Technical Memorandum 11 (Task 8b)
WRIA 27/28 Watershed Plan

Effect of Exempt Wells on Baseflow
Washougal River Watershed

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Lower Columbia Fish Recovery Board

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1.0 Introduction And Purpose Of Study

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. This report describes one of the investigations of the Washougal River basin. Specifically, the committee wishes to better understand the magnitude of exempt well effects on baseflow in the river and its tributaries. For the current study, the Lacamas Creek watershed was included as part of the Washougal sub-basin, although it was identified as a separate sub-basin by the Planning Unit.

A well is considered to be "exempt" from the need for a permit if it provides stock water, irrigation of lawn or non-commercial garden not exceeding ½ acre, single or group domestic uses, or industrial uses, so long as the groundwater withdrawal does not exceed 5,000 gallons per day (gpd). An exempt well is, in effect, automatically awarded a water right with a priority date for the day that the well construction was completed.

Exempt water use typically varies seasonally, with higher usage during the dry summer months for irrigation of lawns, gardens, and other cultivation. In areas where domestic wells are numerous, it is conceivable that the cumulative withdrawals of many exempt wells could capture a significant portion of baseflow[1] during the dry season. For example, a large number of shallow wells withdrawing from an unconfined aquifer that discharges directly to a small stream could reduce the streamflow in a matter of hours or days. If the withdrawals peak during low flow periods, when the flow is mostly or entirely baseflow, the combination of the greatest rate of capture with the lowest streamflow could be detrimental to instream habitat. This report presents an examination of the potential effects of exempt wells in the Washougal River Watershed, Clark and Skamania Counties, Washington.

2.0 Summary Of Findings

This report presents the most thorough study of the hydrologic effects of exempt wells for any area in Washington. The analysis used readily available geologic, topographic, hydrologic, and well construction data to estimate how much baseflow would be captured by exempt wells within the Washougal River Basin. Baseflow is streamflow that originates as groundwater discharge through springs and seeps.

Wells are concentrated in some parts of the watershed and absent in others (**Figure 1**). Obviously, some streams or reaches of streams could be affected much more than others. Therefore, we analyzed the effects by sub-watersheds, which we refer to as sub-basins (not be confused with the sub-basins delineated by the WRIA 27/28 Planning Unit).

Geology often has a profound influence on baseflow. Therefore, starting with the sub-basin delineation by Clark County GIS for Clark County and Dept. of Natural Resources for Skamania

▪ [1] *See Glossary for definitions of technical terms.*

County, we further sub-divided a couple more areas so that either bedrock or unlithified sedimentary units dominated the surficial geology (**Figure 2**).

The lowest average monthly baseflow (i.e., lowest average for any month) for each sub-basin was estimated from data for three streamflow gages in the watershed. These estimates range from 0.4 to 11.8 cfs (**Table 1**).

The number of exempt wells in each sub-basin was estimated simply by counting the number of well logs in Ecology's on-line database. The number of exempt wells ranges from zero in eight mountainous sub-basins to 517 in one Lacamas Creek sub-basin. This method was checked by counting the number of developed parcels in the Clark County sub-basins, minus the estimated number of parcels served by municipal Group A water systems. The two methods were found to be in reasonable agreement.

The groundwater withdrawal for each exempt well was assumed to average 290 gallons per day (gpd), or 0.00045 cubic feet per second (cfs), as a year-around average. Return flow to the uppermost aquifer through septic systems and excess irrigation was assumed to be 70% of the 290 gpd, based on an estimate by Sapik and others (1988) for Island County. Therefore, actual water consumption was estimated to be 30% of the withdrawal rate, or 87 gpm (0.00013 cfs) per well.

Based on well depths compared to aquifer depths, it appears that the primary aquifers tapped by domestic wells in the watershed are either bedrock or the Upper Troutdale (sedimentary) aquifer.

Based on relative hydrogeologic homogeneity within either aquifer, it was assumed, as a first approximation, that the sub-basin within which a given well would capture all its consumed surface water could be identified by comparing well bottom elevations to the streambed elevation at the outlet (mouth) of each sub-basin. If the well did not penetrate below the elevation of the sub-basin outlet, it is more likely to capture most of its water from the sub-basin within which it is located. Otherwise, it is more likely to capture its water from the first downstream sub-basin to have an outlet elevation lower than the well bottom. Given the range of depths and distances from each stream reach, this should be a reasonable assumption. Short of preparing a three-dimensional groundwater flow model whose preparation would far exceed the scope and cost of the current work, the method probably is as accurate as possible given available data.

To estimate the % of baseflow that would be captured by exempt wells, the 70% return flow for the withdrawal from each well was assumed to return to the unconfined aquifer within the sub-basin where the well was located.

The estimated baseflow capture per sub-basin ranged from gains of up to 0.06 cfs to losses as high as 0.34 cfs (next to last column in Table 1). The capture losses are as much as 3.3 % of estimated lowest mean monthly baseflow (positive values in last column in **Table 1**). The capture gains are as much as 6.8 % of baseflow (negative values in last column in **Table 1**. Net baseflow gains occur when return flow from deeper wells in a sub-basin exceeds the capture by shallower wells in the sub-basin or deeper wells in upstream sub-basin. A key concept for net gain is that all the groundwater pumped by these deeper wells is captured from a downstream sub-basin, whereas 70% of the withdrawal returns to the sub-basin where the well is located. The net gain indicates that at least 43% (3/7ths) of the exempt wells in the sub-basin capture from downstream sub-basins.

3.0 Study Area

The Washougal River lies partly in Clark County and partly in Skamania County (**Figure 1**). Its headwaters are in the foothills of the Cascade Range in the Gifford Pinchot National Forest at elevations as high as 4,000 feet above sea level. The river discharges into the Columbia River, near the City of Camas, Washington, at an elevation of about 14 feet. The western two-thirds of the Washougal River basin lies within Clark County, while the eastern one-third of the basin lies within Skamania County. The basin's major tributaries include Lacamas Creek and the Little Washougal River. Lacamas Creek enters the Washougal River at river mile 0.8, and the Little Washougal River enters at about river mile 5.6.

The WRIA 27/28 Planning Unit has designated the Lacamas Creek drainage as a separate sub-basin; however, for the purposes of this study, we have included the Lacamas drainage as part of the Washougal basin. In scoping this investigation, it became apparent that the designated Washougal River sub-basin contains so few exempt wells that their effect on baseflow is negligible. On the other hand, the Lacamas Creek watershed is more densely populated and has a smaller unit-area baseflow, so it is more likely to be significantly affected by exempt wells. Therefore, the Lacamas watershed was added to the analysis.

The cities of Camas and Washougal are served by public water systems and, therefore, were excluded from the subject study area under the assumption that there are few exempt wells still in use within the city limits or other areas served by the water systems.

4.0 Data Sources

The data and other information used in this study were obtained from the following sources:

- Well logs from Department of Ecology's well database,
- Parcel GIS coverage from Clark County GIS,
- Digital elevation model (DEM) data from the University of Washington Geospatial Library,
- Well database GIS coverage from Clark County,
- 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.

5.0 Study Approach

The following sub-sections present the theory of capture of surface water by groundwater withdrawals and, based on that theory, the methodology of the investigation.

5.1 Conceptual Model of Capture of Surface Water by Groundwater Withdrawals

The established theory for capture of surface water by groundwater withdrawals was summarized by a recent technical committee (Washington 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, as occurs along "losing" stream reaches.

Groundwater pumping captures surface water by reducing heads in the surrounding materials (Heath, R. C., 1983; Theis, C. V., 1940). Two types of capture are possible—either the well pulls in 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.) determines which of these two capture mechanisms occurs. If the head in the aquifer is higher, the first form occurs; if the head in the surface water body is higher, the second form occurs. 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 shallow unconfined aquifer generally is dominated by local groundwater flow, withdrawals from it are more likely to influence nearby surface water bodies, irrespective of 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:

- The distance between the well and the surface water body,

- The geometry and hydraulic properties of aquifers and aquitards between the well and the surface water body,
- Patterns of groundwater flow and recharge, and
- The well completion elevation (depth of screened interval)

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.

5.2 Methods

ArcView® GIS software was used to map the stream gaging locations, well locations, hydrography, geology, and WRIA and sub-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 methods. (Further details of the methods are described in ensuing sections.)

- To discriminate among the potential exempt well effects on the smallest perennial tributaries, the Washougal River, Little Washougal River, and Lacamas Creek watersheds were divided into tributary sub-basins (**Figure 1**). A sub-basin set was obtained from the Lower Columbia Fish Recovery.

- Locations of wells that were obtained from Ecology's well log database were mapped and then counted (**Figure 1**). The well locations are listed only to the ¼-¼ section (40 acres) scale, so the mapped locations may be inaccurate by hundreds of feet. 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 were compared to surficial geology and subsurface hydrogeologic units to search for a means to assign groundwater withdrawals to hydrogeologic units. Based on this comparison, two sub-basins were further subdivided, so that the surficial geology of each sub-basin was dominated by either Older Rocks or sedimentary units.

- The lowest mean (average) monthly baseflow for each tributary sub-basin was estimated as follows:
  - ◊ Estimates of the lowest mean monthly unit-area baseflow (cfs/mi^2) were obtained from Sinclair and Pitz (1999) for gaged areas on the Little Washougal and Washougal Rivers. An estimate for Lacamas Creek was calculated as part of the current study using unpublished data provided by Clark County Public Works Department. The estimation method of Sloto and Crouse (1996) was used in both analyses.
  - ◊ The estimated unit-area baseflow values were assigned to each tributary sub-basin under the assumption that the unit-area baseflow was equivalent throughout each tributary sub-basin.

- ◊ The assigned unit-area baseflow was multiplied by the sub-basin area to estimate the lowest mean monthly baseflow rates for the tributaries or reaches within each sub-basin.

- The ratio of streamflow capture by exempt wells to lowest mean monthly baseflow was estimated as follows:
  - ◊ For each exempt well, the sub-basin where it is most likely to capture surface water was estimated based on geology, well depth, streambed elevation, and sub-basin outlet elevation was identified.
  - ◊ The number of wells estimated to capture surface water from each sub-basin was counted.
  - ◊ Exempt withdrawals were assumed to equal 290 gpd per well, based on the water use analysis by Economic and Engineering Services (2002).
  - ◊ Return flow (part of the withdrawal that is not consumed) for exempt wells due to onsite septic systems was assumed to equal 70% (Sapik, and others, 1988). This is the lowest value found in our literature search and was chosen because its use in the current analysis results in the maximum capture potential, or worst-case scenario.
  - ◊ The potential cumulative exempt-well stream capture for each sub-basin was estimated by assigning capture of the full withdrawal rate for a given well to the sub-basin in which it is located and assigning the return flow (non-consumptive use) to the sub-basin in which that well is located.
  - ◊ The ratio of estimated capture rate (cfs) to lowest mean monthly baseflow rate (cfs) was calculated for each sub-basin.

6.0 Hydrogeology

The geology and hydrogeology of the Washougal River basin were investigated in order to interpret whether the effects of exempt wells could be related to source aquifers and outcrop areas of the hydrogeologic units along streams and rivers.

6.1 Geology

The geology of the project area can be divided into two major rock groups: older bedrock and younger unconsolidated (unlithified and semi-lithified) sediments. **Figure 2** shows surficial geology in the Washougal basin and the alignments of three subsurface hydrogeologic cross-sections (**Figures 3, 4, and 5).** 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. Contacts between the sedimentary units dip to the southwest and indicate continued downwarping during deposition. The sediments crop out on the terraces and plains that cover about two-thirds of Clark County and the westernmost part of the Washougal basin. They contain the principal aquifers in the area.

The representative geologic units, from oldest to youngest, are described below.

6.1.1 Older Rocks

The Older Rocks (bedrock) crop out in the foothills and mountains in the eastern and northern portions of Clark County and the southwestern part of Skamania County and underlie the younger sedimentary rocks (**Figure 2**). In the western part of the Washougal basin, the older rocks occur at a maximum depth of approximately 1,400 feet (Swanson and others, 1993). The older rocks are primarily igneous, both intrusive and extrusive, with some sedimentary rocks, and range in age from the Eocene to Miocene Epochs (58 to 5 million years old). Rock types include andesite, basalt, granodiorite, pyroclastics (breccia, tuff, and agglomerate), conglomerate, and shale. The sedimentary rocks are generally hard and compact as a result of Miocene deformation. Most of the fractures, joints, and fault openings in all rock types have been closed by secondary mineralization. These rocks may yield small amounts of water to domestic wells but tend to be aquitards, rather than aquifers. The older rocks behave mostly as aquitards because of their low permeability. Yields of a few gpm to 50 gpm occur in parts of the unit containing abundant and unobstructed joints and fractures but are not common.

6.1.2 Troutdale Formation

The Troutdale Formation overlies older bedrock and comprises unlithified and semi-lithified sediments. Over most of the basin, and in many areas of Clark County, younger unlithified deposits cover the unit. The unit is absent where the older rocks are exposed. In the Washougal basin, the Troutdale is exposed along the valley walls within the Lacamas watershed and in some tributaries to the lower part of the Little Washougal and Washougal watersheds (**Figure 2)**.

The Troutdale Formation was divided into stratigraphic or hydrostratigraphic units by Mundorff (1964), Carr and Associates (1985), and Swanson and others (1993). 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. Carr identified four hydrostratigraphic units within the Troutdale, while Swanson identified five. The current analysis prefers the sub-divisions of Mundorff and Swanson.

All three authors recognize a partially cemented upper gravel unit at the top of the Troutdale Formation. This unit, which is encountered in wells throughout the basin and over most of Clark County, appears to be fairly continuous. Its thickness ranges between 100 and 300 feet; the thickest sections occur in southwestern Clark County. The unit generally consists of gravel within a matrix of coarse sand, is silt-bound and cemented in many places, includes sand lenses and stringers, and functions as an aquifer. For the current study, the unit is called the Upper Troutdale aquifer (Qtu).

A fine-grained unit (confining unit 1 of Swanson, and others, 1993) underlies the upper gravel unit of the upper member of the Troutdale Formation. 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 as the Upper Confining Unit (Qc1).

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. For the current study, this unit is referred to as the Lower Troutdale aquifer (QTl). The unit is exposed in the southeast part of Clark County (Swanson, and others, 1993). The unit has also been identified through recent drilling by Clark Public Utilities (CPU) at several locations within the Salmon Creek basin. Within the Washougal basin, its texture consists predominantly of either fine sand or and sand and gravel sub-units, with variable amounts of silt. The unit may be up to 180 feet thick in the western part of the basin.

Both Carr and Swanson describe a lower confining unit that lies beneath the Lower Troutdale. For the current study, this unit is referred to as the Lower Confining unit (Qc2).

Swanson also identified a deep sand-and-gravel unit, which he called the "Sand and Gravel aquifer", that lies beneath the Lower Confining unit. He interpreted this unit as a coarse-grained facies of the Sandy River Mudstone that Trimble (1963) identified from exposures along the Sandy River in Oregon. Willis (1977, 1978) and Robinson and Noble (1992) identified this same unit at the City of Portland's well field, at Ellsworth Springs, at Vancouver's Well Station 7, and at the Vancouver Fish Hatchery. For the current study, this unit is called the Sand-and-Gravel aquifer, abbreviated as SGA. Recent interpretations of deep well logs for the Meadow Glade and Pioneer vicinities, several miles north of the Washougal River basin, indicate that the SGA likely extends from the Portland well field vicinity northward to the East Fork Lewis River. The SGA consists predominantly of layers of fine and fine-to-medium sand, with lenses of silty sand and clay; locally, it contains some sand-and-gravel lenses. The unit typically displays coarser textures in the vicinity of the Portland well field and grades progressively finer northward. Typically, the SGA is 60 to 130 feet thick in the Washougal basin, but it attains thicknesses exceeding 400 feet to the north along the East Fork Lewis River.

6.1.3 Boring Lava

The Boring Lava consists of fine-grained, vesicular basalt of Pliocene and early Pleistocene ages. The Boring Lava generally overlies the Troutdale Formation, however, some evidence suggests that the part of the unit was formed at the same time as the upper part of the Troutdale Formation. Within the Washougal basin, the Boring Lava crops out in the vicinity of Green Mountain. It is also encountered beneath the Pleistocene alluvium in wells at the southern edge of the basin (**Figure 5**). The Boring Lava can be a moderately productive aquifer within its vesicular and scoriaceous interflow zones and within pyroclastic deposits, but often the unit functions as an aquitard.

6.1.4 Pleistocene Flood 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. Today, the deposits are exposed on broad plains and terraces in the southwestern part of Clark County. Within the Washougal basin, they occur on the valley floor in the Lacamas valley and as a veneer on the upland between the Little Washougal and Washougal Rivers. They cover about a third of Clark

County, dipping gently to the southwest. Within the Washougal basin, the unit comprises up to about 100 feet of fine sand and silt. The thickest deposits occur outside the Washougal watershed, where they filled several ancestral drainage channels in the Orchards vicinity and on the Columbia River floodplain with sand, gravel, and cobbles. In the Washougal watershed, the unit generally functions as an aquitard but can yield small amounts of water to domestic wells.

6.1.5 Recent Alluvial Deposits

Recent alluvium is generally encountered within the floodplains and low terraces along many of the study area's rivers and creeks. It is deposited as a thin veneer over the Troutdale Formation and Pleistocene alluvial deposits. The texture of the alluvium ranges from coarse sand and gravel, to silty sand. The unit functions as an aquifer where it is saturated but usually is too thin and localized to serve as an important source of supply.

6.2 Principal Aquifers

The hydrogeology of the area has been generalized into a few alternating principal aquifers and aquitards. The cross sections (**Figures 3, 4, and 5**) illustrate the interpreted subsurface relationships among the various hydrogeologic units.

The principal aquifers in the Washougal River basin occur primarily within the Troutdale Formation.

Within the Troutdale Formation, the aquifers include:

- The Upper Troutdale aquifer (uppermost gravel unit)
- The Lower Troutdale aquifer (intermediate sand-and-gravel unit)
- The Sand and Gravel aquifer (SGA; lowermost sand-and-gravel unit).

7.0 Baseflow

7.1 Sub-Basin Delineations

The Washougal drainage basin can be sub-divided into three watersheds: Lacamas Creek, Little Washougal River, and the Washougal River. A stream gaging station is, or was, located within each of these watersheds.

Each of the three watersheds was sub-divided into a number of sub-basins. Sub-basin names indicate the hierarchy within each watershed. Names begin with letters to reflect the watershed and are followed by numbers to reflect the location relative to the watershed outlet. Sub-basin L121 indicates it is in the Lacamas watershed and discharges into L12, which discharges into L1, the lowest sub-basin in the watershed. **Figure 1** shows the boundaries of the Washougal drainage basin and the sub-basins. Using ArcView®, the area of each sub-basin was calculated. **Figure 6** shows the locations of the stream gages, the outlet for each sub-basin, and the Lacamas, Little Washougal, and Washougal watersheds.

Each stream gage is located some distance upstream from its watershed outlet; however, we have assumed that the measured baseflow at each gage provides a reasonable approximation of the unit area baseflow for its watershed. The gage on the Washougal River (USGS gage 14143500, Washougal River near Washougal) is located above the confluence with the Little Washougal River. The gage on Little Washougal River (USGS gage 14144000, Little Washougal River near Washougal) is located just upstream of the confluence with the Washougal River. The gage on Lacamas Creek is located at Goodwin Road. The areas draining to these gages are:

- 108 square miles for the gage on the Washougal River,
- 24 square miles for the gage on Little Washougal River, and
- 53 square miles for the gage on Lacamas Creek.

The area draining to the Washougal River gage represents about 50 percent of the Washougal River watershed.

7.2 Unit-Area Baseflow

Estimates of the lowest mean monthly baseflow were used in this investigation because the effects of stream capture by exempt wells are of greatest concern during periods of lowest flow. The estimates for the Washougal and Little Washougal watersheds were obtained from the Department of Ecology's report by Sinclair and Pitz (1999). Their analysis used a computer program, HYSEP, developed by the U. S. Geological Survey (Sloto and Crouse, 1996). The program uses daily discharge values as input and then separates storm runoff peaks from the underlying more steady discharge, which is assumed to be baseflow. The program estimates a baseflow value for each day, calculates monthly mean baseflow for each calendar month by averaging the estimated daily values, and calculates the mean monthly flow by averaging the monthly means for a given month from all the years of record. The current study then used the lowest of the mean monthly flows for a given watershed, which were August for the Washougal River and

September for the Little Washougal River from Sinclair and Pitz (1999). Lastly, the unit area baseflow was calculated by dividing the lowest mean monthly values by the watershed area in square miles (**Table 1**).

The lowest monthly mean baseflow for Lacamas Creek was obtained by the same method used by Sinclair and Pitz (1999). Data from 1999 through 2002 for the Goodwin Road gaging station on Lacamas Creek was provided by Clark County. The assumed area used for the HYSEP analysis included all the sub-basins in the Lacamas gaging basin, except L-1, which is downgradient from the Goodwin Road gaging station. The estimated lowest monthly mean baseflow for Lacamas Creek occurs in August. The unit-area baseflow for Lacamas Creek is listed in **Table 1**.

It is noted that the measured daily flows on all three streams represent what remains after water is lost to surface-water diversions and well capture. This introduces additional uncertainty into the baseflow estimates, but corrections for water use were outside the scope of this preliminary analysis. It is also noted that the unit area baseflows for the three gaged basins vary by a factor of nearly 5. Interpreting the reasons for the wide range was beyond the scope of this analysis, but is probably due to a number of factors, including surficial and subsurface geology, topography, average annual precipitation, and water use. For example, a greater part of the catchment for the Washougal River gage lies at higher elevations (in the mountains) than do the catchments for the other two gages, and so may receive much higher rainfall. The Lacamas Creek gage's catchment is more likely to have greater surface-water diversions or its recharge may be reduced by impervious surfaces.

For each sub-basin, the lowest mean monthly baseflow (hereinafter referred to simply as "baseflow") was calculated by multiplying the unit-area baseflow by the area of the sub-basin. This assumes that the unit-area baseflow for each sub-basin equals that of the entire gaged area in the particular watershed. Discharge values for the sub-basins are not available to test this assumption, but it is the only available surrogate. It is possible that the actual unit-area baseflow varies several fold among sub-basins in the same watershed. The "cumulative" baseflow for downstream sub-basins include baseflow from upstream sub-basins. For example, the cumulative baseflow for sub-basin L1 is the sum of the baseflow for all the sub-basins in the Lacamas Creek watershed, and for sub-basin W1, it is the sum of baseflow for the Washougal and Little Washougal drainage basins. **Table 1** summarizes the unit-area mean monthly lowest baseflow, sub-basin areas, estimated baseflow per sub-basin, and cumulative baseflow. Sub-basins are grouped by baseflow ranges in **Figure 7.**

8.0 Exempt Wells

Because drillers were not required to file well logs before 1971, the possibility exists that many older wells are not represented in the well log database. Therefore, two sources of data were used to estimate the number of exempt wells:

- The number of well logs in Ecology's database, and
- The County Assessor's tax parcel database.

8.1 Number of Well Logs

Only water supply wells were considered in this analysis. Well logs in Ecology's database for abandoned and resource protection wells were not counted. It was assumed that the Camas/Washougal vicinity is largely served by public system wells (non-exempt), and, therefore, only wells north of the densely populated Camas/Washougal area were considered in the count of the wells. Some non-exempt wells may be included in the count, but this number probably is very small compared to the total number of wells.

Ecology's well log database was carefully queried to remove duplicate wells. After duplicates were removed, there were 3,642 well logs for the study area.

8.2 Developed Parcels

The Clark County assessors' data provides information on current land use. In accordance with its Clean Water Program billing criteria, Clark County considers a parcel as developed if it has a building value of more than $10,000 (Jim Johnson, pers. comm, 2003). Parcels in Skamania County could not be readily assessed because parcel data is not available in digital format.

For the current study, it was assumed that each developed parcel represents an exempt well, except those that are served by a public water system (Group A or Group B). Therefore, the number of developed parcels less the number of Group A and Group B services represents an estimate of the number of exempt wells in each sub-basin. Some Group B systems consist of six or fewer connections and so the well serving such systems may be exempt from a water right. For the purpose of approximately comparing the numbers of wells and parcels, this possibility was considered to not be significant.

Using the Department of Health's water system database, the number of connections for Group A and B water systems were counted for each sub-basin in the Clark County part of the study area. We also reviewed the water distribution system (water mains, etc.) for the Cities of Camas and Washougal, and for Clark Public Utilities. Based on the extent of this piping, sub-basins being partially served by large public well systems were identified (**Table 2**). Connections for one Group A well owned by Camas Municipal Water and Sewer (well log ID 5411) and one Group A well owned by Clark Public Utilities (well log ID 26061) were not included in the total count of connections, because most of the connections for these two wells are located outside the study area. Because of the latter systems, the number of connections in some basins could not be estimated from the available data.

Using the count of Group A and B connections, the estimated number of developed parcels served by exempt single domestic wells per sub-basin (**Figure 1**) was calculated as the total number of developed parcels minus the number of Group A and B connections.

8.3 Number Of Exempt Wells

The *ratio* of the estimated number of parcels served by exempt wells to the number of well logs was calculated for the sub-basins, in the Clark County part of the Washougal River watershed, that are not partially served by large municipal water systems. **Table 2** summarizes the number of well logs, the total number of developed parcels, the number of Group A and B connections, the adjusted number of developed parcels, and the calculated ratio for each sub-basin. A ratio of 1 would indicate that the number of wells in Ecology's database corresponds to the estimated number of developed parcels served by exempt wells. A ratio of 2 would indicate that the wells are present on approximately half of the developed parcels in the study area.

Table 2 indicates that, in sub-basins in Clark County that are not served by large public systems, the estimated number of parcel serve by exempt wells is approximately equal to the number of well logs posted on Ecology's web database. Ratios of parcels to well logs ranged from 0.7 to 1.1. It appears that the number of well logs provides a reasonable estimate of the number of exempt wells in the study area and, therefore, stream capture estimates were developed using these numbers.

To illustrate the estimated number of exempt wells, sub-basins were grouped by ranges of the number of wells **(Figure 8).** Sub-basins with the largest number of exempt wells occur in the Lacamas and the lower Washougal watersheds. Many sub-basins in the upper Washougal have no wells.

Figure 8 also contains a bar graph for each sub-basin that indicates the distribution of wells based on depth. The bar graphs indicate that the largest percentage of the wells are completed at depths less than 200 feet.

9.0 Exempt Well Withdrawal, Consumptive Use, And Return Flow

Withdrawals for exempt wells in each sub-basin were calculated based on an estimate of 290 gpd per home (per well), an average, year-round value (Economic and Engineering Services, 2002). The year-around average is probably much less than the summer peak use. However, the current analysis cannot discriminate the monthly distribution of capture from streams, because the effects will be lagged by days to months depending on well depth and distance from the stream. Exempt well withdrawals no doubt are higher during the dry months, but the capture effects may occur months later, depending on distance and intervening geologic materials. Therefore, as a first approximation, the average daily pumpage was used.

Return flow is that water which is not consumed, but is returned to the groundwater system via septic drainfields. Consumptive use is counted as that water, which is evaporated or transpired, and so does not return to the groundwater system. It was assumed that return flow equals 70% of well withdrawal, based on a report by the USGS for Island County, Washington (Sapik and others, 1988). Therefore, consumptive use equals 30% of the withdrawn amount.

10.0 Capture Of Surface Water By Exempt Wells

All groundwater in the Washougal basin will eventually discharge to a stream within the basin or to the Columbia River, if it is not first withdrawn and consumed. Therefore, all well withdrawals potentially capture surface water. Capture of surface water by exempt wells was calculated for each sub-basin, as described below. This section provides more detail than the description of methods in section 5.2, above. To our knowledge, this method has not been previously applied to the analysis of exempt well effects.

10.1 Streambed Elevations At Sub-Basin Outlets

The three principal watersheds – Lacamas Creek, Washougal River, and Little Washougal River – were divided into sub-basins in order to estimate exempt well densities and capture for the more densely populated areas in the middle parts of the basins. The upper sub-basins are thinly populated, or unpopulated, so significant exempt well effects can be ruled out without further examination. However, the upper basins were retained in the analysis for accounting purposes.

For this study, the outlet of a sub-basin is defined as the point where the stream exits the sub-basin and enters the next downgradient sub-basin. Some of the outlets are not the mouths of the streams, because the streams were split into two reaches and sub-basins.

The elevation of each sub-basin outlet was estimated from the DEM for that location. The uncertainty of the outlet elevation, which may be more than ten feet, is limited primarily by the accuracy of DEM data and the topographic map from which the DEM was interpolated. **Table 3** includes the outlet elevation for each of the sub-basins.

10.2 Well Completion Elevation

The well intake elevation for each well was estimated using digital elevation data for the land surface and the well depths listed in Ecology's well log database. The accuracy of the completion elevation is limited by accuracy of the well location (nearest ¼-¼ section center) and the accuracy of the digital elevation data. Therefore, well-head elevations may be inaccurate by tens of feet in areas of high relief. Details on well intake screens or perforations are not described in Ecology's database, therefore, the bottom of the well was assumed to be the intake depth.

10.3 Identification Of Capture Basins For Exempt Wells

The sub-basin from which a given well captures the majority of its water is defined here as the "capture" sub-basin and is identified using the well completion elevation and/or the local geology. Details of the method are given below. It is likely that some wells capture surface water from reaches spanning two or three sub-basins, but as a first approximation, this assumption appears to be reasonable. Capture sub-basin were identified for each well. **Table 3** includes a summary of the number of exempt wells estimated to capture water from each sub-basin.

10.3.1 Wells Withdrawing From Bedrock Aquifer

The permeability of bedrock aquifers is usually much lower than the permeability of unconsolidated aquifers; consequently, drawdown due to pumping from a well in bedrock generally does not extend as far as it would in unconsolidated aquifers. For this study, wells that are completed in areas where bedrock is at the surface (**Figure 2**) were assumed to affect the sub-basin in which they reside.

In places, the surficial Quaternary basalt unit (e.g. Boring Lava) may overly the Troutdale Formation. For such areas, the well logs were examined individually to assess whether the casing had openings in basalt or in underlying sedimentary units. If a well is completed in the basalt, the capture basin was identified as the sub-basin in which it resides. If it is completed in a sedimentary deposit, the capture basin was identified using criteria for wells completed in sedimentary deposits, as described in the following section.

10.3.2 Wells Withdrawing From Sedimentary Aquifers

Based on the hydrogeologic information, a well that withdraws from a shallow sedimentary aquifer in the Washougal River watershed is more likely to capture groundwater that would have discharged into a stream in the sub-basin where the well resides. Alternately, if a well withdraws from a deeper sedimentary aquifer, it may capture groundwater that would have discharged into a stream in a sub-basin lying downgradient from the one in which it resides. On this basis, the capture basins for wells in sedimentary units were obtained by one of two methods. First, if the well completion elevation was higher than the outlet elevation of the basin in which it resides then the capture basin was identified as the sub-basin in which it resides. Alternately, if the well completion elevation was lower than the outlet elevation of the sub-basin in which it resides, then it was compared to the outlet elevations of the downgradient sub-basins and its capture was assigned to the first downgradient sub-basin with a lower outlet elevation. For example, using **Table 3**, a well completion elevation of 75 feet in sub-basin LW11 would be assigned W1 as its capture basin.

Because the capture sub-basin for sedimentary aquifers is assumed to depend on the well completion elevation, the well depth distribution was examined to see if there are significant trends in well depths that may provide insight to trends in the assignment of capture basins to wells. In theory, shallow wells tend to capture from nearby streams, and deeper wells tend to capture from more distant streams.

The bar chart for each sub-basin in **Figure 8** summarizes the distribution of well depth within each sub-basin. The bar graphs indicate that most of the wells in the basin are less than 200 feet deep and that a very small percentage of the wells are greater than 400 feet deep. Comparison of the subsurface hydrogeology (**Figures 3, 4 and 5**) to the well depth distributions (**Figure 8**) indicate that most of the wells are completed in the Upper Troutdale aquifer, at elevations above the outlet of the Washougal River. Therefore, most of the wells probably capture surface water from sub-basins within the Washougal watershed. The procedure described above applies to all but a small number of deep wells that are completed below the Washougal outlet elevation and probably capture from the Columbia River (**Table 1**).

10.4 Capture Estimates

As discussed above, as a first approximation, each exempt well is assumed to capture surface water from only one sub-basin, as a first approximation. The effect of a given well on the sub-basin where the capture was estimated to occur is the amount of groundwater withdrawn by that well. However, return flow for that well was assumed to return to the underlying water table via septic drainfields or excessive irrigation in the sub-basin in which the well resides.

Capture of surface water by exempt wells was calculated for each sub-basin. Stream capture within each sub-basin was calculated by summing the discharge due to exempt wells (290 gpd per well) estimated to capture surface water from a given sub-basin, based on outlet elevations, and subtracting the return flow (70% of well withdrawal) for wells located in the sub-basin.

Table 1 summarizes sub-basins, lowest mean monthly baseflow, number of exempt wells, number of wells affecting each sub-basin, capture estimates, and capture estimates as a percentage of the cumulative lowest mean monthly baseflow. A negative value for capture indicates that baseflow is enhanced because return flow from septic systems and excessive irrigation in the sub-basin exceeds the amount of surface water captured by wells within the sub-basin. For example, capture in L11 is -6.8%. This value indicates that withdrawals for many of the wells in L11 capture water from downstream sub-basins L1 or W1, rather than from L11, and that the return flow from wells in this sub-basin is greater than the total capture from this sub-basin. **Table 1** indicates that the highest rates of capture may occur in sub-basins L1, L1221, and L121111 (all within the Lacamas watershed) at about 3% of the cumulative lowest mean monthly baseflow. Capture in the remaining sub-basins is less than 1% of the cumulative lowest mean monthly baseflow.

Capture would be larger than estimated during periods of peak summer withdrawals if a large percentage of the wells in a given sub-basin are near to the stream that they capture from, such that the lag times between groundwater withdrawal and streamflow capture are on the order of days rather than months. Capture, as a percentage of baseflow could be larger during periods when the daily low baseflow is less than the estimates of lowest mean monthly baseflow. Conversely, capture, as a percentage of baseflow would be less during periods when baseflow is larger than the lowest mean monthly baseflow. Although the combined uncertainties of the many factors cast doubt on the accuracy of the capture estimates, it is also evident that if the total capture in the sub-basins were 3-fold greater than estimated, it would still be less than 10% of the baseflow in the most highly affected basins. Certainly, the reliability of the estimates could be improved with additional investigation, but if 10% capture of baseflow is not considered to be significant, then there may be not need to further refine the estimates. In the same light, although the study does not explicitly evaluate growth in exempt well use, the current estimate of baseflow capture is low enough that growth in exempt well use will likely continue to have a relatively low impact on baseflow.

11.0 References

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12.0 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 comprehensive 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.

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 a 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.

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 Dept. of Ecology.