

**PRELIMINARY WATERSHED ASSESSMENT
FOR THE
SNOQUALMIE AQUIFER PROJECT**

DRAFT

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1 INTRODUCTION

This purpose of this document is to develop watershed goals and objectives for the Snoqualmie Aquifer Project; identify watershed-scale factors that might affect its design; and quantify effects (positive or negative) to watershed processes from the proposed project.

1.1 Project Location and Background

The project is located in the Snoqualmie Basin, east of the Seattle/Bellevue/Redmond metropolitan area. The Snoqualmie Aquifer is located in the upper Snoqualmie Basin, above Snoqualmie Falls. This aquifer has been referenced previously by others as the "North Bend" Aquifer.

The project was initially conceived in 1991, partially as a result of the previous year's drought and the resulting moratoriums on water use in the central Puget Sound region. Previous geologic theories provided a basis for concluding a large groundwater supply was possibly available from the upper Snoqualmie Basin.

A feasibility study (CH2M Hill, 1993) was conducted in 1992 to evaluate possible groundwater supply and transmission options for the Upper Snoqualmie Basin. It concluded there was potential for a regional supply from the Upper Snoqualmie basin. The project was conceived as a conventional wellfield and pipeline, delivering groundwater from the Upper Snoqualmie valley to the regional supply system. An exploration program (Golder Associates, 1994) was then undertaken to further evaluate the hydrogeology of three portions of the watershed: Area 1 (Snoqualmie Confluence), Area 2 (Middle Fork Snoqualmie) and Area 3 (North Fork Snoqualmie). Golder Associates (1994) identified a favorable test well location in Area 2 and recommended additional work focus on this sub-basin.

A joint water right application (G1-27384) was filed with the Washington Department of Ecology (WDOE) by the East King County Regional Water Association (EKCRWA) and Seattle Water Department (now Seattle Public Utilities) on January 19, 1994 to withdraw 60 million gallons per day (MGD) from the Upper Snoqualmie basin. This is equivalent to 92 cubic feet per second (cfs), or 67,200 acre-feet per year (AF/y). Subsequent to the application, a test well was installed and tested in the Middle Fork Snoqualmie drainage (Golder Associates, 1995) which encountered a highly transmissive and productive deep aquifer with excellent water quality.

A monitoring program (Golder Associates, 1996) was initiated in 1995 in area wells. Two additional monitoring wells, a precipitation gage, and several automated data loggers were also installed in the upper Snoqualmie basin. The monitoring program has continued uninterrupted.

A preliminary groundwater model was developed in 1996 (Golder Associates, unpublished) to estimate ultimate wellfield yields and to develop the capability to simulate complex stream/aquifer interactions. This model indicated that two wellfield s

would probably be necessary to develop 40 MGD. The model also indicated a significant data gap in the vicinity of North Bend with respect to the continuity of aquifer strata and resulting interconnections with the Snoqualmie River. The model did suggest that time-lags would exist, between the onset of pumping and establishment of a 1-to-1 reduction in baseflow discharge.

An engineering study was conducted (HDR, 1996) to re-evaluate pipeline transmission alignments and costs. This was followed by a meeting with Ecology in January, 1997 to outline the process for obtaining a preliminary permit for the project. It was agreed that a "preliminary permit", as defined in WAC 90.03.290, was the appropriate process for defining the basis, or "road map" for future studies and determinations on the project.

In October 1997 EKRWA hosted a series of public informational meetings at Ecology Regional Headquarters to discuss project elements and solicit comments from interested parties. Based on the comments received at these meetings and the pending listing of Chinook salmon as under the Endangered Species Act (ESA), a new project alternative was developed in December of 1997 to incorporate the conjunctive use of surface water and groundwater. This concept, described detail in the following section, was submitted to Department of Ecology in March 1998.

Since 1998, the direction, framework, and process for watershed planning, ESA recovery, and regional water governance/planning has been uncertain and continually evolving. For this reason, the project has focused primarily on routine monitoring and exploration.

1.2 Location and Description of Proposed Project

Figure 1-1 shows the Snohomish Basin (WRIA-7) and the basic components of the proposed project. The proposed project consists of two wellfields in the upper Snoqualmie Basin, a surface water intake in the lower Snoqualmie River below Carnation, a water treatment plant in the Novelty Hill area, and two short pipelines, one to connect the intake to the treatment plant, another to connect the treatment plant to the regional supply system. The main element of this design is the conjunctive use of surface water from the Snoqualmie River and groundwater from the Snoqualmie Aquifer. A conceptual description of the operation of the system is provided below. Figure 1-2 show the conceptual wellfield layouts and Figure 1-3 shows the river intake and filtration plant locations. This alternative is still in the conceptual design stage. A conceptual depiction of the proposal is shown on Figure 1-4.

Wellfield

The wellfield would be designed for a 60 cfs (40 MGD) capacity. Wells would only be operated during the summer months. Water would be pumped into the Snoqualmie River above Snoqualmie Falls. Pumping groundwater into the river will increase river flows and improve water quality. The amount that river flows are increased at any point in time is determined by the amount of groundwater storage that is withdrawn from the aquifer. This relationship has been simulated by a preliminary groundwater flow model.

Figure 1-5 shows the predicted net increase in steamflow (expressed as a percentage of total wellfield pumping), as a function of the days of continuous pumping. This relationship is preliminary and may change as further data are collected and analyzed in the model.

Dispersion Structures

The wellfield discharge would be put into the Snoqualmie River either via dispersion structures that allow the flow to upwell into the river, or surface discharges engineered to prevent erosion and streambed disturbances. The location and design of these structures has not been determined, but they could be integrated with adjacent wetlands or placed directly in the Middle, South, or Main Stem of the Snoqualmie River above the falls. Water entering the dispersion structures could be aerated to increase dissolved oxygen (DO) levels. Temperature, DO and flow rate would be monitored prior to discharge.

River Intake

A surface water intake would be located on the Snoqualmie River in the vicinity of Novelty Hill to withdraw water for potable water supplies. The location and design of these structures has not been determined, but the intake facility would consist solely of the intake structure, which would include fish screens, debris grates, and a booster pump to transport water from the intake to the filtration plant.

Filtration Plant

A filtration plant would filter and treat water from the river intake. The location and design of the plant has not been determined, but a proposed location is on the Novelty Hill Plateau. The final design capacity for the facility is estimated at 80 cfs. This is greater than the capacity of the wellfield to allow larger withdrawals during periods when flows in the Snoqualmie River are above minimum in-stream flow levels.

Pipelines

Two pipelines would be constructed along existing powerline alignments. One pipeline would convey water from the river intake to the treatment plant, and another would convey water from the treatment plant to the regional supply pipeline (Tolt Phase 2). Total pipeline lengths are estimated at less the 3 miles.

1.3 Project Operation

The project would operate as a conjunctive use system. Physically, the filtration plant would receive a constant supply of surface water from the Snoqualmie River. Because the Snoqualmie River is subject to minimum instream flow requirements under WAC 173-507, the wellfield will supply water to the treatment plant during these flow-limited periods. When the wellfield is in operation, the Snoqualmie River will be used

for conveyance of groundwater for the supply system. Operation of the wellfield upstream of Snoqualmie Falls will augment streamflows with groundwater, which can then be “withdrawn” from the river at the downstream supply intake. This concept has been termed the conjunctive use and river enhancement or CURE concept.

The wellfield would operate between June and October at rates of up to 60 cfs. Wellfield operation will be based on weekly flow targets. Daily changes in wellfield flow rate are not anticipated. During wellfield operation, the predicted net increase in flow at Snoqualmie Falls will be calculated with the groundwater model. Additional streamflow and groundwater monitoring will provide data on wellfield operation. The wellfield will be shut down gradually to compensate for time-lag effects in the reduction of groundwater discharge.

On days when minimum instream flow requirements on the Snoqualmie River at Carnation are met, the filtration plant will operate at its design capacity or whatever is available above the minimum in streamflow requirement. This is the “normal operating condition”. On days when minimum instream flow requirements are not met, the filtration plant will operate at a capacity defined by the predicted net increase in flow provided by the wellfield. This is the “reduced operating condition”.

An example of an operational scenario is as follows: Assume that, during July, the wellfield is withdrawing 60 cfs from the aquifer and increasing flows in the Snoqualmie River by 40 cfs over naturally occurring flows. For the first week of July, flows in the Snoqualmie River are above minimum instream flow requirements. Therefore, the filtration plant could operate at its normal operating capacity of 80 cfs. For the second week of July, flow in the Snoqualmie River is below minimum instream flow requirements. Therefore, the filtration plant operates at a maximum 40 cfs, defined by the amount of augmentation provided by the wellfield

2 PROPOSED WATERSHED FRAMEWORK

The current design concept is intended to enhance the ecosystem, provide regional water supply operational flexibility, and create opportunities for further protection of the watershed. The ability of the Snoqualmie Aquifer project to “do no harm” to the Snohomish Basin ecosystem and not impair existing water rights and in-stream flows is key to successful permitting, final design, construction and operation. The current regulatory atmosphere created by the listing of threatened salmonid species under the Endangered Species Act (ESA) in the Snohomish Basin has created another layer of complexity in evaluating water supply projects and their effect on streamflows and the living ecosystem.

Although there has been significant regulatory activity on developing guidelines and policies that are consistent with ESA, there has been no clear framework for assessing specific water supply projects in the context of ESA. Much of this activity is anticipated to occur through the watershed planning process mandated by the Watershed Planning Act. In the Snohomish Basin, this work has been very slow to move forward and has not provided clear guidance that would be applicable to assessing the Snoqualmie Aquifer project.

This section provides a proposed watershed/ecological framework from which impacts and benefits from the proposed project can be evaluated.

2.1 Current Watershed Habitat Frameworks in the Snohomish Basin

The geology, climate, vegetation, soils, topography, hydrology, land-use, and other characteristics of watersheds influence the suitability of habitats for all aquatic species. Specific habitat requirements of anadromous salmonids differ, yet all share some common habitat needs. Washington Department of Ecology and other state and local regulatory agencies are advocating a “system” approach to watershed management that addresses multiple watershed functions as a system, rather than addressing or improving specific watershed functions. It therefore becomes difficult to evaluate specific projects in a system context unless some sort of framework or criteria is established which are consistent with the system context. Obviously, a project that either has no effect or improves key elements of the system framework is preferable to one that has a negative effect.

Current habitat can provide a set of criteria related to salmonid habitat needs that will form the basis for evaluating the benefits and impact of the proposed operation of the Snoqualmie Aquifer project. These criteria are based on four core habitat framework documents discussed below.

2.1.1 Pacific Northwest Salmon Habitat Indicators Pilot Project

In 1998, the Washington Department of Ecology completed a pilot project in the Snohomish Basin aimed at identifying regional salmon habitat indicators. A work group consisting of representatives from seven northwest environmental management

agencies was convened to assess regional salmon habitat indicators. The work group included representatives from Alaska, British Columbia, Idaho, Oregon, and Washington. A total of 113 candidate indicators were identified originally, which were then pared down to a set of 15 core indicators in five functional categories.

1. Fish Abundance
 - 1.1 Salmonids
2. Water Quantity
 - 2.1 Instream Flow
 - 2.2 Flow Hydrogeology
3. Water Quality
 - 3.1 Temperature
 - 3.2 Biological Water Quality Index
 - 3.3 Chemical Water Quality Index
4. Land Use/Land Cover
 - 4.1 Land Use Conversion
 - 4.2 Transportation Impacts
 - 4.3 Impervious Surface
5. Physical Habitat
 - 5.1.1 Impediments and Accessibility to Salmon Habitat
 - 5.2.1 Large Woody Debris
 - 5.2.2 Stream Depth
 - 5.3.1 Sediment
 - 5.3.2 Spawning Area
 - 5.4.1 Habitat Type Associated with Water

2.1.2 Snohomish Basin (WRIA 7) Watershed Framework

Also in 1998, Washington State Department of Ecology formed an interagency team consisting of a stream geomorphologist, hydrogeologist, fisheries biologist, water quality specialist, ecologist, GIS analyst, and a GIS technician. The goal of this team was to develop landscape-scale tools that assist local watershed efforts in finding solutions to declining salmon stocks, degrading water quality, increasing flood peaks, and declining baseflow. To do this, the team identified five key natural processes for analysis:

1. Water delivery;
2. Sediment;
3. Large wood;
4. Nutrients/toxicants/bacteria; and
5. Heat.

These processes create and maintain fish habitat structure, water quality, peak flow, and baseflow. The Snohomish Basin was then subdivided in 60 sub-basins, and GIS coverages were developed for pre-disturbance, current, and future land use/land cover

conditions. Team members then developed and evaluated river-basin-scale tools that characterize where human land use has changed (and continue to will change) the delivery and routing of key processes. This information then was used to develop recommendations for using characterization products to assist local technical experts in resource recovery efforts. A series of GIS maps was prepared showing sub-basins that may be problematic. These maps are presented in Appendix A. Table 2-1 summarizes the results of the analysis.

2.1.3 Snohomish Basin (WRIA 7) Salmonid Recovery Framework

In 1999, the Snohomish Basin Salmonid Recovery Technical Committee evaluated over 50 potential problems affecting chinook salmon population in Snohomish Basin (Initial Snohomish River Basin Chinook Salmon Conservation/Recovery Technical Work Plan, 1999). Based on the assessment of over 15 technical experts, 35 problems were identified in the basin. Of these, nine high priority known or suspected problems were identified:

1. Loss of channel area and complexity due to bank protection and diking of the river and major tributaries, cutting off the channel from its floodplain.
2. Death of in-channel large woody debris.
3. Flood flows that scour redds at high frequencies.
4. Increased sediment input to streams as a result of slope failures.
5. Poor quality riparian forests.
6. Loss of wetlands due to draining for land conversion that eliminates habitat and reduces water retention.
7. In redd mortality due to siltation or water quality contamination.
8. Urbanization (road construction commercial and residential construction, additional bank hardening) that further reduces chinook salmon viability in the basin.
9. Artificial barriers (dams, tide gates, diversions, culverts, pump stations) prevent juveniles from reaching rearing habitat.

2.2 Proposed Composite Framework

Figure 2-1 summarizes the current watershed indicator frameworks. Figure 2-2 shows the composite framework proposed for evaluation of water supply projects. The framework closely follows the approach developed by WDOE in the 1999 Snohomish Basin watershed framework in structure, but incorporates the elements of other watershed frameworks as well.

Figure 2-2 also shows the proposed geographic extent of the analysis. The Snoqualmie Aquifer project does not affect all areas of WRIA-7, so some geographic scope needs to be applied in evaluating the project. The WDOE framework identified and evaluated 60 sub-basins within WRIA-7. This is currently the most comprehensive and detailed assessment of the entire watershed, and provides an appropriate level of details for

assessing individual projects. The Snoqualmie Aquifer will extract water that could potentially directly affect 6 of the 60 sub-basins in WRIA-7. These are mainstem sub-basins along the Snoqualmie, and include:

1. Lower Middle Fork Snoqualmie
2. Lower South Fork Snoqualmie
3. Coal Creek (Above Snoqualmie Falls)
4. Upper Mainstem Snoqualmie
5. Middle Mainstem Snoqualmie
6. Snoqualmie Mouth

The Snoqualmie Aquifer project will return water to the same 6 of the 60 sub-basins in WRIA-7, and will also contribute flow to another 60 mainstem sub-basins, including:

1. Cathcart Drainages;
2. Marshland;
3. Fobes Hill; and
4. Snohomish Estuary.

During periods of wellfield augmentation, these mainstem sub-basins will experience no reduction in streamflow over naturally occurring conditions since surface water withdrawal would be limited to the amount of wellfield augmentation.

3 WATER QUANTITY TECHNICAL ASSESSMENT

3.1 Overview

The Snoqualmie basin drains 693 square miles of the southern portion of the WRIA, before meeting the Skykomish River to create the Snohomish River. The upper basin, the area above Snoqualmie Falls, is mostly forestland managed privately and by the U.S. Forest Service. Commercial and residential land use in the upper basin is becoming more common along the Interstate 90 corridor. Population centers and mixed agricultural uses such as dairies, berry fields, pastures, and row crop fields are numerous in the lower valley. Wildlife reserves, golf courses, and other recreational facilities are also present along the river. Snoqualmie Falls creates an impassable fish barrier, with a drop of 268 feet (81.7 m) and is a predominant feature at river mile (RM) 40.4. The Tolt River, which drains a 101 square mile basin, is the largest tributary in the lower river and flow is controlled by the Tolt Reservoir, operated by Seattle Public Utilities.

Progressing in the upstream direction, principal tributaries to the Snoqualmie, are Cherry Creek, Harris Creek, the Tolt River, Griffin Creek, Patterson Creek, Raging River, Tokul Creek, and the South, Middle, and North Forks of the Snoqualmie River. The average annual precipitation ranges from about 40 inches in the Lower Mainstem Snoqualmie to over 80 inches in the upper Lower Middle Fork Snoqualmie. In the higher elevations, precipitation is in excess of 120 inches per year (Appendix A). Over the period of record, precipitation has varied in a somewhat cyclical pattern, that can be shown using the method of cumulative departures (Kresch, 1994). Figure 3-1 shows the cumulative departure of precipitation at Cedar Lake, located on the topographic divide between the Snoqualmie and Cedar basins. This figure shows that two significant periods of below-normal precipitation occurred in the 1940's and again in the mid 1980's. While not explicitly part of the watershed assessment framework this graphical method shows the range of variability in precipitation in the basin. This variability is directly related to variability in streamflow.

3.2 Baseflow Assessment (WDOE, 1999)

WDOE evaluated baseflow in WRIA 7 and defined it as ground-water discharge to seeps and springs, as well as snow and glacier melt. These are the primary natural sources of streamflow between storms and during the dry season of summer through early fall. WDOE used surrogate information to estimate the reduction in baseflow due caused by human activities. The assessment examined 5 factors:

1. Groundwater recharge was estimated for historic, current, and future conditions based on land-use published equations relating the factors of annual precipitation and surficial geology (Woodward, et al., 1995).
2. Annual runoff for sub-basins was interpolated from a published map (Gebert, et al. 1987).

3. The annual amounts of ground-water rights and claims were compared to estimated annual ground-water recharge. Sub-basins with appropriations exceeding 10% of recharge were highlighted as potentially having significant reductions in baseflow due to ground-water withdrawals.
4. The annual amounts of surface-water rights and claims were compared to estimated total annual runoff (stormwater plus baseflow). Sub-basins with appropriations exceeding 5% of runoff were highlighted as potentially having significant reductions in baseflow.
5. Reduction in annual recharge was estimated using land use and road information. Recharge was reduced by 30% in urban areas and by 100% for roads (effective width 100 feet) in areas of other land uses. Sub-basins with the highest (4th quartile) estimated reductions of baseflow for current conditions were highlighted as potentially having significant reductions in baseflow.

The results are summarized in Table 2-2 and Appendix A (Figure B-1 through B-12). The results show that none of the sub-basins potentially affected by the Snoqualmie Aquifer project are experiencing excessive allocation of groundwater rights, or excessive allocation of precipitation. The Lower South Fork and Middle Mainstem Snoqualmie are shown to have a high allocation of estimated run-off to surface water rights and claims.

3.3 Hydrologic Indicators – Range of Variability

Streamflow, baseflow, and water quantity are typically included in technical frameworks related to habitat assessment of limiting factor analysis. However, quantifying the importance of streamflows to biologically important processes in a watershed at any given time is not typically captured in a simple determination of mean, maximum and minimum flows. This section outlines a number of hydrologic and geomorphologic criteria that can be used quantitatively to assess the effects of developing the Snoqualmie Aquifer Project.

Geomorphic and habitat conditions in a stream are dependent on a number of complex hydrologic phenomenon. In the Nooksack Basin (WRIA-1), an instream flow framework and technical approach has been developed that includes the use of time series, duration curves (i.e. exceedance levels) and threshold analysis as an integral part of determining the productivity for aquatic organisms in a stream system. This type of approach is also being favored by other agencies such as the Bonneville Power Administration over frameworks such as IFIM.

Richter et al. (1996 and 1997) and Capra (1995) have used what is termed threshold analysis in an attempt to characterize streamflow and habitat parameters in a manner that describes periods of flow. The method developed by Richter (1996) is termed Range of Variability Analysis (RVA), which identifies a suite of 32 biologically relevant hydrologic parameters. These parameters include standard hydrologic statistics, but also include threshold-type parameters that relate to specific events in the streamflow record. RVA can be evaluated from historical streamflow records and predicted through

numerical modeling. The various parameters can be differentially weighted or used “as-is” to quantitatively define the current hydrologic regime and potential future hydrologic regimes and conduct sensitivity analysis. We propose that a Range of Variability Analysis (RVA) form the basis for evaluating the water quantity/water delivery effects from the Snoqualmie Aquifer project, since it will provide an analysis that will support instream flow and habitat assessments that will occur as part of overall watershed planning. These RVA parameters are summarized below:

1. Monthly flow magnitudes,
2. Magnitude and duration of annual extremes,
3. Timing of annual extremes,
4. Frequency and duration of high and low pulses, and
5. Rate and frequency of hydrograph changes.

Table 3-1 (A, B, and C) shows selected results of the RVA analysis for streamflow at Carnation. Appendix B contains the complete RVA analysis. Statistical indicators related to low streamflow conditions include the 1-day, 3-day, 7-day and 30-day minimum flows.

3.4 Assessment of Snoqualmie Aquifer Project Water Quantity Effects

To assess the potential improvements to these statistical indicators, a simple comparison of RVA statistics for the historical base case (no augmentation) and a simulated flow record (base case plus 40 cfs between July and October) was made. The results for the stream gage at Carnation are shown on Table 3-2. This table shows that, during low flow years, mean monthly flows at Carnation could be improved by as much as 6% by the CURE concept. Threshold flows (e.g., 1, 3, and 7-day minimums) could be improved by as much as 9%. During the normal or wet years, flow improvement would typically be less than 5% for all RVA indicators.

Other RVA indicators include the count and duration of low flow pulses, and rate of flow changes. Predicted improvements to these statistics are more difficult to determine without evaluating a specific operational regime. However, it is clear that these statistics could be improved (i.e. fewer low flow pulses with shorter duration) with the operation of the Snoqualmie Aquifer project CURE concept.

4 WATER QUALITY TECHNICAL ASSESSMENT

4.1 Basin Scale Sedimentation (WDOE, 1999)

WDOE characterized basin-scale sedimentation in WRIA 7 based on methods developed by Fitzgerald et al (1998). Sub-basins were first grouped by natural drainage features. Second, a Potential Sediment Transport Coefficient (PSTC) was developed for each sub-basin. This coefficient characterizes a stream's ability to transport and store sediment. Next, an equation for the Cumulative Source Coefficient was developed. This coefficient is composed of two basic inputs: 1) natural, surface erosion and mass wasting; and 2) mass wasting and surface erosion as the result of management activities. Lastly, Sediment Yield Hazard was calculated by multiplying the Potential Sediment Transport Coefficient and the Cumulative Source Coefficient. Each sub-basin was defined in terms of its geomorphic and hydrologic properties. After calculating a set of quantitative, dimensionless indices, each sub-basin was ranked relative to its pre-disturbance, current, and future sediment production, yield, and delivery. A list was then developed of sub-basins having the greatest potential for human alteration in the delivery of water and sediment.

Table 2-2 summarizes the sediment results for sub-basins affected by the Snoqualmie Aquifer Project. Appendix C (Figures C-1 through C-5) show the GIS results. The results show that the Coal Creek sub-basin and all of the mainstem reaches are experiencing "high risk" changes in fine sediment input and accumulation. A more detailed analysis of sedimentation was therefore conducted.

4.2 Bank and Streambed Erosion

From a salmonid habitat perspective, fine sediment input is critical to the development of redds (egg nests in the streambed). Streambed particles in the redd at the end of spawning, and organic and inorganic particles that settle into the redd and surrounding substrate during incubation, affect the rate of water interchange between the stream and the redd, the amount of oxygen available to the embryos, the concentration of embryo wastes, and the movement of alevins, especially when they are ready to emerge from the redd (Meehan 1991). Fine sediments could negatively effect incubation of fish in the channel if they settle in the interstitial spaces, preventing water to flow through, removing waste, and circulating oxygen to the eggs. Juvenile coho salmon avoid water with turbidities that exceed 70 NTU, and 25-50 NTU may reduce growth and cause more young coho salmon and steelhead to emigrate from turbid streams (Mantec, 1991). Measured turbidities on the Snoqualmie at Carnation (WDOE) rarely exceed 15 NTU. Therefore, it is unlikely that the Project could adversely affect fine sediment accumulation. Appendix B contains water quality data on the Snoqualmie River.

A more detailed assessment of the potential for geomorphic change resulting from augmentation of flows by the Snoqualmie Aquifer Project was also evaluated. A "reconnaissance reach" of the Snoqualmie River during between Neal road (off State highway 202) and the Tolt River was visually surveyed at a flow condition of 1310 cfs to

assess erosion potential on channel, bar, and bank features. Of the reaches potentially affected by increased flows from augmentation, this reach appears most susceptible to geomorphic change because of high sinuosity, which exposes a number of channel banks.

In general, channel meandering on the Snoqualmie River is typical of channels with small width to depth ratios and erosion resistant banks. Small width to depth ratios maximize forces on the channel bed by increasing bed shear stresses and the ability of bedforms and bar surfaces to disperse flow forces. The analysis of channel bank, bar, and bed erosion focused on determining whether the magnitude of forces resulting from augmentation is enough to mobilize and transport sediments from bedforms and bar features. Mid-channel bars are observed upstream of the Tolt River confluence, and bank erosion has caused channel widening in some areas. In these areas, a local excess supply of sediment has formed mid-channel bars that are vegetated. Non-perennial vegetation on the bar tops indicates they are dynamic, since no perennial vegetation is apparent. Channel slope also appears to increase in the vicinity of these bars, and streambed is largely composed of small to large gravels.

A determination of bed shear stress increases was also made using hydraulic geometry curves from USGS gage at Carnation during low flow periods of WYs 1986 through 1996. The analysis indicates that augmented flows will not affect sediment transport frequency from June through October. At the finest resolution, flow augmentation may winnow small inter-granular particles from larger particles on the bank and bars. However, this level of detail cannot be theoretically modeled or easily monitored in the field.

Bank erosion may occur during low flow since the low flow channel does access the riverbank. However, bank erosion appears to occur primarily during bankfull conditions (1 to 2 year events) due to the protection of overhanging vegetation. Bankfull floods are infrequent during the proposed flow augmentation months of the year. Even when they do occur, augmented flows will only increase bankfull discharge by less than 0.3 percent. Therefore, augmented flows are not likely to increase the erosion rate of Snoqualmie River streambanks from Snoqualmie Falls to Carnation.

4.3 Nutrient Assessment (WDOE, 1999)

WDOE (1999) characterized basin-scale nutrient loading rates in WRIA using an approach by Reckhow et al. 1980. Published nutrient loading rates were compiled on land use and land cover. Of all the compiled values of loading rates for total nitrogen and total phosphorous, the lower and upper quartile loading rate values were determined. In addition, a "most likely" loading rate was established by matching each land cover with a specific study that most closely reflect the geologic and climatic conditions observed in WRIA-7. The estimated nutrient loading rates for each land cover were summed within each sub-basin. Resulting loading rates are presented for each sub-basin in pre-disturbance, current, and future land cover conditions in Appendix A.

The results suggest that the lower mainstem reaches are experiencing “high ” changes in nitrate load compared to historic conditions. Future changes in phosphate load are considered potentially problematic for all sub-basins except the Lower Middle Fork.

Water quality data over the past 20 years has not demonstrated significant increases in nitrate or phosphate in the Snoqualmie River. Nitrate concentrations in the Snoqualmie River at Carnation are typically around 0.2 mg/L and rarely exceed .4 mg/L. Total phosphorous is more variable ranging from 0.011 to 0.028 mg/L.

One nutrient that was not evaluated by WDOE was dissolved oxygen. Salmonids require high levels of dissolved oxygen (DO). Reduced DO can affect embryos and alevin development, fry growth, and the swimming ability of adult and juvenile migrants (Mantec, 1996). Water solubility and potential DO are inversely related, but both are a function of water temperature (Meehan, 1991). Solubility increases and DO decreases with increasing temperature. Dissolved oxygen at the Snoqualmie River at Carnation typically ranges from 9 to 13 mg/L.

4.4 Heavy Metals Assessment (WDOE, 1999)

WDOE (1999) characterized mean annual loadings of copper, lead, and zinc in WRIA using the nationwide regression models developed from the National Urban Pollution Project (Tasker and Driver 1988). These regression models estimate loadings of pollutants for a single storm event whose rainfall is greater than 0.05 inches in an urban area. Loadings are reported on a per area basis (kg pollutant per storm event, per square kilometer). The average number of storms per year was developed from precipitation data and multiplied by the average loading rate per area to estimate annual loading. It should be noted that estimated loading rates only represent non-point sources associated with urban development and do not include natural metal loading rates for the weathering of Cascade rock.

The results suggest that the Lower South Fork, Coal Creek and Mid-mainstem sub-basins are experiencing increased loadings of lead, copper and zinc. These loading factors are predicted to continue at high levels in the future. The Lower Middle Fork and Upper Mainstem have relatively low loading rates, both currently and in the future.

4.5 Temperature Assessment (WDOE, 1999)

WDOE (1999) attempted to evaluate river-basin-scale tools for the delivery and routing of heat. Efforts focused on quantifying stream canopy closure, stream depth, and groundwater discharge by sub-basin. After numerous attempts, landscape scale values could only be compiled for stream canopy closure. Additional work will be required to develop usable river-basin-scale tools.

However, no other environmental factor has a more pervasive influence on salmonids and other aquatic biota than temperature (MANTEC, 1996). The Snoqualmie Falls to Carnation reach is affected by removal or alteration of native riparian vegetation,

resulting in less shade cover for the channel. Unnaturally high temperatures may alter adult migration timing and distribution; accelerate development of eggs and alevins; result in earlier fry emergence; increase metabolism; increase susceptibility of both adults and juveniles to certain parasites and diseases; alter competitive interaction between species and reduce overall biodiversity of the aquatic community. Table 4-1 summarizes typical temperature requirements for Salmonids.

Temperature at Carnation typically ranges from 5 to 15°C. Temperatures in excess of 15°C have been observed during low flows.

4.6 Assessment of Snoqualmie Aquifer Project Water Quality Effects

Using the WDOE study as a guide, the potential beneficial effects of the Snoqualmie Aquifer Project are assessed.

4.6.1 Temperature

The groundwater to be augmented to the Snoqualmie River is cooler than the river. The samples taken from the aquifer are on the order of 8 to 9° C. At a flow of 600 cfs (typical summer flow) complete mixing of 15° streamflow and 8° groundwater at 40 cfs would lower water temperature by about .5° C. No salmonids reside near the proposed area of augmentation except possibly trout species. Salmonids exist below the falls, beyond which point the water temperature would probably return to its naturally occurring temperature. However, lower water temperatures near the well field and source of augmentation, may lower unnaturally occurring high levels of algae and other biologic production, and increase dissolved oxygen. A more targeted use of groundwater in downstream reaches of the Snoqualmie River could be explored.

4.6.2 Nutrients

Groundwater above Snoqualmie Falls has an average DO content of 3.0 mg/L (U.S. Geologic Survey, 1995). EPA measurements of DO at an unspecified location on the mainstem Snoqualmie River indicate 6 to 9 mg/L concentrations were not exceeded for any of 218 samples collected from 1990 to 1998. This data comparison does not allow specific measures of DO changes by intermixing flow with different DO concentrations, but suggests direct DO changes by flow augmentation will be negligible.

In general, fish may be adversely affected by surface water with pH 5.6 or less. In addition, low pH alters the specific form of metals in soils, increasing both their mobility and bioavailability to aquatic organisms. The lowest observed pH level in the aquifer was of 7.29. Current pH on the Snoqualmie at Carnation is between 6.8 and 7.4. The augmented water would not effect the pH levels in the augmented reach.

Nitrate and phosphate levels in the Snoqualmie River at Carnation are very similar to the levels in groundwater. Although mixing of groundwater and surface water is not

expected to significantly increase the dilution capacity of the river, introduction of groundwater will not impair nutrient levels.

4.6.3 Metals

The metals loading analysis conducted by WDOE does not provide a means to estimate actual water quality in the Snoqualmie River. The analysis is based on loadings, which will not change with the proposed project. Concentrations of dissolved metals in the groundwater are very low. Similar to the nutrient analysis, mixing of groundwater with streamflow in the Snoqualmie River is not expected to significantly increase the dilution capacity of the river, but will not impair metals concentrations in the River.

5 PHYSICAL HABITAT ASSESSMENT

5.1 Large Woody Debris (WDOE, 1999)

Few tools are available to characterize change in the delivery and routing of large woody debris (LWD). Using pre-disturbance and current land cover coverages, sub-basins having greater than 50% of their riparian stream length in mid- and late-seral stage trees were considered by WDOE to have the best potential for delivering large wood to streams. Sub-basins having the least proportion of stream length in mid- and late-seral stage trees (upper quartile) were considered to have the greatest potential for alteration in the delivery of wood. The potential for change in the routing of wood was measured by calculating average stream crossings per mile of stream for each sub-basin. Sub-basins with the highest stream crossings per mile of stream (upper quartile) were assumed to have the greatest potential for a change in the routing of LWD.

WDOE's results suggest that all sub-basins in the Snoqualmie are experiencing some LWD problem (routing or delivery). These results are presented in Appendix A.

5.2 Habitat Structure

The physical structure of streams, rivers, and estuaries plays a significant role in determining the suitability of aquatic habitat to salmonids as well as other organisms upon which salmonids depend for food. These structural elements are created through interactions between natural geomorphic features, the power of flowing water, sediments that are delivered to the stream channel, and riparian vegetation, which provides bank stability and inputs of large woody debris (Mantec, 1996).

5.2.1 Substrate Type

The suitability of gravel substrate for spawning and incubation depends mostly on fish size; large fish can use larger substrate materials than can small fish. Substrate may also provide cover and hiding for juvenile fish, depending on location and size of substrate. Directly downstream of a large boulders in the channel can create a hiding and resting area for larger fish. Table 3-1 summarizes typical substrate requirements for salmonids.

5.2.2 Spawning, Nursery and Hiding Diversity (Pools/Riffles/Debris)

The physical structure of streams, rivers, and estuaries plays a significant role in determining the suitability of aquatic habitats to salmonids as well as other organisms upon which salmonids depend for food. These structural elements are created through interactions between natural geomorphic features, the power of flowing water, sediments that are delivered to the stream channel, and riparian vegetation, which provides bank stability, and inputs of large woody debris (Mantec 1996).

5.2.3 Flow Depth and Channel Width

Besides substrate composition, spawnable area is regulated by streamflow coverage over, flow depth above, and flow velocities at and within the redd. As flows increase, flow depth and gravel coverage increase with velocity to suitable magnitudes for spawning. As flows increase further, depths and velocities can exceed suitable limits for spawning, thus canceling the benefit of increases in usable spawning area. Generally speaking, usable spawning area plotted against streamflow reveals a rise to a relatively wide plateau followed by a gradual decline as floodflow magnitudes are reached (Meehan, 1991). Table 5-2 summarizes typical velocity and depth requirements for salmonids.

An analysis of river velocity, width, and depth was conducted at the USGS Carnation gage only. Flow velocity, stage and depth for the daily, weekly, and monthly average flow were determined with hydraulic geometry equations. The hydraulic geometry is based on the USGS rating curve and cross section for the gage at Carnation. Historical streamflow and corresponding velocity, stage, and depth were ranked and assigned an exceedance probability. Figure 5-1 shows the exceedance plots for historical averages and simulated averages with an additional 40 cfs during the augmentation period. The figure shows that, even at higher exceedance probabilities (e.g., dry, lower flow years), the improvement in flow depth is less than 3%. The improvement in channel width is similar.

5.3 Land-Use Assessment (WDOE, 1999)

WDOE assessed land-use changes in WRIA-7. Geographic Information System (GIS) coverages for pre-disturbance, current, and future land use/land cover allowed team members to assess process change both from pre-disturbance to current conditions and from current to future conditions. A pre-disturbance coverage was developed using vegetation data compiled from 1869 to 1873 Government Land Office surveys for Snohomish County (microfiche at the Washington State Library, Olympia, WA). The intent was to sample tree species and seral stage within generalized vegetation regions throughout the Snohomish Basin. Current conditions were developed using the most recent land use/land cover developed for Puget Sound from satellite imagery. And finally, a future land use/land cover coverage was developed by synthesizing Growth Management Act planning documents from King and Snohomish Counties and some cities in the Snohomish Basin.

Assessment of potential land use changes from the development of the Snoqualmie Aquifer project are beyond the scope of this analysis.

5.4 Assessment of Snoqualmie Aquifer Project Physical Habitat Effects

In general, flow augmentation is predicted to cause small, but statistically measurable increases in daily, weekly, and monthly average width, depth, and velocity at Carnation.

The project would not affect the geomorphic and physical structure of the augmented reach or its ability to deliver or route large woody debris (LWD). Habitat structure, substrate type or structural diversity would not be affected by the project.

6 SALMONID POPULATION ABUNDANCE ASSESSMENT

6.1 Background

The Snohomish Basin is a large, complex system and a major contributor of water, biota and organic materials to the central Puget Sound marine ecosystem. This ecosystem supports significant populations of native salmonids including coho, chinook, chum and pink salmon; steelhead, cutthroat, rainbow and bull trout; and mountain whitefish (Initial Snohomish River Basin Chinook Salmon Conservation/Recovery Technical Work Plan, 1999). Table 6-1 shows the typical life cycle timings of chinook salmon.

Fish productivity of the Snohomish River Basin has diminished as a result of floodplain draining, water quality impairment, tributary channelization, riparian forest destruction, elimination of salt marshes, diking of river and estuary channels, and log rafting in saltmarshes. Fish productivity of the Snohomish River Basin is naturally limited by low flow conditions. Previous fisheries research has shown that productivity of coho, summer chinook, and steelhead tends to be higher in years with relatively high summer flows and lower in year with relatively low summer flows (Smoker 1953, Neave 1948 and 1949).

Five anadromous salmonid species (chinook, coho, pink, chum salmon, and steelhead trout) utilize the Snohomish River Basin (WDFW, 1994). Appendix C contains maps of salmonid distribution in WRIA-7.

1. Chinook salmon stocks in the Snohomish system are separated into four distinct stocks: Snohomish summer chinook, Snohomish Fall chinook, Bridal Veil Creek fall chinook, and Wallace River summer/fall chinook. The Snohomish summer chinook spawn primarily in September, while the Snohomish fall and Bridal Veil chinook spawn primarily from late September through October. Wallace River chinook spawn throughout September and October.

Based on anecdotal information, it is likely that adult chinook salmon in the 1930s and 1940s were entering the river as early as May. Whether these were a separate spring stock or an early timed component of the summer stock is impossible to establish based on available information (Initial Snohomish River Basin Chinook Salmon Conservation/Recovery Technical Work Plan, 1999).

2. Snohomish Chum salmon are geographically separated from other chum stocks. Within the system, chum is tentatively divided into three stocks: Skykomish, Snoqualmie, and Wallace. Entry timing of chum salmon in the Snohomish is primarily October through December with the peak around early to mid-November.
3. Coho salmon in the Snohomish are separated into four stocks: Snohomish, Skykomish, South Fork Skykomish, and Snoqualmie. Coho utilize nearly all tributaries accessible to the mainstem. Coho returning to these tributaries typically enter freshwater in September and October and spawn from late

- October through January, with some variation among streams and among years within streams.
4. Snohomish pink salmon are separated into odd- and even-year spawners. Odd-year stock spawns mid-September through October of odd-numbered years and is found throughout the drainage in all accessible mainstem waters and in larger tributaries. Even-year stock spawns primarily in September of even-numbered years in the mainstem Snohomish and in over reaches of the Skykomish.
 5. Snohomish steelhead are separated into three summer and three winter stocks. Wild summer steelhead in the Tolt River, the upper North Fork Skykomish River, the upper South Fork Skykomish River and wild winter steelhead in the Snohomish/Skykomish, Snoqualmie, and Pilchuck Rivers are distinct stocks. Summer steelhead in the Tolt and North Fork Skykomish are native and South Fork Skykomish summer steelhead stock developed from colonization by non-native fish. Wild winter steelhead in each stock are native. Run-timing of summer steelhead stock are May through October; winter stock timing is November through April.

Five salmonid species utilize the Snoqualmie River for spawning: chinook, chum, coho, pink, and steelhead:

1. The chinook salmon stock in the basin is of native origin and a wild run named Snohomish River Fall, spawning between late September through mid November. Spawning occurs in the Tokul Creek, Raging River, Tolt River, and the mainstem Snoqualmie River immediately downstream of these tributaries.
2. The chum salmon stock in the basin is of native origin and a wild run named Snoqualmie, spawning between mid-November to mid-January in the mainstem Snoqualmie River, and in a side channel near Fall City.
3. Two runs of coho salmon utilize the Snoqualmie; the Skykomish and Snoqualmie. The Skykomish run is a mixed origin of wild and hatchery fish, and a produced from wild and hatchery runs. The Snoqualmie run is also of wild and hatchery origin and but hatchery fish are not produced, only wild runs utilize the drainage. Both runs spawn late October through January. The Skykomish run spawn throughout the Snoqualmie River mainstem. The Snoqualmie run spawn in Cherry Creek from the mouth to river mile (RM) 0.5; Harris Creek; Stossel Creek; Griffen Creek from the mouth to headwaters and in an unnamed tributary at RM 5.0; Patterson Creek at RM 6.5; Canyon Creek for one mile; and the Tolt River, and in a lower reach of a tributary on the Tolt at RM 5.5.
4. One native, wild run of pink salmon utilizes the Snoqualmie, the Snohomish odd-year. This run spawns in mid-September through October in the North Fork Snoqualmie River from the confluence to approximately 12 miles upstream and the South Fork Snoqualmie River from the confluence to Sunset Falls.

One wild steelhead trout run of unknown origin utilizes the Snoqualmie, the Tolt

summer run. They spawn from February to April in the Tolt River from the mouth upstream to the reservoir.

6.2 Assessment of Snoqualmie Aquifer Project Salmonid Abundance Effects

Most of the factors affecting salmonid populations are captured in the elements discussed in previous sections. A commonly utilized technical framework for salmonid life-cycle requirements was developed by Mantec (1996), and includes five basic classes of environmental factors:

1. Food Source;
2. Water Quality;
3. Habitat Structure;
4. Flow Regime; and
5. Biotic Interactions.

The two factors not evaluated in previous sections of this report are food sources and biotic interactions. Based on the assessment of flow, water quality and habitat effects, it is highly unlikely that the proposed project would affect salmonid food sources or other biotic interactions (e.g., predators).

7 CONCLUSIONS AND RECOMMENDATIONS

The conjunctive use and river enhancement (CURE) concept proposed for the development of the Snoqualmie Aquifer is an innovative and technically sound proposal that provides additional water supply capacity without impacting sensitive ecosystem functions on the Snoqualmie River. The concept relies on the seasonal withdrawal of groundwater storage that would not otherwise discharge to the Snoqualmie River, and returning that groundwater to the Snoqualmie River above Snoqualmie Falls. This approach therefore constitutes a real enhancement of streamflow above what would occur naturally. Based on the assessment of current watershed frameworks and conditions in the Snohomish/Snoqualmie Basin (WRIA-7), it is clear the current CURE concept for the Snoqualmie Aquifer project will not impair any of the currently defined ecosystem indicators in the Snohomish Basin. The project will increase instream flows and will directly contribute to achieving flow regimes adequate for salmonid access and unimpeded movement within and among aquatic and edge habitats of the Snoqualmie River. The project acronym CURE is appropriate to the concept and will contribute to a cure for declining ecosystem health in the basin. Specifically:

1. The CURE concept will improve flows in the Snoqualmie River by as much as 8% during low flow years, and will improve depth, width and velocity conditions by 3% or less. This analysis applies only to the reach near Carnation, and improvements may be greater or lesser depending on specific locations.
2. It is unlikely that the CURE concept will significantly or measurably improve water quality in the Snoqualmie River, but will also not impair water quality with respect to temperature, dissolved chemicals, and suspended sediments
3. The CURE concept will not change physical habitat conditions or existing natural obstacles to fish movement, such as waterfalls and seasonal thermal barriers.
4. The CURE concept can, in conjunction with other habitat restoration efforts, contribute to improved structural complexity, connectivity, and elevation gradients needed for favorable hydraulics and the activities of fish and other organisms in the water column and bed materials at locations where these functions would occur naturally.

The consumptive water supply element of the project will involve the construction of a diversion on the Snoqualmie River. This component of the project will have a localized impact on the ecosystem that can be mitigated through sound engineering design and maintenance. The water supply yield to the region for this project will take advantage of “excess” streamflow above current instream flow requirements, while providing some supply capacity during instream flow limited periods through the use of the augmented groundwater storage. Other water sources in the region can be used conjunctively with the Snoqualmie Project to optimize the net water supply to the region. This provides for the most efficient and ecologically sound human use of water from this basin, and maintains its status as one of the least allocated watersheds in Western Washington.

In summary, there does not appear to be a “fatal flaw” with the CURE concept and there is significant opportunity for a collaborative effort at the state and local level for developing a truly new water supply that does not affect, and in fact improves, the condition of a watershed. The following recommendations are offered:

1. Establish a small, but multi-stakeholder, advisory group to discuss and promote feedback regarding the CURE concept. Ideally, this group should be closely aligned with the WRIA 7 Watershed Planning effort, and other watershed planning being conducted by King County.
2. Establish, either independently or (preferably) through collaboration with other agencies, a series of stream monitoring stations along the Snoqualmie River between Snoqualmie Falls and Duvall. These stations should monitor physical, chemical and biological characteristics of the river and adjacent riparian area in order to establish a baseline from which augmentation benefits can be measured.
3. Establish an electronic database and internet information site that describe the project, provides access to data, and promotes communication and feedback on the project.
4. Continue exploration, testing and modeling of the Snoqualmie Basin Aquifer to develop a detailed operational plan and wellfield configuration. This should include a large scale pilot test of the augmentation concept in order to demonstrate its operation and monitor it's effects.
5. Once a collaborative atmosphere is established and baseline information is being collected and/or catalogued, the details of a project specific environmental impact statement should be developed and offered to WDOE and other stakeholders as a process for water right permitting.

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TABLES

Summary of WDOE (1999) Watershed Assessment

Sub-Basin Name	Units	Lower Middle Fork Snoqualmie	Lower South Fork Snoqualmie	Coal Creek_Lower	Coal Creek_Upper	Upper Mainstem Snoqualmie	Mid-Mainstem Snoqualmie	Snoqualmie Mouth
Fisheries Basin		Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie
Size	Acres	24006	15079	4538	9733	9256	15493	12814
WATER QUANTITY INDICATORS								
Mean Annual Precip	Inches	82.30	72.05	53.30	53.30	43.35	40.83	43.51
Mean Annual Precip	Acre-ft	164641	90537	20156	43231	33437	52715	46461
Mean Recharge (Historic)	Inches		44.00	29.42	29.42	25.29	19.56	20.68
Mean Recharge (Historic)	Acre-ft		55290	11126	23862	19507	25254	22083
Mean Recharge (Current)	Inches		42.70	28.37	28.37	25.04	21.55	20.14
Mean Recharge (Future)	Inches		40.26	25.53	25.53	24.73	21.22	20.08
Mean Run-off (Current)	Inches	94	80	39	39	28	28	28
Groundwater Rights and Claims	Acre-ft	302	1822	421	1021	1092	997	1274
Surface Water Rights and Claims	Acre-ft	121	11030	256	74	852	2827	739
Total Rights and Claims	Acre-ft	423	12852	677	1095	1944	3824	2013
Historic Recharge Allocated to Groundwater Rights and Claims	%		3	4	4	6	4	6
Precipitation Allocated to All Rights and Claims	%		14	3	3	6	7	4

Summary of WDOE (1999) Watershed Assessment

Sub-Basin Name	Units	Lower Middle Fork Snoqualmie	Lower South Fork Snoqualmie	Coal Creek_Lower	Coal Creek_Upper	Upper Mainstem Snoqualmie	Mid-Mainstem Snoqualmie	Snoqualmie Mouth
Fisheries Basin		Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie
Size	Acres	24006	15079	4538	9733	9256	15493	12814
Current/Historic Recharge Ratio	%		3	4	4	1	3	3
Future/Historic Recharge Ratio	%		9	13	13	2	9	3
Run-off Allocated to Surface Water Rights and Claims	%		11	2	2	4	8	2
2-Yr Peak Flow		2.88	4.03	0.75	0.75	2.16	6.37	1.83
Current Peak Flow Problem (1= Urban 2=Forest)			2	0	0	0	2	0
Future Peak Flow Problem (1= Urban 2=Forest)			1	1	1	0	1	0
WATER QUALITY INDICATORS								
Change in Nitrate Load (Historic to Current)	lbs/acre/year	-0.82	-1.32	0.40	0.40	1.00	3.10	1.48
Change in Nitrate Load (Current to Future)	lbs/acre/year	1.00	1.70	2.20	2.20	5.90	2.80	2.90
Change in Phosphate Load (Historic to Current)	lbs/acre/year	-0.06	-0.16	0.00	0.00	0.10	0.20	0.04
Change in Phosphate Load (Current to Future)	lbs/acre/year	0.30	0.90	1.20	1.20	1.20	1.30	0.90
Change in Copper Load (Historic to Current)	lbs/acre/year	4.65	56.66	42.92	42.92	7.52	32.36	7.96

Summary of WDOE (1999) Watershed Assessment

Sub-Basin Name	Units	Lower Middle Fork Snoqualmie	Lower South Fork Snoqualmie	Coal Creek_Lower	Coal Creek_Upper	Upper Mainstem Snoqualmie	Mid-Mainstem Snoqualmie	Snoqualmie Mouth
Fisheries Basin		Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie
Size	Acres	24006	15079	4538	9733	9256	15493	12814
Change in Lead Load (Historic to Current)	lbs/acre/year ¹	32.17	392.12	297.08	297.08	52.07	223.94	55.11
Change in Zinc Load (Historic to Current)	lbs/acre/year ¹	32.02	390.33	295.72	295.72	51.83	222.92	54.86
Change in Copper Load (Current to Future)	lbs/acre/year ¹	25.80	215.70	384.40	384.40	20.90	168.90	10.80
Change in Lead Load (Current to Future)	lbs/acre/year ¹	177.80	1493.00	2660.50	2660.50	144.60	1168.70	74.80
Change in Zinc Load (Current to Future)	lbs/acre/year ¹	177.80	1486.10	2648.40	2648.40	144.00	1163.40	74.50
Historic Fine Sediment Input		88.27	39.55	202.99	17.64	7.68	31.90	24.92
Change in Fine Sediment Input		4.07	4.99	170.89	6.93	406.77	284.79	304.44
Historic Mass Wasting Input		18.09	6.17	10.20	0.97	7.35	10.39	10.83
Change in Mass Wasting Input		106.75	30.79	4.57	4.57	4.36	1.70	11.98
Sediment Transport		9.31	1.43	14.24	0.04	0.50	0.16	0.21
Historic Sediment Accumulation		9.48	27.74	14.25	175.70	197.10	0.00	53.95
Change in Sediment Accumulation		0.00	1.46	10.36	1482.71	1742.93	2288.78	2205.42

Summary of WDOE (1999) Watershed Assessment

Sub-Basin Name	Units	Lower Middle Fork Snoqualmie	Lower South Fork Snoqualmie	Coal Creek_Lower	Coal Creek_Upper	Upper Mainstem Snoqualmie	Mid-Mainstem Snoqualmie	Snoqualmie Mouth
Fisheries Basin		Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie	Snoqualmie
Size	Acres	24006	15079	4538	9733	9256	15493	12814
Sediment Yield (Historic)		0.17	0.01	0.15	0.00	0.00	0.00	0.00
Change in Sediment Yield (Historic to Current)		4.96	0.57	4.86	0.02	0.16	0.05	0.09
	PHYSICAL HABITAT INDICATORS							
River miles cleared or in Early Seral Stage	miles	81	45	46	46	34	66	47
% River miles cleared or in Early Seral Stage	%	53	62	70	70	84	81	86
Number of Road Crossings	Units	247	142	173	173	68	126	74
Road Crossing density	Crossings/mile	1.60	1.91	2.61	2.61	1.69	1.50	1.36
LWD Delivery Problem (Current)		Y	Y	Y	Y	Y	Y	Y
LWD Routing Problem (Current)		Y	Y	Y	Y	Y	Y	
LWD Delivery Problem (Future)			Y	Y	Y	Y	Y	Y
LWD Routing Problem (Future)			Y	Y	Y	Y	Y	
								X

RVA Analysis - Snoqualmie River at Snoqualmie

Station number: 12144500 Snoqualmie River Near Snoqualmie (Snoqualmie Falls)

<i>Monthly Magnitude</i>				
	Mean Discharge (cfs)	Standard Deviation (cfs)	Mean + 1 Std Dev (cfs)	Mean - 1 Std Dev (cfs)
January	3609.2	1392.6	5001.8	2216.6
February	3121.1	1578.3	4699.4	1542.9
March	2580.0	997.4	3577.4	1582.6
April	2978.3	837.6	3815.9	2140.7
May	3782.3	947.4	4729.7	2834.9
June	3481.1	1372.3	4853.4	2108.7
July	1870.5	1013.6	2884.1	856.9
August	870.3	420.7	1291.0	449.6
September	1073.6	557.1	1630.7	516.6
October	1750.0	1007.1	2757.0	742.9
November	3437.0	1982.4	5419.5	1454.6
December	3611.8	1607.2	5219.0	2004.6
<i>Magnitude and Duration of Annual Extremes</i>				
	Mean Discharge (cfs)	Standard Deviation (cfs)	Mean + 1 Std Dev (cfs)	Mean - 1 Std Dev (cfs)
1 day minimum	414.0	105.9	519.9	308.2
3 day minimum	428.7	104.6	533.2	324.1
7 day minimum	444.1	110.3	554.4	333.9
30 day minimum	573.3	218.4	791.7	355.0
90 day minimum	893.9	350.4	1244.3	543.5
1 day maximum	24924.9	11517.7	36442.6	13407.1
3 day maximum	17187.6	7644.1	24831.8	9543.5
7 day maximum	11493.0	4153.4	15646.5	7339.6
30 day maximum	6237.3	1781.9	8019.2	4455.4
90 day maximum	4345.5	970.2	5315.8	3375.3
<i>Frequency and Duration of High and Low Pulses</i>				
	Mean	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
Count (number)				
Low Pulses	7.5	3.4	10.9	4.2
High Pulses	18.7	3.2	21.9	15.4
Duration (days)				
Low Pulses	16.0	14.1	30.1	2.0
High Pulses	5.0	0.9	5.9	4.1
<i>Rate and Frequency of Hydrograph Changes</i>				
	Mean	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
Count (number)				
Fall	58.9	5.3	64.2	53.6
Rise	57.7	5.0	62.6	52.7
Rate (cfs/day)				
Fall	-498.5	157.6	-340.9	-656.1
Rise	1031.0	357.8	1388.9	673.2

RVA Analysis - Snoqualmie River at Carnation

Station number: 12149000 Snoqualmie River at Carnation

<i>Monthly Magnitude</i>				
	Mean Discharge	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
	(cfs)	(cfs)	(cfs)	(cfs)
January	5400.1	2014.5	7414.6	3385.6
February	4618.4	2169.0	6787.4	2449.4
March	3808.6	1427.4	5236.0	2381.1
April	4113.3	1107.9	5221.2	3005.4
May	4792.9	1183.4	5976.2	3609.5
June	4290.7	1719.5	6010.2	2571.2
July	2348.7	1200.8	3549.5	1147.9
August	1162.7	500.5	1663.2	662.2
September	1433.9	724.0	2158.0	709.9
October	2272.9	1195.1	3467.9	1077.8
November	4685.2	2558.0	7243.2	2127.2
December	5332.3	2305.6	7637.9	3026.7
<i>Magnitude and Duration of Annual Extremes</i>				
	Mean Discharge	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
	(cfs)	(cfs)	(cfs)	(cfs)
1 day minimum	608.2	155.6	763.8	452.6
3 day minimum	620.0	155.8	775.8	464.1
7 day minimum	639.2	162.8	802.0	476.4
30 day minimum	806.0	292.4	1098.4	513.6
90 day minimum	1212.6	504.5	1717.1	708.1
1 day maximum	28357.1	12459.7	40816.9	15897.4
3 day maximum	22011.7	9359.5	31371.2	12652.2
7 day maximum	15284.9	5474.0	20758.9	9811.0
30 day maximum	8552.9	2484.6	11037.5	6068.3
90 day maximum	6050.6	1440.3	7490.9	4610.2
<i>Frequency and Duration of High and Low Pulses</i>				
	Mean	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
Count (number)				
Low Pulses	7.1	3.1	10.2	3.9
High Pulses	18.1	2.6	20.6	15.5
Duration (days)				
Low Pulses	17.3	14.8	32.1	2.5
High Pulses	5.2	0.8	5.9	4.4
<i>Rate and Frequency of Hydrograph Changes</i>				
	Mean	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
Count (number)				
Fall	57.0	5.5	62.5	51.5
Rise	55.7	5.5	61.2	50.2
Rate (cfs/day)				
Fall	-591.7	181.6	-410.1	-773.3
Rise	1227.2	395.4	1622.6	831.8

RVA Analysis - Snoqualmie River at Monroe

Station number: 12150800 Snohomish River at Monroe

<i>Monthly Magnitude</i>				
	Mean Discharge (cfs)	Standard Deviation (cfs)	Mean + 1 Std Dev (cfs)	Mean - 1 Std Dev (cfs)
January	13078.5	4860.9	17939.5	8217.6
February	11269.0	5400.6	16669.6	5868.4
March	9480.5	3679.6	13160.1	5800.8
April	10339.7	2863.8	13203.5	7475.9
May	13206.8	3073.4	16280.1	10133.4
June	12559.1	4708.0	17267.1	7851.0
July	6918.0	3730.6	10648.6	3187.3
August	3051.6	1447.4	4499.0	1604.1
September	3506.2	1706.3	5212.5	1800.0
October	6065.0	3547.3	9612.3	2517.6
November	12338.0	6887.7	19225.7	5450.3
December	13319.0	5747.8	19066.9	7571.2
<i>Magnitude and Duration of Annual Extremes</i>				
	Mean Discharge (cfs)	Standard Deviation (cfs)	Mean + 1 Std Dev (cfs)	Mean - 1 Std Dev (cfs)
1 day minimum	1526.2	351.6	1877.9	1174.6
3 day minimum	1539.9	357.9	1897.8	1181.9
7 day minimum	1590.3	386.5	1976.8	1203.9
30 day minimum	2051.1	778.4	2829.5	1272.7
90 day minimum	3125.8	1203.0	4328.8	1922.8
1 day maximum	60065.7	23478.4	83544.1	36587.3
3 day maximum	51811.4	19284.0	71095.4	32527.5
7 day maximum	38369.5	12743.3	51112.8	25626.2
30 day maximum	22045.5	6310.1	28355.6	15735.4
90 day maximum	15477.2	3328.3	18805.5	12148.9
<i>Frequency and Duration of High and Low Pulses</i>				
	Mean	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
Count (number)				
Low Pulses	6.6	2.6	9.3	4.0
High Pulses	16.0	2.7	18.7	13.3
Duration (days)				
Low Pulses	16.2	7.3	23.5	8.9
High Pulses	5.9	1.1	7.0	4.8
<i>Rate and Frequency of Hydrograph Changes</i>				
	Mean	Standard Deviation	Mean + 1 Std Dev	Mean - 1 Std Dev
Count (number)				
Fall	53.0	5.6	58.6	47.4
Rise	51.1	4.6	55.7	46.4
Rate (cfs/day)				
Fall	-1339.3	400.7	-938.6	-1740.0
Rise	2780.8	810.1	3590.9	1970.7

TABLE 3-2

Comparison of Selected RVA Statistics for Historical Conditions and with Flow Augmentation during the Summer

	Base Case Historical Record			Augmentation Changes Historical Record Plus 40 cfs (July-October)		
	Mean Discharge (cfs)	Mean + 1 Std Dev (cfs)	Mean -1 Std Dev (cfs)	Mean Discharge (cfs)	Mean + 1 Std Dev (cfs)	Mean -1 Std Dev (cfs)
Mean Flow Magnitudes (cfs)						
January	5,400	7,415	3,386	0%	0%	0%
February	4,618	6,787	2,449	0%	0%	0%
March	3,809	5,236	2,381	0%	0%	0%
April	4,113	5,221	3,005	0%	0%	0%
May	4,793	5,976	3,610	0% / 0	0%	0%
June	4,291	6,010	2,571	0%	0%	0%
July	2,349	3,550	1,148	2%	1%	3%
August	1,163	1,663	662	3%	2%	6%
September	1,434	2,158	710	3%	2%	6%
October	2,273	3,468	1,078	2%	1%	4%
November	4,685	7,243	2,127	0%	0%	0%
December	5,332	7,638	3,027	0%	0%	0%
Annual Threshold Extremes (cfs)						
1 day minimum	608	764	453	7%	5%	9%
3 day minimum	620	776	464	6%	5%	9%
7 day minimum	639	802	476	6%	5%	8%
30 day minimum	806	1,098	514	5%	4%	8%
90 day minimum	1,213	1,717	708	3%	2%	6%

Temperature Requirements
for Salmon and Trout

Species	Life Phase			
	Migration of Adults	Spawning	Incubation	Rearing
Fall chinook	10.6 - 19.4	5.6-13.9	5.0-14.4	12-14
Spring chinook	3.3 - 13.3	5.6-13.9	5.0-14.4	12-14
Summer chinook	13.9-20.0	5.6-13.9	5.0-14.4	12-14
Chum	8.3-15.6	7.2-12.8	4.4-13.3	12-14
Coho	7.2-15.6	4.4-9.4	4.4-13.3	
Pink	7.2-15.6	7.2-12.8	4.4-13.3	
Rainbow trout	N/A	2.2-20.0		
Cutthroat trout		6.1-17.2		

All Temperatures in Celcius
from Meehan, 1991

The higher and lower values are threshold temperatures beyond which mortality increases.

Eggs survive and develop normally at lower temperatures than indicated, provided initial development of the embryo has progressed to a stage that is tolerant of cold water.

Substrate Requirements for Salmonids

Species	Substrate Size (cm)	Source
Fall chinook	1.3-10.2a	Thompson (1972)
Spring chinook	1.3-10.2a	Thompson (1972)
Summer chinook	1.3-10.2a	Reiser and White (1981a)
Chum	1.3-10.2a	Smith (1973)
Coho	1.3-10.2a	Thompson (1972)
Pink	1.3-10.2a	Collings (1974)
Steelhead	0.6-10.2c	Smith (1973)
Rainbow trout	0.6-5.2	Smith (1973)
Cutthroat trout	0.6-10.2	Hunter (1973)

Adapted from Meehan 1991.

aFrom Bell (1986).

bEstimated from criteria for other species.

cFrom Hunter (1973).

TABLE 5-2

Water Depths and Velocities Used by Anadromous and Resident Salmonids for Spawning

Species	Depth (cm)	Velocity (cm/s)	Source
Chinook salmon (race not specified)	15 - 43* 52 - 128† 30 - 460	37 - 69* 55 - 113†	Bovee (1978) Graybill et al. (1979) Chapman (1943)
Spring Chinook salmon	= 24 18 - 38* 5 - 122 13 - 720 45 - 52 30 - 107	30 - 91 24 - 61* 30 - 150 52 - 68 22 - 64 30 - 53 15 - 100	Thompson (1972) Bovee (1978) Burner (1951) Vronskiy (1972) Collings et al. (1972) Smith (1973) Chambers et al. (1955) Neilson and Banford (1983)
Summer Chinook salmon	= 30 5 - 700	32 - 109 10 - 189	Reiser and White (1981) Healey (1991)
Fall Chinook salmon	10 - 120 = 24 122 - 198 28 - 41 30 - 45 to 700	25 - 115 30 - 91 84 - 114 30 - 76 30 - 68 19 - 81 37 - 189	Bovee (1978) Thompson (1972) Chambers et al. (1955) Briggs (1953) Collings et al. (1972) Smith (1973) Chapman et al. (1986)
Chum salmon	= 18 13 - 50† 20 - 110 30 - 100	46 - 101 21 - 84† 10 - 20 10 - 100	Smith (1973) Johnson et al. (1971) Sano and Nagasawa (1958) Soin (1954)
Coho salmon	= 18 4 - 33 12 - 35` 20 - 25 10 - 20	30 - 91 30 - 55 25 - 61' 25 - 70 30 - 75	Thompson (1972) Gribanov (1948) Bovee (1978) Li et al. (1979) Briggs (1953)
Pink salmon	= 15 10 - 150	21 - 101 30 - 140	Collings (1974) Heard (1991)
Steelhead trout (race not specified)	= 24 18† 12 - 70 27 - 88†	40 - 91 30 - 91† 37 - 109 46 - 91†	Smith (1973) Stober and Graybill (1974) Hunter (1973) Graybill et al. (1979)
Winter Steelhead trout	24 - 55*	43 - 87*	Bovee (1978)
Rainbow trout	= 18 15 - 43 21 - 30	48 - 91 27 - 79 30	Smith (1973) Chambers et al. (1955) Li et al. (1979)
Cutthroat trout	= 6 17 - 30	11 - 72 15 - 46	Hunter (1973) Chambers et al. (1955)
Mountain whitefish	> 23 610 - 1220	30 - 66* = 15	Bovee (1978) Li et al. (1979)

* Values indicate 50% probability range

† Values indicate 80% probability range

TABLE 6-1

Typical Western Washington Chinook Salmon Life Cycle

Life Phase	J	F	M	A	M	J	J	A	S	O	N	D
Upstream Migration							X	X	X	X	X	
Spawning									X	X	X	
Incubation									X	X	X	
Juvenile Rearing	X	X	X	X	X	X	X	X	X	X	X	X
Outmigration					X	X	X					

TABLE 6-1.doc

FIGURES

APPENDIX A

**WDOE WATERSHED INDICATORS
GIS OUTPUT**

APPENDIX B
HYDROLOGICAL ANALYSIS

APPENDIX C

SALMONID DISTRIBUTION MAPS