Washington State Department of Ecology

Eocene Epoch – The period in geologic history between about 57.8 and 36.6 million years ago, when grasslands first formed and primitive horses and camels evolved.

Extrusive **–** Igneous rocks that formed from molten lava that was extruded and solidified at the earth's surface. Includes near-surface sills and dikes that form a continuum with the same body of rock that reaches the surface.

gpm - Gallons per minute; a unit of measurement used to describe pumping rate.

GIS - Geographic Information System; a computer-based system that provides an interface between many types of graphical and non-graphical data over geographic areas.

Head (potentiometric or piezometric head) **–** the level to which water will rise in a well cased to the aquifer. In engineering or hydraulic terms, it is a measure of total energy per unit mass of water. Water will tend to flow from areas of greater head to areas of lower head (see "hydraulic gradient" below).

Hydraulic conductivity - A coefficient of proportionality describing the rate at which water can move though a porous medium, commonly expressed in units of feet per day (ft/day) or centimeters per second (cm/sec). It is equal to the transmissivity of an aquifer divided by its saturated thickness.

Hydraulic gradient - The change in total head (or water level) with a change in distance in a given direction; the coefficient of proportionality that expresses the "driving force" of groundwater flow.

Intrusive **–** Igneous rocks formed from molten lava that cooled and hardened within the earth's crust.

Lithify **–** To turn to rock, such as the process of induration of loose sediment.

Miocene Epoch **–** The period in geologic history between about 23.7 and 5.3 million years ago, when flowering plants began and apes, whales, and monkey-like primates first appeared.

Pleistocene Epoch - The period in geologic history between about 1.6 million to about 10,000 years ago. Also known as the time of glaciers, or the "ice age."

Recent Epoch **–** Also called the Holocene Epoch. The last 10,000 years of geologic history.

Static water level - A water level measurement obtained under non-pumping conditions, when water levels are not changing in response to recent pumping.

Storativity - Also referred to as "storage coefficient," a measure of the volume of water an aquifer releases from or takes into storage per unit surface area of an aquifer per unit change in head. It is expressed in dimensionless units.

Synoptic **–** Pertaining to simultaneously existing hydrologic conditions.

Unconfined aquifer - An aquifer that is not overlain by a confining unit and in which pore water pressure is atmospheric; water levels in such an aquifer lie below the top of the aquifer.

USGS - United Stated Geological Survey

WRIS - Water Rights Information System at Washington Dept. of Ecology.