Technical Memorandum

Task 1A Water Quantity Assessment

Subtask 0600: Hydraulic Continuity Evaluation

Level I Technical Assessment

Water Resource Inventory Areas 27 and 28

June 29, 2001

For

Lower Columbia Fish Recovery Board

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FOR
LOWER COLUMBIA FISH RECOVERY BOARD

INTRODUCTION

This Technical Memorandum presents the results of our hydraulic continuity evaluation for the Level I Technical Assessment in Water Resource Inventory Areas (WRIAs) 27 and 28. The study area includes all of Clark County and portions of Cowlitz and Skamania Counties in Southwest Washington, as shown on Figure 1. Our services were performed in accordance with our November 13, 2000 contract with the Lower Columbia Fish Recovery Board (Board) which was authorized on November 17, 2000.

Ground water is used extensively throughout the study area (see Water Quantity and Streamflow Analysis and Water Use Technical Memorandums), and the vast majority of consumptive-use water rights are for ground water use (see Water Rights Technical Memorandum).

The purpose of this hydraulic continuity assessment is to analyze the streamflow/ground water relationships in each of the watersheds and to evaluate specific watersheds within the study area where ground water use may influence streamflow during the entire water year, and especially the dry season.

HYDRAULIC CONTINUITY

Ground Water/Streamflow Relationships

In almost all watersheds, surface water and ground water flow systems are hydraulically connected to some degree (Winter et al., 1998). Creeks and rivers may be fed by ground water discharge at springs and seeps along some reaches, and water may flow out of a stream and recharge aquifers in other areas. The flow in a stream or river that originates from ground water is referred to as "baseflow", and the remaining streamflow is referred to as "run off" (Fetter, 1994).

Hydraulic continuity refers to the hydraulic interaction between surface and ground water within the watershed (Ecology, 1998). A surface water body that loses water and recharges ground water is referred to as "losing" and surface waters that receive flow from ground water are referred to as "gaining" (Fetter, 1994). Depending on watershed-specific factors, the hydraulic connection between ground water and surface water may be significant or negligible. These factors are, in part, described by Bredehoeft et al. (1982) and Theis (1940) and include:

- The hydraulic parameters of the aquifer (hydraulic conductivity, storage).
- The vertical and horizontal position of the aquifer in relation to the surface water body.

- The presence (or absence) of confining units or low-permeability zones between the aquifer and stream or lake bed.
- The hydraulic head differential between surface and ground water,
- The amount of surface or ground water withdrawn from the regional flow system and the location and timing of withdrawal.
- The hydraulic conductivity and thickness of the bottom sediments of surface water bodies.
- Other physical factors, i.e. water temperature, density, salinity, etc.

For watersheds where the hydraulic connection between surface and ground water is minimal, ground water and surface water flow systems may have very little interaction. However, for watersheds where the hydraulic connection between surface and ground water is significant, ground water and surface water flows may be inter-dependent. For those types of watersheds, losing streams may lose so much of the streamflow as recharge to aquifers that the stream ceases to flow, and the flow of gaining streams may originate entirely from ground water, particularly during dry periods when runoff from precipitation is negligible.

Toth (1963) showed that aquifers can be characterized as regional or local flow systems. The deep aquifers of a watershed are likely to comprise regional aquifer systems which receive recharge over a large area and discharge at locations many miles from the primary recharge source. Most watersheds also have many smaller flow systems at the local scale which are composed of shorter recharge and discharge systems. Local flow systems may be further divided into sub-local systems because an individual creek or stream may have many gaining and losing reaches along specific stream reaches (Woessner, 2000).

Ground Water Pumping and Streamflow

Pumping of ground water creates a capture-zone, or an area where the equipotential surface is depressed and ground water flow is directed towards the location of pumping (Bair, et al., 1990). Previous research has shown that capture zone areas can affect streamflow through both local and regional flow systems over time (Morgan and Jones, 1999). Pumping ground water may increase recharge to the aquifer and has the potential to decrease the flow in creeks and rivers through two mechanisms: 1) by decreasing the amount of baseflow provided from ground water to gaining streams and, 2) by increasing the amount of water seeping from a losing stream as aquifer recharge. The extent and amount of streamflow depletion is dependent upon the watershed-specific factors listed above.

The rate of natural aquifer recharge from precipitation is frequently misunderstood as a measurement of the "safe yield" at which an aquifer may be pumped without affecting ground water levels or surface water bodies (Sophocleous, 1997). This concept of safe yield incorrectly assumes that the amount of recharge provided to an aquifer can be withdrawn without affecting the ground water flow system or streamflow/aquifer hydrodynamics (similar to a bathtub being filled and drained at the same rate without affecting the water level). However, previous researchers have shown that the influence of ground water pumping on streamflow is dependent on the dynamic equilibrium established between pumping and the capture of natural ground water discharge, and is not solely based on the rate of natural recharge available to the aquifer (Koreny and Fisk, 2000; 2001; Ecology, 1998; Torak et al., 1996; Miles and Chambet, 1995; Johnston, 1989; Bredehoeft et al., 1982).

The potential influence on streamflows from the use of surface water is relatively straightforward, because each cubic feet per second (cfs) of surface water removed from the stream is a direct and equal reduction in streamflow. However, the influence of ground water use on streamflow is more complicated, due to both spatial and temporal factors related to recharge. The recharge area for a specific ground water point-of-diversion may be spread out over a very large area. Alternatively, surface water bodies may act as sources of additional recharge in specific (often unknown) areas due to the spatial relationship between the aquifer and surface water bodies, aquifer heterogeneity, the presence or absence of confining units or other watershed-specific factors. Also, the timing of ground water use is critical in evaluating the potential influence of ground water pumpage on streamflow, especially during the dry summer period when streamflow is lowest (Ecology, 1998). Because of the potential to decrease streamflow, ground water pumping may indirectly decrease water quality or conflict with the flow requirements for fisheries habitat (Washington State Conservation Commission, 2001; 2000).

WASHINGTON STATE REGULATORY STATUS

Hydraulic continuity is an increasingly important consideration in Washington State. West of the Cascade Divide, many of the aquifers used for water supply are relatively shallow and most creeks and streams receive recharge from ground water in at least some portions of the watersheds. Although it is difficult to generalize the hydrogeologic setting of any area, the ground water flow systems in the region tend to be fairly complicated. Ground water recharge and discharge patterns are often unknown, and the effects of ground water pumping on streamflow can extend over a large area depending on the presence of confining units, aquifer heterogeneity and discharge/recharge zones, many of which are poorly defined or unknown (Morgan and Jones, 1999).

Water resource policy in Washington State is mainly under the regulatory purview of the Washington State Department of Ecology (Ecology). Ecology generally evaluates the effect of ground water pumping on streamflow when considering new water rights applications. Although subject to case-by-case considerations, Ecology generally does not allocate new water rights that would cause a decrease of surface water flow in streams that are closed to further appropriation or where the flow is insufficient for habitat requirements (see Water Rights Technical Memorandum). As part of the water rights application process, Ecology has required studies on the potential influence of ground water pumping on streamflow.

Because evaluating the influence of ground water use on streamflow is complicated and subject to professional interpretation, Ecology developed a draft guidance manual, "The Report on the Technical Advisory Committee on the Capture of Surface Water by Wells" dated 1998. The guidance manual presents recommended methods for evaluating the influence of ground water pumping on streamflow. The manual describes three types of watersheds (Level I, II, III) depending on watershed-specific factors including the hydrogeologic setting, water rights priorities, available streamflow, extent of ground water use and potential for water quality degradation or reduction of flow lower than fish habitat requirements. A recommended level-of-effort for evaluating aquifer/streamflow relationships is presented for each of the three watershed categories, depending on the complexity of the watershed hydrology and the potential for impact from each of the watershed-specific factors, as summarized below and shown on Table 1.

- **Level I –** These watersheds have a low potential for streamflow to be affected from ground water use because water-use demand and population density are low. These watersheds may be adequately characterized by fairly simple water balance accounting methods.
- **Level II –** Level II watersheds have a moderate potential for streamflow to be affected by ground water use, a moderate water-use demand and population density, and an increasingly complex watershed hydrogeology. These watersheds require an increased level of analysis (typically simple numerical modeling) to characterize potential impacts on streamflow from ground water use.
- **Level III –** These watersheds have a high potential for streamflow to be affected by ground water use. Water-use demand and population density are high and forecast to increase. The hydrogeology of the watershed is complex, and the effects of ground water pumping are often difficult to quantify and dependent upon temporal factors. These types of watersheds generally require transient, three-dimensional numerical modeling to characterize the potential impacts on streamflow from ground water use.

PREVIOUS STUDIES ON HYDRAULIC CONTINUITY IN WRIAs 27 AND 28

The following regional studies provide some information on the relationship between ground water and surface water. Other smaller studies completed on a local scale have already been referenced in the Water Quantity and Streamflow Analysis Technical Memorandum.

U.S. Geological Survey Portland Basin Study

The U.S. Geological Survey (USGS) completed the Portland Basin study in Oregon and Washington to evaluate regional ground water hydrology, recharge, overall water use within the basin, aquifer response to ground water use, and surface water/ground water relationships (Snyder et al., 1996; McFarland and Morgan, 1996; Morgan and McFarland, 1996; Snyder et al., 1994; Collins and Broad, 1993). The study involved collecting data on ground water hydrology, surface water flow and water use during the period from 1987 to 1988. The USGS study showed that all of the tributaries to the Columbia River within the study area are net gaining streams, although some individual stream reaches lost flow to ground water. A numerical ground water flow model was developed for the Portland Basin, which was calibrated to steady-state conditions.

The data collection and numerical model developed by the USGS provide a good framework upon which to base more detailed future evaluations of ground water use and aquifer/streamflow relationships. However, since the late 1980s a large amount of ground water exploration has been completed and ground water pumping has expanded significantly. Also, the coarse grid size of the model and the lack of transient calibration limit the effectiveness of the model in evaluating streamflow/aquifer relationships and the potential influence of specific ground water withdrawals on streamflow (Morgan and McFarland, 1996).

Clark Public Utilities Ground Water Development Program

Clark Public Utilities has completed an extensive ground water exploration and development program in southwestern Clark County in the East Fork Lewis River, Salmon Creek and Burnt Bridge Creek watersheds. Clark Public Utilities has also installed and aquifer tested approximately 35 to 40 production wells (rough estimate), although not all of these are currently used for ground water supply. These wells are completed in the Upper and Lower Troutdale Aquifer. We understand that Clark Public Utilities regularly measures ground water levels in the Salmon Creek and East Fork Lewis River watersheds and streamflows on Salmon Creek (PGG, 1997; 2000).

Salmon Creek Water Resources Management Plan

Ecology, Clark Public Utilities and the Washington Department of Health (DOH) performed data compilation, aquifer testing, streamflow gaging and limited evaluations of stream/aquifer relationships as part of a Water Resources Management Plan developed for the Salmon Creek watershed (Ecology et al., 1996). The study was focused on the lower portion of the Salmon Creek watershed. The study concluded that ground water pumping in the Salmon Creek watershed was influencing streamflow, but insufficient data and analyses were completed to quantitatively define the total potential influence of ground water pumping on streamflow.

City of Vancouver Ground Water Development Program

The City of Vancouver has completed an extensive ground water exploration and development program south of the Clark Public Utilities service area in the Salmon Creek and Burnt Bridge Creek watersheds. The city has installed many large capacity production wells at ten stations throughout the city's water district service area. Most of these wells are completed in the shallow Orchards Aquifer, although several wells are completed in the Lower Troutdale (Sandy River Mudstone, or Sand and Gravel) Aquifer. We understand that the City of Vancouver regularly monitors ground water levels (Gray & Osborne, 1996).

Portland Basin Deep Aquifer Study

The City of Portland performed data compilation and developed a ground water flow model to evaluate the hydraulic continuity and aquifer yield potential of the deep aquifers (Lower Troutdale Formation, also known as the Sand and Gravel Aquifer or Sandy River Mudstone Aquifer) of the Portland Basin. The model included most of the known areas of the deep aquifers in Clark County and was used to evaluate the aquifer yield and ground water/surface water relationships between the deep aquifer, the overlying shallow aquifer and the Columbia River. However, the major focus of the model was on the Oregon portion of the basin.

West Skamania County Ground Water Quality Study

Skamania County completed an assessment of the hydrogeology, aquifer yield potential and ground water quality in Western Skamania County (PGG, 1997). Limited information is available on ground water use and aquifer/streamflow relationships.

Ecology Baseflow Characteristics Study for Washington Rivers and Streams

Ecology completed a baseflow analysis for Washington rivers and streams using the USGS flow gaging data (Sinclair and Pitz, 1999). The baseflow estimates were calculated by using the hydrograph separation program HYSEP (Sloto and Crouse, 1996) which is based on the methods of Pettyjohn and Henning (1979). Hydrograph separation methods are intended to evaluate natural flows in watersheds. Hydrograph separation assumes minimal changes in watershed runoff from snowpack, urbanization or retention/detention facilities, reservoirs or any other factor that violates the simple conceptual watershed model assumed by the method (Linsley et al., 1983). The advantage of hydrograph separation is that it provides a relatively simple method for estimating the baseflow contribution of ground water to streamflow, but the disadvantage is that it can lead to erroneous baseflow estimates if the gage records do not reflect natural flows or include significant flow from snowpack melt (Mau and Winter, 1997). The baseflow calculations by Sinclair and Pitz (1999) can be considered rough estimates for watersheds that do not violate the assumptions of the hydrograph separation method and may be accurate during periods when runoff from snowpack melt is minimal and for watersheds where the gage records still reflect natural flows.

METHODS USED TO EVALUATE THE RELATIONSHIP BETWEEN GROUND WATER AND STREAMFLOW

DATA COMPILATION

The USGS, Ecology, Clark, Cowlitz and Skamania County and the major municipalities and water purveyors within the study area were requested to provide information on previous studies of water use and hydraulic continuity between ground water and surface water. Ground water use information was received by all of the larger purveyors within the study area and was evaluated to determine actual use from points-of-diversion (see Water Use Estimate Technical Memorandum). Daily streamflow records were requested from the USGS, Clark County and Clark Public Utilities and were used to evaluate the baseflow characteristics of streamflow and to assess ground water/streamflow relationships.

STREAMFLOW ANALYSIS

Estimates of low flow in the major river or creek systems within the watershed were prepared from streamflow analyses completed previously for this study (see Water Quantity and Streamflow Analysis Technical Memorandum). The monthly average of daily 90 percent exceedance during August was selected as an approximate estimate for comparison to mean baseflow calculated from hydrograph separation (described below), and is summarized in Table 2. The monthly average of daily 90 percent exceedance observed during the dry summer months (i.e., August) is generally considered to be a rough estimate of low-flow conditions and is sometimes used as an approximation of baseflow when other data are not available.

HYDROGRAPH SEPARATION

Baseflow was summarized from the hydrograph separation calculations calculated by Sinclair and Pitz (1999) for the Kalama, North Fork Lewis River, East Fork Lewis River, Salmon Creek and Washougal River.

GeoEngineers estimated baseflow for the Salmon Creek and Burnt Bridge Creek watersheds using the hydrograph separation methods outlined in Pettyjohn and Henning (1979). Streamflow data were compiled for Salmon Creek at the Clark Public Utilities gaging station Northcutt Residence (No. S-08), and the Burnt Bridge Creek gage stations Burnt Bridge Creek at 112th Avenue, Vancouver (No. 14211895) and Burnt Bridge Creek at 19th Street, Vancouver (No.14211898). The baseflow estimates for the available period of record from these three gage stations were averaged to obtain an estimate of mean baseflow. The results of hydrograph separation analysis are shown on Figures 2 through 10, and the low-flow statistics (using mean flows from the month of August) are summarized on Table 3.

The baseflow estimates were used according to the conditions described below:

- Baseflow estimates were not available for the Lacamas Creek or the Columbia River Tributaries watersheds due to the lack of streamflow gage records.
- The Lower and Middle Sub-basins of the North Fork Lewis River are controlled by dam storage and releases and it is our opinion that the flow data collected from gages within these sub-basins should not be used to calculate baseflow.
- The baseflow calculations for the Kalama River, Upper Sub-basin of the North Fork Lewis River, the East Fork Lewis River and the Washougal River are likely influenced by snowpack melt. Consequently, baseflow estimates in these watersheds may be over-estimated and should be compared to the 90 percent exceedance flow.
- The baseflow calculations for Burnt Bridge Creek only include one year of streamflow data from 1999, and may show evidence of flow alterations within the watershed (very high winter baseflows). The best estimates of baseflow for this watershed may be in the late summer and should be compared to the 90 percent exceedance flow.
- The Salmon Creek watershed has a fairly long streamflow record without snowpack accumulation. Consequently, the baseflow estimates from hydrograph separation are expected to be fairly reliable.

WATERSHED CRITERIA

Data were compiled on the factors affecting the influence of ground water use on streamflow for each of the watersheds from the previous evaluations conducted for this project (see previous Technical Memorandum). These watershed-specific factors included:

- Water use (ground water and surface water use)
- Population (current and projected)

- Hydrogeologic complexity of watershed
- Water rights status
- Fish habitat flow requirements
- Water quality

These categories of data were ranked according to the criteria recommended by Ecology for evaluating ground water/streamflow relationships (Ecology, 1998). The watershed-specific ranking is summarized in Table 4. The purpose of developing this ranking system was to determine the appropriate basin classification and recommended level-of-effort for evaluating ground water/streamflow relationships. Next, the findings from previous studies were summarized for each of the watersheds within the study area. The watershed classification was compared to the available data and the level-of-effort completed in previous studies to determine if sufficient information was available to answer the following two questions:

1. Are sufficient data available to assess the influence of ground water use on streamflow based on the watershed complexity?

2. Have previous studies addressing the influence of ground water use on streamflow included a sufficient level-of-effort to appropriately quantify the potential reduction in streamflow?

Based on the answers developed for each of the two questions presented above, the potential influence from ground water use on streamflow was evaluated for each of the watersheds. If previous studies included insufficient data or analyses to make conclusions regarding the potential impacts from ground water on streamflow, recommendations are provided for further assessment.

EVALUATION OF HYDRAULIC CONTINUITY BY WATERSHED

The hydraulic continuity evaluation for each watershed is presented below. Some of the data presented below are summarized from previous Technical Memorandums on Water Rights, Water Quantity and Streamflow Analysis, Water Use, and Future Projections.

KALAMA RIVER WATERSHED

Streamflow Analysis

The Kalama River Watershed is primarily composed of low-permeability rock formations with minor alluvial deposits in the lower portion of the watershed. The mean flow for the Kalama River near Kalama (USGS Station No. 14223600) was 314 cfs during the month of August and the monthly average of daily 90 percent exceedance for August was 223 cfs for the period of record from 1947 to 1975 (Table 2). Streamflow at gage No. 14223600 drains 198 square miles of the 224 square mile watershed, and provides a good estimate of the flow characteristics of the entire watershed. The mean baseflow estimated from hydrograph separation during the month of August was 290 cfs, which represented 92 percent of total flow (Table 3). The difference between the 90 percent exceedance and baseflow estimates from hydrograph separation may be due to snowpack melt from Mt. St. Helens. The monthly average of daily 90 percent exceedance for August and baseflow estimates indicate that baseflow forms almost all of the total flow during the dry summer months (Figure 2).

Watershed Classification

The Kalama River Watershed was ranked as a Level I watershed because water use is low, surface water rights are available, population density is low and the vast majority of the basin remains undeveloped (Table 4). Also, most ground water use is within the lower portion of the watershed. The year 2000 population was approximately 5,300 persons (based on year 2000 U.S. Census Bureau data) and total consumptive water use was approximately 0.8 million gallons per day (mgd). Population is expected to increase by approximately 3,400 persons and water-supply demand is expected to increase by approximately 0.5 mgd by year 2020.

Recommendations

It is our opinion that the potential impacts of ground water use on streamflow are low, and a water balance analysis is sufficient to evaluate various water resources demands in the watershed. No additional evaluations are recommended to evaluate hydraulic continuity between ground water and streamflow.

NORTH FORK LEWIS RIVER WATERSHED

Streamflow Analysis

The North Fork Lewis River Watershed is composed of low permeability volcanic and intrusive rocks. A small area of the lower portion of the watershed is composed of alluvial deposits, and the sand and gravel deposits of the Troutdale Formation. The dams and reservoirs of the Lewis River hydroelectric project dominate streamflow in the Lower and Middle Sub-basins. The only gages that are above the influence of dam releases are within the Upper Sub-basin. The upper portion of the watershed has significant accumulations of snowpack, and snowpack melt influences the runoff hydrograph in the two gages located in the Upper Sub-basin (Figures 3 and 4).

The gage data collected at Lewis River above Muddy River near Cougar (No. 14216000) were analyzed for the available period of record from 1927 to 1970. Streamflow at gage No. 14216000 drains 227 square miles of the 848 square mile watershed and only represents flow in the upper portion of the watershed. The gages in the lower portion of the watershed are influenced by reservoir storage and were not analyzed. The mean August flow at gage No. 14216000 was 425 cfs and the monthly average of daily 90 percent exceedance for August was 292 cfs (Table 2). The mean August baseflow was estimated at 404 cfs, a total of approximately 95 percent of total flow (Table 3). The discrepancy between the 90 percent exceedance flow and baseflow estimates from hydrograph separation may be due to the influence of snowpack melt from the Cascade mountains in the upper portion of the watershed.

Watershed Classification

The North Fork Lewis River Watershed was ranked as a Level I watershed because surface water rights are available and water-use demand and population density are low (Table 4). The year 2000 population was approximately 14,300 persons, and the consumptive water use was approximately 1.8 mgd. The lower portion of the basin is developed with some ground water use, but streamflows are dominated by the extensive hydroelectric project in the Middle and Upper sub-basin. Future growth over the next twenty years is expected to result in a population increase of approximately 9,000 persons and water-supply demand is projected to increase by 1.6 mgd.

Recommendations

Because of the low rate of ground water use, the dominant influence of the hydroelectric reservoir storage on streamflow, and the relatively low water-supply demand over the next twenty years, it is our opinion that a water balance analysis is sufficient to evaluate water resources demands. No additional studies are recommended to evaluate the influence of ground water on streamflow.

EAST FORK LEWIS RIVER WATERSHED

Streamflow Analysis

The East Fork Lewis River is composed of low-permeability rock formations in the upper portion of the watershed in the Cascade Mountains and the lower portion of the watershed is composed of deposits of alluvium and the Troutdale Formation. The streamflow data from the gage East Fork Lewis River near Heisson (No. 14222500) were evaluated for the available period of record from 1929 to 1997. Streamflow at this gage drains 125 square miles of the 212 square mile watershed and is representative of the upper half of the watershed. At gage No. 14222500, the mean August flow was 84 cfs and the monthly average of daily 90 percent exceedance for August was 49 cfs (Table 2). The mean August baseflow calculated by hydrograph separation was 71 cfs (Table 3, Figure 5). The baseflow estimates show that approximately 84 percent of August flow originates from baseflow assuming that the hydrograph separation method is accurate for this watershed. If snowpack accumulation is a significant factor in the upper portion of the watershed, this estimate may be inaccurate and the percentage of baseflow is probably lower than 84 percent. However, the snopack should be gone from this watershed by August. These flow statistics indicate that baseflow is an important component of streamflow, especially during the dry summer months.

Watershed Classification

The year 2000 population within the East Fork Lewis River watershed was estimated at approximately 24,400 persons and the consumptive water use was estimated at 4.1 mgd. The population is expected to increase by approximately 30,600 persons over the next twenty years and water-supply demand is expected to increase by approximately 5.4 mgd. Ground water use is primarily within the lower portion of the watershed, and includes municipal, agricultural and domestic uses. Ground water use is from aquifers at varying depths and distances from the stream and, according to our knowledge, the potential effect of ground water use on streamflow has not been well-characterized. A low-flow restriction has been placed on some water rights for one-half of the low flow. Habitat requirements for some fish species may not be sufficient for a portion of the year, although recommended instream flows have not been finalized by Ecology. The East Fork Lewis River Watershed was ranked as a Level II watershed because of the moderate current and future increased ground-water supply demand, the hydrogeologic complexity of the lower portion of the watershed and the competing demands on instream flows between water use and habitat requirements.

Recommendations

Sufficient data are available to evaluate hydraulic continuity in the watershed. Based on our understanding of the watershed hydrology and the watershed-specific factors presented above, a water balance will be useful to develop a general understanding of overall water use. However, a more detailed quantitative spatial analysis will be required to evaluate the effects of expanded ground water use on streamflow. To our knowledge, this level of analysis has not been completed for the watershed.

SALMON CREEK WATERSHED

Streamflow Analysis

Almost the entire portion of the Salmon Creek watershed is composed of deposits of the Troutdale Formation. Snowpack influences are expected to be low and no dams or reservoirs, which may alter the runoff characteristics, are located on the watershed. Streamflow was compiled for two gages: Salmon Creek near Battle Ground (No. 14212000) for the period of record from 1944 to 1976, and the Clark Public Utilities gage near Northcutt Residence (CPU-S08) for the period from 1997 to 1999. Gage No. 1412000 drains 18 square miles and gage No. CPU-S08 drains 77 square miles of the total 92 square mile watershed. The watershed runoff characteristics are well reflected by these gages, although the lower gage CPU-S08 has a short period-of-record.

The mean August flow for gage No. 14212000 was 4.4 cfs and the mean August flow for gage No. CPU-S08 was 23 cfs. The monthly average of daily 90 percent exceedance for August was 4.0 cfs for gage No. 1412000. The 90 percent exceedance was not calculated for gage No. CPU-S08 due to the short period-of-record (Table 2). The estimates of baseflow from hydrograph separation are 3.8 cfs for gage No. 14212000 and 21 cfs for gage no CPU-S08 (Table 3). The majority of streamflow during the dry season (between 86 and 91 percent during August) is from baseflow. The 90 percent exceedance and the hydrograph separation baseflow estimates for gage No. 14212000 are similar, probably due to the lack of snowpack or reservoirs within the watershed. Baseflow estimates are shown on Figures 6 and 7.

Watershed Classification

The year 2000 population of Salmon Creek was approximately 82,000 and consumptive water use was approximately 13.7 mgd. Population is forecasted to increase by 85,500 persons and water use is predicted to increase by 15 mgd by year 2020. Ground water is used heavily throughout the Salmon Creek watershed by many wells completed either in shallow or deeper aquifers. New surface water rights are unavailable for the watershed. Streamflow in Salmon Creek does not meet recommended minimum instream flows of 42 cubic feet per second (cfs) for the upper Salmon Creek and 63 cfs for the lower Salmon Creek proposed for habitat requirements (Ecology, 1992a; 1992b; 1992c). However, it should be noted that the 10 percent exceedance flows recorded at the gage in Battle Ground from 1944 to 1975 show that historic summer flows never met the recommended 42 cfs instream flow, and it may be possible that the historic summer flows for Salmon Creek have never met the recommended instream flows due to factors other than ground water use in the watershed (Ecology et al., 1996; Beecher and Dugger, 1991). Water quality in Salmon Creek is impaired with respect to temperature, fecal coliform, turbidity and phosphorous, and water quality may continue to degrade if streamflow is reduced.

Clark Public Utilities regularly monitors streamflow, ground water pumping, ground water levels and water quality within the watershed. If streamflow decreases below a threshold of 12 cfs at the Northcutt gage (No. CPU-S08), Clark Public Utilities implements mitigation measures to increase streamflow (PGG, 1997). Clark Public Utilities reported in 1997 that the gage data for the available period of record indicates that streamflow decreased below 12 cfs during August of 1994 and August of 1992 (PGG, 1997).

Ground water pumping has decreased water levels in areas of the Salmon Creek watershed (Ecology et al., 1996). As ground water levels decline, the possibility exists that baseflow contributions to the stream may decrease, or streamflow may be withdrawn from the stream to recharge ground water (Washington Conservation Commission, 2001). Ground water levels in shallow wells in the Orchards area that were completed in the Upper Troutdale Formation declined by at least 15 to 20 feet during the 1980s (Wildrick et al., 1998; Ecology et al., 1996). Most of these shallow wells experienced 15 or more feet of recovery during the 1990s. Much of this water level recovery is related to increased precipitation and recharge, as well as a shift in water production from shallow sources to deeper sources (PGG, 1999).

We have classified the Salmon Creek Watershed as a Level III watershed because of the large use of ground water from a multiple aquifer/confining unit system, the potential for water quality degradation from decreased streamflow, the high current and projected population and water-use demand, and the potential conflict between senior water rights and instream flows for fish habitat.

Recommendations

The USGS completed a steady-state ground water flow model for the Portland Basin including the Salmon Creek watershed (Morgan and McFarland, 1996; Collins and Broad, 1993). The USGS simulated year 1987 ground water use in Clark County at 79 mgd, and expanded ground water use of 114 mgd (total use) for year 2010. Based on the simulated expanded ground water use of 114 mgd for year 2010, the USGS predicted baseflow to Salmon Creek would decrease by 8 percent. Our water use estimates indicate that total use in Clark County is currently approximately 103 mgd (90 mgd consumptive use), and water use will increase by approximately 64 mgd in 2020. These figures are rough estimates, but show that the current and forecast water use estimates have increased from the water use estimates incorporated into the USGS study. The USGS also stated that the model was generally insufficient for predicting the potential for specific ground water uses to reduce streamflow due to the large grid size used in the model and the lack of transient calibrations (Morgan and McFarland, 1996).

Ground water use in Salmon Creek is from deep and shallow aquifer systems with many wells pumping a large volume of ground water. A comprehensive data set is available to evaluate the potential influence of widespread pumping on streamflow within the watershed. However, the studies completed to date are insufficient to fully characterize these potential influences. We recommend that an evaluation should be completed for the watershed, which incorporates the location and timing of existing and future ground water use and estimates the potential streamflow, as recommended in the Habitat Limiting Factors study for WRIA 28 (Washington Conservation Commission, 2001). Such an analysis could also be used to evaluate the potential influence on streamflow from future water rights allocations.

BURNT BRIDGE CREEK WATERSHED

Streamflow Analysis

The Burnt Bridge Creek Watershed is composed of the Orchards Aquifer and the Upper Troutdale Formation. There are no snowpack accumulations or reservoirs to alter the watershed runoff characteristics, although the natural hydrology of the watershed has been altered significantly during development of the basin. Streamflow data were obtained for two recording gages: Burnt Bridge Creek at 112th Avenue at Vancouver (No. 14211895) and Burnt Bridge Creek at 19th Street at Vancouver (No. 14211898) (Figures 8 and 9). The drainage area is 8 square miles for gage No. 14211895 and 18 square miles for gage No. 14211898. The entire watershed drainage is 27 square miles, so the watershed is adequately represented by these gages, although streamflow data were only available for the 1999 water year at both gages.

The average mean flow for August was 3.9 cfs at gage No. 14211895 and 7.8 cfs at gage No. 14211898. August baseflow estimates from hydrograph separation were 3.4 cfs and 6.6 cfs at each respective gage, which are between 85 and 87 percent of mean August flow (Table 3). These flow statistics show that mean August flow is low within the watershed, and baseflow from ground water contributes the vast majority of flow during the dry summer months and a large percentage of the total flow for the rest of the year.

Watershed Classification

The Burnt Bridge Creek watershed has the highest population and water use of the entire study area. Population in the Burnt Bridge Creek Watershed for year 2000 was estimated at 190,000 persons and consumptive water use was estimated at 57 mgd. The year 2020 population is forecasted to increase by 182,000 persons and water use is projected to increase by 32 mgd. Surface water rights are closed to further appropriation in the watershed, and the instream flow habitat requirements for Burnt Bridge Creek have not been evaluated. Ground water use in the

Orchards Aquifer has lowered ground water levels in shallow wells in the Orchards area by up to 25 feet during the 1980s (Ecology et al., 1996). Most of these shallow wells experienced 15 or more feet of recovery during the 1990s. Much of this water level recovery is related to increased precipitation and recharge, as well as a shift in water production from shallow sources to deeper sources (PGG, 1999). Lower ground water levels may cause baseflow contributions to streamflow to be reduced or may cause streamflow to seep out of the stream as recharge to ground water (Washington Conservation Commission, 2001). Ground water use has decreased spring flow in Southern Clark County in the upper aquifer (Wildrick et al., 1998; Morgan and McFarland, 1996; Mundorff, 1964), and it is likely that increased ground water use will continue to influence the surface waters of the watershed. The water quality of Burnt Bridge Creek is impaired with respect to temperature, pH, fecal coliform and dissolved oxygen, and decreases in baseflow have the potential to increase temperature and further decrease water quality.

Ground water use occurs mainly in the unconfined Orchards Aquifer and to a lesser extent in the deeper aquifers. The Orchards Aquifer is likely to strongly influence streamflow. The amount of recharge contributed to the deep aquifers through confining units between the two aquifers is unknown. Consequently, the relationship between use of the deep aquifers and streamflow of tributaries to the Columbia River within the study area is also unknown. We have classified the Burnt Bridge Creek Watershed as a Level III watershed because of the large use of ground water from a complicated multiple aquifer/confining system, the high current and forecast population and water-use demand, the significant potential for decreased water quality and the competing water rights between senior users and instream flow for fish habitat.

Recommendations

Burnt Bridge Creek is a complex watershed with many competing water resource demands. A water balance evaluation only provides a general overview of various watershed hydrology components, and does not include sufficient detail for evaluating the potential influence on streamflow from ground water use. To our knowledge, the USGS Portland Basin Study and the City of Portland Deep Aquifer Study are the only efforts to characterize the relationship between ground water use and streamflow within the watershed. Neither of these studies included sufficient detail to evaluate the spatial or temporal relationships between ground water use and Burnt Bridge Creek flow. We recommend that an evaluation be completed, using the high-quality data available for the watershed, which incorporates the location and timing of existing and future ground water use and estimates the potential effects of streamflow depletion. This evaluation could be used to evaluate the potential impact of future water-use scenarios and water rights allocations on streamflow in Burnt Bridge Creek.

LACAMAS CREEK WATERSHED

Streamflow Analysis

No streamflow gage records are available for any of the water courses in this watershed and estimates of baseflow were not possible due to the lack of available data.

Watershed Classification

The year 2000 population of the Lacamas Creek Watershed was estimated at 23,800 persons and consumptive water use was estimated at 7.7 mgd. The year 2020 population is forecast to increase by 35,000 persons and water-use demand is anticipated to increase by approximately 6.1 mgd. The major aquifer utilized for ground water supply is the Upper Troutdale Formation (CH2M Hill, 1996). Water quality within the watershed is impaired for fecal coliform, temperature, pH and dissolved oxygen, which will worsen if streamflows decrease. Because of these factors, we have ranked the Lacamas Creek Watershed as a Level II watershed.

Recommendations

To our knowledge, no watershed-specific studies have been performed to evaluate the relationship between ground water use and streamflow depletion. If ground water use in the watershed expands significantly, a simple numerical analysis should be prepared which evaluates the effects of proposed ground water use on streamflow. Regular ground water level and surface water flow monitoring and data collection should be implemented. However, two recently completed studies concluded that there is little opportunity to develop major ground water supplies in this area (PGG, 1998, 2001).

WASHOUGAL RIVER WATERSHED

Streamflow Analysis

The Washougal River watershed includes low-permeability rock formations found within portions of the Gifford Pinchot National Forest and private timberlands, which comprise the upper and middle areas of the watershed. The upper portion of the watershed may be subject to significant snowpack accumulation. The lower area of the watershed includes the Troutdale Formation and alluvial deposits of the Washougal and Columbia River. Streamflow gage data were obtained for the Washougal River gage near Washougal (No. 14143500), which represents 108 square miles of the 148-square mile watershed drainage (not including the Lacamas River drainage). The mean monthly streamflow for the available period-of-record from 1944 to 1981 is shown on Figure 10.

The total mean flow for the month of August is 106 cfs, and the monthly average of daily 90 percent exceedance for the same month is 62 cfs (Table 2). The estimate of mean August baseflow from hydrograph separation methods was calculated at 86 cfs (Table 3). These statistics show that base flow is an important part of total streamflow, especially during the dry summer months.

Watershed Classification

The population of the Washougal River Watershed was estimated at 12,800 persons with an estimated consumptive water use of 5.2 mgd. Population is estimated to increase by 21,200 persons and water-supply demand is estimated to increase by 3.7 mgd by year 2020. Although several municipal diversions are located high in the watershed, they are surface water diversions. The majority of the ground water use within the watershed is by the City of Camas and Washougal, located in the lowest portion of the watershed. The hydrogeologic complexity of the watershed is fairly simple. Based on these factors, we have ranked the Washougal River as a Level I watershed.

Recommendations

It is our opinion that a water balance analysis is sufficient to evaluate water resource demands and the influence of ground water on streamflow in the Washougal River watershed.

COLUMBIA RIVER TRIBUTARIES

Streamflow Analysis

No streamflow gage records are available for any of the water courses in this watershed and estimates of baseflow were not possible due to the lack of available data.

Watershed Classification

The year 2000 population for the Columbia River Tributaries watershed was estimated at approximately 7,000 persons with an estimated consumptive water use of 1.0 mgd. The population is expected to increase by 21,200 persons and water-supply demand is anticipated to increase by 0.6 mgd. No information was available on the influence of ground water use on streamflow. However, most ground water use is in the area around North Bonneville and is expected to have very little influence on the flow of the small creeks and streams in the watershed. We have classified the Columbia River Tributaries as a Level I watershed based on the low population density, water-supply demand and location of ground water use in relation to the streamflow.

Recommendations

It is our opinion that the potential impacts of ground water use on streamflow are low, and a water balance analysis is sufficient to evaluate various water resources demands in the watershed. No additional evaluations are recommended to evaluate hydraulic continuity between ground water and streamflow.

DATA LIMITATIONS

1. Hydrograph separation is a relatively simple and often inexact hydrologic method. The method has many limiting assumptions and can only be used to obtain rough estimates of baseflow and stream runoff. Detailed low-flow measurements conducted throughout the watershed combined with detailed watershed-scale hydrologic mass-balance accounting and geochemical sampling provide a much more accurate estimate of baseflow. The 90 percent exceedance flows for streams with a long-term period-of-record may be a more accurate estimate of baseflow for streams with significant snowpack accumulation due to the limiting assumptions of the hydrograph separation method.

2. Streamflow records for the most urbanized watersheds are either not available or contain a period of record which is insufficient to evaluate the long-term trends of the influence of ground water use on streamflow.

3. Water balance analyses are probably sufficient to evaluate water resource demands and the influence of ground water use on streamflow for the Level I watersheds.
4. Detailed numerical modeling studies by the USGS are based on water use data from 1987 to 1988 and are not sufficient to evaluate the spatial and temporal impacts of specific ground water pumping in the complex Level II and Level III watersheds with heavy population, ground water use, competing demands on instream flow and limited available water rights.
5. To our knowledge, no other detailed regional evaluations have been completed to evaluate the potential impact of ground water pumping on streamflow in the Level II or Level III watersheds. More complex analyses are required which incorporate spatial, and temporal (depending on the seasonal water-supply demand) factors for Level II and Level III watersheds.

We appreciate the opportunity to be of service. Please call if you have any questions concerning this report.

Yours very truly,

GeoEngineers, Inc.

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Charles S. Lindsay, P.G., PHG
Principal

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TABLE 1
SUMMARY OF GENERIC WATERSHED CLASSIFICATION FOR HYDRAULIC CONTINUITY[1]
LEVEL I TECHNICAL ASSESSMENT FOR WRIAs 27 AND 28
LOWER COLUMBIA FISH RECOVERY BOARD

	Watershed Type		
	Level I	Level II	Level III
Watershed Classification			
Surface Water Rights	Available	Near Closure or Closed to Further Appropriation	Closed to Further Appropriation or Senior Rights Impaired
Regulatory Constraints on Surface Water Flows	None	Potential to Not Meet Instream Flow or Habitat Requirements	Instream Flows or Habitat Requirements Not Met
Potential for Decreased Water Quality from Reduced Stream Flow	Low	Moderate	High
Existing Ground Water Use	Low	Low to Moderate	Moderate to High
Population	Low	Low to Moderate	Moderate to High
Hydrogeologic Complexity	Low	Low to Moderate	Moderate to High
Recommended Data and Analysis			
Hydrologic Data Required	Simple	Moderate	Complex
Spatial Effects	No	Yes	Yes
Temporal Effects	No	Yes or No (Depends on Watershed-Specific Factors)	Yes
Type of Analysis	Water Balance	Simple Model	Three-dimensional Transient Model

Notes
[1] Based on ranking factors presented in Washington State Department of Ecology 1998 publication, "Draft Report on the Technical Advisory Committee on Capture of Surface Water by Wells."

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TABLE 2

SUMMARY OF AUGUST 90% FLOW EXCEEDANCE STATISTICS[1,2]

LEVEL I TECHNICAL ASSESSMENT FOR WRIAs 27 AND 28
LOWER COLUMBIA FISH RECOVERY BOARD

Watershed	USGS Station No.	Name/ Location	Drainage Area (square miles)	Period of Record	Mean August Flow[1] (cfs)	Mean 90% August Exceedance[2] (cfs)	Mean 90% August Exceedance[2] (cfs/square mile)
Kalama River	14223600	Kalama River below Italian Creek near Kalama	198	1947-1975	314	223	1.1
Lewis River	14213200	Lewis River near Trout	127	1959-1972	218	147	1.2
Lewis River	14216000	Lewis River above Muddy River near Cougar	227	1927-1970	425	292	1.3
East Fork Lewis River	14222500	East Fork Lewis River near Heisson	125	1929-1997	84	49	0.39
Salmon Creek	14212000	Salmon Creek near Battle Ground	18	1944-1976	4.4	4	0.22
Burnt Bridge Creek	14211898	Burnt Bridge Creek at 19th St, at Vancouver	18	1999	5.8	5	0.27
Washougal River	14143500	Washougal River near Washougal	108	1944-1981	106	62	0.57

Notes
[1] Mean low flow from August averaged over the available period of record.
[2] The monthly average of daily 90% exceedance flow estimates for August were used as typical of low-flow conditions when the influence from hydraulic continuity is greatest. See Water Quantity/Streamflow Tech Memo. for

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TABLE 3
SUMMARY OF MEAN AUGUST BASEFLOW ESTIMATES FROM HYDROGRAPH SEPARATION
LEVEL I TECHNICAL ASSESSMENT FOR WRIAs 27 AND 28
LOWER COLUMBIA FISH RECOVERY BOARD

Watershed	USGS Station No.	Name/ Location	Drainage Area (square miles)	Period of Record	Mean August Flow[3] (cfs)	Mean August Baseflow[3] (cfs)	Mean August Runoff[3] (cfs)	Mean August Baseflow[3] (% of Total)	Mean August Baseflow[3] (cfs/square mile)
Kalama River[1]	14223600	Kalama River below Italian Creek near Kalama	198	1947-1975	314	290	24	92	1.5
Lewis River[1]	14213200	Lewis River near Trout	127	1959-1972	218	197	20	90	1.6
Lewis River[1]	14216000	Lewis River above Muddy River near Cougar	227	1927-1970	425	404	20	95	1.8
East Fork Lewis River[1]	14222500	East Fork Lewis River near Heisson	125	1929-1997	84	71	13	85	0.57
Salmon Creek[1]	14212000	Salmon Creek near Battle Ground	18	1944-1976	4.4	3.8	0.60	86	0.21
Salmon Creek[2]	14213000	Salmon Creek near Northcutt Residence (CPU-S08)	77	1997-1999	23	21	2.0	91	0.27
Burnt Bridge Creek[2]	14211895	Burnt Bridge Creek at 112th Ave, at Vancouver	8	1999	3.9	3.4	0.5	87	0.43
Burnt Bridge Creek[2]	14211898	Burnt Bridge Creek at 19th St, at Vancouver	18	1999	7.8	6.6	1.2	85	0.36
Washougal River[2]	14143500	Washougal River near Washougal	108	1944-1981	106	86	20	81	0.80

Notes
[1] Based on Sinclair and Pitz, 1999, Estimated Baseflow Characteristics of Selected Washington Rivers and Streams, Washington State Department of Ecology Water-Supply Bulletin No. 60.
[2] Calculated by GeoEngineers using the method of Pettyjohn & Henning (1979).
[3] August baseflow estimates from hydrograph separation were used as typical of low-flow conditions when the influence from hydraulic continuity is greatest. See Figures 2 to 10 for baseflow estimates for entire water year.

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TABLE 4

HYDRAULIC CONTINUITY RANKING FOR SPECIFIC WATERSHEDS[1,2]

LEVEL I TECHNICAL ASSESSMENT FOR WRIAs 27 AND 28

LOWER COLUMBIA FISH RECOVERY BOARD

	Watersheds							
	Kalama River	North Fork Lewis River	East Fork Lewis River	Salmon Creek	Burnt Bridge Creek	Lacamas Creek	Washougal River	Columbia River Tributaries
Surface Water Rights	Available	Available	Near Closure (Low-Flow Restriction)	Closed to Further Appropriation	Closed to Further Appropriation	Near Closure (Low-Flow Restriction)	Near Closure (Low-Flow Restriction)	Available[4]
Regulatory Constraints on Surface Water Flows[3]	Habitat Requirements May Exceed Stream Flow	Unknown	Habitat Requirements May Exceed Stream Flow	Habitat Requirements May Exceed Stream Flow	Unknown	Unknown	Habitat Requirements May Exceed Stream Flow	Unkown
Potential for Decreased Water Quality from Reduced Stream Flow	Low	Low	Low to Moderate	High	High	Moderate	Low	Low
Water Use Demand	Low	Low	Moderate	High	High	Moderate	Moderate	Low
Population Density	Low	Low	Moderate	High	High	Moderate	Low	Low
Hydrogeologic Complexity	Low	Low	Moderate	High	High	Moderate	Low	Low
Watershed Classification[2]	Level I	Level I	Level II	Level III	Level III	Level II	Level I	Level I

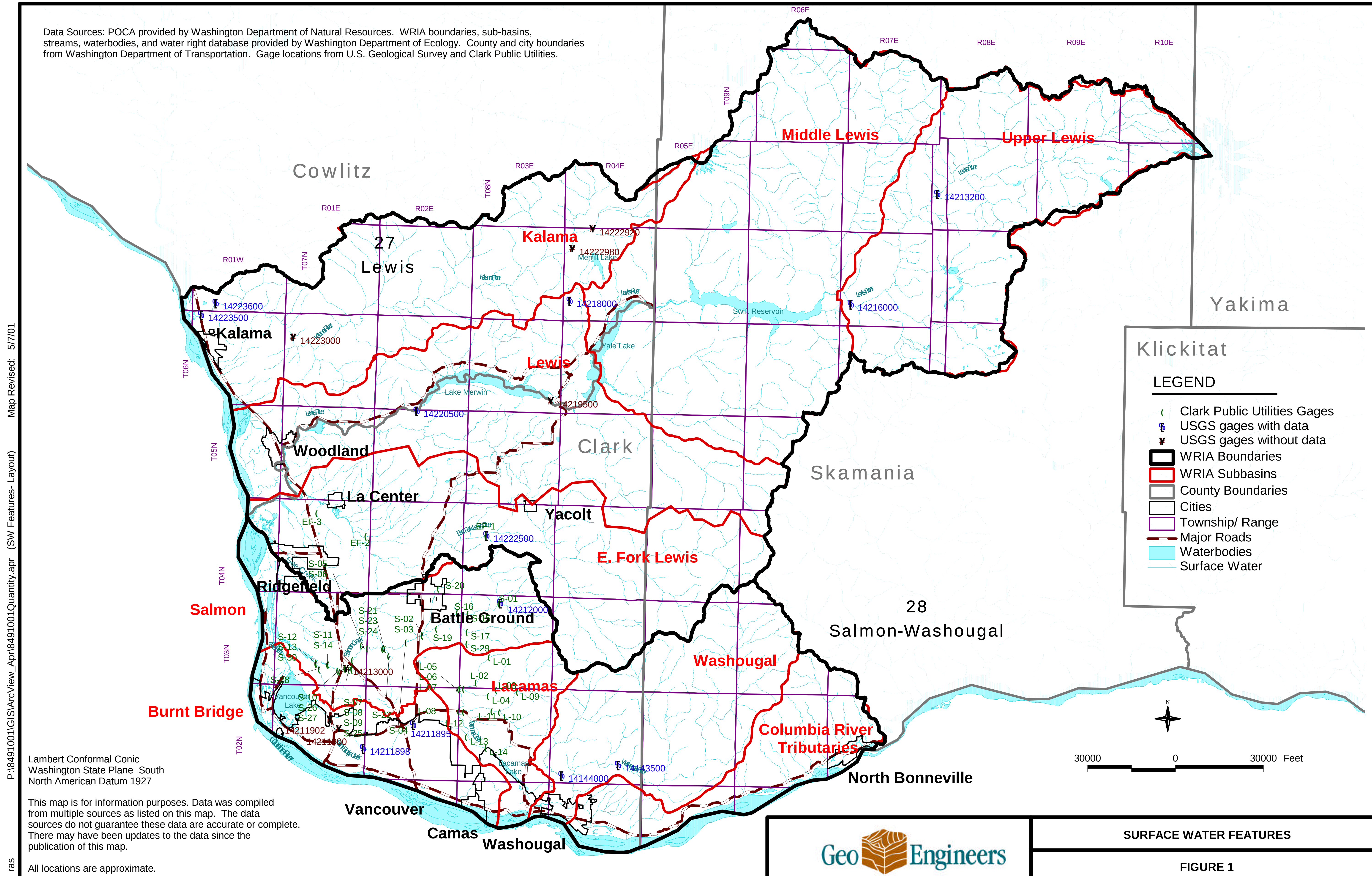
Notes

[1] Hydraulic continuity rankings based on data presented in previous Technical Memorandum for the Level I Technical Assessment.

[2] Watershed classification based on ranking factors presented in Washington State Department of Ecology 1998 publication, "Draft Report on the Technical Advisory Committee on the Capture of Surface Water by Wells."

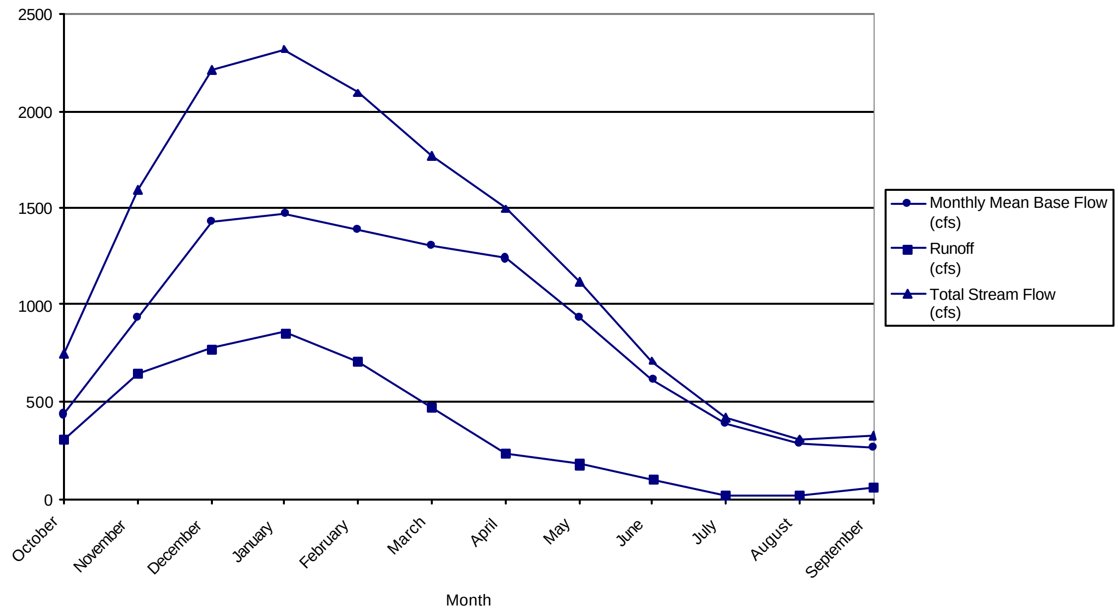
[3] Instream flows have not been formally established within the WRIA 27/28 watersheds. Ranking is based on preliminary instream flow studies.

[4] Gibbons Creek is closed to further appropriation.

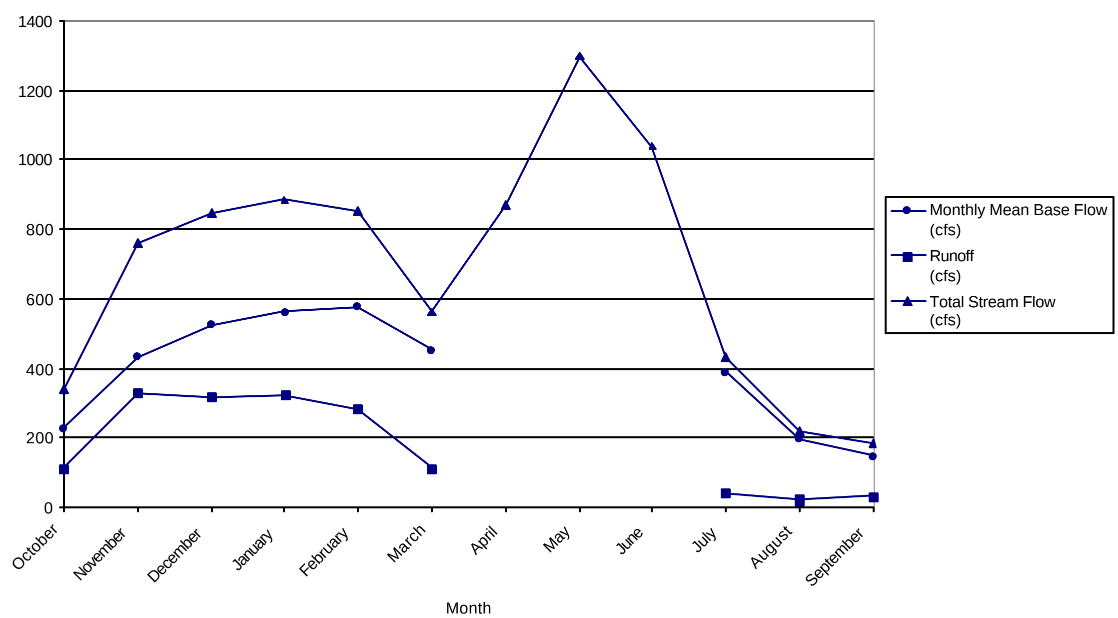


SURFACE WATER FEATURES

FIGURE 1



USGS Station No. 14223500, Kalama River below Italian Creek near Kalama. Period of Record 1947-1975.
Data from Sinclair and Pitz (1999).

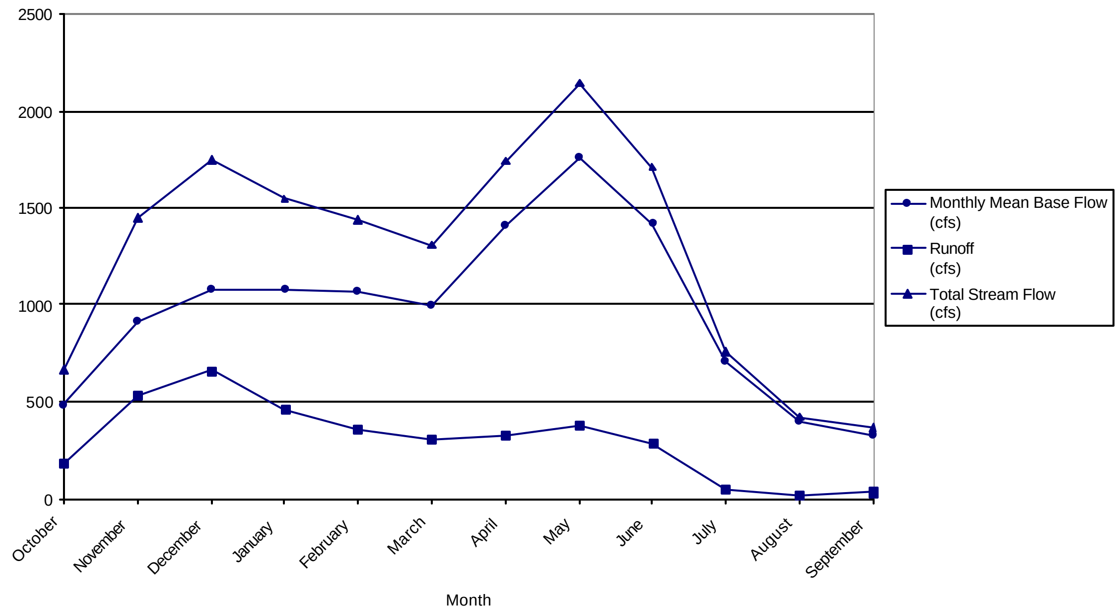


USGS Station No. 14213200, Lewis River near Trout Lake. Period of Record 1959-1972.
Data from Sinclair and Pitz (1999).

GeoEngineers

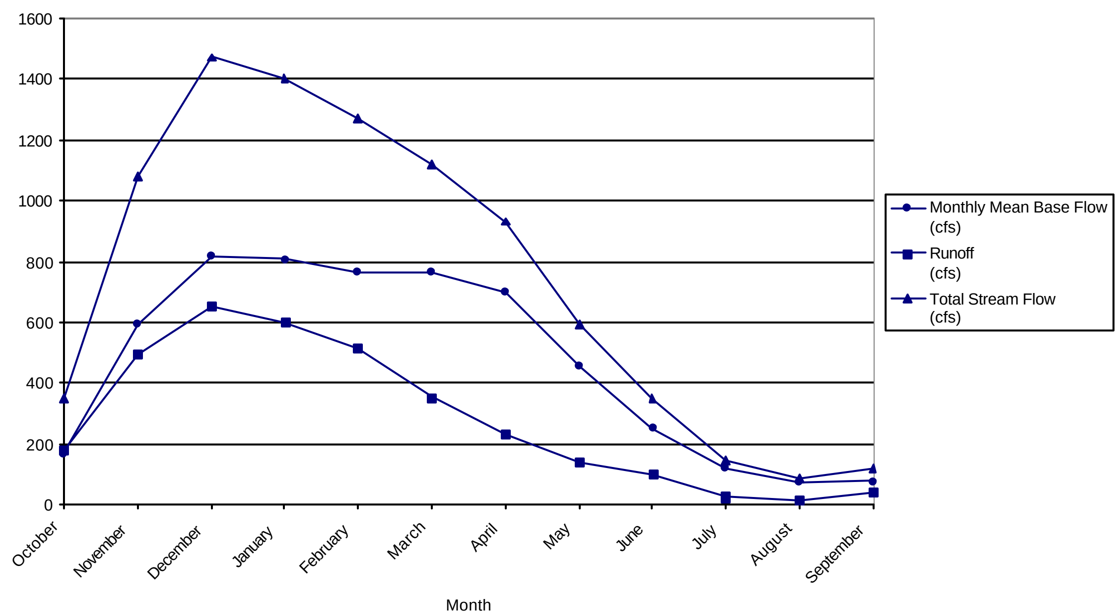
FIGURE 2 **Mean Monthly Baseflow Estimates for Kalama River near Kalama**

FIGURE 3 **Mean Monthly Baseflow Estimates for Lewis River near Trout Lake**



USGS Station No. 14216000, Lewis River above Muddy Creek near Cougar. Period of Record 1927-1970.

Data from Sinclair and Pitz (1999).



USGS Station No. 14222500, East Fork Lewis River near Heisson. Period of Record 1929-1997.

Data from Sinclair and Pitz (1999).

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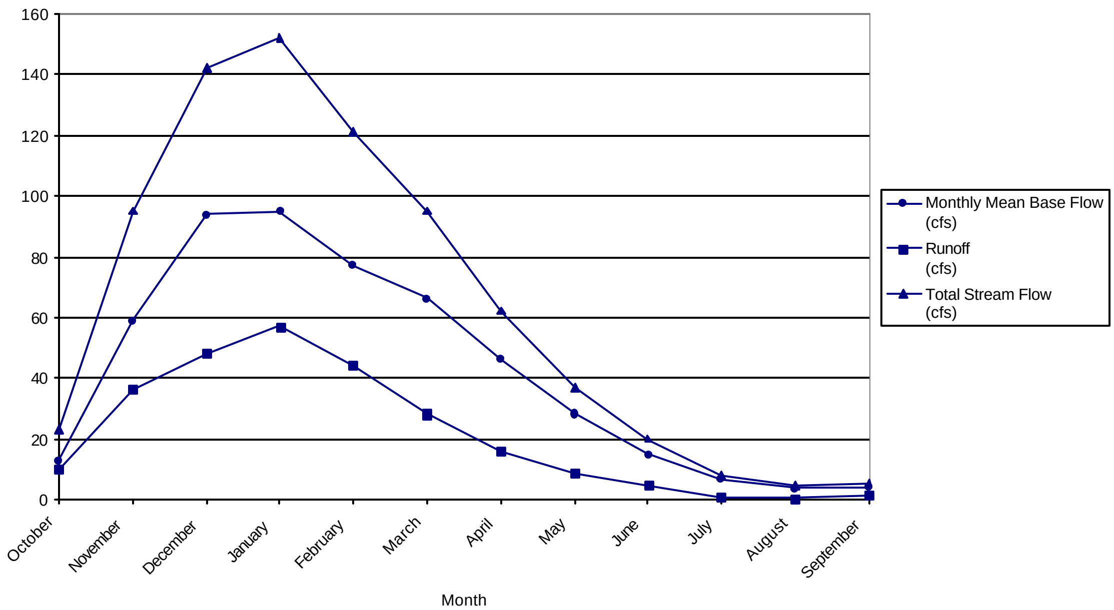
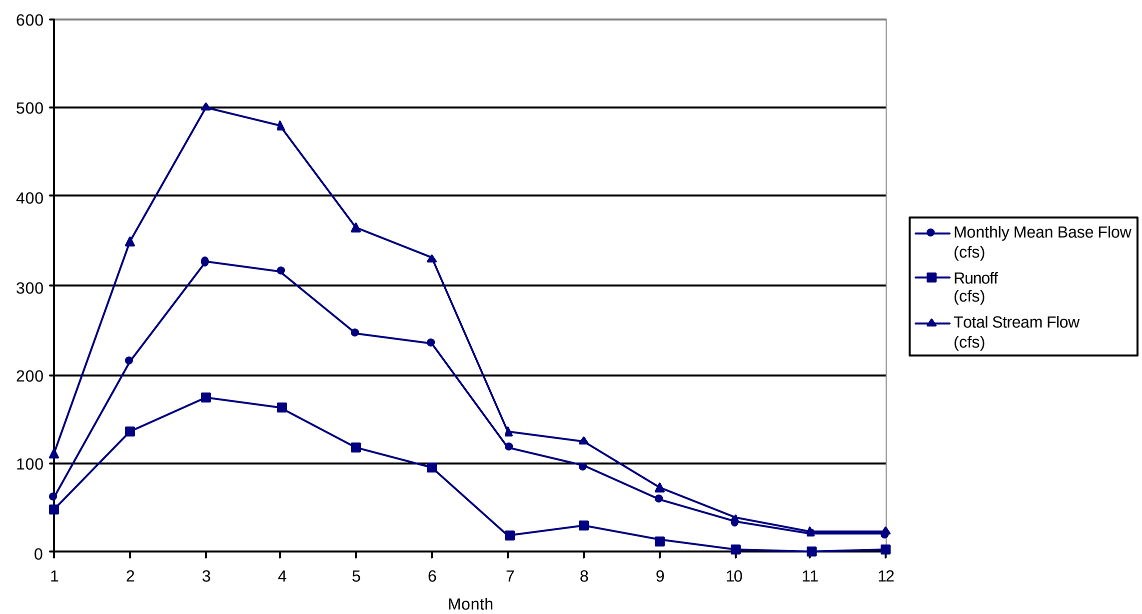
FIGURE 4	**Mean Monthly Baseflow Estimates for Lewis River near Cougar**
FIGURE 5	**Mean Monthly Baseflow Estimates for East Fork of the Lewis River near Heisson**



USGS Station No. 14212000, Salmon Creek near Battle Ground. Period of Record 1944-1976.

Data from Sinclair and Pitz (1999).



USGS Station No. 14213000, Salmon Creek at Northcutt Residence (CPU-S08). Period of Record 1997-1999.

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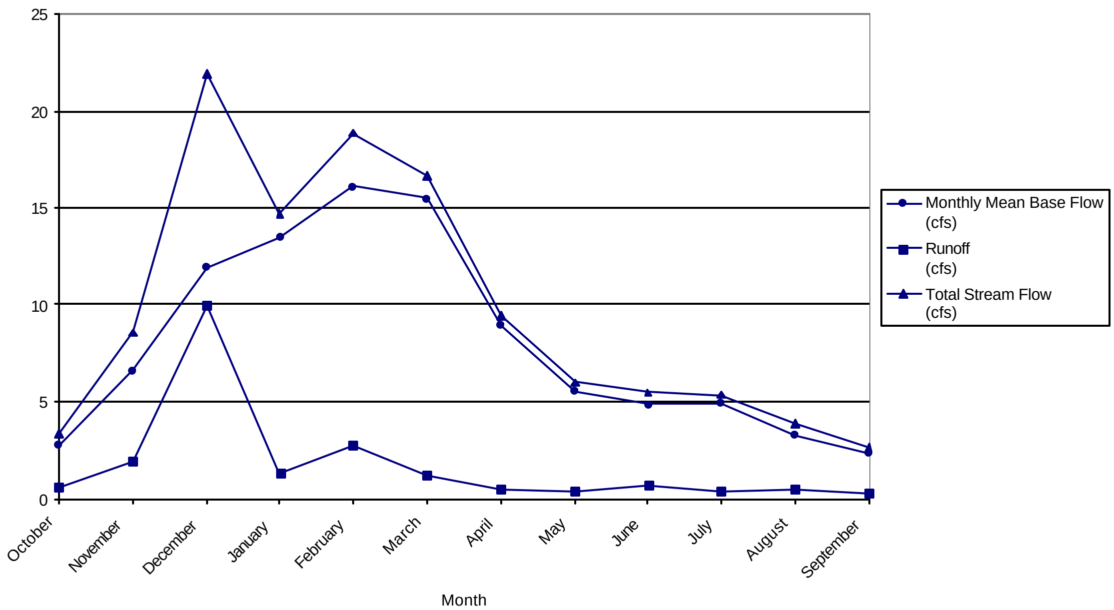
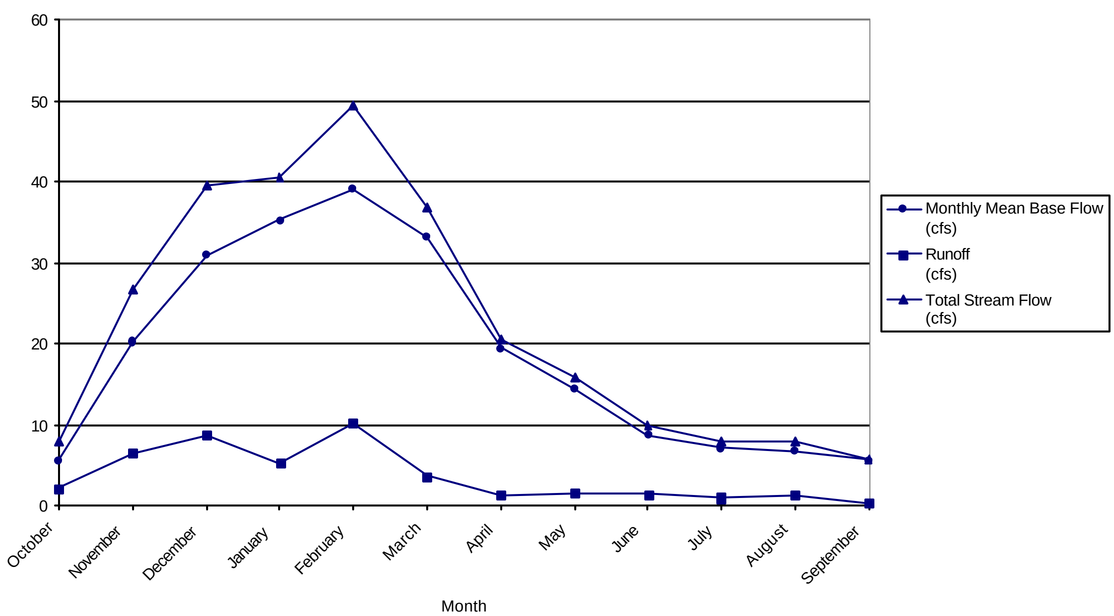
FIGURE 6	**Mean Monthly Baseflow Estimates for Salmon Creek near Battle Ground**
FIGURE 7	**Mean Monthly Baseflow Estimates for Salmon Creek at Northcutt Residence (CPU-S08)**



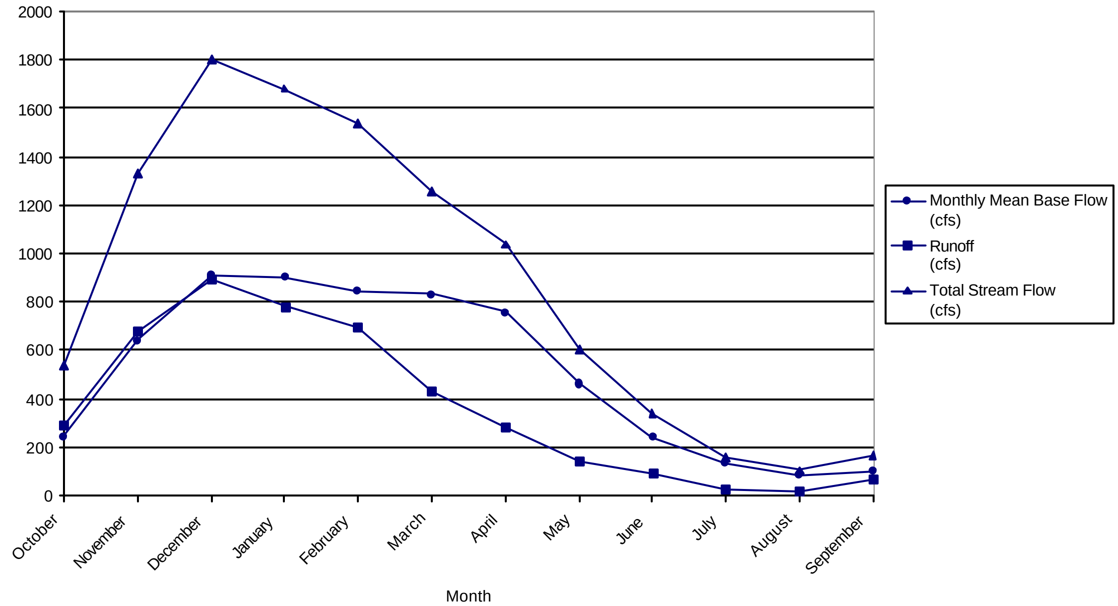
USGS Station No. 14211895, Burnt Bridge Creek at 112th Ave, at Vancouver. Period of Record 1999-2000.
Data from Sinclair and Pitz (1999).



USGS Station No. 14211898, Burnt Bridge Creek at 19th St, at Vancouver. Period of Record 1999-2000.
Data from Sinclair and Pitz (1999).

GeoEngineers

FIGURE 8	**Mean Monthly Baseflow Estimates for Burnt Bridge Creek at 112th Avenue**
FIGURE 9	**Mean Monthly Baseflow Estimates for Burnt Bridge Creek at 19th Street**



USGS Station No. 14143500, Washougal River near Washougal. Period of Record 1944-1981.

Data from Sinclair and Pitz (1999).

GeoEngineers

FIGURE 10 **Mean Monthly Baseflow Estimates for Washougal River near Washougal**